National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Aztec Ruins National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/SCPN/NRR—2019/1984

ON THE COVER

Sunset over the West Ruin at Aztec Ruins National Monument. Photo Credit: © Bettymaya Foott.

Aztec Ruins National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/SCPN/NRR—2019/1984

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Water Resources Division, provides a multidisciplinary synthesis of existing scientific data and knowledge about current conditions of important national park natural resources through the development of a park-specific report. The NRCA process for Aztec Ruins National Monument(NM) was initiated in 2018 as a collaborative effort between the national monument staff, the NPS Southern Colorado Plateau Inventory and Monitoring Network staff, the NPS Intermountain Region, and Utah State University. Nine focal resources were selected for condition assessment reporting.

The national monument's nine natural resources evaluated for current conditions were grouped into five broad categories: landscape patterns and processes (i.e., viewshed), air, geology, water, and biological integrity (i.e., vegetation and wildlife topics). Most of the resources are considered to be in condition states of moderate concern, with the exception of the wildlife focal resources, whose conditions are largely unknown.

Acknowledgements

We thank Aztec Ruins National Monument's Natural Resource Program Lead, Dana Hawkins, and the National Park Service (NPS) Southern Colorado Plateau Inventory and Monitoring Network's (SCPN) Plant Ecologist, Jim DeCoster, who initially discussed and refined the list of monument resources. After the call, Dana Hawkins and Aztec Ruins NM Chief of Resources, Aron Adams, further refined and guided the selection and focus of natural resource information. They, along with additional SCPN staff, reviewed drafts and provided substantial comments throughout the development of the report.

Phyllis Pineda Bovin, NPS Intermountain Region Office Natural Resource Condition Assessment (NRCA) Coordinator (former), assisted with overall project facilitation and served as subject matter expert review manager. Jeff Albright, NPS NRCA Program Coordinator, provided programmatic guidance.

And finally, to all of the additional reviewers and contributors, who are listed in Appendix A, we thank you. Your contributions have increased the value of Aztec Ruin NM's NRCA report.


A photo of a cloudy day with the Aztec Ruins in the foreground. Photo Credit: NPS.

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 Geographic Information System (GIS) products;[4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

[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-up 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.

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; 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

Grinding stones. Photo Credit: NPS.

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.

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 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 an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website at http://www.nature.nps.gov/water/nrca/.

[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.

Landscape at Aztec Ruins NM. Photo Credit: NPS/P. Pineda Bovin.

Introduction and Resource Setting

Introduction

Enabling Legislation/Executive Orders

Aztec Ruins National Monument (NM) was established in 1923 to "protect an exceptionally well-preserved great house community along the banks of the Animas River, and provide opportunities for greater understanding of the evolution of the Chacoan culture. (NPS 2015a). The architecture at the monument includes great houses from the late CE (Common Era) 1000s to 1300 (NPS 2015a). Aztec Ruins is connected to "other Chacoan outliers by a system of regional road segments (NPS 2015a).

Supporting the monument's purpose are four significance statements explaining why its "resources and values are important enough to merit designation as a unit of the national park system" (NPS 2015a). These statements are as follows (text excerpted from NPS (2015a)):

1. Aztec Ruins National Monument contains some of the best-preserved monumental great house architecture in the Southwest. This community, strategically constructed along the Animas River, is characterized by its symmetrical layout and unique complex of architectural features that include rare tri-walled structures
2. Aztec Ruins National Monument protects the only fully reconstructed great kiva in the Southwest, providing visitors a unique opportunity to connect to the past and experience the scale of this monumental architecture.
3. Aztec Ruins National Monument illustrates the evolution and adaptation of cultures, including the Chacoan and Mesa Verdean traditions that continue today through American Indian peoples who trace their history here.
4. The incredible condition of the great house architecture and landscape modifications today highlights the long-standing role of Aztec Ruins National Monument as a leader in the science of preservation. Because original wooden roofs still cover many rooms,extensive tree ring dating has been completed, making Aztec Ruins one of the best dated sites in the Southwest.

Because of its significance on a global scale, in 1987, Aztec Ruins NM, along with Chaco Culture National Historical Park and five Chacoan sites managed by the Bureau of Land Management was designated as a World Heritage Site (NPS 2015a). There are only 23

United Nations Educational, Scientific, and Cultural Organization UNESCO World Heritage Sites in the United States (World Atlas 2019).

Geographic Setting

The 129 ha- (318 ac-) Aztec Ruins NM is situated along the Animas River in northwestern New Mexico in San Juan County. The City of Aztec, New Mexico surrounds the monument (Figure 1). The monument is located approximately 294.5 km (183 mi) from Albuquerque, New Mexico's international airport and 59.5 km (37 mi) south of Durango, Colorado.

As of April 1, 2010, the population estimate for the City of Aztec, New Mexico was 6,763 (U.S. Census Bureau 2018). The population percent change from 2010 to July 1, 2018 was unavailable since no population estimate was provided for 2018 (U.S. Census Bureau 2018).

Over 117 years (1895-2012), the average temperature at Aztec Ruins NM was 10.8 °C (51.4 °F), and the average precipitation was 208 mm (8.2 in) (Figure 2). The warmest temperatures occur during July and August and coldest temperatures occur between mid-October-March. Relative humidity is generally highest during the coldest months, and conversely, most arid during the spring (approximately April - June) and summer months (climate information is based on the diagrams developed for vegetation studies by Walter and Lieth in 1967 as cited by NPS SCPN 2018).

Visitation Statistics

Visitation data for Aztec Ruins NM are available from 1923-2018 (NPS Public Use Statistics Office 2019). The highest number of visitors was 89,220 in 1991 (Figure 3). In 2018, 54,933 visitors were recorded at Aztec Ruins NM (NPS Public Use Statistics Office 2019).

Natural Resources

Ecological Units and Watershed

Aztec Ruins NM is located in the Southern Colorado Plateau Ecoregion, which includes portions of Arizona, Utah, Colorado, and New Mexico. The entire area encompasses 9.3 million ha (22.9 million ac) and

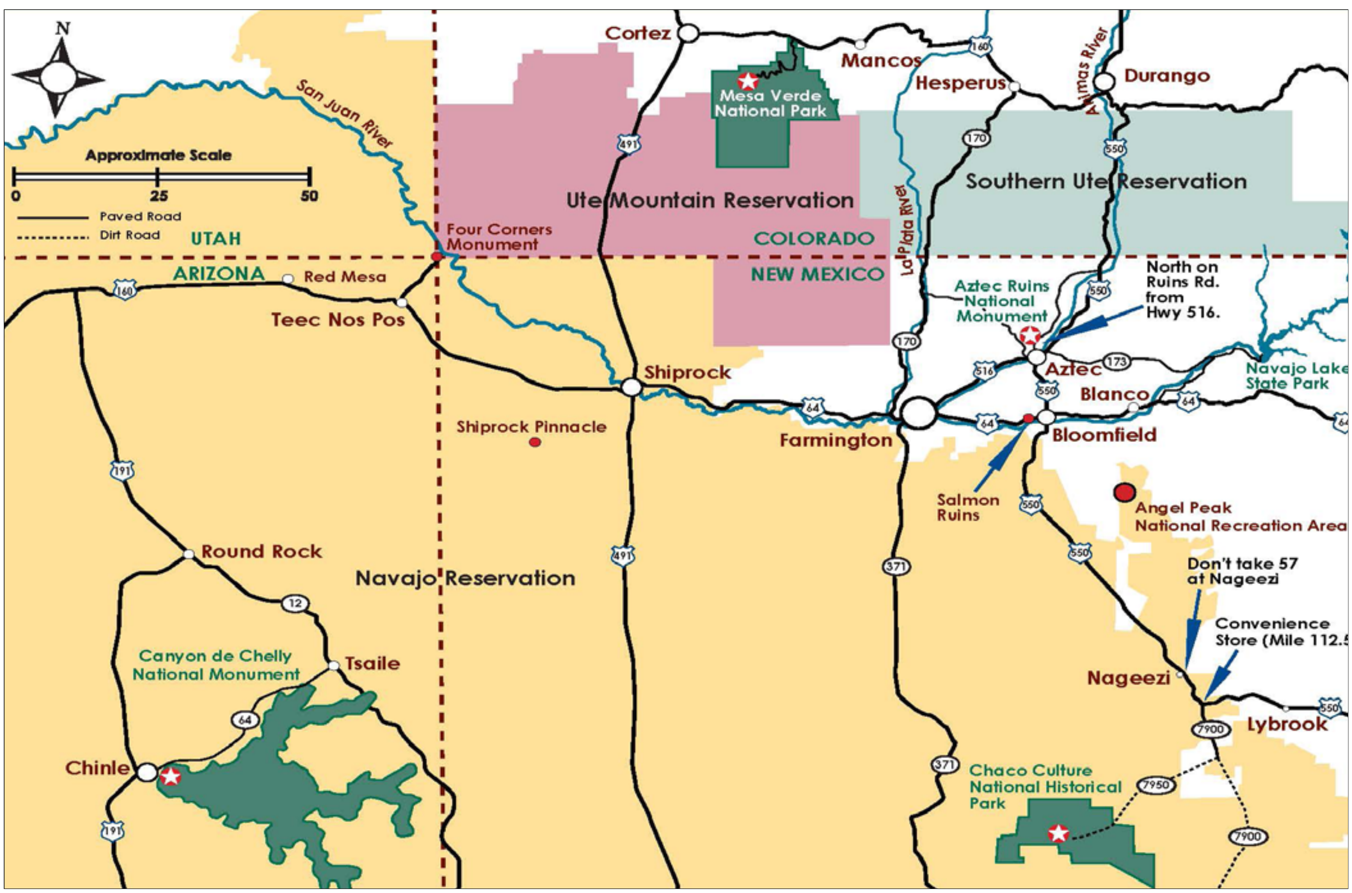


Figure 1. Aztec Ruins NM is located in the City of Aztec, New Mexico. Figure Credit: © Farmington Convention and Visitors Bureau.

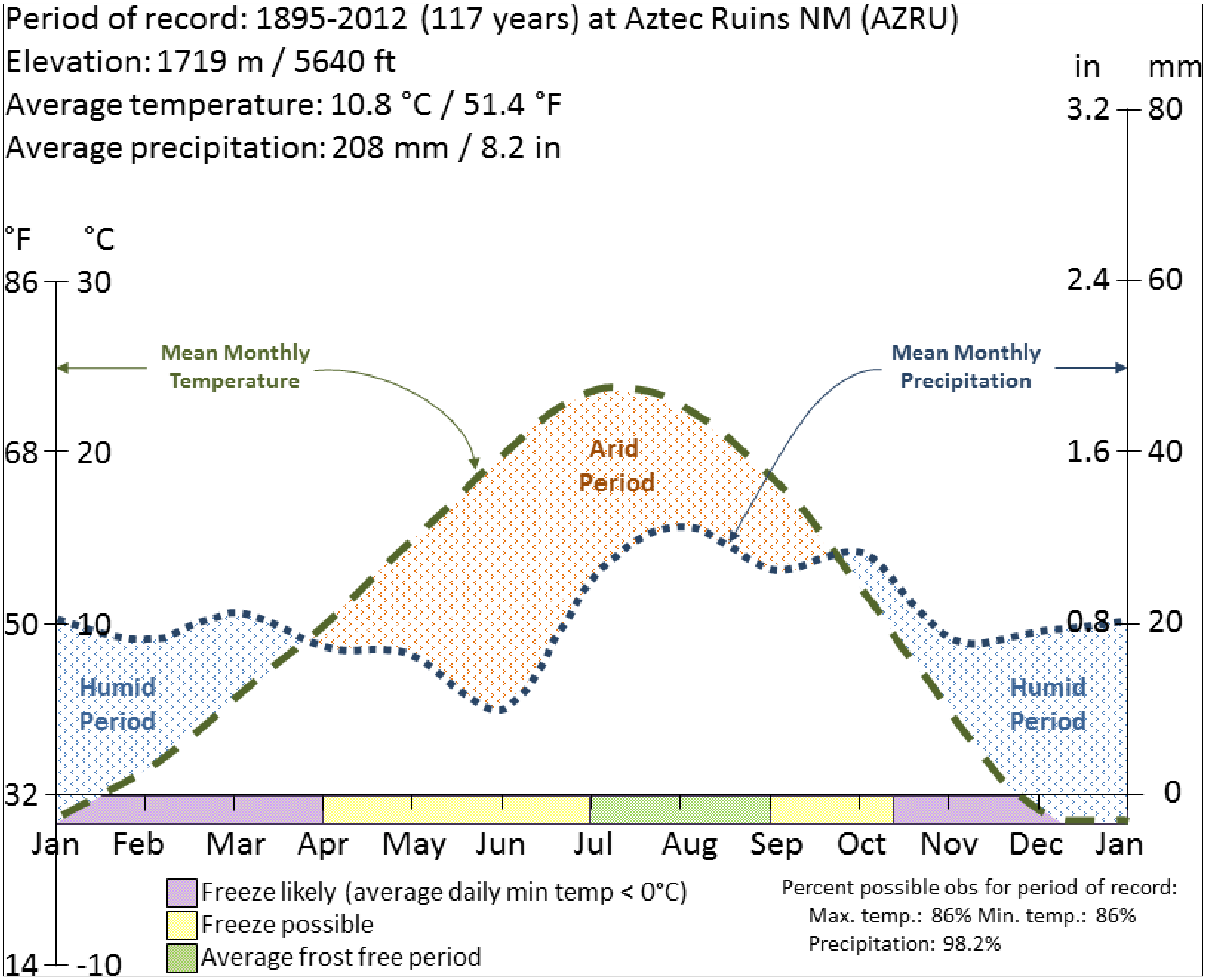


Figure 2. **The average temperature and precipitation at Aztec Ruins NM (1895-2012) was 51.4°F and 8.2 inches, respectively. Figure Credit: NPS SCPN 2018.**

much of the region is characterized by desert scrub and shrublands. Elevations reach as high as 2,804 m (9,200 ft) throughout the ecoregion. The elevation at Aztec Ruins NM ranges between 1,716-1,764 m (5,592 to 5,786 ft) and lies within the Semi-desert Grassland/Shrub Steppe and Pinyon-Juniper Woodland life zones (NPS SCPN 2018).

Aztec Ruins National Monument (NM) lies within the Animas River valley watershed—a 3,550 km^2 (1,371 mi^2) area in southern Colorado and northern New Mexico (U.S. Department of Agriculture [USDA] 2010). The high water line of the Animas River delineates 1.6 km (1.0 mi) of the monument's southeastern boundary (Filippone and Martin 2014, NPS 2015a). The perennial flowing Animas River once served as the primary water supply for the Ancestral Puebloans who inhabited the region from the late A.D. 1000s to about 1300 (NPS 2015a). Today, the Animas River continues to remain unregulated (i.e., no dams) along its length, which is rare for rivers in the western U.S. (Chen and Olden 2017).

Resource Descriptions

The National Park Service's (NPS) Southern Colorado Plateau Inventory and Monitoring Network (SCPN) (2018) describes Aztec Ruins NM's resources as having an unusually high diversity of vegetation communities and wildlife species despite its small size. The Animas River, which forms the eastern border of the park, provides a perennial source of water. Nine major groups of resources were evaluated for current conditions in this report. Please refer to each of the

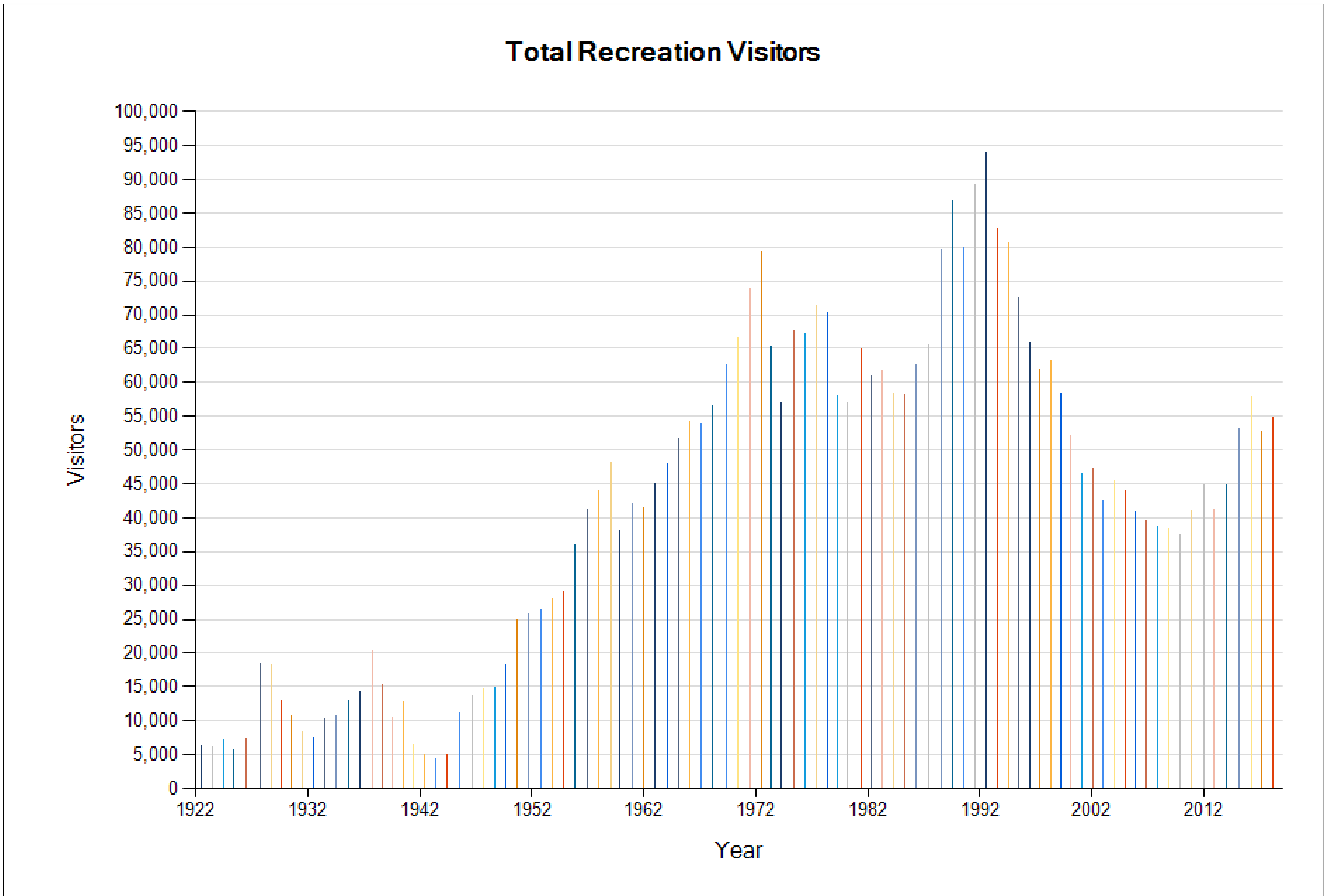


Figure 3. Total number of annual visitors to Aztec Ruins NM from 1923-2018. Figure Credit: NPS Public Use Statistics Office 2019.

condition assessments for more details on resource information.

Resource Issues Overview

Like many places, the Southwest is already experiencing the impacts of climate change. According to Kunkel et al. (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 0.9 °C (34 °F) (greatest in winter months) and more than double the number of four-day periods of extreme heat. The western U.S., especially the Southwest, has also experienced decreasing rainfall (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).

Monahan and Fischelli (2014) evaluated which of 240 NPS parks have experienced extreme climate changes during the last 10-30 years, including Aztec Ruins NM. Twenty-five climate variables (i.e., temperature and precipitation) were evaluated to determine which ones were either within <5th percentile or >95th percentile relative to the historical range of variability (HRV) from 1901-2012. Results for Aztec Ruins NM were reported as follows:

- Four temperature variables were "extreme warm" (annual mean temperature, maximum temperature of the warmest month, mean temperature of the driest quarter, and mean temperature of the warmest quarter).
- No temperature variables were "extreme cold."
- No precipitation variables were "extreme dry."
- No precipitation variables were "extreme wet."

Results for the temperature of each year between 1901-2012, the averaged temperatures over progressive 10-year intervals, and the average temperature of 2003-2012 (the most recent interval) are shown in Figure 4. The blue line shows temperature for each

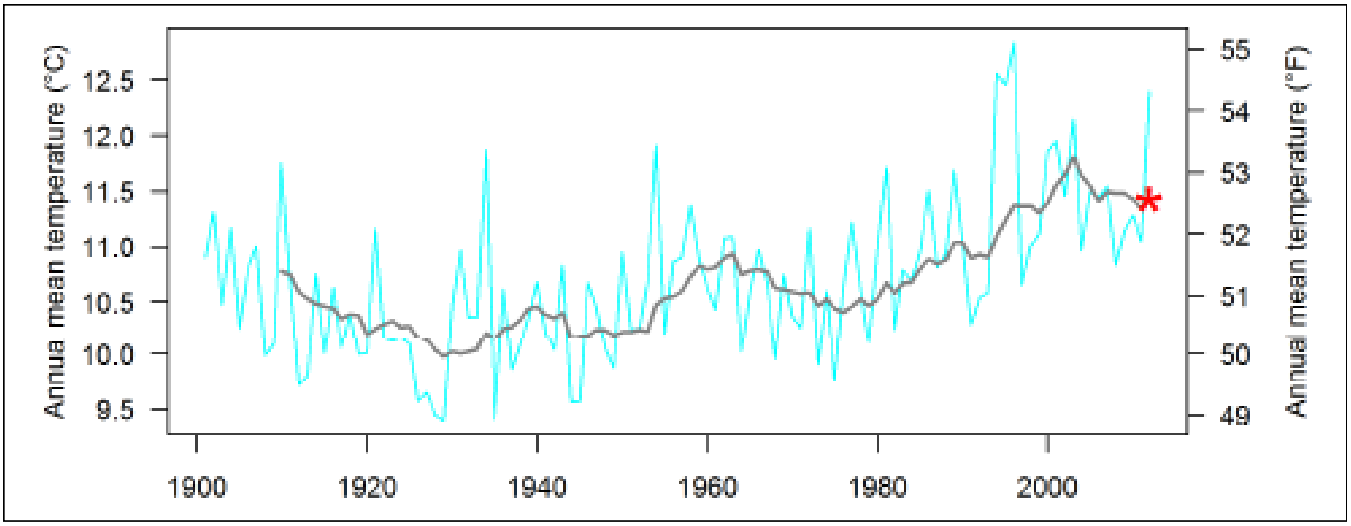


Figure 4. **Time series used to characterize the historical range of variability and most recent percentile for annual mean temperature at Aztec Ruins NM (including areas within 30-km [18.6-mi] of the park's boundary). Figure Credit: Monahan and Fisichelli (2014).**

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. The results indicate that recent climate conditions have already begun shifting beyond the HRV, with the 2003-2012 decade representing the warmest on record for the national monument.

There is a general consensus among climate models that the Southwest will likely continue to become warmer and drier with climate change (Garfin et al. 2014, Monahan and Fisichelli 2014). Kunkel et al. (2013) estimate that temperatures could rise between 2.5 °C (37 °F) and 4.7 °C (40 °F) for 2070-2099 (based on climate patterns from 1971-1999). Monahan and Fisichelli (2014) state that "climate change will manifest itself not only as changes in average conditions, but also as changes in particular climate events (e.g., more intense storms, floods, or drought). Extreme climate events can cause widespread and fundamental shifts in conditions of park resources."

Additional issues of concern relative to natural resources include adjacent land use and associated view and night sky impacts, and invasive non-native plants. Conflicts between natural and cultural resources are another issue. Non-native species such as feral dogs, cats, and domestic rabbits are found at the monument and survive by depredating native species Even mammals that might not normally be considered pests, such as native Gunnison's prairie dog (*Cynomys gunnisoni*) threaten archeological structures and sites by burrowing. Details pertaining to these and additional resource threats, concerns, and data gaps are included in each Chapter 4 condition assessment.

Resource Stewardship

Management Directives and Planning Guidance

In addition to the NM'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 natural resources for this condition assessment. This included the SCPN, I&M NPScape Program for landscape-scale measures, Air Resources Division for air quality, the Natural Sounds and Night Skies Program for the night sky assessment, and the Geologic Resources Division for the geology assessment.

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. Aztec Ruins NM is part of the SCPN, which includes 19 additional parks. Through a rigorous multi-year, interdisciplinary scoping process, SCPN 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 to help managers make sound decisions about the future.

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 Resource Stewardship Strategy reports rely on credible information found in NRCAs as well as a variety of other sources.

Foundation documents describe a park's purpose and significance and identify fundamental and other important park resources and values. A foundation document was completed for Aztec Ruins NM in 2015 (NPS 2015a) and was used to identify some of the primary natural features throughout the monument for the development of its NRCA.

A Resource Stewardship Strategy 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 for the monument will be initiated in 2019.

Status of Supporting Science

Available data and reports varied depending upon the resource topic. The existing data used to assess the condition of each indicator and/or to develop reference conditions are described in each of the Chapter 4 assessments in this report.

Aztec Ruins National Monument's scoping meeting participants select viewshed vantage points. Photo Credit: NPS.

Study Scoping and Design

The Natural Resource Condition Assessment (NRCA) for Aztec Ruins National Monument (NM) was coordinated by the National Park Service (NPS) Intermountain Region Office (IMRO), Utah State University (USU), and the Colorado Plateau Cooperative Ecosystem Studies Unit through task agreements, P14AC00749 and P15AC01212. The NRCA scoping process was a collaborative effort between the staffs of Aztec Ruins NM, NPS Southern Colorado Plateau Inventory and Monitoring Network (SCPN), the NPS IMRO NRCA Coordinator, and USU's NRCA team.

Preliminary scoping for Aztec Ruins NM's NRCA began on January 4, 2018 with a conference call. Prior to the call, USU staff reviewed the monument's foundation document (NPS 2015a) and website (NPS 2018b), SCPN's website (NPS SCPN 2018), and the NPS integrated resource management applications (IRMA portal; NPS 2018c). The NPS Natural Resource Stewardship and Science Directorate (NRSS) divisions provided data for night sky, soundscape, air quality, geology, and climate topics (NPS 2018d).

Based on the information gathered from these sources, an initial list of potential focal resources for the monument's NRCA was developed and discussed during the January conference call. Aztec Ruins NM's conference call participants, Natural Resource Program Lead, Dana Hawkins, and SCPN Plant Ecologist, Jim DeCoster, discussed and refined the list of resources. After the call, Dana Hawkins and Aztec Ruins NM Chief of Resources, Aron Adams, further refined the natural resource topics and associated content.

USU NRCA writers reviewed reports and datasets to determine a logical study plan of the prioritized resources. USU writers then developed the Phase I draft indicators, measures, and reference conditions for the nine preliminary focal resources selected by monument staff, reflecting the proposed study plan. Note that non-native invasive plants were used as an indicator for the upland vegetation topic instead of a stand-alone assessment. The draft tables served as the primary discussion guide during Aztec Ruins NM's on-site NRCA scoping workshop.

The NRCA workshop and field outing was held over a two day period from April 24-25, 2018 at Aztec, New Mexico public library and park (a list of meeting attendees is included in Appendix A). During the workshop, meeting participants reviewed, discussed, and refined the Phase I tables, which formed the basis of USU's study plan for the monument's NRCA report. Additional datasets and reports were identified and gathered for the selected focal resources. Monument staff also identified threats, issues, and data gaps for each natural resource topic, which are discussed in each of the nine Chapter 4 condition assessments.

Study Design

Indicator Framework, Focal Study Resources and Indicators

An NRCA report represents a unique assessment of key natural resource topics for each park. Aztec Ruins NM's NRCA focal resources, indicators, and measures are listed in Tables 1-5. The associated threats for each topic are listed in Table 6. Due to USU's timeline and budget constraints, this list of resources *does not* include every natural resource of interest to monument staff, rather the list is comprised of the natural resources and processes that were of greatest interest/concern to monument staff at the time of this effort.

The selected natural resources were grouped using the NPS Inventory & Monitoring (I&M) Program's "NPS Ecological Monitoring Framework" (NPS 2005), which is endorsed by the Washington Office NRCA Program as an appropriate framework for listing resource components, indicators/measures, and resource conditions. Additionally, SCPN's Vital Signs Plan (Thomas et al. 2006), and the RM-77 NPS Natural Resource Management Guideline (NPS 2004) are all organized similarly to the I&M framework.

Table 1. Aztec Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for landscapes patterns and processes.

Resource	Indicators	Measures
Viewshed	Scenic and Historic Integrity	Conspicuousness of Non-contributing Features
	Scenic and Historic Integrity	Extent of Development
	Scenic and Historic Integrity	Proportion of Viewshed Protected
Night Sky	Sky Brightness	All-sky Light Pollution Ratio
	Sky Brightness	Zenith Sky Brightness

Table 2. Aztec Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for air and climate.

Resource	Indicators	Measures
Air Quality	Visibility	Haze Index
	Ozone	Human Health
	Ozone	Vegetation Health
	Wet Deposition	Nitrogen
	Wet Deposition	Sulfur
	Wet Deposition	Mercury
	Wet Deposition	Predicted Methylmercury Concentration

Table 3. Aztec Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for geology.

Resource	Indicators	Measures
Geology	Disturbed Lands	Abandoned Mineral Lands Prioritization Ranking
	Disturbed Lands	Non-native Invasive Plants Associated with Oil and Gas Development and Production
	Known Deterioration of Geological or Paleontological Resources	Anthropogenic Incidents
	Seismic Activity	Presence/Absence

Table 4. Aztec Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for water.

Resource	Indicators	Measures
Water Resources	Groundwater	Depth to Groundwater (m)
	Surface Water Quantity	Animas River Discharge (cfs)
	Surface Water Quantity	Farmers Ditch Discharge (cfs)
	Animas River Watershed	Percent of Watershed Protected

Table 5. Aztec Ruins NM natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Upland Vegetation and Soils	Erosion Hazard	Bare Ground and Undifferentiated Soil Crust Cover
	Erosion Hazard	Biological Soil Crust Cover
	Erosion Hazard	Soil Aggregate Stability
	Erosion Hazard	Basal Gap Between Perennials
	Community Composition and Structure	Tree Cover
	Community Composition and Structure	Perennial Grass Cover
	Community Composition and Structure	Native Species Richness
	Non-native Plants	Frequency
	Non-native Plants	Cover
Birds	Species Occurrence	Richness and Composition
	Species Occurrence	Presence of Species of Conservation Concern
Mammals	Species Occurrence	Richness and Composition
	Species Occurrence	Presence of Species of Conservation Concern
Herpetofauna	Species Occurrence	Richness and Composition
	Species Occurrence	Presence of Species of Conservation Concern

Reporting Areas

The primary focus of the reporting area was within Aztec Ruins NM's legislative boundary; however, some of the data and analyses encompassed areas beyond its boundary. Natural resources assessed at the landscape level included viewshed, night sky, and water resources. The NRCA Chapter 5 discussion summarized condition findings by the natural resource management zones identified in the monument's vegetation management plan and environmental assessment (Figure 5; NPS 2012a).

General Approach and Methods

The general approach to developing the condition assessments include reviewing literature and data and/or speaking to subject matter expert(s) for assistance in condition reporting. Following the NPS NRCA guidelines (NPS 2010a), each Chapter 4 condition assessment includes five sections (listed below), with a condensed literature cited section at the end of the report.

1. The background and importance section of each condition assessment provides information regarding the relevance of the resource to the national monument.
2. The data and methods section describe the existing datasets and methodologies used for evaluating the indicators/measures for current conditions.
3. The reference conditions section describe the good, moderate concern, and significant concern definitions used to evaluate the condition of each measure.
4. The condition and trend section provides a discussion for each indicator/measure based on the reference condition(s). Condition icons are presented in a standard format consistent with State of the Park reporting (NPS 2012b) and served as visual representations of condition/trend/level of confidence for each measure. Table 7 shows the condition/trend/confidence level scorecard used to describe the condition for each assessment, Table 8 provides examples of conditions and associated interpretations.

Circle colors convey condition. Red circles signify that a resource is of significant concern; yellow circles signify that a resource is of moderate concern; 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 measure. An upward pointing arrow signifies that the measure is improving; 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 to low and is symbolized by the border around

Table 6. Resource condition assessment topic threats and stressors.

Resource	Threat/Stressor
Viewshed	Urban development along periphery North Mesa potential subdivision Powerlines (in the process of burying) and roads Potential solar energy development Four non-federal oil and gas wells within and adjacent to monument Air pollution
Night Sky	Surrounding towns Peripheral development Air quality (haze, dust) Lights associated with drilling Light pollution from more distant cities, including those in San Juan County (e.g., Farmington) and beyond Headlights on the roads
Air Quality	Climate change Large metropolitan areas Drilling Methane hot spot (four corners region) Power plants Oil and gas development and production Fugitive dust
Geologic Resources	Extractive uses, including seismic activities, directional drilling, oil and gas pads, especially of the Nacimiento Formation (most likely to contain fossils) Adjacent development, including roads and housing Localized and regional subsidence, especially near the East Ruin Piping – erosion by percolating water in a layer of subsoil that results in caving, the formation of narrow conduits, tunnels, or pipes through which materials move Access roads around periphery Gas line going through monument through North Mesa
Water Resources	Declining flows and reduced water quality in the Animas River may affect groundwater Agricultural runoff Farmers Ditch - soils and other nutrients that would otherwise be deposited in the monument are carried downstream, alteration of natural hydrological processes Climate change – specifically drought Extractive uses may contaminate ground and surface water, reduce streamflow in Animas, and affect groundwater levels Pending Water Rights and neighboring irrigation concerns Management of surrounding lands Right-of-Way activities
Upland Vegetation and Soils	Well development has disturbed surrounding vegetation and soils Non-native plants threaten native vegetation and also the structural integrity of ruins in some places Long history of disturbance (orchards, grazing, agricultural fields). Storm water runoff from potential development near North Mesa Right-of-Way disturbance of vegetation (roads and along Farmers Ditch) Climate change
Birds	Climate change changing patterns of distribution and occurrence Changes in riparian vegetation, but currently undergoing restoration Non-native species (plants, birds, domestic animals) Lack of follow-up monitoring
Mammals	Habitat fragmentation Lacking apex predators Nuisance species relative to archaeological resources Lack of follow-up monitoring Potential prairie dog plague outbreak
Herpetofauna	Declining flows and reduced water quality in the Animas River Climate change – specifically drought Agricultural runoff - pollution Lack of follow-up monitoring

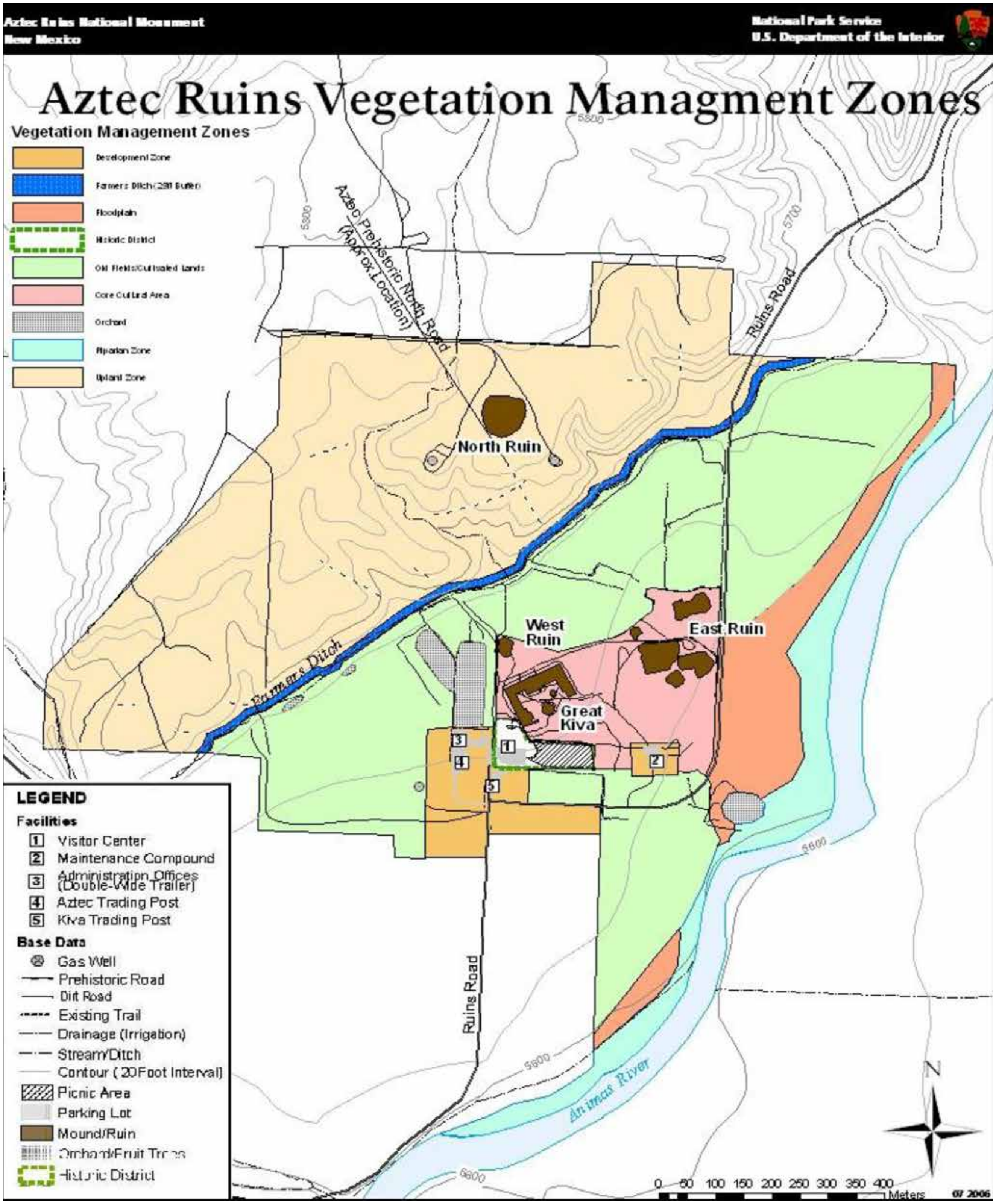


Figure 5. **Aztec Ruins NM's vegetation management zones. Photo Credit: NPS 2012a.**

Table 7. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in good condition.		Condition is Improving.		High
	Resource warrants moderate concern.		Condition is unchanging.		Medium
	Resource warrants significant concern.		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.				

Table 8. Example indicator symbols and descriptions of how to interpret them.

Symbol Example	Description of Symbol
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

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

5. The sources of expertise list the individuals who were consulted. Assessment author(s) are also listed in this section for each condition assessment.

After the report is published, a disk containing a digital copy of the published report, copies of the literature cited (with exceptions listed in a READ ME document), original GigaPan viewshed images, reviewer comments and writer responses if comments weren't included, and any unique GIS datasets created for the purposes of the NRCA is sent to Aztec Ruins NM staff and the NPS IMRO NRCA Coordinator.


Collared lizard. Photo Credit: NPS.

Natural Resource Conditions

Chapter 4 delivers current condition reporting for the nine important natural resources and indicators selected for Aztec Ruins National Monument's NRCA report. The resource topics are presented following the National Park Service's (NPS) Inventory & Monitoring Program's NPS Ecological Monitoring Framework that is presented in Chapter 3.

Viewshed

Background and Importance

The conservation of scenery was 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 2006 Management Policies 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. Aesthetic conservation, interchangeably used with scenic preservation, has been practiced in the NPS since the early twentieth century (Wondrak-Biel 2005). Aesthetic conservation strives 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.

Viewsheds are considered an important part of the visitor experience at Aztec Ruins National Monument (NM), and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the area's cultural significance (NPS 2015a). Although Aztec Ruins NM is within the city limits of Aztec, New Mexico, cultural features on the landscape, such as ancestral Puebloan kivas and the reconstructed Great House, allow visitors to literally "visualize" their connection to past cultures. Along with Chaco Culture National Historical Park and five other Chacoan sites in the region, Aztec Ruins NM was designated as a World Heritage Site by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 1987 (NPS 2015a). The views offered at Aztec Ruins NM represent much more than just scenery; they represent a way to better understand the connection between the past and the present. Inherent in virtually every aspect of this assessment is how features on the visible landscape influence the enjoyment, appreciation, and understanding of the national monument by visitors.

Data and Methods

The indicator (scenic and cultural integrity) and measures (conspicuousness of non-contributing features, extent of development, and conservation status) used for assessing the condition of Aztec Ruins NM's viewshed were based on studies related to perceptions people hold toward various features and attributes of scenic landscapes. The scenic and cultural integrity indicator is defined as the state of natural and cultural features that contribute to the scenic attractiveness of an area (USFS 1995). Integrity focuses on the features of the landscape

View of ancestral Puebloan ruins at Aztec Ruins National Monument. Photo Credit. NPS.

Figure 6. Viewshed locations in and around Aztec Ruins NM.

related to non-contributing human alteration/development. In general, there has been a wealth of research demonstrating that people tend to prefer natural landscapes 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, modern buildings, power lines, 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 and historical 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 were perceived more positively when they were considered in harmony with the landscape (e.g., Kaplan and Kaplan 1989, Gobster 1999, Kearney et al. 2008). Kearney et al. (2008) showed that survey respondents tended to prefer development that blended with the natural setting through use of colors, fine scale features, 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.

Three key observation points were selected by Utah State University and Aztec Ruins NM staff for inclusion in the viewshed analysis. The points were chosen based on viewsheds that are accessible to the public, are located upon a prominent landscape feature, and are inclusive of cultural resources, natural resources, and scenic views (Figure 6). The three observation points are as follows: Animas River, Site 18 Overlook, and North Mesa. Although the North Mesa point is not accessible to visitors, the location is of cultural significance to the region's previous inhabitants, offering views of the Animas River Valley and surrounding landscape. We used panoramic images collected at these three locations in addition to GIS analyses of modeled visible areas overlaid with housing density, road density, and land management datasets to evaluate viewshed conditions from the monument.

The conspicuousness of non-contributing features, the first measure, was evaluated using high-quality panoramic photos of the three key observation points. Photos were taken on 25 April 2018 with a Canon PowerShot digital camera mounted to a GigaPan Epic 100 system. Panoramas were collected from the four cardinal directions (i.e., north to east, east to south, south to west, and west to north). The images for each direction were then stitched together into a single high-resolution panoramic image using GigaPan Stitch software. These photos portray the viewshed from an observer's perspective and provide a means of assessing the non-contributing features on the landscape. Non-contributing features were qualitatively evaluated based on four characteristics of human-made features, the first of which is distance to objects in the viewshed.

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. For this assessment, we have used the distance classes that have been recently used by the NPS:

- *Foreground* = 0-0.8 km (0-0.5 mi) from key observation point
- *Middle ground* = 0.8-5 km (0.5-3 mi) from key observation point
- *Background* = 5-97 km (3-60 mi) from key observation point.

Over time, different agencies have adopted minor variations in the specific distances used 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 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 between 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 is another characteristic that may influence how conspicuous a given feature is on the landscape, and how it is perceived by humans. For example, Kearney et al. (2008) found human preferences were lower for man-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 was 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 Aztec Ruins NM as belonging to one of six size classes (Table 9), 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 is the third characteristic we considered in this assessment. 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 vegetation, or other blending factors (Figure 7). 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 was consistent with the findings of Kearney et al. (2008) who found

Table 9. Six size classes used for conspicuousness of human-made features.

Size	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

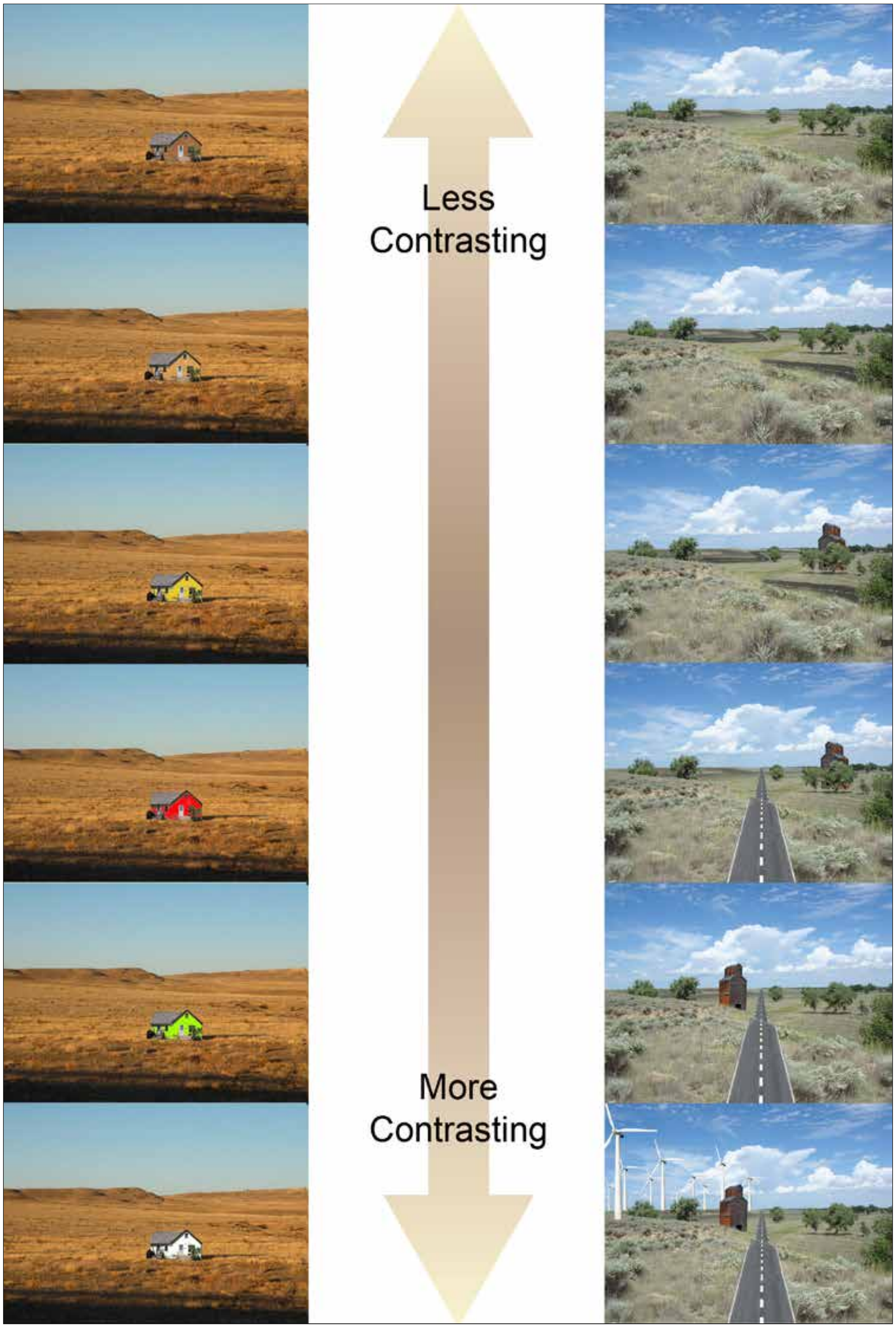


Figure 7. Graphic illustration of how color (left) and shape (right) can influence whether features were in harmony with the environment, or were in contrast.

that darker color was one of the factors contributing to a feature blending in with its environment and therefore preferred.

Some research indicates 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 influence how they are perceived (Ribe 2005). The Visual Resource Management Program of the Bureau of Land Management (BLM 2016), 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.

Lastly, noise and movement can both influence 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).

In summary, these four characteristics do not act independently with respect to their influence on the conspicuousness of features; rather, they tend to have a hierarchical effect (Figure 8). 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 characteristics.

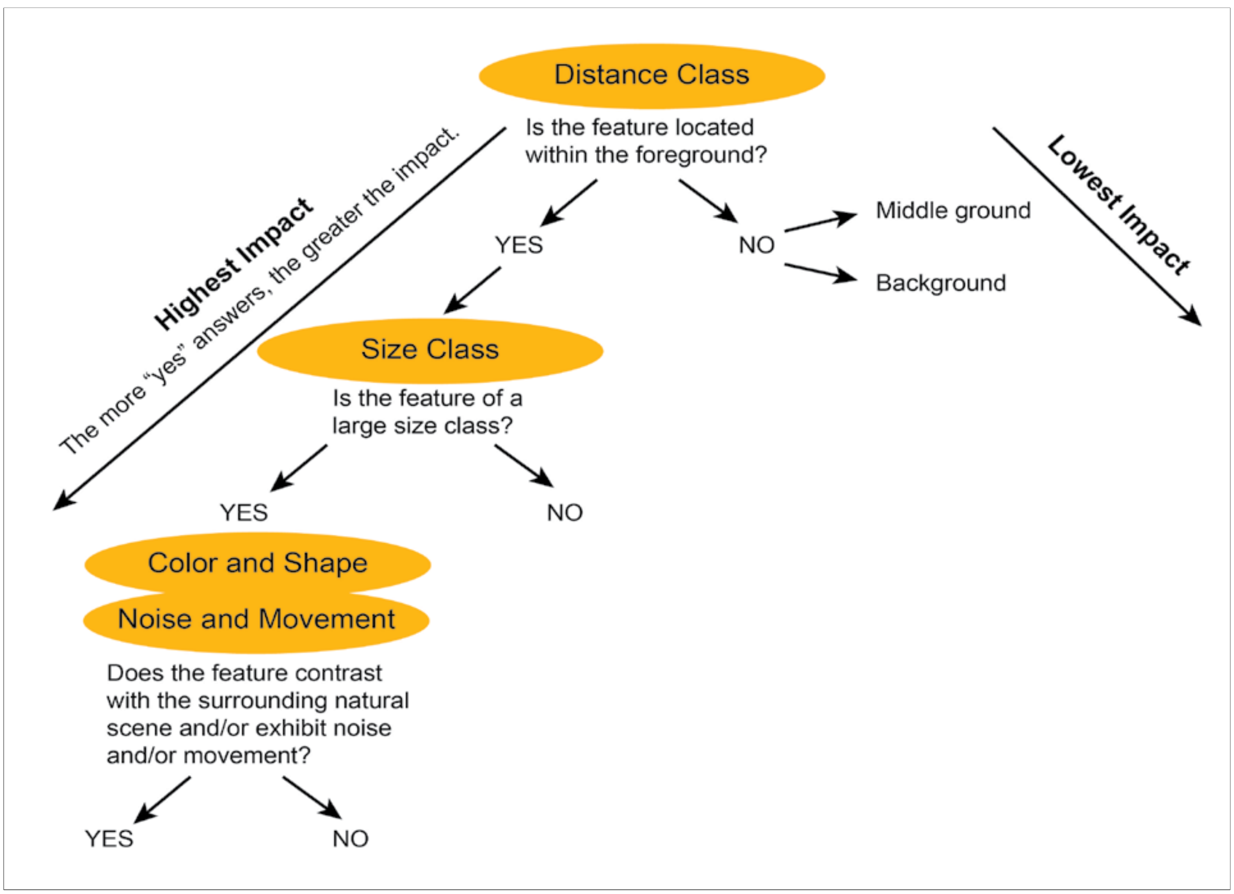


Figure 8. **Conceptual framework for hierarchical relationship of characteristics that influence the conspicuousness of features within a viewshed.**

The second component of the conspicuousness of non-contributing features included a geographic information system (GIS) analysis of the visible and non-visible areas from each of the three key observation points. Viewshed analyses were conducted using ArcGIS's Spatial Analyst Viewshed tool. We identified the viewshed area of analysis (AOA) as a 98 km^2 (61 mi^2) area surrounding each of the three key observation points. The viewshed analyses were calculated for this area since it represents the distance to which the average observer may distinguish man-made features depending on the above-mentioned characteristics (USFS 1995). We used the U.S. Geological Survey's (USGS) National Elevation Datasets (NED) at 1/3 arc-second resolution (approximately 10 m/32.8 ft resolution) to determine which areas should be visible from each observation point based on elevation within the AOA (USGS 2018a). The viewshed analysis for each location was used to support the GigaPan images described for the previous measure. The three AOAs were then combined to create a composite viewshed. Composite viewsheds are a way to show multiple viewsheds as one, providing an overview of the visible/non-visible areas across all observation points. The analysis assumes that the viewsheds were not hindered by non-topographic features such as vegetation; the observer was at ground level viewing from a height of 1.68 m (5.5 ft), which is the average height of a human; and visibility did not decay due to poor air quality. Additional details are listed in Appendix B. The composite viewshed was used to support the following two measures (i.e., extent of development and conservation status).

The extent of development provides a measure of the degree to which the viewshed has been 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 1995, Johnson et al. 2008). We considered two key factors in extent of development: road density and housing density.

Data for these two factors were derived from NPScape—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 2016, Monahan et al. 2012). NPScape data include seven major categories (measures), three of which were used in the viewshed condition assessment: housing, roads, and conservation status. These metrics were 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 Aztec Ruins NM. NPScape data were consistent, standardized, and collected in a repeatable fashion over time, and yet were flexible enough to provide analyses at many spatial and temporal scales. The NPScape datasets used in this analysis were described in the sections that follow.

The U.S. Census Bureau's TIGER/Line (Topologically Integrated Geographic Encoding and Referencing) shapefiles were used to calculate the road density within the monument's AOA (U.S. Census Bureau 2017). TIGER/Line products were last updated 1 January 2017 (U.S. Census Bureau 2017). We downloaded the "All Roads" shapefile, which includes primary, secondary, local neighborhood roads, rural roads, city streets, and vehicular trails (4WD) (U.S. Census Bureau 2017). Within the AOA, new road density rasters, feature classes, and statistics were generated from these data using the NPScape road density standard operating procedures (NPS 2015b). Finally, the road density output was overlaid with the composite viewshed from the three key observation locations in order to visualize density within the monument's viewshed.

The NPScape 2010 housing density metrics were 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 were grouped into six classes as shown in Table 10. NPScape's housing density standard operating procedure (NPS 2015c) and toolset were used to clip the raster to the monument's AOA then to recalculate the housing densities. The 2010 output was overlaid with the composite viewshed from the three key observation locations in order to visualize housing density within the monument's viewshed. Using the output from this analysis, we also calculated the percent change in housing density from 1970 to 2010 using ArcGIS Spatial Analyst's Raster Calculator tool.

According to Monahan et al. (2012), "the percentage of land area protected provides an indication of

Table 10. Housing density classes.

Grouped Housing Density Class	Housing Density Class (units / km^2)
Urban-Regional Park	Urban-Regional Park
Commercial / Industrial	Commercial / Industrial
Urban	>1,235
Suburban	146-1,234
Exurban	7-145
Rural and Private Undeveloped	0-6

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 NPS boundary), as well as opportunities (e.g., connectivity and networking of protected areas)." The USGS's GAP Analysis Program's Protected Area Database (PAD) provides GIS data on public land ownership and conservation lands in the U.S. (USGS GAP 2016). The lands included in the PAD were assigned one of four GAP Status codes based on the degree of protection and management mandates. Aztec Ruins NM is considered GAP Status 1, 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 2012).

NPScape's conservation status toolset was used to clip the PAD-US version 1.4 (USGS GAP 2016) to the monument's AOA, and then to recalculate the GAP Status and broad land ownership categories (e.g., federal, state, tribal, etc.) within the AOA (NPS 2015d). Finally, the conservation status output was overlaid with the composite viewshed from the three key observation locations in order to determine which GAP Status lands and lands by agency were most likely to be visible from the national monument.

Reference Conditions

We used qualitative reference conditions to assess the scenic and cultural integrity of Aztec Ruins NM's viewshed, which are presented in Table 11. Measures were described for resources in good condition, moderate concern condition, or significant concern condition.

Condition and Trend

Below we describe the conspicuousness of non-contributing features at each of the three key observation points beginning with the Animas River observation point. The GIS analysis for the Animas River key observation location shows a narrow but distant viewshed to the north northeast and west southwest (Figure 9). The most visible areas are located in the foreground and middle ground, but the viewshed extends at least as far as the farthest extent

Table 11. Reference conditions used to assess viewshed.

Indicator	Measures	Good	Moderate Concern	Significant Concern
Scenic and Cultural Integrity	Conspicuousness of Non-contributing Features	The distance, size, color and shape, and movement and noise of the non-contributing features blended into the landscape.	The distance, size, color and shape, and movement and noise of some of the non-contributing features were conspicuous and detracted from the natural and cultural aspects of the landscape.	The distance, size, color and shape, and movement and noise of the non-contributing features dominated the landscape and significantly detracted from the natural and cultural aspects of the landscape.
	Extent of Development	Road and housing densities were low, with minor to no intrusion on the viewshed.	Road and housing densities were moderate, with some intrusion on the viewshed.	Road and housing densities were high with significant intrusion on the viewshed.
	Conservation Status	Scenic conservation status was high. The majority of land area in the monument's viewshed was GAP Status 1 or 2.	Scenic conservation status was moderate. The majority of land area in the monument's viewshed was GAP Status 3.	Scenic conservation status was low. The majority of land area in the monument's viewshed was GAP Status 4.

of the background. This is generally consistent with the panoramas. In Figures 10 and 11, the visible areas extend to the foreground and portions of the middle ground, but not to the background. The background is mostly obscured by cottonwood (*Populus* spp.) trees in the riparian area and buildings in the foreground and middle ground. The viewshed analysis did not account for vegetation height or man-made structures. Although the buildings are non-contributing features, they are partially obscured by trees, especially when the cottonwoods leaf out. Aside from the buildings, other non-contributing features include the pedestrian bridge from which the panoramas were taken, light fixtures along the bridge, and power poles and lines in the foreground to the north and east. A staff member working to restore the riparian area is visible in the foreground to the north, but normally this area is not open to visitors. Finally, the NPS administrative buildings can be seen to the west through the trees, but as with the other structures, they will be less visible when the cottonwoods are leafed out. These NPS buildings are not part of the monument's historic district because of significant changes to the architecture over time (NPS 2002).

The pedestrian bridge was completed in 2014 as a joint effort between the New Mexico Department of Transportation, the NPS, and other stakeholders (Hannum 2012). The bridge connects the Aztec Trail System and the downtown area of the City of Aztec, New Mexico to the national monument (Hannum 2012). The purpose of the bridge was to improve visitor access to the monument and to encourage visitors to walk to events rather than drive, which may have positive effects on the viewshed since there is a road to the northwest (Hannum 2012). Although the road was not visible in the panoramas, any traffic along the road would be visible.

Most of the viewshed from this key observation point occurs outside of the monument. The observation point was located just inside the monument boundary

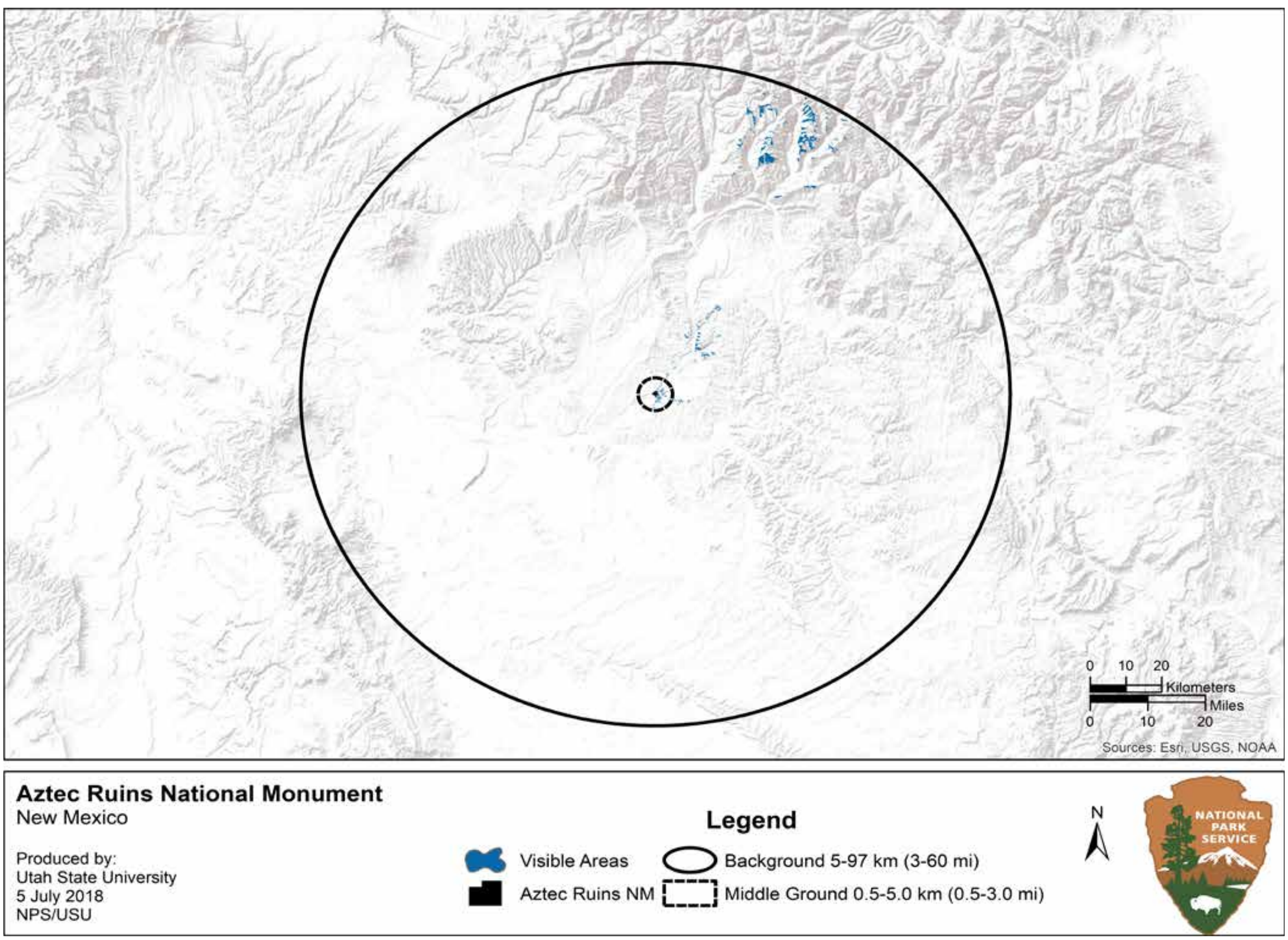


Figure 9. **The viewshed analysis from the Animas River key observation location.**

Figure 10. The north to east (top) and east to south (bottom) viewshed from the Animas River.

Figure 11. The south to west (top) and west to north (bottom) viewshed from the Animas River.

with the Animas River forming the monument's eastern boundary. Because there are several non-contributing features visible from this location, the overall viewshed is moderate concern. However, with continued restoration of the riparian area, the viewshed will likely improve. Confidence in the condition rating is high. Because these are baseline data, trend is unknown.

The viewshed from the Site 18 Overlook key observation location is limited to the foreground, middle ground, and only small portions of the background (Figure 12). The most distant views occur to the northeast and southwest. The observation location is situated within the ruins behind the visitor center and is within the monument's historic district, which includes the picnic area, the Puebloan structures, the visitor center and museum, the historic irrigation ditches, and the parking lot (NPS 2015a).

The viewshed analysis is generally consistent with the panoramas shown in Figures 13 and 14. Figure 13 shows the viewshed from the north to east in the top image and the view from the east to south in the bottom image. From this location, the most distant views are to the northeast. Views directly north and east are limited by topography but also by vegetation. Vegetation height was not accounted for in the viewshed analysis, however. In Figure 13 nearly all visible features contribute to the natural (e.g., trees) or cultural (e.g., ruins) viewshed, except for the gas well on the North Mesa and buildings outside the monument. The views to the south to north as shown in Figure 14 are similar with mostly contributing features in the foreground, including the ruins and trees. The visitor center and parking area to the west are also visible contributing features (NPS 2002). The visitor center was formerly the historic Earl Morris residence, and is composed of materials recovered from the archaeological site (NPS 2015a). Earl Morris was the first to excavate and reconstruct the ruins between 1916 and 1934 (NPS 2015a). Overall, the viewshed from this location is good. Most features contribute to the historic, natural, and cultural landscape and those that do not are limited in extent and visibility for at least part of

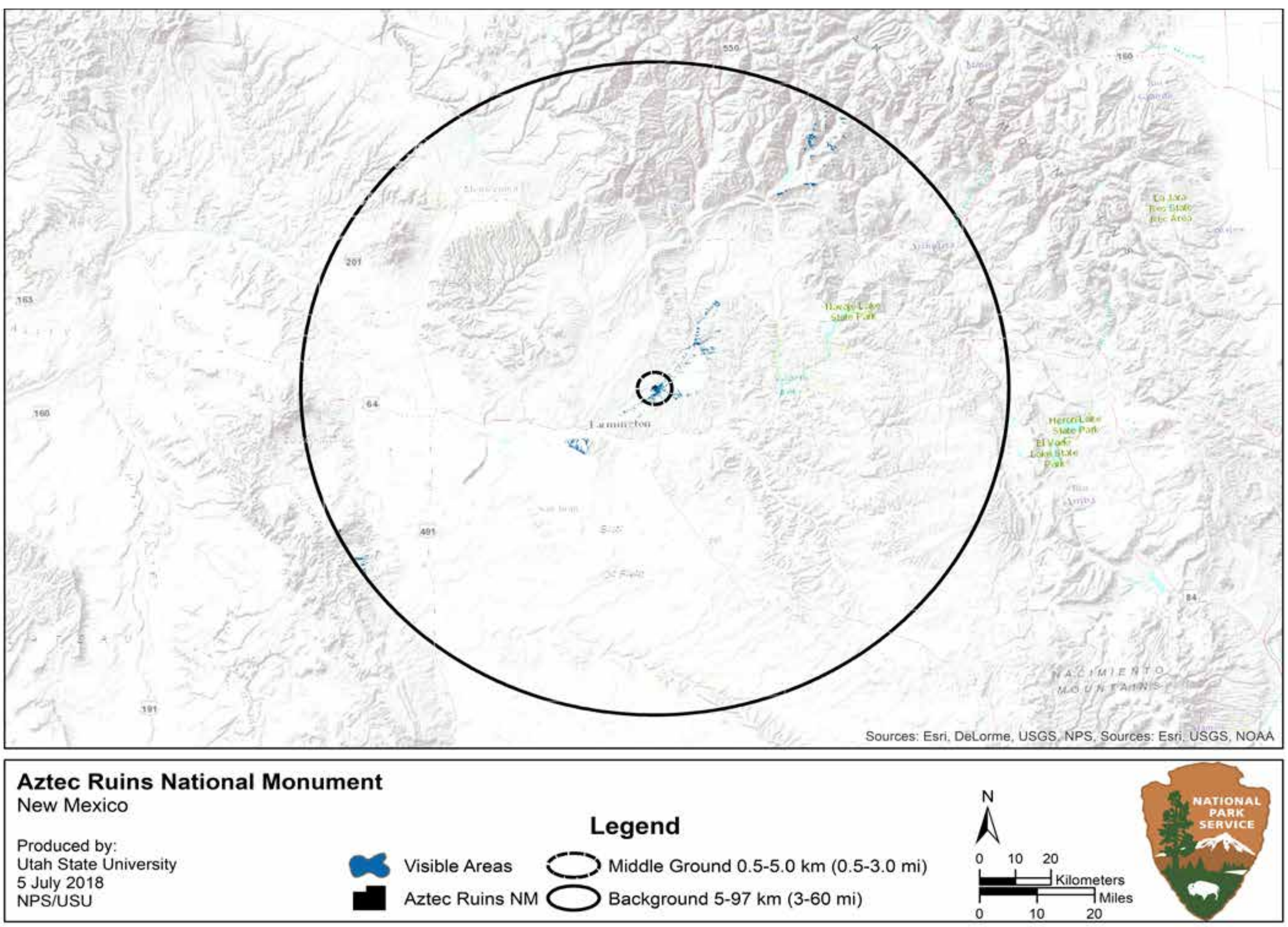


Figure 12. **The viewshed analysis from the Site 18 Overlook key observation location.**

Figure 13. **The north to east (top) and east to south (bottom) viewshed from Site 18 Overlook.**

Figure 14. **The south to west (top) and west to north (bottom) viewshed from the Site 18 Overlook.**

the year when trees are leafed out. Confidence in the condition rating is high. Trend is unknown.

As with the two other locations, the North Mesa viewshed occurs mostly in the foreground and middle ground with portions of the background visible to the north northeast and west southwest (Figure 15). These results are generally consistent with the panoramas shown in Figures 16 and 17. The views in Figure 16 show distant views from north to south. But because of the relatively flat topography of the landscape, judging distance is difficult. The North Mesa is an important cultural area, although most structures and artifacts are below the ground surface. The North Mesa is located on the north edge of the Animas River Valley and is registered as a cultural property by the State of New Mexico's Historic Preservation Division (NMHPD 2012). Non-contributing features in Figure 16 include power poles and associated power lines in addition to portions of the exurban community outside of the monument, including roads and housing. Figure 17 also includes portions of the exurban community below in the river valley. Power poles and lines are visible as is an active gas well that is fenced. In the middle ground, roads are also visible. For the most part, the viewshed from this location is good. The power lines, poles, and active gas well detract from the cultural sense of the landscape, but the viewshed of most significance is of the Animas River Valley and the ruins.

To summarize the conspicuousness of non-contributing features, the viewsheds at the three locations in Aztec Ruins NM are mostly intact. There are few non-contributing features and those that are visible detract little from the overall viewshed because of either distance, color, or context (e.g., pedestrian bridge). Although the monument is located in a non-urban setting as defined by the U.S. Census Bureau (2010), it is located within the city limits of Aztec, New Mexico. As a result, some non-contributing features are expected. Even so, they do not detract substantially from the monument's viewshed. Therefore, the

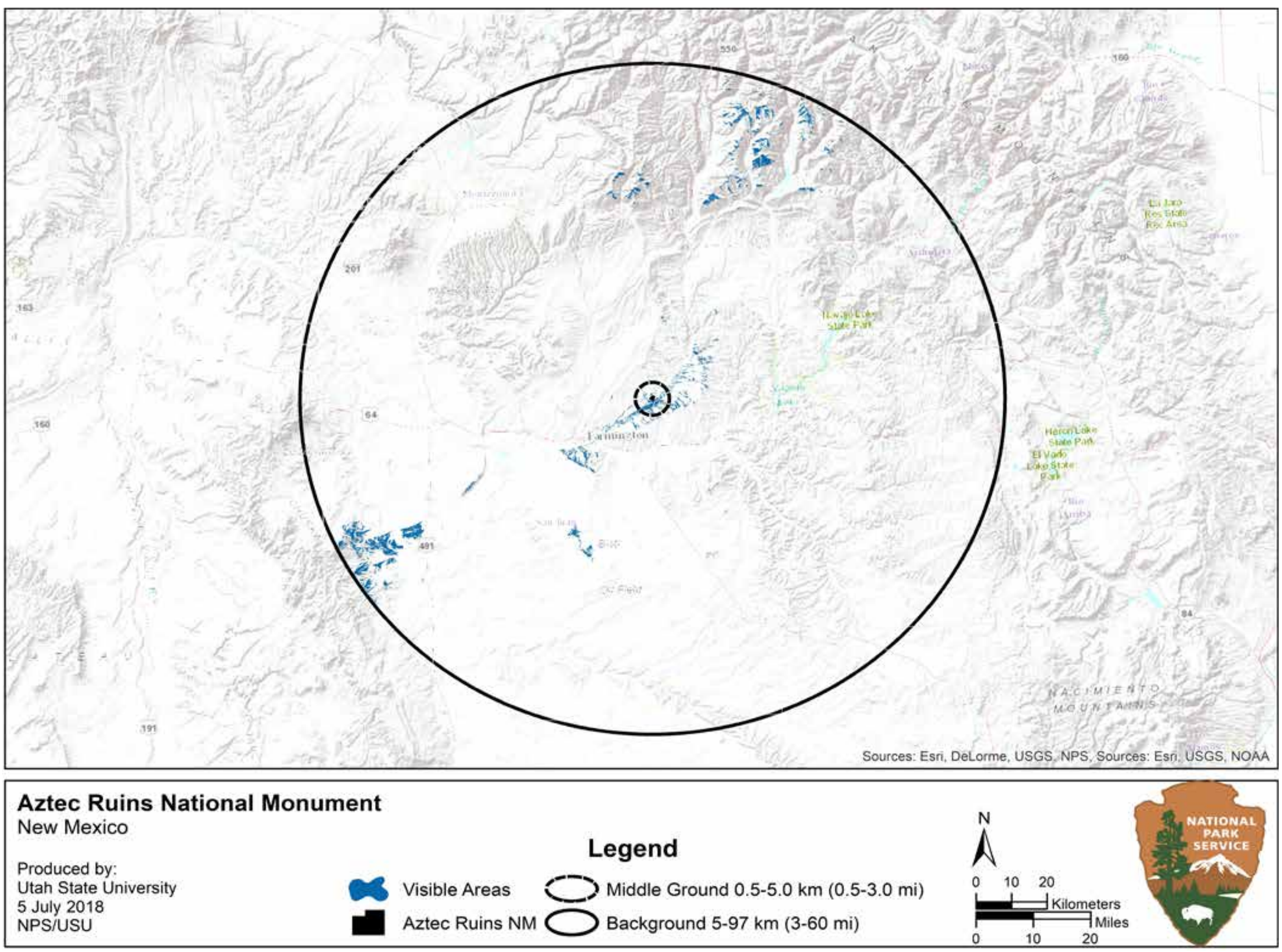


Figure 15. **The viewshed analysis from the North Mesa Overlook key observation location.**

Figure 16. **The north to east (top) and east to south (bottom) viewshed analysis from the North Mesa key observation location.**

Figure 17. **The south to west (top) and west to north (bottom) viewshed analysis from the North Mesa key observation location.**

condition is good. Confidence in the condition rating is high. Trend could not be determined. Rather, these images provide baseline data that can be used to compare to future panoramas.

The second measure, extent of development, was evaluated using road density and housing density. Figure 18 shows road density by various classes. Total road density within the 98 km (61 mi) AOA surrounding the monument was 1.41 km/km^2, which is moderate to high. More importantly, the monument's viewshed lies primarily within these roaded areas. However, roads were not evident in the panoramas, primarily as a result of the topography despite the viewshed analysis, which indicates that at least some of these roads should be more visible.

Based on data compiled in NPScape (Monahan et al. 2012), housing densities surrounding the monument were low (Table 12). Nearly all housing consisted of rural and private undeveloped lands (91.8%). The white spaces within the 98 km (61 mi) boundary shown in Figure 19 indicate no census data; thus, housing densities could not be calculated for these areas. However, these data originated with the U.S. Census Bureau, and units with unknown densities were probably not reported, which likely indicates undeveloped areas. The more distant viewshed to the west-southwest occurs within a rural or private undeveloped setting, whereas distant views to the north-northeast occur largely within unclassified white space, while the viewshed closer to the monument is located primarily within exurban and commercial/industrial areas. To the southwest, the viewshed was primarily within rural and private undeveloped areas. From 1970 to 2010, 37% of the AOA showed

Table 12. Housing densities within a 98 km (61 mi) buffer around Aztec Ruins NM.

Density Class	Area (km^2)	Percent
Rural and Private Undeveloped	17,135	91.8
Exurban	1,332	7.1
Suburban	59	0.3
Urban	1	0.01
Urban-Regional Park	81	0.4
Commercial/Industrial	63	0.3
Total Area	18,671	100

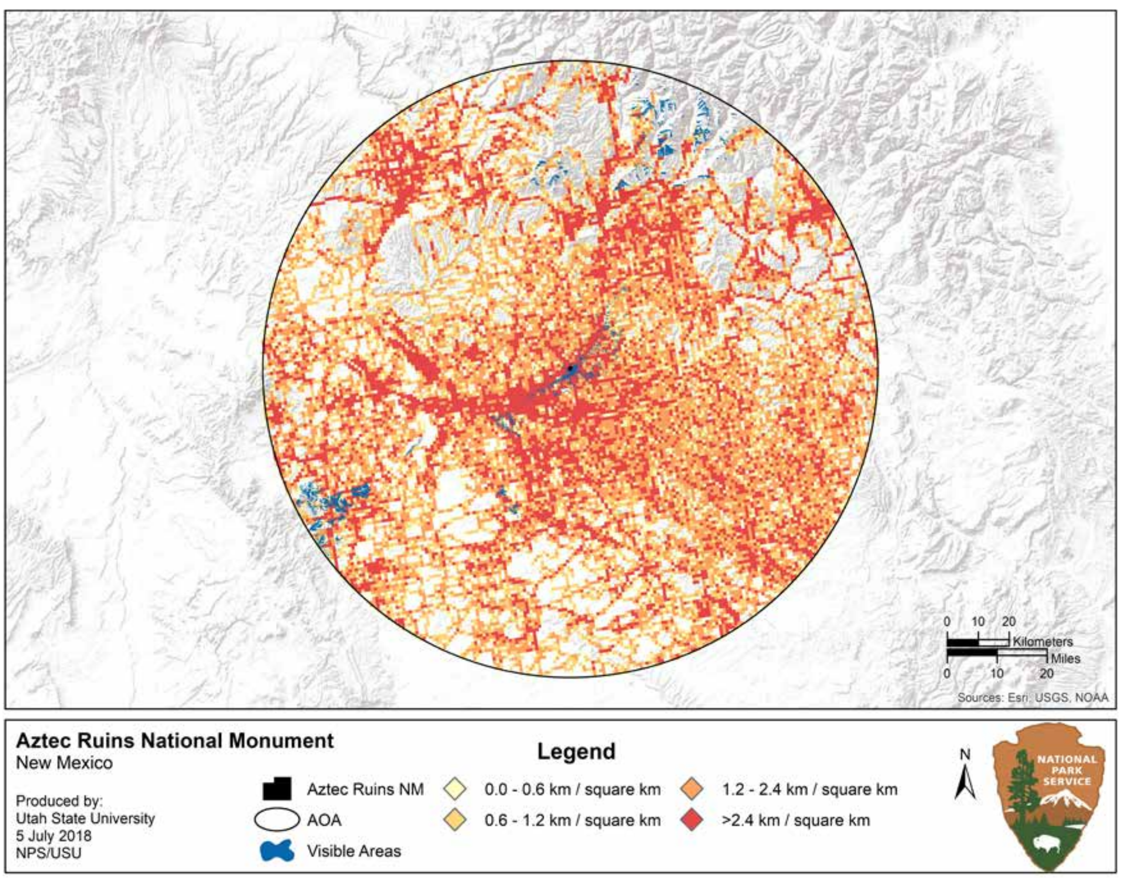


Figure 18. A map of road density surrounding Aztec Ruins NM.

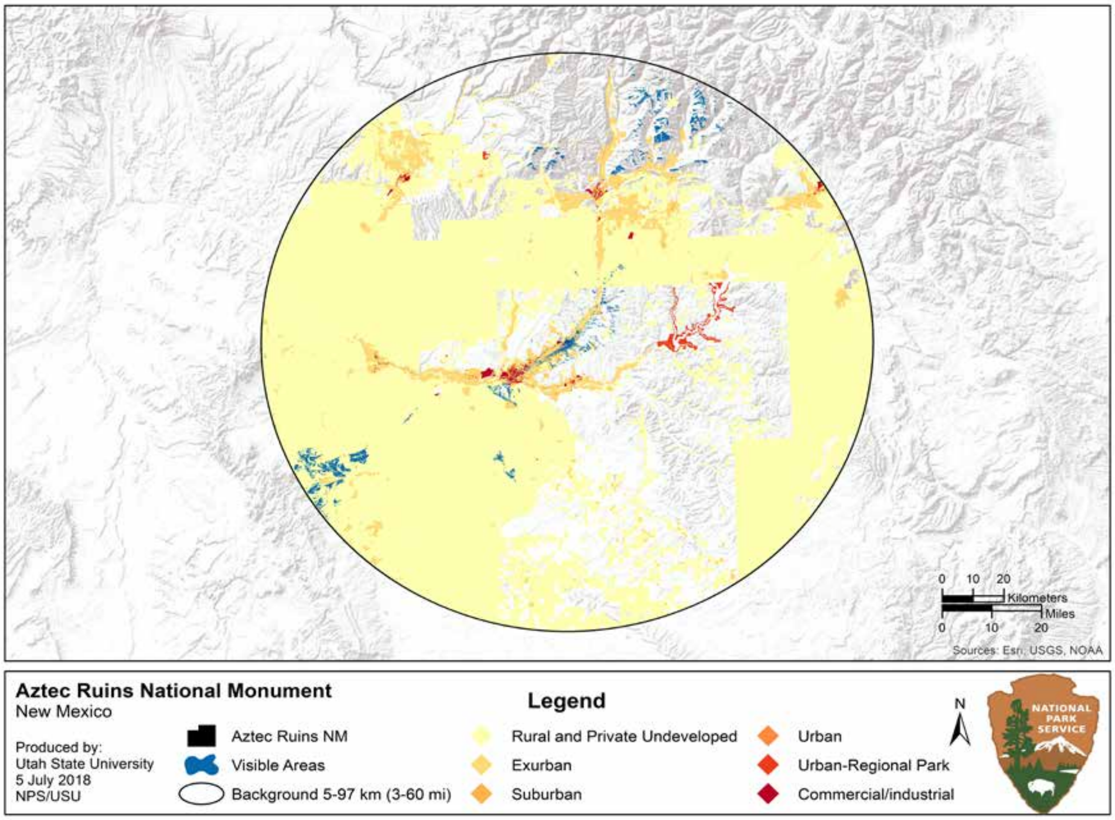


Figure 19. A map of housing density surrounding Aztec Ruins NM.

no change in housing density, while 63% of the AOA showed an increase in housing density. Less than 1% of AOA declined in housing density.

To summarize the extent of development measure, road density was moderate and housing density within the visible areas was almost entirely exurban and rural/private undeveloped, which indicates good condition. However, the visible areas closest to the monument were classified as high density housing. Since these areas are most visible from the monument, the overall condition is of moderate concern. Confidence is medium because of the resolution of the DEM. Finer-scale data would have allowed for a more refined viewshed analysis. Trend in housing density, which is related to road density, has deteriorated.

The following summarizes the condition for the third and final measure—conservation status. Figure 20 shows the amount of land within the composite viewshed and AOA. Of the total AOA, 99% was categorized in one of the four GAP status classes. More than half (53.3%) of land area within the AOA was within GAP Status 4, or lands with no known protections. Another 41.7% of classified lands were designated as GAP Status 3, or lands with permanent protection from conversion of natural land cover managed for multiple uses, ranging from low intensity (e.g., logging) to high intensity (e.g., mining). Only 5.4% of land within the AOA was GAP Status 1 (permanently protected lands managed for biodiversity and natural processes) or GAP Status 2 (permanently protected lands managed for biodiversity but with suppression of disturbances). The remaining 1% of land was not classified in any of the GAP status categories, which indicates private lands that are not enrolled in conservation easements or other conservation programs. The monument's viewshed lies primarily hin GAP Status 3 (closer to the monument) and 4 (more distant from the monument).

Figure 21 shows the management agencies that administer land within the AOA. The Bureau of Indian Affairs (BIA) administers the largest land area within the AOA (50.7%) followed by the USFS (34.9%). Most of the remaining lands (14.8%) are lands managed by the Bureau of Land Management (BLM), the State of New Mexico, New Mexico county or city lands, or the NPS. The viewshed surrounding the monument is managed by the BLM and the State Land Board. The viewshed to the southwest is managed by the BIA and

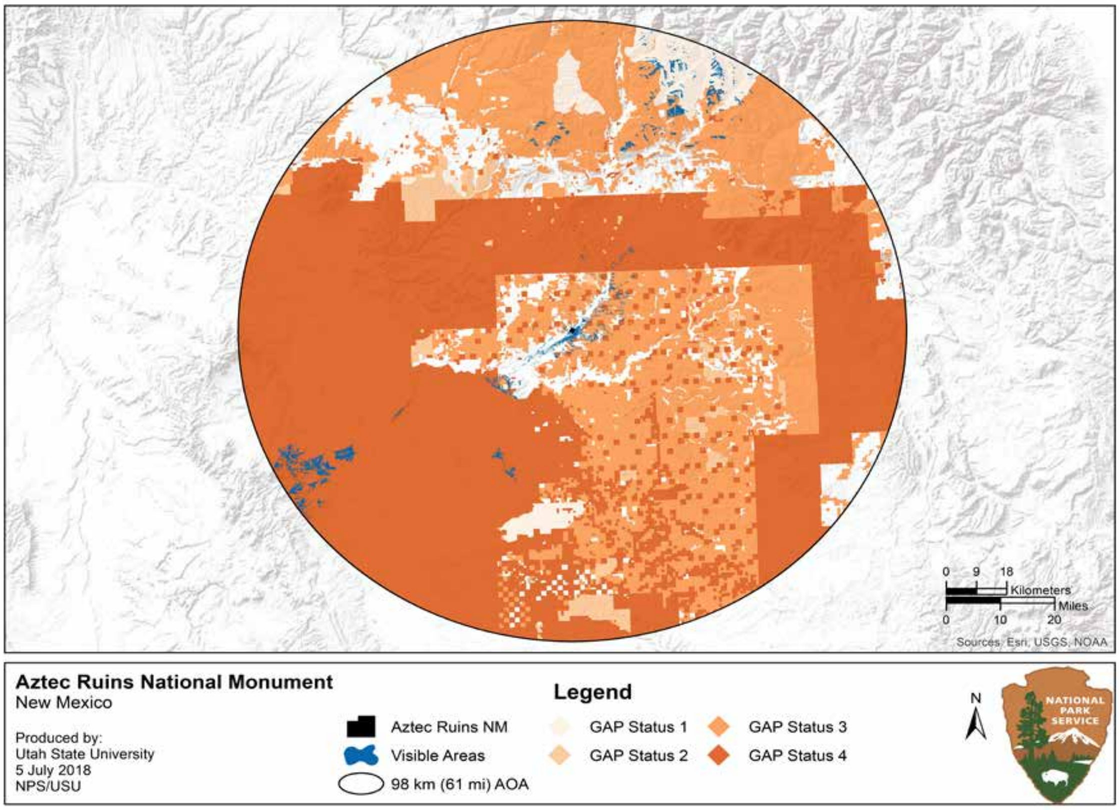


Figure 20. A map of GAP status lands surrounding Aztec Ruins NM.

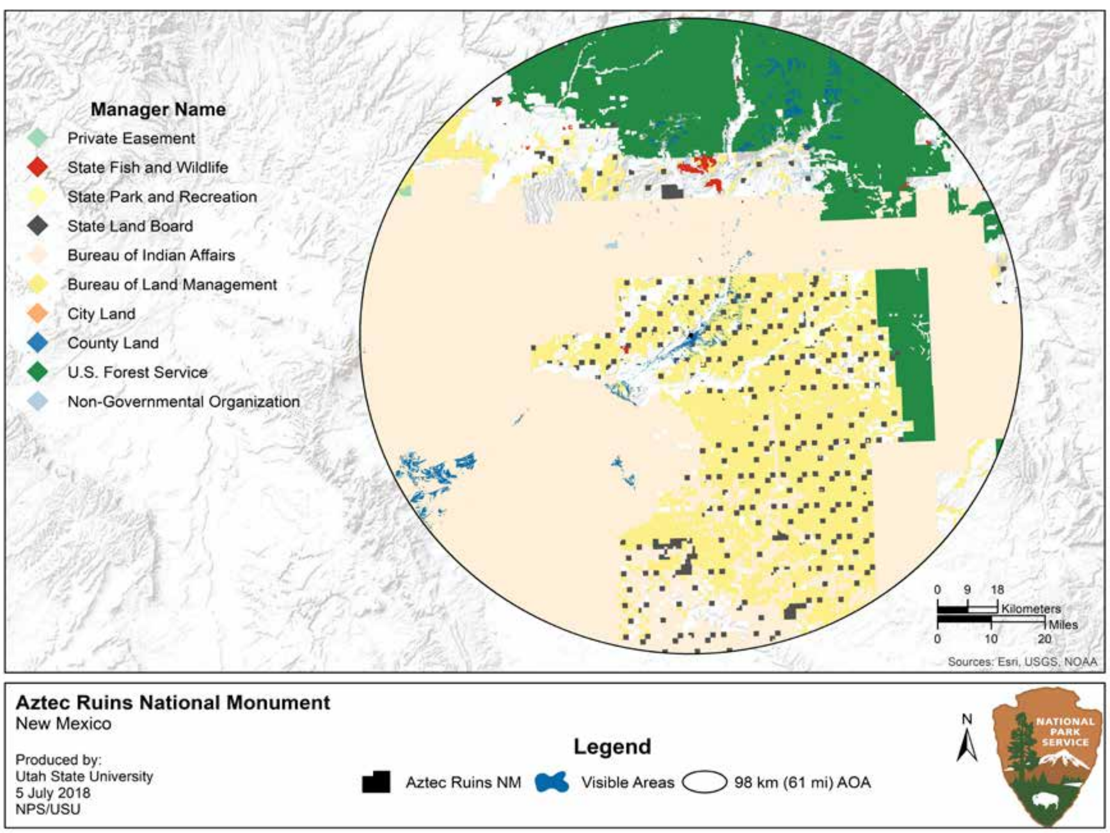


Figure 21. A map of lands managed by various agencies surrounding Aztec Ruins NM.

the viewshed to the northeast is managed primarily by the USFS.

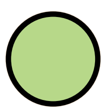
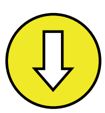
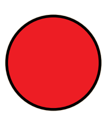
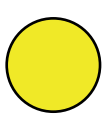
Overall, scenic conservation status was low, with most of the viewshed occurring in GAP Status 3 and 4 lands managed primarily by the BIA and USFS. Based on these results, the conservation status condition warrants significant concern. Trend is unknown. Although confidence in the GAP Status and land management agency data is high, the viewshed analysis has medium confidence. A finer resolution DEM coupled with an offset to account for vegetation height would possibly increase accuracy.

Overall Condition, Threats, and Data Gaps

Based on this assessment, the viewshed condition at Aztec Ruins NM is of moderate concern (Table 13). Because this assessment represents baseline conditions, we could not report on trend. Two of the three measures were assigned medium confidence and one was assigned high confidence. Factors that influence confidence level include age of the data (<5 years unless the data were part of a long-term monitoring effort), repeatability, field data versus modeled data, and whether data can be extrapolated to other areas of the monument. We assigned medium confidence to extent of development and conservation status measures because the viewshed analysis was based entirely on modeled data with a relatively coarse resolution DEM and did not account for vegetation or other factors that may have influenced the viewshed analysis. Thus, the overall confidence is medium. The viewshed analysis should not be used for planning purposes until ground-truthed.

Currently, the most significant threat to the viewshed at Aztec Ruins NM is development along the periphery of the monument, especially adjacent to the North Mesa. A housing development on this private land has been initiated but not completed. There are currently established driveways and roads but no structures. If a housing development were constructed, the viewshed would be significantly impacted by the intrusion of modern structures within view of the ruins (NPS 2015a). There are also important cultural artifacts on this private land, including a prehistoric North Road, which has already been damaged as a result of development (NPS 2015a). There are also two active gas wells located within the monument and one active gas well located outside the monument. Three other formerly active wells also occur in and around the monument. The active wells are accessed via a dirt road that is adjacent to the Great House site, which results in noise and dust (NPS 2015a). Factors that

Table 13. Summary of the viewshed indicators, measures, and condition rationale.

Indicator	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Scenic and Historic Integrity	Conspicuousness of Non-contributing Features		There were several non-contributing features in the monument's viewshed as observed from the three key observation locations. Most of these features were in the foreground and middle ground. But given the fact that the monument is located within city limits, the number and visibility of non-contributing features was not high. Trend is unknown and confidence is high.
	Extent of Development		The majority of all housing within the AOA consisted of rural and private undeveloped lands (~92%), but the areas that were most visible nearest the monument were high in housing density. Total road density (1.41 km/km^2) was moderate to high. Since 1970, 63% of the AOA increased in housing density while 37% has not changed. Based on these results, the condition for this measure warrants moderate concern. Trend has deteriorated and confidence is medium.
	Conservation Status		While there were some areas where scenic conservation status was high, many of the land management agencies responsible for the lands that were visible from Aztec Ruins NM's key observation points were not protected or allow for extractive uses. Therefore, the condition warrants significant concern. Because of uncertainties with the viewshed analysis, confidence is medium. Trend is unknown.
Overall Condition	Summary of All Measures		There were some non-contributing features in the monument's viewshed. The housing and road density analyses show that the region surrounding the monument is mostly rural, but the viewshed was located in areas of high road and housing densities. Most of the landscape in the AOA was GAP Status 4 followed by GAP Status 3. Confidence in the overall condition rating is medium. Overall trend is unknown.

influence air quality may also influence the viewshed. The haze index, which is a measure of visibility as described in the air quality assessment, warrants moderate concern at Aztec Ruins NM. Other threats include the deterioration of cultural features as a result of natural processes, vandalism, and theft of cultural artifacts (NPS 2015a). Light pollution from nearby communities as indicated in the night sky assessment and potential solar development are also threats to the viewshed (NPS 2012). Although power poles and power lines were visible from all three key observation points, they will eventually be buried and out of view, which would improve the viewshed (NPS, D. Hawkins, natural resource program lead, NRCA scoping meeting, 24 April 2018).

Data gaps include the need for fine-scale DEM. The 30-m DEM used in this assessment may have excluded some areas that should be visible or, conversely, included areas that are not visible. Although higher resolution LIDAR (light detection and ranging) data exist for the monument, these data were not available for the entire AOA.

Sources of Expertise

Assessment author was Lisa Baril, wildlife biologist and science writer, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A. Note that the measures and methods used for assessing the condition of the monument's viewshed are different from the measures/methods recommended by the NPS Visual Resources Program in the Air Resources Division under 2018 draft guidance that post-dates this viewshed assessment. Please contact the NPS Visual Resource Program for more information: visual_resources@nps.gov.

Night Sky

Background and Importance

Natural dark skies are a valued resource within the National Park Service (NPS) as reflected in NPS management policies (NPS 2006), which highlights 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 2010b). Additionally, in an estimated 20 national parks, stargazing events are the most popular ranger-led program (NPS 2010b).

The value of night skies goes 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 (Longcore and Rich 2004). Natural light intensity varies during the day-night (diurnal) cycle, the lunar cycle, and the seasonal cycle. Animal species 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 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.

At Aztec Ruins National Monument (NM) celestial phenomena influenced Ancestral Puebloan architecture. For example, the West great house was constructed to align with the summer and winter solstices (D. Hawkins, pers. comm., 7 June 2018). Ranger-led programs highlight these types of celestial events, including full moon walks, star talks, and its first "Shooting Star Party" in August 2017 in honor of the annual Perseid meteor shower. Preserving a dark night sky is essential for the continuation of these programs.

The Milky Way at Aztec Ruins NM. Photo Credit: © Bettymaya Foott.

Data and Methods

The NSNSD goals of measuring night sky brightness are to describe the quality of the lightscape, quantify how much it deviates from natural conditions, and to describe changes over time as a result of both natural and anthropogenic sources in areas within and outside of national parks (Duriscoe et al. 2007). In this assessment, we characterize the night sky environment in Aztec Ruins NM using two measures that quantify sky brightness. The two measures are all-sky light pollution ratio and zenith sky brightness, both of which are described in more detail below.

The all-sky light pollution ratio (ALR) describes the amount of light that is due to man-made sources compared to light from a natural dark sky. It is the average anthropogenic sky luminance presented as a ratio over natural conditions (Moore et al. 2013). 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 the natural components of the night sky allow separation of anthropogenic light from natural features, such as the Milky Way. 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 (Moore et al. 2013). 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% as bright as the natural light from the night sky (Moore et al. 2013).

This metric is a convenient and robust measure. It 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. Modeled ALR data were based on 2015 National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) Day/Night Band data collected by the Visible Infrared Imaging Radiometer Suite instrument located on the Suomi National Polar Orbiting Partnership satellite (NASA 2018).

Zenith sky brightness describes the amount of light observed in the night sky overhead (Duriscoe 2016). The zenith is generally considered the darkest part of a pristine sky. Data were collected using an International Dark Sky Association-approved Unihedron Sky Quality Meter (SQM) on 21 September 2017. Bettymaya Foott, a representative from the Colorado Plateau Dark Skies Cooperative collected these data at the following four locations: Hubbard Site, North Wall, East Wall, and Plaza. Four measurements were collected at each site for a total of 16 measurements. Measurements were collected between 9:10 p.m. and 10:36 p.m. Sky conditions were initially clear, but cloud cover increased throughout the observation period. Data were provided to park staff via e-mail on 30 November 2017.

Reference Conditions

Table 14 summarizes the condition thresholds for measures in good, moderate concern, and significant concern condition. 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 2010b). Aztec Ruins NM is considered an urban NPS unit, or area with at least 90% of its property located within an urban area (Moore et al. 2013). For urban NPS units the thresholds separating reference conditions are less stringent than those for non-urban NPS units because on an already altered urban sky, it is less sensitive to the effects of additional light pollution.(Moore et al. 2013).

For the light pollution ratio measure, the threshold for night skies in good condition is an ALR of <2.00 and the threshold for warranting moderate concern is an ALR between 2.00 and 18.00. An ALR of >18.00 would warrant significant concern (Moore et al. 2013).

Table 14. Reference conditions used to assess the night sky.

Indicator	Measures	Good	Moderate Concern	Significant Concern
Sky Brightness*	All-sky Light Pollution Ratio (ALR)	ALR <2.00 (<156 nL average anthropogenic light in sky)	ALR 2.00-18.00 (156 - 1404 nL average anthropogenic light in sky)	ALR >18.00 (>1404 nL average anthropogenic light in sky)
	Zenith Sky Brightness (msa)	≥21.20	19.70-21.19	<19.70

*National Park Service Natural Sounds and Night Skies thresholds for urban parks. Urban parks are those with at least 90% of their land located within an urban area (Moore et al. 2013).

Reference conditions for zenith 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 (NPS NSNSD 2016). For the minimum night sky brightness measure, the darkest part of a natural night sky is generally found near the zenith (NPS NSNSD 2016). 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 10x; thus a 19.5 msa sky would be 10x brighter than natural conditions (NPS NSNSD 2016). Minimum night sky brightness values of 21.4 to 22.0 msa, are generally considered to represent natural (unpolluted) conditions (Duriscoe et al. 2007). For urban NPS units, a good condition would be a zenith sky brightness of ≥21.20 and a significant concern rating would be a zenith sky brightness of <19.70.

Condition and Trend

The NPS Night Skies Program modeling show a median monument-wide ALR of 5.91, which corresponds to 591% brighter than average natural conditions. This value falls within the moderate concern condition rating. Confidence in this condition rating is medium since the data were modeled and there are no supporting field measurements. Trend could not be determined.

Figure 22 shows the modeled ALR for the region surrounding Aztec Ruins NM. The figure shows that the monument is most influenced by lights from the surrounding cities of Farmington and Aztec, New Mexico. Although the light domes of Albuquerque, New Mexico; Denver, Colorado; and Phoenix, Arizona do not seem to affect the overall ALR at Aztec Ruins NM, lights within 300 km (~200 mi) could be seen from the monument during a clear night.

Zenith sky brightness varied from 20.74 msa to 20.07 msa (darkest to brightest) (Table 15). All 16 values fell within the moderate concern condition rating. Therefore, the overall condition for this measure of sky brightness warrants moderate concern. The values

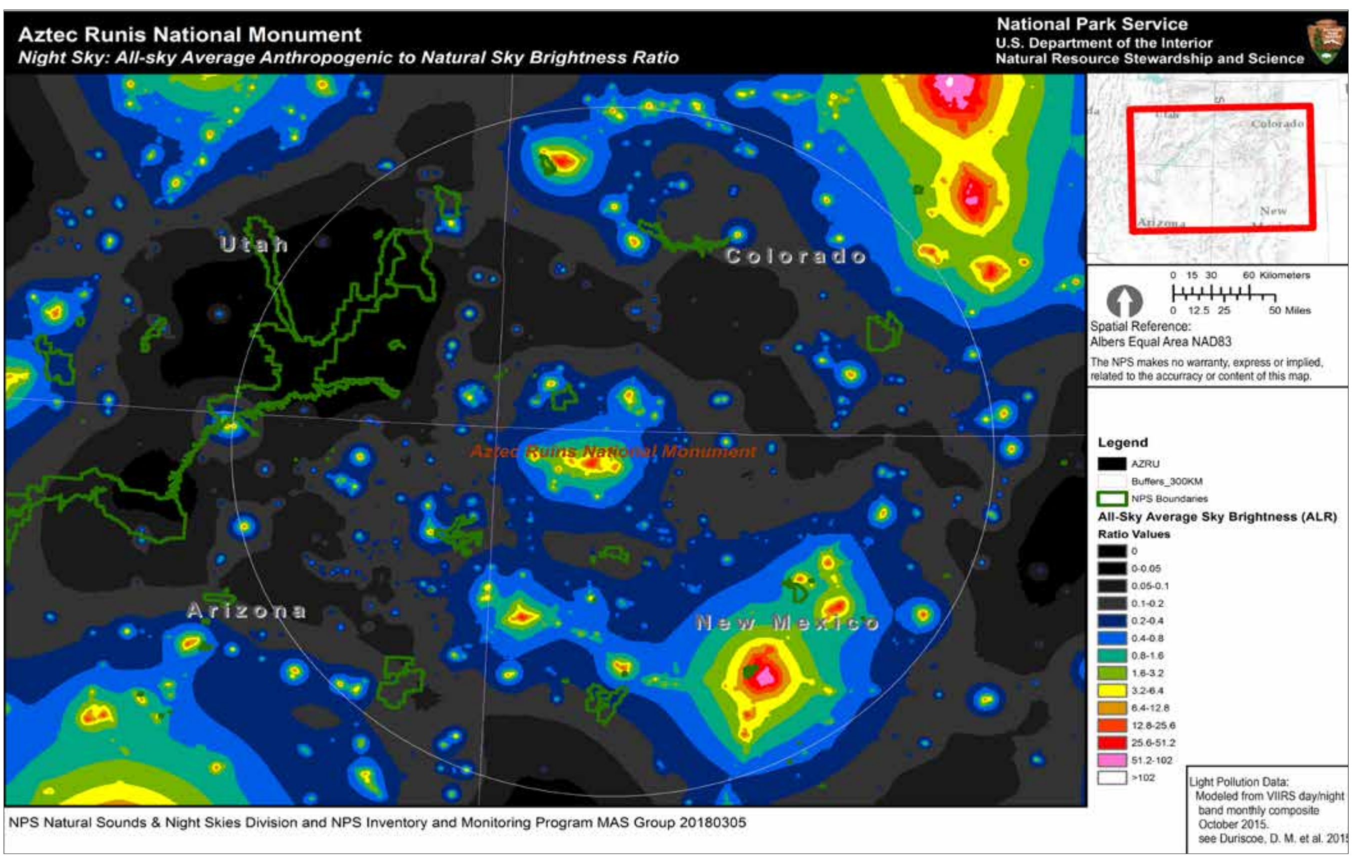


Figure 22. **Modeled ALR map for Aztec Ruins NM. Figure Credit: NPS Natural Sounds and Night Skies Division.**

Table 15. Unihedron sky quality meter measurements collected 21 September 2017 at Aztec Ruins NM.

Location	Zenith Sky Brightness (msa)
Hubbard Site	20.74
	20.64
	20.72
	20.68
North Wall	20.58
	20.27
	20.34
	20.53
East Wall	20.11
	20.50
	20.52
	20.40
Plaza	20.11
	20.07
	20.16
	20.10

Source: Data provided by Aztec Ruins NM staff and were collected by the Colorado Plateau Dark Skies Cooperative.

indicate that sky brightness increased by site; however, the increase in cloud cover over the observation period is likely the reason for the apparent increase in this measure. Although there may be differences in sky brightness at each site, measurements collected over a clear night with unchanging conditions would better address potential site differences. Confidence in the condition rating is medium because the Unihedron SQM has a wide field of view so that artificial sky glow along the horizons may be partially captured by the instrument (NPS NSNSD 2016). Nevertheless, these data provide a useful way to monitor the night sky over time. Furthermore, these values are conservative measures of sky brightness because of the wide field of view. Trend could not be determined based on a single night of measurements.

Overall Condition, Threats, and Data Gaps

In summary, the overall condition for the night sky in Aztec Ruins NM is of moderate concern based on the two measures of sky brightness (Table 16). Confidence in the condition rating is medium. Generally, measures with high confidence weigh more heavily into the overall condition rating than measures with medium or low confidence. In this assessment, however, both measures were assigned medium confidence. Trend could not be determined.

Aztec Ruins NM lies within the Four Corners region of the Colorado Plateau and is within the Colorado Plateau Dark Sky Cooperative (CPDSC)—the first effort to protect dark night skies across a large region (CPDSC 2018). There are 17 national parks, state parks, and communities on the Colorado Plateau that have been designated as International Dark Sky Parks or Dark Sky Places (CPDSC 2018). The low population density of the region coupled with good air quality and large amount of public lands makes the Colorado Plateau an ideal place for promoting the importance of dark night skies.

Because Aztec Ruins NM is located in an urban area, lighting from the city of Aztec, New Mexico as well as other nearby cities including Farmington,

Table 16. Summary of night sky indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Sky Brightness	All-sky Light Pollution Ratio (ALR)	(yellow circle)	The modeled park-wide ALR of 5.91 corresponds to a condition rating of moderate concern. Confidence in this condition rating is medium since data were modeled. Trend could not be determined.
	Zenith Sky Brightness (msa)	(yellow circle)	Zenith sky brightness varied from 20.74 to 20.07 msa on 21 September 2017. All measures were within the moderate concern condition rating. Confidence is medium because the Unihedron Sky Quality Meter may include anthropogenic light along the horizons in addition to light at the zenith. Therefore, these data serve as a conservative estimate of zenith sky brightness. Trend could not be determined based on one night of data collection.
Overall Condition	Summary of All Measures	(yellow circle)	Overall, the night sky at Aztec Ruins NM warrants moderate concern. This condition rating is based on two measures of sky brightness. Confidence in the condition rating is medium since both measures were assigned medium confidence. Overall trend could not be determined.

New Mexico and other cities in San Juan County, influence the quality of the night sky in the monument. Development along the periphery, headlights from road traffic, and lights associated with oil and natural gas development all contribute to anthropogenic light pollution. Additionally, light pollution also originates from gas production activities, more broadly. Drilling rigs are temporary, but refineries, plants, and other infrastructure likely contribute more light pollution over time, and possibly overall. Also, coal power plants near Kirtland and Shiprock, New Mexico likely contribute to light pollution in the surrounding area. However, the city of Aztec has retrofitted some of their lighting structures to reduce nighttime light pollution (NPS, D. Hawkins, natural resource program lead, verbal communication during NRCA scoping meeting, 24 April 2018). Bloomfield and Farmington, New Mexico could also be a part of the Western Area Power Administration (WAPA) agreement, and could very well be working towards energy friendly and lower impact lighting as well (WAPA n.d.)

On a broader scale, air pollution (e.g., haze and dust) may degrade the night sky environment. The Four Corners region is known as a methane hotspot, and methane causes atmospheric haze (Frankenberg et al. 2016). The haze index, which is a measure of visibility, warrants moderate concern at Aztec Ruins NM (refer to air quality assessment). Data gaps include the absence of other night sky measures such as the Bortle Dark Sky scale, vertical and horizontal illuminance, and ground-based ALR measurements. It would also be useful to repeat measurements on a regular basis to track changes over time.

Sources of Expertise

The NPS Natural Sounds and Night Skies Division helps parks manage the night sky in a way that protects park resources and the visitor experience. They provide technical assistance to parks in the form of monitoring, data collection and analysis, and in developing baselines for planning and reporting purposes. For more information, visit the NPS NSNSD website (NPS NSNSD 2018). Assessment author is Lisa Baril, science writer, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Air Quality

Background and Importance

The National Park Service's (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA), guide the NPS to protect air quality and any air quality related values (e.g., scenic, biological, cultural, and recreational resources) within national parks that may be impaired from air pollutants.

Among the main purposes of the CAA is "to preserve, protect, and enhance the air quality in national parks" and other areas of special national or regional 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 Air Resources Division [ARD] 2018a).

Two 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).

While Aztec Ruins National Monument (NM) is designated as a Class II airshed, NPS management policies do not distinguish between the levels of protection afforded to any park of the National Park System (NPS 2006). All units of the National Park System are managed to protect resources for the benefit of the current and future generations.

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 U.S. Environmental Protection Agency (USEPA) 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 (USEPA 2016). The two types of NAAQS are primary and secondary, with the primary standards establishing limits to protect human health, and the secondary standards establishing limits to protect public welfare from air pollution effects, including decreased visibility, and damage to animals, crops, vegetation, and buildings (USEPA 2016).

The NPS ARD (NPS ARD) uses USEPA's NAAQS, natural visibility goals and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout Park

A clear blue sky at Aztec Ruins NM. Photo Credit: © L. Baril.

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

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, powerplants, industry, fire, and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Wondrak-Biel 2011). It is one of the most widespread air pollutants, and the major constituent in smog. Ozone can be harmful to human health. Exposure to ozone can irritate the respiratory system and increase the susceptibility of the lungs to infections (NPS ARD 2018b).

Ozone is also phytotoxic, causing foliar damage to plants (NPS ARD 2018c). Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters physiological and biochemical processes (NPS ARD 2018c). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death but more often reduces the plant's resistance to insects and diseases, limits growth, and lowers reproductive capability (NPS ARD 2018c). Foliar damage requires the interplay of several factors, including the sensitivity of the plant to the ozone, the level of ozone exposure, and the exposure environment (e.g., soil moisture). The highest ozone risk for plants exists when a species is 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 (NPS ARD 2018c).

Air pollutants can be deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen and sulfur air pollutants are commonly deposited as nitrate, ammonium, and sulfate ions and can have a variety of effects on ecosystem health, including acidification, fertilization or eutrophication. Mercury or toxins can also be deposited to ecosystems (NPS ARD 2010, Fowler et al. 2013). 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 nitrogen or sulfur deposition 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, and some grasslands (NPS ARD 2018c). Increases in nitrogen have been found to promote invasions of fast-growing non-native annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and forbs (e.g., Russian thistle [*Salsola tragus*] at the expense of native species (Allen et al. 2009, Schwinning et al. 2005). Increased grasses can increase fire risk (Rao et al. 2010), with profound implications for biodiversity in non-fire adapted ecosystems. Nitrogen may also increase water use in plants like big sagebrush (*Artemisia tridentata*) (Inouye 2006).

According to the USEPA (2017), in the United States, roughly two thirds of all sulfur dioxide (SO_2) and one quarter of all nitrogen oxides (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, impacting resources (USEPA 2017), including at Aztec Ruins NM.

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health. Elevated levels of mercury and other airborne toxic pollutants such as pesticides in aquatic and terrestrial food webs can act as neurotoxins in biota that accumulate fat and/or muscle-loving contaminants. 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 2018d).

Additional air contaminants of concern include pesticides (e.g., DDT), industrial by-products (PCBs), and emerging chemicals such as flame retardants for fabrics (PBDEs). These pollutants enter the atmosphere from historically contaminated soils, current day industrial practices, and air pollution (Selin 2009).

Data and Methods

The approach we used to assess the condition of air quality within Aztec Ruins NM's airshed was developed by the NPS ARD for use in Natural Resource Condition Assessments (NPS ARD 2018e). NPS ARD uses three indicators with a total of six measures. The indicators are visibility (one measure), level of ozone (two measures), and wet deposition (three measures) (Table 17). NPS ARD uses all available data from NPS, USEPA, state, and/or tribal monitoring stations to interpolate air quality values. Even though the data were derived from all available monitors, data from the closest stations "outweigh" the rest. Trends are computed from data collected over a 10-year period (2006-2015) at on-site or nearby representative monitors. Trends are calculated for sites that have at least six years of annual data and an annual value for the end year of the reporting period.

Table 17. Summary of indicators and their measures.

Indicators	Measures
Visibility	Haze Index
Level of Ozone	Human Health, Vegetation Health
Wet Deposition	Nitrogen, Sulfur, Mercury, Predicted Methylmercury Concentration

The haze index is the single measure of the visibility indicator used by NPS-ARD. Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS ARD 2010) and annual average measurements for Group 50 visibility (i.e,. days during which the visibility is between the 40th and 60th percentiles) are averaged over a 5-year period (2011-2015) 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 Aztec Ruins NM's boundaries is reported as the visibility condition from this national analysis. There were no on-site or nearby monitors with which to determine trends. Representative monitors to evaluate trends must be within 30.5 m (100 ft) or 10% of maximum and minimum elevation of the park and at a distance of no more than 150 km (93 mi).

The second indicator (ozone) is monitored across the U.S. through air quality monitoring networks operated by the NPS, USEPA, states, and others. Aggregated ozone data were acquired from the USEPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the USEPA Clean Air Status and Trends Network (CASTNet) database. Trends were derived from AQS monitor 350450009, NM located south of Aztec Ruins NM.

The first measure of ozone is related to human health and is referred to as the annual 4th-highest 8-hour concentration. The primary NAAQS for ground-level ozone was set by the USEPA based on human health effects. The 2015 NAAQS for ozone is the 4th-highest daily maximum 8-hour ozone concentration of 70 parts per billion (ppb) (USEPA 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 were averaged over a 5-year period (2011-2015) at all monitoring sites. Five-year averages were 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 was the maximum estimated value within its boundaries derived from this national analysis.

The second measure of ozone is related to vegetation health and is referred to as the 3-month maximum 12-hour 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 from March to September was reported in "parts per million-hours" (ppm-hrs) and was used for vegetation health risk from ozone condition assessments. Annual maximum 3-month 12-hour W126 values were averaged over a 5-year period (2011-2015) at all monitoring sites with at least three years of complete annual data. Five-year averages were 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 was the maximum value within its boundaries derived from this national analysis.

The indicator of atmospheric wet deposition was evaluated using a measure of nitrogen and sulfur. Nitrogen and sulfur were monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) for nitrogen and sulfur wet deposition. Wet deposition was used as a surrogate for total deposition (wet plus dry), because wet deposition is the most widely monitored source of nitrogen and sulfur deposition data. Values for nitrogen (N) from ammonium and nitrate and sulfur (S) from sulfate wet deposition were 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 was averaged over a 5-year period (2011-2015) at monitoring sites with at least three years of annual data. Five-year averages were 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 were reported from this national analysis. To maintain the highest level of protection in the park, the maximum value was assigned a condition status. NPS ARD considers stations located farther than 16 km (10 mi) from the park outside the range that is representative for calculating trends (Taylor 2017).

The last measure of the wet deposition indicator was evaluated using a mercury risk assessment matrix. The matrix combines estimated 3-year average (2013-2015) mercury wet deposition (ug/m^2/yr) and the predicted surface water methylmercury concentrations at NPS Inventory & Monitoring parks. Mercury wet deposition was monitored across the United States by the Mercury Deposition Network (MDN). Annual mercury wet deposition measurements were averaged over a 3-year period at all NADP-MDN monitoring sites with at least three years of annual data. Three-year averages were then interpolated across all monitoring locations using an inverse distance weighting method to estimate 3-year average values for the contiguous U.S. The maximum estimated value within park boundaries derived from this national analysis was used in the mercury risk status assessment matrix.

Conditions of predicted methylmercury concentration in surface water were 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 (U.S. Geological Survey [USGS] 2015). The predicted methylmercury concentration at a park was the highest value derived from the hydrologic units that intersect the park. This value was used in the mercury risk status assessment matrix.

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 they are biologically available and able to accumulate in food webs (NPS ARD 2018d). 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 (Taylor 2017).

NPS ARD considers wet mercury deposition monitoring stations located farther than 16 km (7 mi) outside the range that is representative for calculating trends (Taylor 2017). There were no representative wet deposition monitoring stations for the monument.

Reference Conditions

The reference conditions against which current air quality parameters were assessed are identified by Taylor (2017) for NRCAs and listed in Table 18.

A haze index estimated at less than 2 dv above estimated natural conditions indicates a “good” condition, estimates ranging from 2-8 dv above natural conditions indicate a “moderate concern” 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.

The human health ozone condition thresholds were based on the 2015 ozone standard set by the USEPA (2016) at a level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 70 ppb. The NPS ARD rates ozone condition as: “good” if the ozone concentration was less than or equal to 54 ppb, which is in line with the updated Air Quality

Table 18. Reference conditions for air quality parameters.

Indicator and Measure	Very Good	Good	Moderate Concern	Significant Concern
Visibility Haze Index	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
Nitrogen and Sulfur 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
Predicted Methylmercury Concentration (ng/L)	< 0.038	≥ 0.038 and < 0.053	≥ 0.053 and < 0.075	≥ 0.075

Source: Taylor (2017).

Note: NPS ARD includes very good and very high standards. In order to conform with NRCA guidance, very low was considered good and very high was considered significant concern condition.

Index breakpoints; "moderate concern" if the ozone concentration was between 55 and 70 ppb; and of "significant concern" if the concentration was greater than or equal to 71 ppb.

The vegetation health W126 condition thresholds were based on information in the USEPA's Policy Assessment for the Review of the Ozone NAAQS (USEPA 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; this level was considered good; 7-13 ppm-hrs was considered to be of "moderate" concern; and >13 ppm-hrs was considered to be of "significant concern" (Taylor 2017).

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. This was based on studies linking early stages of aquatic health decline with 1.0 kg/ha/yr wet deposition of nitrogen both in the Rocky Mountains (Baron et al. 2011) and in the Pacific Northwest (Sheibley 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 a "moderate concern" condition, and parks with depositions greater than 3 kg/ha/yr are considered to be of "significant concern."

Ratings for mercury wet deposition and predicted methylmercury concentrations can be evaluated using the mercury condition assessment matrix shown in Table 19 to identify one of three condition categories. Condition adjustments may be made if the presence of park-specific data on mercury in food webs is available and/or data are lacking to determine the wet deposition rating (Taylor 2017).

Table 19. Mercury condition assessment matrix.

Predicted Methylmercury Concentration Rating	Mercury Wet Deposition Rating				
	Very Low	Low	Moderate	High	Very High
Very Low	Good	Good	Good	Moderate Concern	Moderate Concern
Low	Good	Good	Moderate Concern	Moderate Concern	Moderate Concern
Moderate	Good	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern
High	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern
Very High	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern	Significant Concern

Source: Taylor (2017).

Condition and Trend

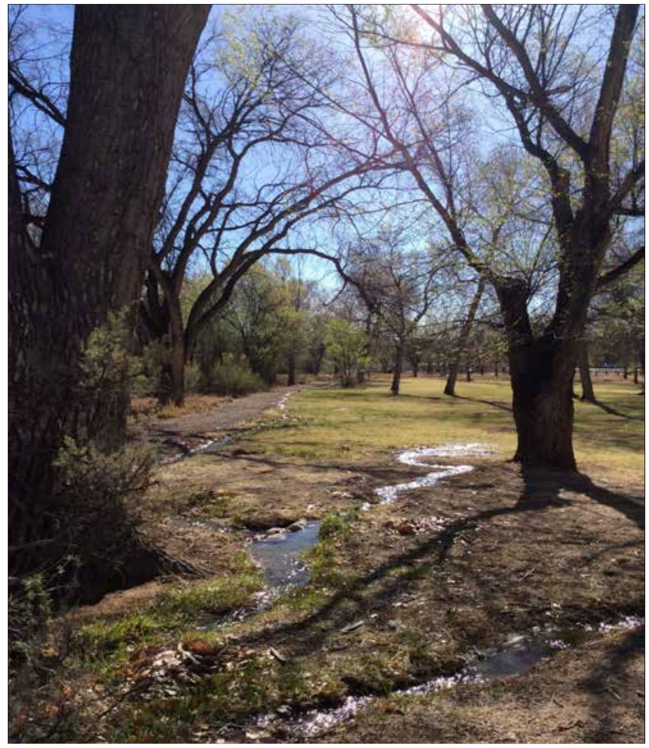
The values used to determine conditions for all air quality indicators and measures are listed in Table 20.

The estimated 5-year (2011-2015) haze index measure of visibility for Aztec Ruins NM's (3.0 dv) fell within the moderate concern condition rating, which indicates visibility was degraded from the good reference condition of <2 dv above the natural condition (Taylor 2017). Confidence in this measure is medium because there is no on-site or nearby visibility monitor.

Data for the major components that impaired visibility were not available for the monument, but ammonium sulfate, coarse mass, and organic carbon are common contributors to haze. Ammonium sulfate originates mainly from coal-fired power plants and smelters, and organic carbon originates primarily from combustion of fossil fuels and vegetation. Sources of coarse mass include dust from roads, agriculture, construction sites, mining operations, and other similar activities.

Data for the human health measure of ozone were derived from estimated five-year (2011-2015) values of 66.2 parts per billion (ppb) for the 4th highest 8-hour concentration, which resulted in a condition rating warranting moderate concern for human health (NPS ARD 2018f). For 2006–2015, the trend in ozone concentration at Aztec Ruins NM remained relatively unchanged (no statistically significant trend) (Figure 23). The degree of confidence at Aztec Ruins NM is high because there is an on-site or nearby ozone monitor.

Data for the vegetation health measure of ozone were derived from estimated five-year (2011-2015) values of 11.9 parts per million-hours (ppm-hrs) for the W126 Index. This value warrants significant concern (NPS ARD 2018f). For 2006-2015, the trend in the W126 Index improved (Figure 24). There are 10 ozone sensitive plant species in Aztec Ruins NM, three of which are biological indicators (Bell, In Review) (Table 21).



Cottonwoods beginning to grow leaves in spring. Photo Credit: © K. Struthers.

Wet N deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 1.0 kg/ha/yr which is right on the threshold but considered to be of moderate concern. No trends could be determined given the lack of nearby monitoring stations. Confidence in the condition is medium because estimates were based on interpolated data from more distant deposition monitors. For further discussion of N deposition,

Table 20. Condition and trend results for air quality indicators at Aztec Ruins NM.

Data Span	Visibility (dv)	Ozone: Human Health (ppb)	Ozone: Vegetation Health (ppm-hrs)	N (kg/ha/yr)	S (kg/ha/yr)	Mecury (µg/m²/yr) and Predicted Methylmercury (ng/L)
Condition	Moderate Concern (3.0) (2011-2015)	Moderate Concern (66.2) (2011-2015)	Moderate Concern (11.9) (2011-2015)	Moderate Concern (1.0) (2011-2015)	Good (0.5) (2011-2015)	Good (4.5, 0.05) (2013-2015)
Trend 2006-2015	No data on trends.	Unchanged (no statistically significant trend).	Unchanged (no statistically significant trend).	No data on trends.	No data on trends.	No data on trends.

Sources: NPS ARD (2018f,g).

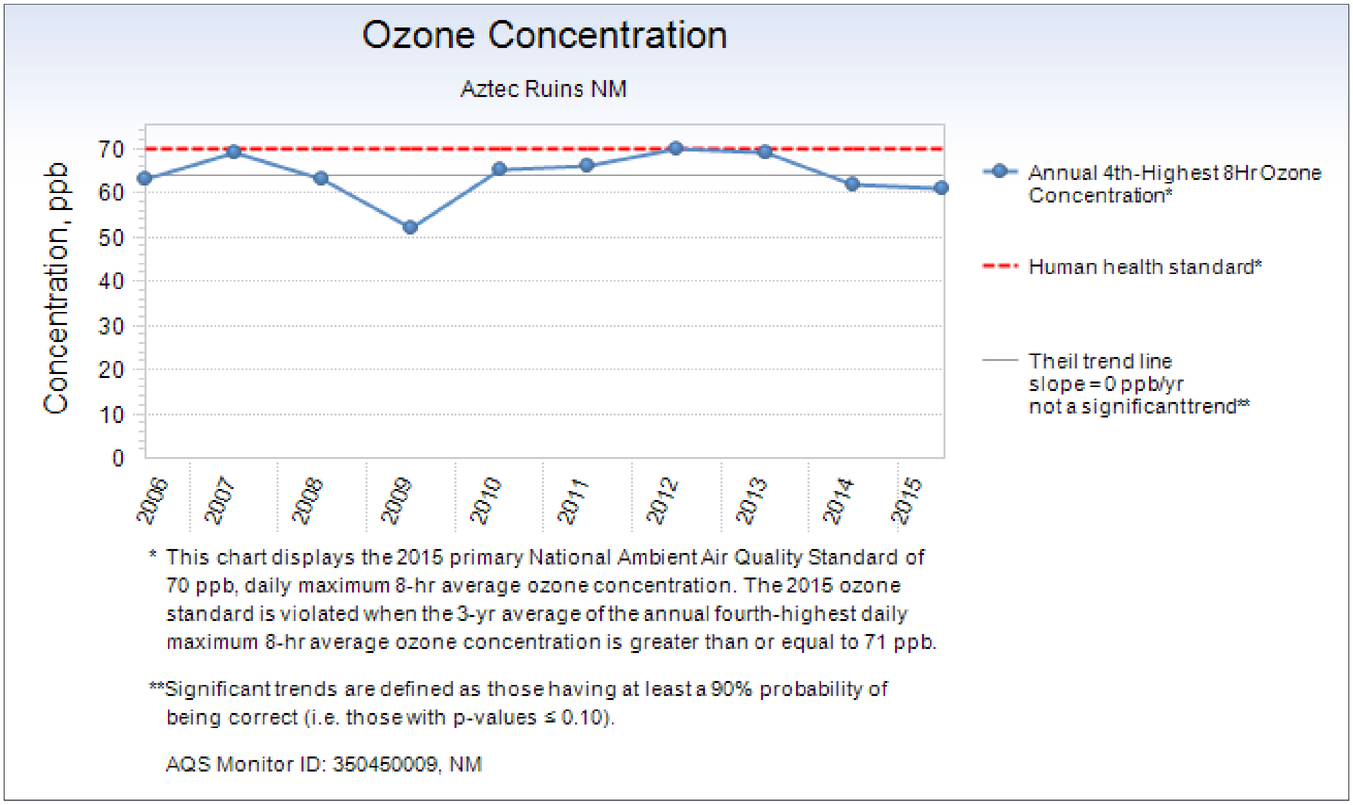


Figure 23. **Ozone trend (2006-2015) for human health at Aztec Ruins NM monitor site 3504500009. The trend is not statistically significant and is considered stable. Figure Credit: NPS ARD 2018f.**

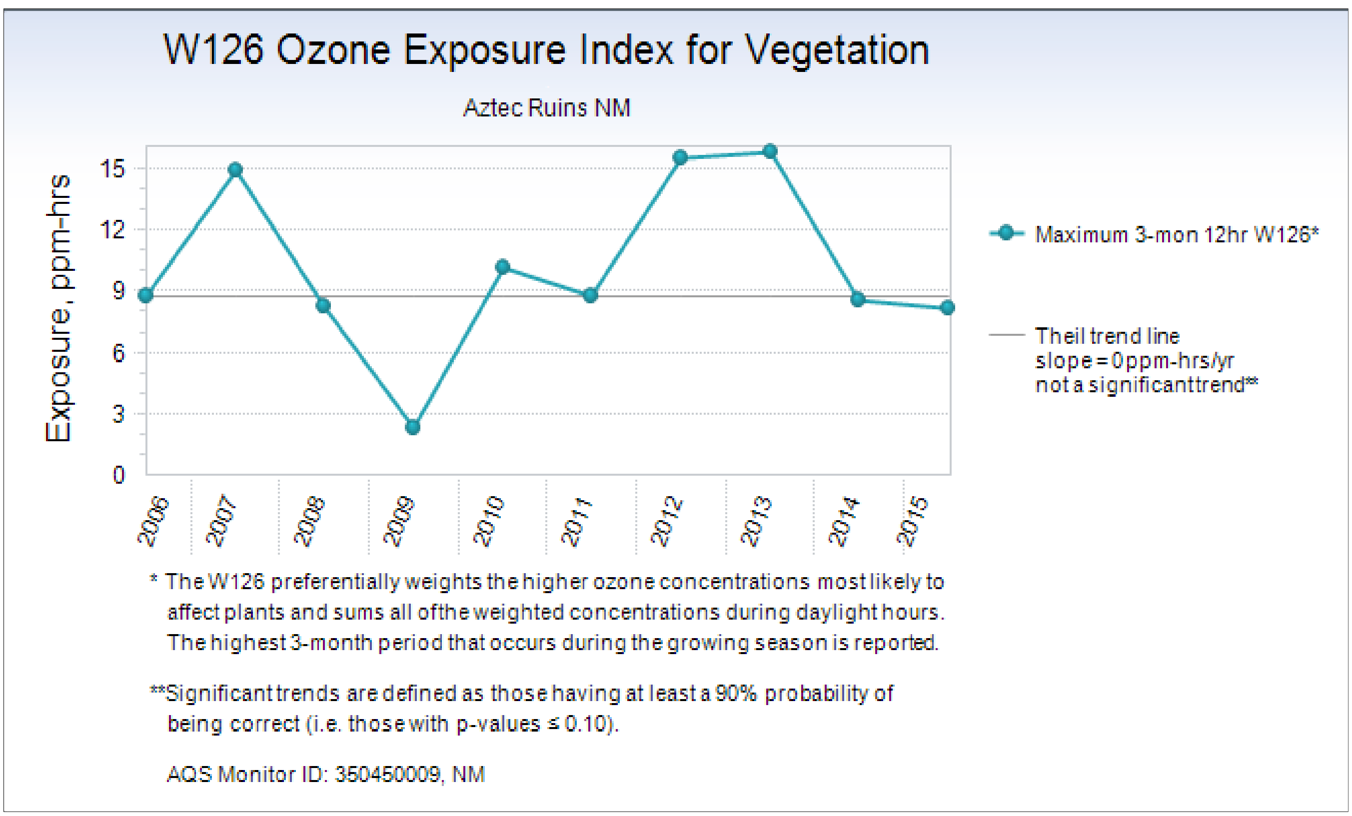


Figure 24. **Ozone trend (2006-2015) for vegetation at Aztec Ruins NM monitor site 350450009. The trend in the W126 Index has significantly improved. Figure Credit: NPS ARD 2018f.**

Table 21. Ozone sensitive plants in Aztec Ruins NM.

Scientific Name	Common Name
*Acer negundo**	Boxelder
Achillea millefolium	Bloodwort
*Mentzelia albicaulis**	White blazingstar
Parthenocissus quinquefolia	Virginia creeper
Populus deltoides	Common cottonwood
*Populus fremontii**	Fremont's cottonwood
Robinia pseudoacacia	Black locust
Salix exigua	Coyote willow
Salix gooddingii	Gooding's willow
Solidago canadensis	Canada goldenrod

* Biological indicator for ozone sensitivity.

see the section entitled "Additional Information for Nitrogen and Sulfur" below.

Wet S deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 0.5 kg/ha/yr, which resulted in a good condition rating (NPS ARD 2018f). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates were based on interpolated data from more distant deposition monitors. For further discussion of sulfur, see below.

Sullivan et al. (2011a,b) studied the risk from acidification from acid pollutant exposure and ecosystem sensitivity for Southern Colorado Network parks, which included Aztec Ruins NM. Pollutant exposure included the type of deposition (i.e., wet, dry, cloud, fog), the oxidized and reduced forms of the chemical, if applicable, and the total quantity deposited. The ecosystem sensitivity considered the type of terrestrial and aquatic ecosystems present at the parks and their inherent sensitivity to the atmospherically deposited chemicals. Note that a more recent report (Sullivan et al. 2016) is available, but because it contains errors, we used data from the earlier report instead (NPS ARD, K. Taylor, planning and data analyst, comments to draft assessment, 10 December 2018).

These risk rankings for the monument were considered moderate for acid pollutant exposure, very low for ecosystem sensitivity, and moderate for park protection with an overall risk ranking of low (Sullivan et al. 2011a). The effects of acidification can include changes in water and soil chemistry that impact ecosystem health.

Sullivan et al. (2011b) also developed risk rankings for nutrient N pollutant exposure and ecosystem sensitivity to nutrient N enrichment. These risk rankings were considered moderate for pollutant exposure, high for ecosystem sensitivity, and moderate for park protection for an overall risk ranking of low. Potential effects of nitrogen deposition include the disruption of soil nutrient cycling and impacts to the biodiversity of some plant communities, including alpine communities, grasslands and meadows, arid and semi-arid communities, and wetlands.

Using three datasets, Landscape Fire and Resource Management Planning Tools Project (LANDFIRE), National Wetlands Inventory (NWI) cover data, and National Land Cover Data (NLCD), nitrogen-sensitive vegetation for the monument was identified (E&S Environmental Chemistry, Inc. 2009). In Aztec Ruins NM, the LANDFIRE dataset mapped 29% of the monument as arid and semi-arid nitrogen-sensitive areas and 9% as meadow and grassland nitrogen-sensitive communities (Figure 25). The NWI mapped 2% of the monument as nitrogen-sensitive wetlands. No nitrogen-sensitive communities were identified by NLCD.

Since the mid-1980s, nitrate and sulfate deposition levels have declined throughout the United States (NADP 2018a). Regulatory programs mandating 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. In 2007, the NADP/NTN began passively monitoring ammonium ion concentrations and deposition across the U.S. in order to establish baseline conditions and trends over time (NADP 2018b). In 2012 hotspots of ammonium deposition were concentrated in the midwestern states in large part due to the density of agricultural and livestock industries in that region (NADP 2018b). It seems reasonable to expect a continued improvement or stability in sulfate and nitrate deposition levels because of CAA requirements, but since ammonium levels are not currently regulated by the EPA, they may continue to remain high in certain areas (NPS ARD 2010). However, once baseline conditions for ammonia are established, those data may be used to support regulatory statutes.

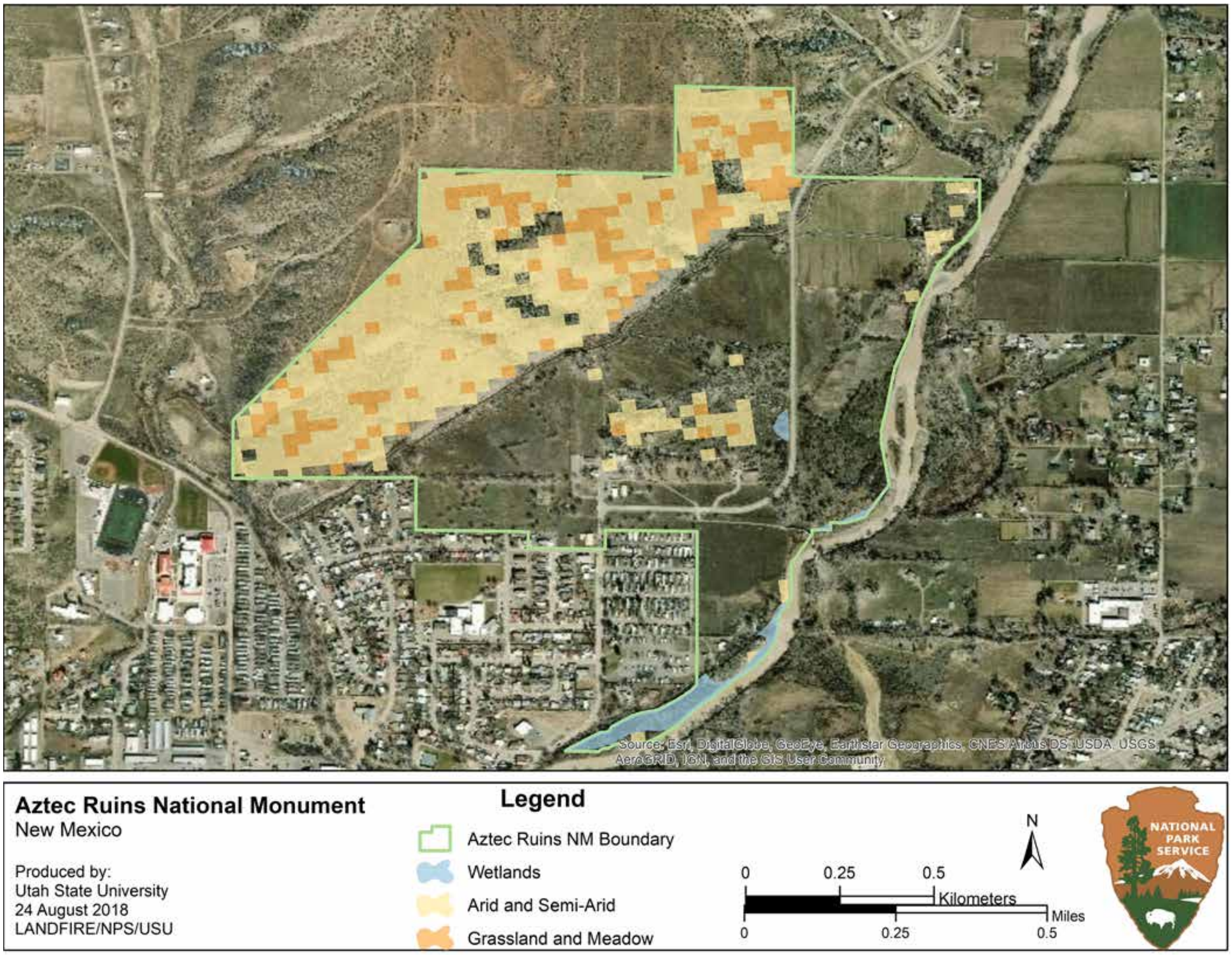


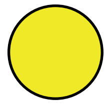
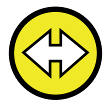
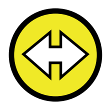
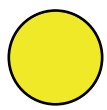
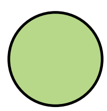
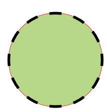
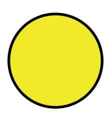
Figure 25. **Map of nitrogen-sensitive plant communities in Aztec Ruins NM.**

Finally, the 2013-2015 wet mercury deposition was low at the monument with a value of 4.5 micrograms per square meter per year (NPS ARD 2018g). The predicted methylmercury concentration in park surface waters was estimated to be 0.05 ng/L (USGS 2015), a low concentration (NPS ARD 2018g). When both measures are available (i.e., wet mercury deposition and predicted methylmercury concentration), the mercury status assessment matrix shown in Table 19 can be used to determine overall mercury/toxics status (Taylor 2017). The matrix indicates a condition of good for the combined effects of wet mercury deposition and predicted methylmercury at Aztec Ruins NM. However, the level of confidence in this measure is low, because the estimates are based on interpolated or modeled data rather than in-park studies, since there are no park-specific studies examining contaminant levels in taxa from park ecosystems. Trend could not be determined.

Overall Condition, Threats, and Data Gaps

For assessing the condition of air quality, we used three air quality indicators with a total of six measures. The indicators/measures for this resource were intended to capture different aspects of air quality, and a summary of how they contributed to the overall condition is summarized in Table 22. Based on the indicators and measures, we consider the overall condition of air quality at Aztec Ruins NM to be of moderate concern. Overall confidence level is medium because some estimates were based on interpolated data from more distant monitors. Those measures for which confidence in the condition rating was high were weighted more heavily in the overall condition rating than measures with medium or low confidence. We did not assign an overall trend for air quality at the monument because trend data were not available for a majority of measures. However, those measures with a trend indicate stable conditions. A key

Table 22. **Summary of air quality indicators, measures, and condition rationale.**

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Visibility	Haze Index		Visibility warrants moderate concern at Aztec Ruins NM. This is based on NPS ARD benchmarks and the 2011-2015 estimated visibility on mid-range days of 3.0 deciviews (dv) above estimated natural conditions. No trend information is available because there are not sufficient on-site or nearby visibility monitoring data. The degree of confidence at Aztec Ruins NM is medium because estimates are based on interpolated data from more distant visibility monitors.
Level of Ozone	Human Health: Annual 4th-Highest 8-hour Concentration		Human health risk from ground-level ozone warrants moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated ozone of 66.2 parts per billion (ppb). For 2006-2015, the trend remained relatively unchanged (no statistically significant trend). The level of confidence is high because there is an on-site or nearby ozone monitor.
	Vegetation Health: 3-month maximum 12hr W126		Vegetation health risk from ground-level ozone warrants moderate concern. This status is based on NPS ARD benchmarks and the 2011-2015 estimated W126 metric of 11.9 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure. A risk assessment concluded that plants in the monument were at low risk for ozone damage. For 2006-2015, the trend remained relatively unchanged (no statistically significant trend). The level of confidence is high because there is an on-site or nearby ozone monitor.
Wet Deposition	N in kg/ha/yr		Estimated wet nitrogen deposition is of moderate concern (1.0 kilograms per hectare per year (kg/ha/yr)) during 2011-2015. Trend could not be determined because there were not sufficient on-site or nearby monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant deposition monitors.
	S in kg/ha/yr		Wet sulfur deposition is good. This status is based on NPS ARD benchmarks and the 2011-2015 estimated wet sulfur deposition of 0.5 kilograms per hectare per year (kg/ha/yr). Trend could not be determined because there were not sufficient on-site or nearby monitoring data. The confidence level is medium because estimates are based on interpolated data from more distant deposition monitors.
	Mercury and Predicted Methylmercury Concentration		For 2013-2015, the estimated wet mercury deposition was 4.5 micrograms per square meter per year, and the predicted methylmercury concentration in park surface waters was low (0.05 nanograms per liter). Trends could not be determined. Confidence in the measure is low because estimates were based on interpolated or modeled data rather than in-park studies; there are no park-specific studies examining contaminant levels in taxa from park ecosystems.
Overall Condition	Summary of All Measures		Overall, we consider air quality at Aztec Ruins NM to warrant moderate concern because the two measures of ozone, visibility, and wet deposition of nitrogen measures are all of significant concern. Trend data were only available for two measures. There were no trend data for the remaining four measures so overall trend is unknown. Confidence is medium.

Note: Condition summary text was primarily excerpted from NPS ARD (2018f).

uncertainty of this assessment is knowing the effect(s) of air pollution, especially of nitrogen deposition, on ecosystems in the monument.

Clean air is fundamental to protecting human health, the health of wildlife and plants within parks, and for protecting the aesthetic value of lands managed by the NPS (NPS 2006). For example, regional air quality plays an important role in maintaining the high-quality scenic vistas and clear night skies of the national monument (NPS ARD 2003).

Air pollutants found in national parks are generated from activities outside protected areas and include vehicles, planes, and trains; power plants, oil refineries, factories, and other industrial facilities; agriculture, cities, and wood burning fire places; and from natural sources such as wind-blown dust, wildfires, and volcanoes (NPS ARD 2018h). Despite the fact that air pollutants originate outside of these protected areas, they can and do impact national parks due to wind (NPS ARD 2018h). Impacts to air quality can result from pollution from urban centers both near and more distant from the national monument. The Four Corners region, in which Aztec Ruins is located, is known as a methane hotspot, and methane causes atmospheric haze (Frankenberg et al. 2016).

In an analysis of 33 national parks across the U.S., Keiser et al. (2018) found that the average annual 8-hour ozone concentrations did not differ significantly from ozone levels in 14 major metropolitan areas. While ozone levels have improved in both parks and cities, improvements have been more modest in parks (Keiser et al. 2018). In metropolitan areas, air quality has improved since about 1990, but in national parks air quality did not improve until after 2000. The authors speculate that the observed improvements may have been the result of the 1999 USEPA Haze Rule, which called for stricter regulations to improve air quality in national parks and wilderness areas (Keiser et al. 2018). Keiser et al. (2018) also showed that on days with higher levels of ozone, visitation in parks was lower than on days with lower ozone levels, probably as a result of USEPA air quality index warnings issued by the NPS or reduced visibility, which may have discouraged visitation. Although Aztec Ruins NM was not part of the study, air quality in the monument may be affected by more distant cities such as Las Vegas, Nevada and Phoenix, Arizona. Monahan and Fisichelli (2014) found climate for the monument and surrounding region departed from the natural range of variation. One effect of climate change is an increase in wildfire activity (Abatzoglou and Williams 2016). Fires contribute a significant amount of trace gases and particles into the atmosphere that affect local and regional visibility and air quality (Kinney 2008). Wildfires have increased across the western U.S., and there is a high potential for the number of wildfires to grow as climate in the Southwest becomes warmer and drier (Abatzoglou and Williams 2016). Warmer conditions also increase the rate at which ozone and secondary particles form (Kinney 2008). Declines in precipitation may also lead to an increase in wind-blown dust (Kinney 2008). Weather patterns influence the dispersal of these atmospheric particulates. Because of their small particle size, airborne particulates from fires, motor vehicles, power plants, and wind-blown dust may remain in the atmosphere for days, traveling potentially hundreds of miles before settling out of the atmosphere (Kinney 2008).

Sources of Expertise

The NPS 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. Information and text for the assessment was obtained from the NPS ARD website and provided by Jim Cheatham, Park Planning and Technical Assistance, ARD. Email NPS ARD (airresources@nps.gov) for more information. The assessment was written by Lisa Baril, biologist and science writer at Utah State University.

Water Resources

Background and Importance

Aztec Ruins National Monument (NM) lies within the Animas River valley watershed—a 3,550 km^2 (1,371 mi^2) area in southern Colorado and northern New Mexico (U.S. Department of Agriculture [USDA] 2010). The high water line of the Animas River delineates 1.6 km (1.0 mi) of the monument's southeastern boundary (Filippone and Martin 2014, NPS 2015a). The perennial flowing Animas River once served as the primary water supply for the Ancestral Puebloans who inhabited the region from the late A.D. 1000s to about 1300 (NPS 2015a). Today, the Animas River continues to remain unregulated (i.e., no dams) along its length, which is rare for rivers in the western U.S. (Chen and Olden 2017).

Below the monument's ground surface lies a shallow alluvial aquifer with soils that consist mostly of sandy loam (Filippone and Martin 2014). Percolation of surface water from precipitation is generally restricted from penetrating the 5-9-m-(15-30 ft) thick sandy-clay soils that lie above the aquifer, creating a localized perched water table (Filippone and Martin 2014). Below the aquifer lies a thick layer of shale bedrock known as the Nacimiento Formation (Filippone and Martin 2014). Recharge of the Nacimiento Formation is supplied from uplands within the watershed and is discharged in the lower elevation river valleys (Filippone and Martin 2014). Because of the overlying shale, some of the deep aquifers are artesian, or confined.

Approximately half of the monument's total annual precipitation (26.7 cm [(10.5 in]) falls during the monsoon season, which occurs from July to October (Filippone and Martin 2014). The remaining precipitation is distributed uniformly from November through June (Filippone and Martin 2014). Other water resources include surface water runoff from outside the monument; infiltration of surface water to groundwater; regional groundwater inflows; and diversion of the Animas River into Farmers Ditch—an irrigation canal that transverses the monument (Filippone and Martin 2014).

Farmers Ditch has supported ranching and agriculture in the Animas River valley for more than 100 years (Filippone and Martin 2014). Water from Farmers Ditch flows south into Farmington Lake, which is the City of Farmington, New Mexico's primary water supply (Stephens et al. 2017). Water flow in Farmers Ditch is manually controlled by the New Mexico Office of the State Engineer/Interstate Stream Commission. The headgate diverting water into the ditch is open from March to November depending on the needs of downstream users (Filippone and Martin 2014). Farmers Ditch also supplies water to the

The Animas River bordering the southeastern edge of Aztec Ruins NM. Photo Credit: © L. Baril.

monument's picnic area and garden, and historically supported an orchard until 2009 when irrigation was discontinued there (Filippone and Martin 2014). In 2000 the National Park Service (NPS) acquired the cultivated Abrams property north of the monument, and irrigation was terminated there as well (Filippone and Martin 2014).

Data and Methods

The selected indicators and measures were based on the Southern Colorado Plateau Inventory and Monitoring Network (SCPN) vital signs (Thomas et al. 2006) and recommendations made by National Park Service (NPS) staff. To assess the current condition of the groundwater indicator, we used one measure: depth to groundwater. Depth to groundwater data were collected at eight wells and two piezometers (10 total locations) in the monument (Figure 26, Table 23). We did not include data for two wells (MW-9 in the terrace zone and FLC #2 in the riparian zone) because MW-9 was not monitored regularly during 2005 to 2012 (Filippone and Martin 2014) and data for FLC

Table 23. Wells and piezometers monitored in Aztec Ruins NM.

Zone	Name	Description	Year Installed
Terrace	Ruins Road	Former water supply well	Unknown
	MW-7	Monitoring well	1979
	MW-8	Monitoring well	1979
	MW-9	Well	1979
	MY II-5	Piezometer	2005
	Hubbard Road	Piezometer	2005
	Visitor Center	Former park water supply well	1931
Riparian	FLC #1	Well	2016
	FLC #2	Well	2016
	FLC #4	Well	2016

Source: Data were provided by Stephen Monroe, NPS hydrologist (retired) and were reported in Filippone and Martin (2014).

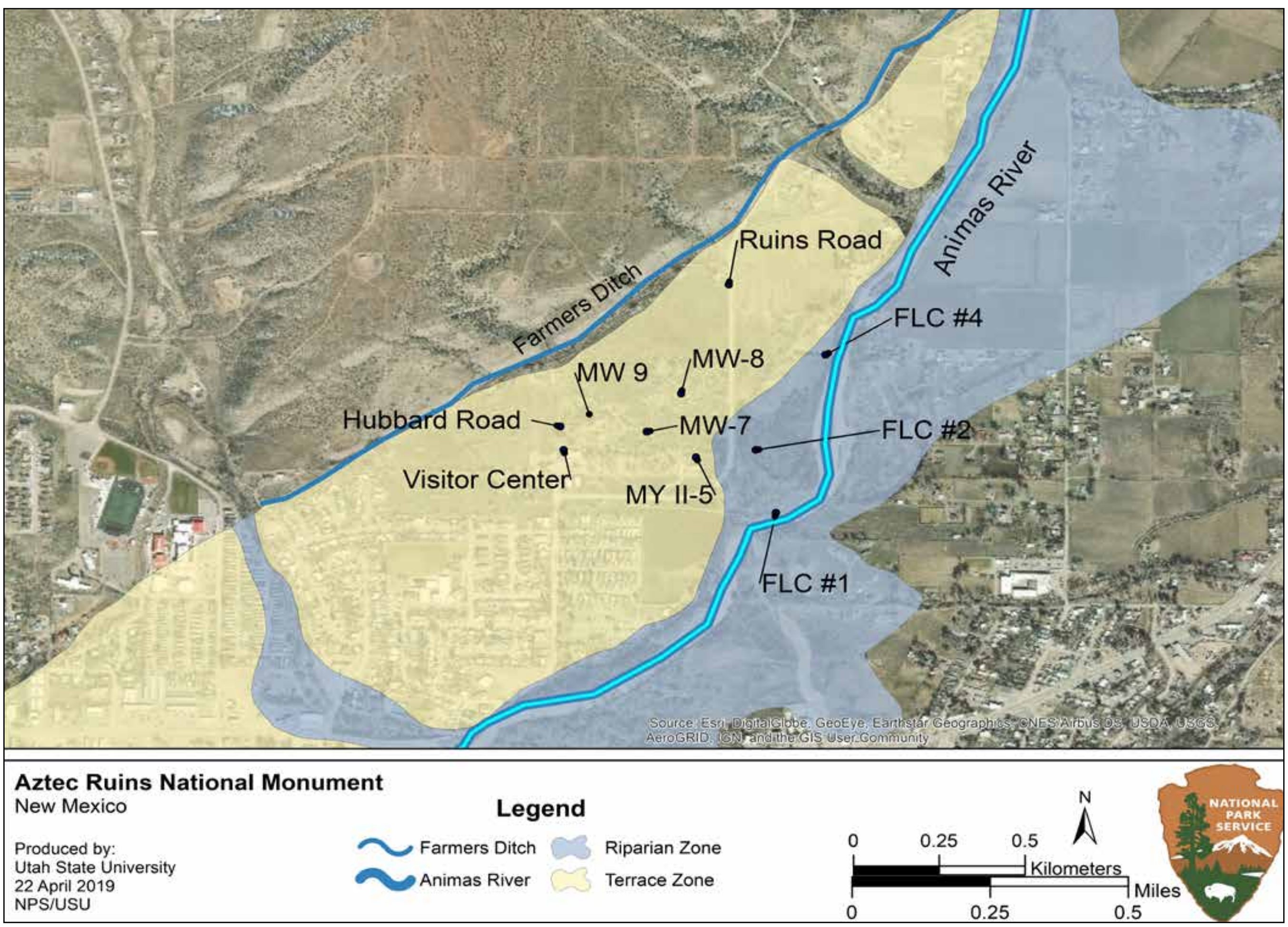


Figure 26. Approximate location of wells and piezometers used to monitor groundwater in Aztec Ruins NM.

#2 had not been validated as of the writing of this assessment (NPS, S. Monroe, hydrologist (retired), 25 January 2019). Nevertheless, the eight monitoring locations that were included provide sufficient data for determining the condition of groundwater resources in the monument.

Depth to groundwater is a measure of how close the water table is to the Earth's surface and is dependent on proximity to rivers, local geology, withdrawal for human uses, and other factors (USGS 2014). The shallower the depth to groundwater, the more available water is to plants. This is especially important for riparian vegetation (Stromberg 2013) as upland plants on the Colorado Plateau are generally drought tolerant and adapted to limited and pulsed water resources (Kray et al. 2012). Shrubs and herbaceous vegetation of the Colorado Plateau use a mix of groundwater and soil moisture depending on the availability of each water resource (Kray et al. 2012). Shrubs tend to utilize groundwater more than soil water, while grasses are more reliant on soil moisture (Kray et al. 2012). In contrast, cottonwoods (*Populus* spp.) and willows (*Salix* spp.) are dependent on access to a shallow water table for establishment, growth, and survival (Stromberg et al. 1996).

The eight well locations occur in one of two zones based on the geologic resources inventory report (KellerLynn 2016) (Table 23). The two zones are the terrace zone and the riparian zone. The terrace zone is less than 3 m (10 ft) above the modern floodplain in the monument (KellerLynn 2016). The riparian zone is located in the modern floodplain along a narrow band on either side of the Animas River. Note that the NPS only has management jurisdiction on northwest side of the river only. All data were reported as the depth to water from the ground surface.

For the terrace zone, we included data from four wells (Ruins Road, MW-7, MW-8, and Visitor Center) and two piezomenters (MY II-5 and Hubbard Road). Data for this zone were available from August 2005 through early October 2018. MW-7, MW-8, MW II-5, and the Hubbard Road sites are shallow, with depths between 6 m and 8 m (19-27 ft) (Filippone and Martin 2014). The Visitor Center and Ruins Road wells are deeper at 21 m and 15 m (69-48 ft), respectively (Filippone and Martin 2014).

For the riparian zone, we included data for two wells (FLC #1 and FLC #4). Data for this zone were available from November 2016 through early October 2018. Because the two riparian zone wells track flows in the Animas River (FLC #1) and Farmers Ditch (FLC #4), we plotted those discharge data along with depth to groundwater. To determine trends over time, we used simple linear regressions for groundwater monitoring locations in the terrace zone, but we did not look for trends over time for the riparian zone wells because there are only two years of data at these locations. The depth of these wells averaged 2 m (7 ft) at both locations. Data are collected by staff at Aztec Ruins NM and S. Monroe.

All depth to groundwater data are provisional (i.e., the data have not undergone quality control or assurance procedures for accuracy) and were provided via e-mail by Stephen Monroe, a hydrologist with the NPS (retired), on 25 January 2019.

For the second indicator (surface water quantity), we used two measures, the first of which is Animas River discharge. Mean daily discharge data in cubic feet/second (cfs) for the Animas River below Aztec, New Mexico (stream gage # 09364010) were downloaded from the USGS National Water Information System Website (NWIS) on 3 March 2019 (USGS 2019). The stream gage is located approximately 4.0 km (2.5 mi) downstream of the monument. Data were available from 17 December 2002 through 3 March 2019. There was a gap in data from 23 June 2015 through 2 March 2016, and 3 March 2016 through 3 March 2019, data were flagged as provisional (i.e., subject to change). All other data were either actual measurements or were estimated values. We also downloaded mean annual discharge data for the years 2003 through 2015 and peak flow data for 2004 through 2017. Average annual discharge data were not available for 2016 through present because of their provisional status, but we calculated mean annual discharge based on daily data. We looked for trends in mean annual discharge, and used the mean daily data to show seasonal patterns in discharge.

The second surface water quantity measure was Farmers Ditch discharge. Data were available from 3 March 2012 through 8 October 2018. Farmers Ditch discharge data are also available through New Mexico's Office of the State Engineer/Interstate Stream Commission website (NMOSE 2011). The gage on Farmers Ditch is located approximately 5.5 km (3.4 mi) upstream from Aztec Ruins NM (NMOSE 2011). As previously mentioned, water from the ditch not only supplies downstream users with water for agriculture, but it is also supplies water to the monument's picnic area and garden, both of which are located in the Terrace zone.

The protected area of the Animas River watershed was the third and final indicator used to assess water resources in the monument. The measure we used was the proportion of the watershed that is protected. 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 NPS boundary), as well as opportunities (e.g., connectivity and networking of protected areas)." The USGS's GAP Analysis Program's Protected Area Database (PAD) provides GIS data on public land ownership and conservation lands in the U.S. (USGS GAP 2016). The lands included in the PAD were assigned one of four GAP Status codes based on the degree of protection and management mandates. Aztec Ruins NM is considered GAP Status 1, 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 2012).

NPScape's conservation status toolset was used to clip the PAD-US version 1.4 (USGS GAP 2016) to the Animas River watershed, and then to recalculate the GAP Status and broad land ownership categories (e.g., federal, state, tribal, etc.) within the watershed in order to determine the proportion of area that is currently protected (NPS 2015d). The Animas River watershed GIS layer was downloaded from the U.S. Department of Agriculture's (USDA) GeoSpatial Data Gateway (USDA 2018).

Reference Conditions

Reference conditions are described for resources in good, moderate concern, and significant concern conditions (Table 24). Reference conditions were developed by Utah State University staff with input and guidance from staffs at Aztec Ruins NM and SCPN. For depth to groundwater in the riparian zone, research has shown that a maximum depth of 3.2 m (10.5 ft) and 5.1 m (16.7 m) is required to sustain mature willow and cottonwood trees, respectively

Table 24. Reference conditions used to assess water resources.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Groundwater	Depth to Groundwater (m)	Depth to groundwater in the riparian zone is less than 2.0 m (6.6 ft) (i.e., the level that supports cottonwood and willow at all life stages).	–	Depth to groundwater in the riparian zone is more than 2.0 m (6.6 ft) (i.e., the level that does not support cottonwood and willow at all life stages).
Surface Water Quantity	Animas River Discharge (cfs)	Stream flow is perennial with zero no-flow days. Furthermore, discharge has not declined over time.	Stream flow is intermittent with some no-flow days and/or a declining trend in discharge over time.	Stream flow is intermittent with many no-flow days and discharge has declined over time.
	Farmers Ditch Discharge (cfs)	Discharge meets the resource needs of the monument without adversely influencing monument resources.	–	Discharge does not meet the resource needs of the monument and/or adversely influences monument resources.
Protected area of the Animas River Watershed	Percent of Watershed Protected	The majority of land area in the monument's watershed was considered GAP Status 1 or 2.	The majority of land area in the monument's watershed was considered GAP Status 3.	The majority of land area in the monument's watershed was considered GAP Status 4.

(Stromberg et al. 1996). A maximum depth of 2.0 m (6.6 ft) is required for juvenile (seedlings and saplings) cottonwoods and willows (Stromberg et al. 1996). To ensure the persistence of woody riparian plants at all life stages, we conservatively set the good reference condition at a depth of 2.0 m (6.6 ft) or less for wells located in the riparian zone. Groundwater during the growing season (May-October) in particular is critical to maintaining these species.

There were no data to develop reference conditions for the terrace zone, but the statewide water assessment provides some context for how conditions in the monument compare to regional groundwater resources. The New Mexico Water Resources Research Institute (NMWRRI 2018) initiated a state-wide water assessment in 2015. One goal of the project was to quantify changes in groundwater levels over time and to produce a statewide water budget (Carroll and Willman 2015). Based on the results of this study, we compared groundwater levels in the monument to that in the San Juan Basin (1983-2013) and San Juan County (1975 to 2010).

Reference conditions for surface water quantity for the Animas River is considered good if there have been no declines in surface flows and the river remains perennial (i.e, no zero flow days). If these conditions are not met, the condition would warrant either moderate or significant concern. Reference conditions for discharge in Farmers Ditch are based on meeting the needs of resources in the monument while having no adverse effects on ecosystem function (e.g., no soil or nutrient loss). This is because while the ditch is man-made with controlled flows, water from the ditch is needed to maintain the picnic area and garden, and may be used for native plant restoration efforts. The unlined ditch also contributes to the shallow alluvial aquifer below the monument.

For the proportion of watershed protected, a good condition is warranted if the majority (≥50%) of all the land within the watershed is considered GAP status 1 or 2. A significant concern condition is warranted if more than 50% of the landscape is within GAP status 4. These reference conditions were developed by the assessment author and are those used in a similar analysis of viewshed for Aztec Ruins NM (included in this report) and in Natural Resource Condition Assessments for other NPS units. Higher levels of protection may lead to an increase in ecosystem function, although we acknowledge that this is not always the case due to factors that transcend management boundaries (e.g., climate change). A properly functioning watershed depends on many factors, including water quality, fire regime, water use, erosion, precipitation, and vegetation, among others. Nevertheless, this measure represents a starting point for identifying areas within the watershed that are most in need of protection.

Condition and Trend

Depth to groundwater measure data for the terrace zone are shown in Figures 27 and 28. For these six locations, depth to groundwater exhibited seasonal trends and was generally less variable and deeper from January through April than during the remainder of the year. Both the Ruins Road well (Figure 27) and the MW-8 well (Figure 28) exhibited the greatest seasonal variation in depth to groundwater of the six locations. The MY II-5 piezometer recorded the shallowest overall depth to groundwater with an average of 4.8 m (15.7 ft) from 2005 to 2018, and the Ruins Road well exhibited the deepest groundwater at an average of about 10.3 m (33.8 ft) during the same time period.

Seasonal changes for wells and piezometers in the Terrace zone are influenced more by seasonal flows in irrigation ditches than by flows in the Animas River (Newton et al. 2017). Wells located farther from the river gain groundwater beginning with the start of irrigation (March or April), peak in groundwater levels in late July, and remain elevated until the end of irrigation in October (Newton et al. 2017). After this point, groundwater loses until irrigation begins again. This was the pattern observed for the locations in the Terrace zone in the monument. Fluctuations in groundwater for this zone tend to be smoother overall than for wells closer to the river because of the controlled flows in the ditch (Newton et al. 2017).

Although rigorous time series analyses were beyond the scope of this assessment, our simple linear regressions revealed that the MY II-5 piezometer (R^2 = 0.10, t = 5.13, p < 0.001), the Hubbard Road piezometer (R^2 = 0.42, t = 9.37, p < 0.001), and the Visitor Center well (R^2 = 0.55, t = 14.3, p < 0.001) declined (i.e., deeper groundwater) in depth to groundwater. The large dip in the Visitor Center well in 2006 was the result of two purges, one in July and the other in September, in order to collect water quality samples (NPS, D. Hawkins, natural resources program lead,

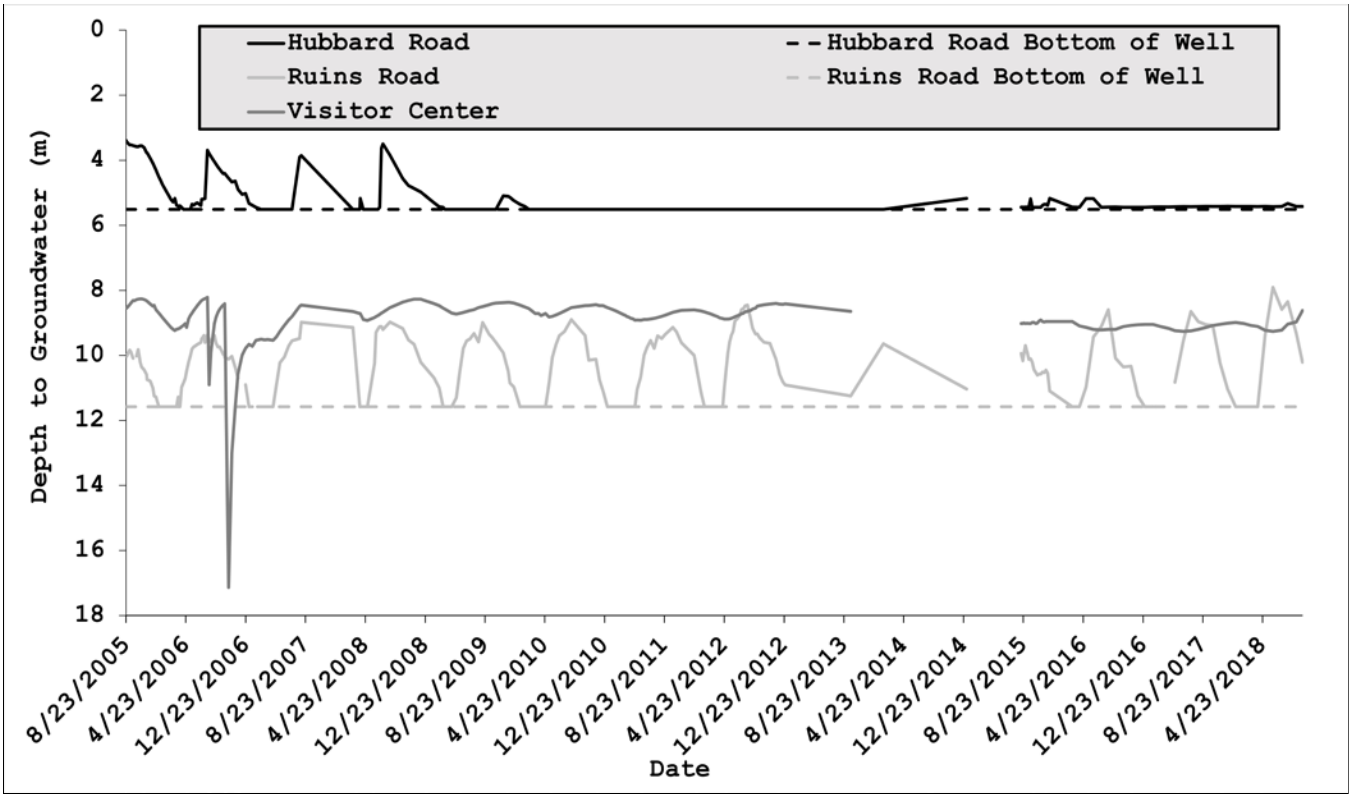


Figure 27. Depth to groundwater at three locations in the terrace zone at Aztec Ruins NM from August 2005 to October 2018.

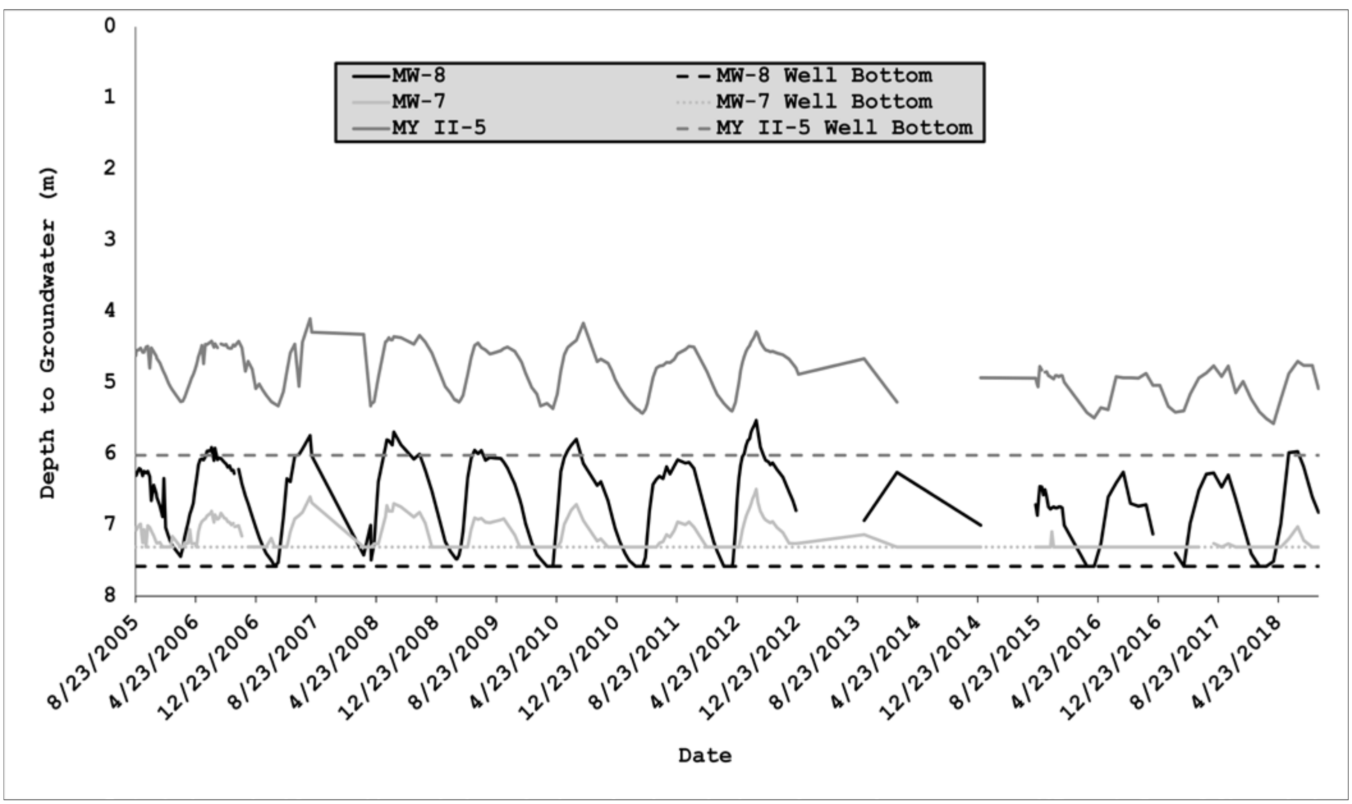


Figure 28. Depth to groundwater at three monitoring locations in the terrace zone at Aztec Ruins NM from August 2005 to October 2018.

received by S. Monroe, phone call, March 2019). As a result, our time series analysis began after the well had recovered. In contrast, there were no significant trends in groundwater levels at the Ruins Road, MW-7, or MW-8 wells ($p > 0.05$).

These results are consistent with the statewide water assessment, which found that groundwater levels in San Juan County from 1975 to 2010 were stable or declined slightly (Carroll and William 2015). Of 17 wells in the San Juan Basin that were included in the assessment, 10 declined in groundwater, while the remaining seven wells increased in groundwater from 1983 to 2013 (Carroll and Willman 2015). During this period, groundwater declined by an average of 0.2 m (0.63 ft) in the shallow water aquifer and 0.1 m (0.37 ft) in the deep water aquifer per year (Carroll and Willman 2015). The rate of decline for the two wells in the monument's terrace zone (MYII-5 and Hubbard Road) was less than 0.01 m/year (0.03 ft/yr). All water used in agriculture in San Juan County is drawn from surface water rather than groundwater and that the county was among the highest water users in the state (Carroll and Willman 2015).

Depth to groundwater measure data for the riparian zone are shown in Figures 29 and 30. At FLC-1 in the riparian zone, depth to groundwater remained well above the minimum required to maintain juvenile cottonwoods and willows (i.e., <2.0 m [<6.6 ft]) (Figure 29). Depth to groundwater at FLC-1 averaged 0.6 m (2.0 ft) from November 2016 to October 2018. Because of its proximity to the Animas River, groundwater at this well reflects patterns of river discharge, which were plotted along with depth to groundwater data for comparison.

At FLC-4 depth to groundwater averaged 1.7 m (5.7 ft) from November 2016 to October 2018, which is 0.3 m (1.0 ft) above that which is required to maintain juvenile cottonwoods and willows (Figure 30). During the winter months, however, groundwater often fell at or below this threshold. Rather than reflecting discharge in the Animas River, this well more closely reflects discharge in Farmers Ditch, which is manually controlled. Although depth to groundwater occasionally fell below that which maintains cottonwood seedlings and saplings, this occurred only during the winter months (i.e., non-growing season) and remained well above the thresholds for mature willow and cottonwood at all times.

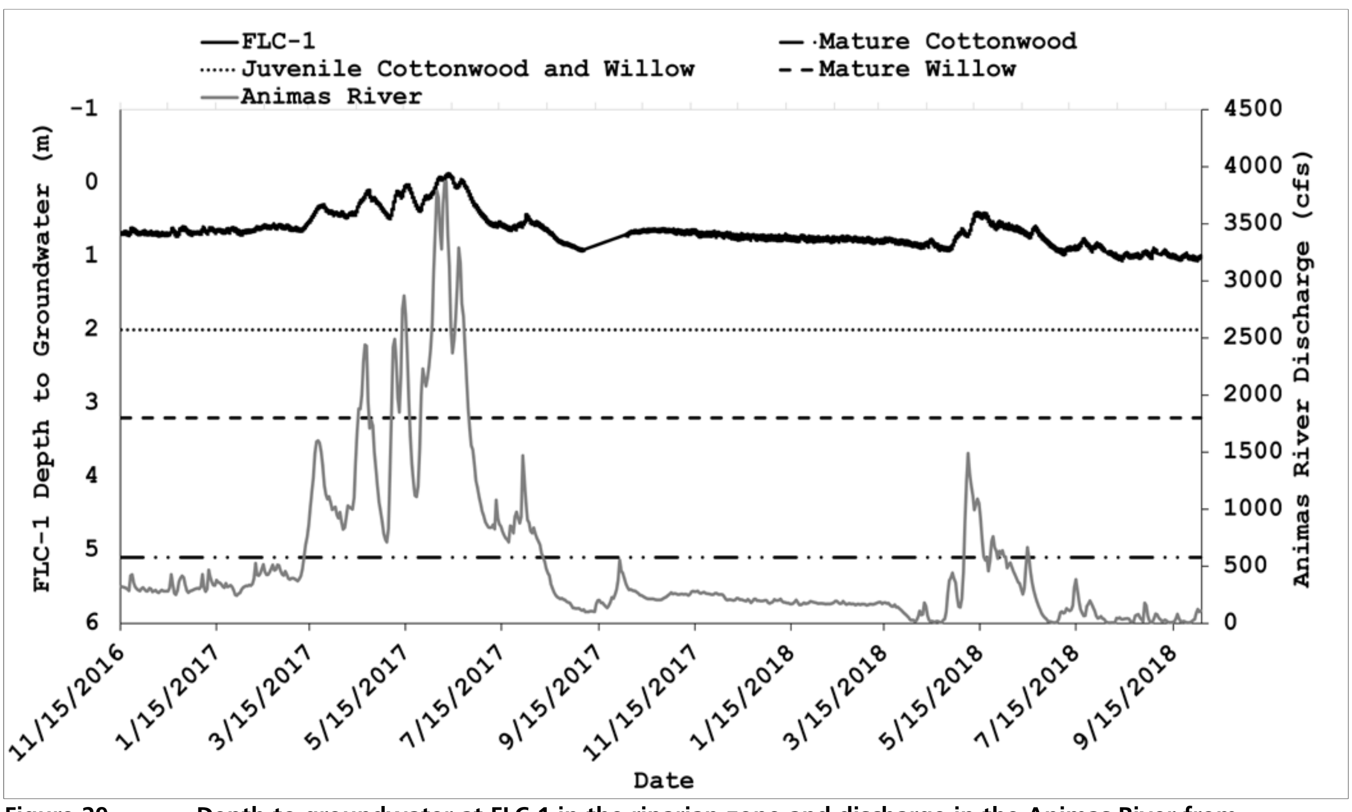


Figure 29. **Depth to groundwater at FLC-1 in the riparian zone and discharge in the Animas River from November 2016 to October 2018.**

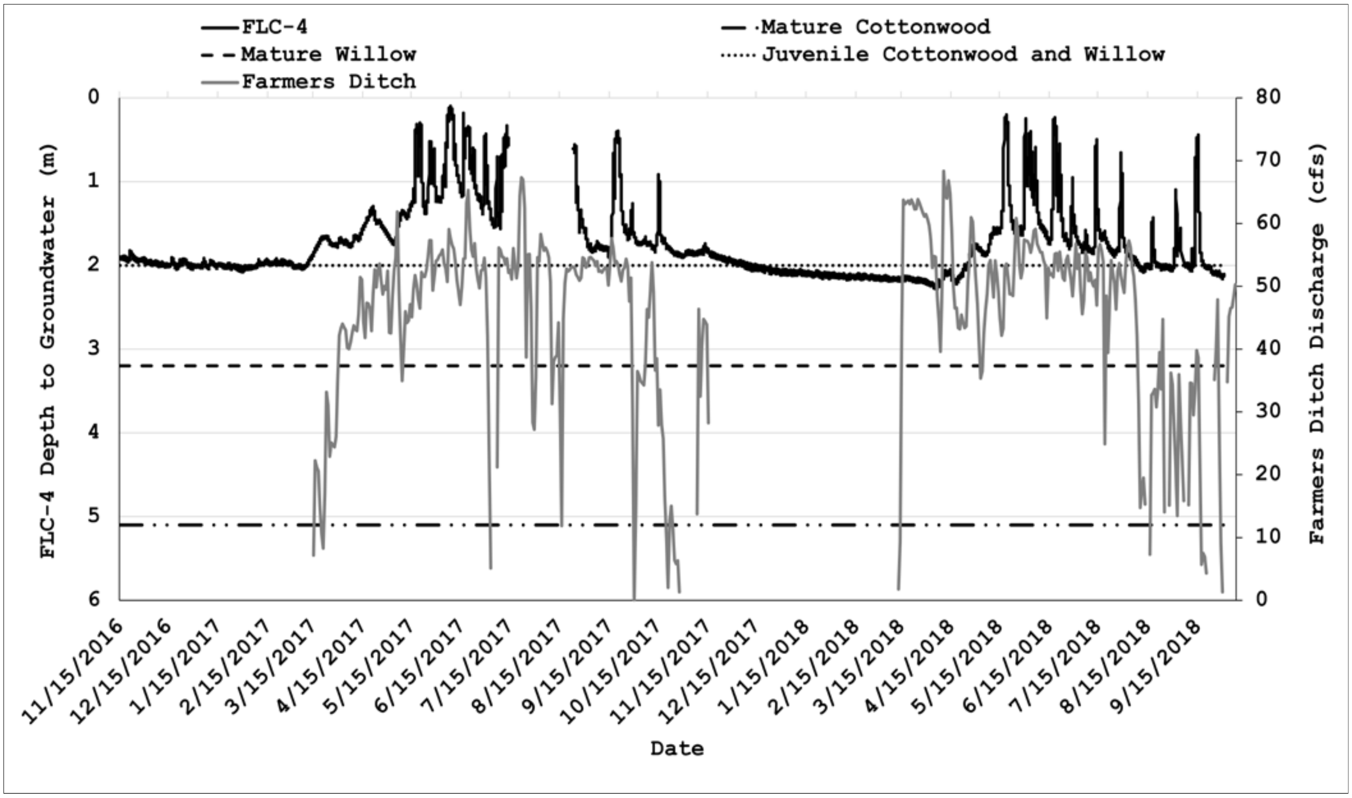


Figure 30. Depth to groundwater at FLC-4 in the riparian zone and discharge in Farmers Ditch from November 2016 to October 2018.

According to the vegetation management and cultural landscape preservation maintenance plan, several non-native species dominate the overstory in the riparian zone, including Russian olive (*Elaegnus angustifolia*) and tamarisk (*Tamarix* spp.) (NPS 2012a). Other non-native species include maple (*Acer* spp.) trees and cultivars (NPS 2012a). Native box elder (*Acer negundo*), cottonwood, and willow also occur in the riparian area but are less dominant (NPS 2012a). This zone is being actively restored to native willows, grasses, and forbs with an overstory dominated by mixed-age box elder, ash (*Fraxinus velutina*), and cottonwood (NPS 2012a, NPS, D. Hawkins, natural resources program lead, NRCA scoping meeting, 24-25 April 2018). Depth to groundwater at the two wells in the riparian zone indicate that conditions are good for plant restoration efforts, at least with respect to water resources.

In summary, the condition of groundwater in the upland terrace zone based on depth to groundwater data could not be determined due to the absence of historic groundwater level data (i.e., prior to groundwater withdrawals and heavy agriculture). Due to the unknown condition, confidence was low. Although groundwater declined at three locations, there was no trend for the three remaining wells. Therefore, the overall trend in the terrace zone is unknown due to conflicting data. In the riparian zone, groundwater levels were adequate for maintaining cottonwood and willow with the exception of occasional dips below the threshold for juveniles of both species at FLC-4. However, these dips generally occurred outside of the growing season (October-April). Trend in groundwater in the riparian zone could not be determined because of the short (2-year) time frame for which data were available. Despite the short time-frame, confidence was high for this condition rating because data were recently collected and data quality is high.

Mean daily discharge in the Animas River, the first measure of the surface water quantity indicator, is shown in Figure 31. The figure includes data from December 2002 through early March 2019. Peak discharge usually occurred during May or June as snow melts in the Animas River headwaters, but in some years, peak discharge occurred in September or October, depending on the timing and amount of monsoon rains (Table 25). The highest discharge occurred on 24 May 2004 with 8,490 cfs and the lowest

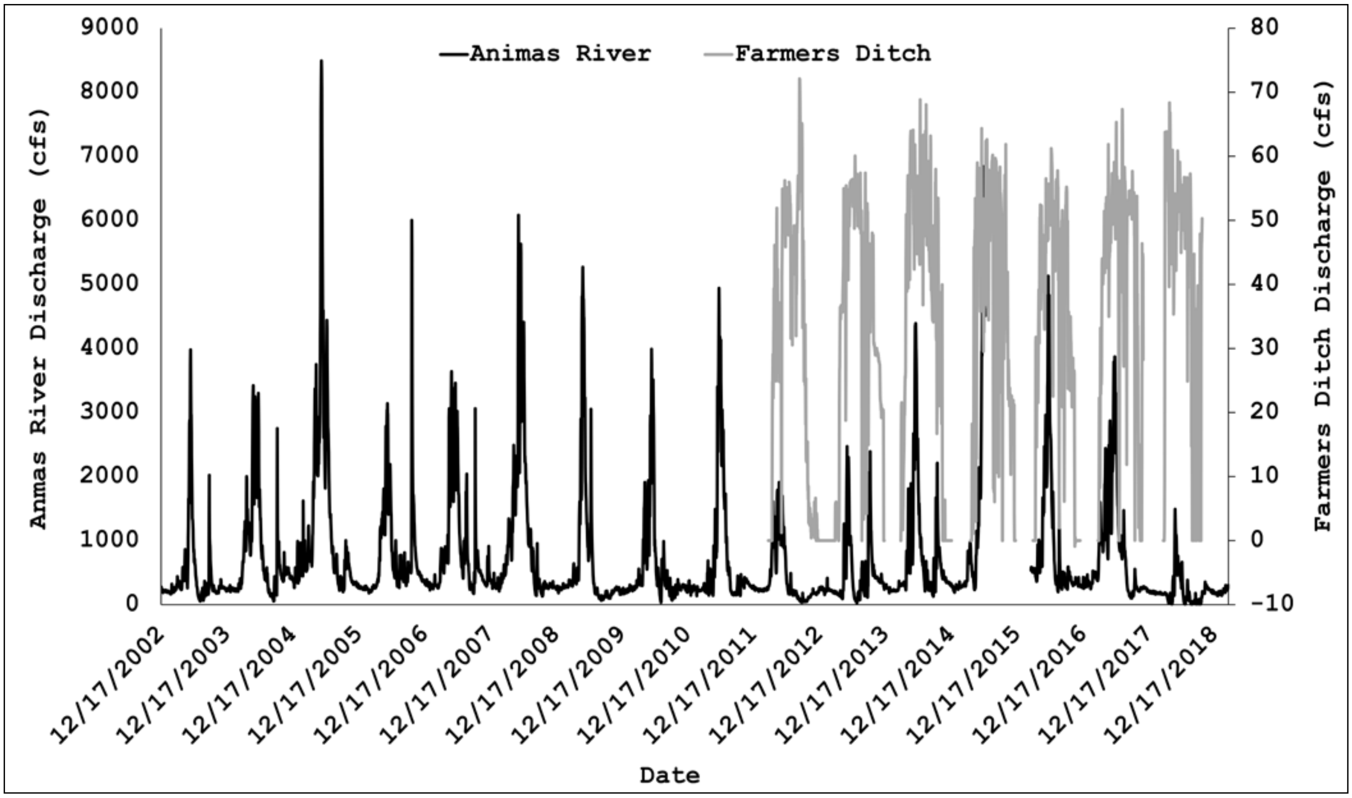


Figure 31. **Mean daily discharge in the Animas River (17 December 2002 through 2 March 2017) and Farmers Ditch (3 March 2012 through 8 October 2018).**

Table 25. Peak discharge as measured at the USGS stream gage below Aztec, New Mexico (gage 09364010).

Date	Peak Discharge (cfs)*
20 September 2004	4,840
23 May 2005	9,130
25 May 2006	3,660
7 October 2006	7,720
21 May 2008	6,930
12 May 2009	5,990
29 May 2010	4,820
7 June 2011	5,750
9 July 2012	2,850
12 September 2013	5,480
1 June 2014	4,940
11 June 2015	7,740
6 June 2016	6,000
11 June 2017	4,330

Source: USGS NWIS (2019).

* Discharge affected to unknown degree by regulation or diversion.

discharge occurred on 10 August 2018 at 5.4 cfs, although this latter value is provisional.

Mean annual discharge was lowest during 2003 and 2018, peaking in 2005, 2008, and 2015 (Figure 32). From 2006 to 2018, mean annual discharge declined, but overall there was no significant trend in discharge over time during 2003 to 2018 ($R^2 = 0.00$, $t = -0.02$, $p = 0.98$) even when excluding provisional data

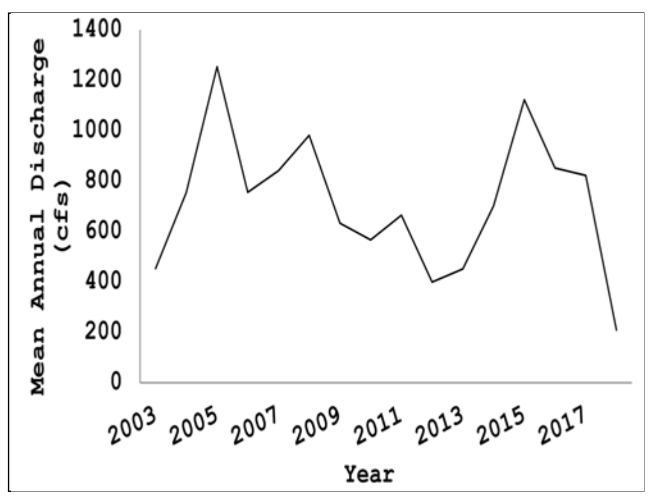


Figure 32. **Mean annual discharge in the Animas River from 2003 to 2018.**

(2003-2015) ($R^2 = 0.16$, $t = -1.36$, $p = 0.20$). Since there were zero no-flow days over the period of record, nor was there a declining trend in mean annual stream flow, the condition for this measure is good. Confidence is medium since data are provisional from 2016 to present.

Mean daily discharge of Farmers Ditch, the second measure of the surface water quantity indicator, is shown in Figure 31. Although discharge in Farmers Ditch is similar to that of the Animas River, flows in the ditch are a reflection of water demands of local users, including agriculture and the City of Farmington, New Mexico. The manually controlled ditch flows from March or April through November depending on the water needs of downstream users. To date, there are no data on how the ditch influences soil erosion or other natural processes in the monument. Therefore, the condition is unknown and confidence is low. However, when water is flowing in the ditch, groundwater is gaining (April to October). There were no changes in the total annual flow in the ditch from 2012 to 2018 ($R^2 = 0.15$, $t = 0.95$, $p = 0.39$). This suggests that water needs downstream of the Farmers Ditch have not changed during the last seven years. The lack of a significant trend also suggests that other factors may be responsible for the declines in the groundwater table for three of the six locations in the Terrace zone.

The single measure of the Animas River watershed shows that approximately 82% of the area was classified into one of the four GAP status categories (Figure 33). Of the area that was classified, 19% was GAP status 1, 2% was GAP status 2, 59 % was GAP 3, and 21% was GAP status 4. Just over half (59%) of lands within the classified areas are managed by the U.S. Forest Service (Figure 34). The BLM manages 19% and the Southern Ute Indian Tribe manages 18%. The remaining 4% of classified lands are managed by local city, county, or state governments and the NPS. The white spaces indicate private lands with no known protections (e.g., conservation easements). Since the majority (59%) of lands within the watershed were in GAP status 3, the condition for this measure is of moderate concern. Confidence in the condition rating is medium because reference conditions were not based on published estimates due to lack of information. Trend could not be determined.

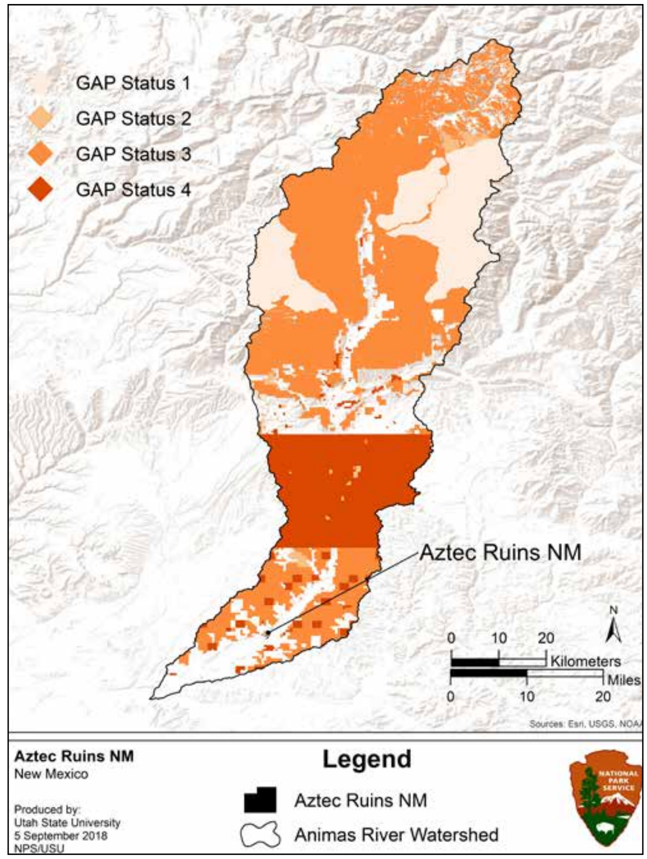


Figure 33. GAP status categories in the Animas River watershed.

Overall Condition, Threats, and Data Gaps

Based on the four measures used in this assessment, the condition of water resources at Aztec Ruins NM is good to moderate concern with an unknown trend and high confidence in the overall condition rating (Table 26). While local groundwater conditions are good (at least in the riparian zone), the watershed as a whole is largely unprotected. Measures with high confidence were given more weight in the overall condition rating than measures with medium or low confidence, and measures without a condition rating were not used to assess overall condition. Confidence in the overall condition rating is medium because some of the data used to determine condition are provisional and because of uncertainties regarding the condition of depth to groundwater in the terrace zone.

Threats to water resources include contamination of ground and surface water from agricultural runoff, oil spills, mining, and right-of-way easements in the monument; potential changes in 9B regulations, which is a framework for safeguarding NPS lands from existing oil and gas leases; climate change; extractive

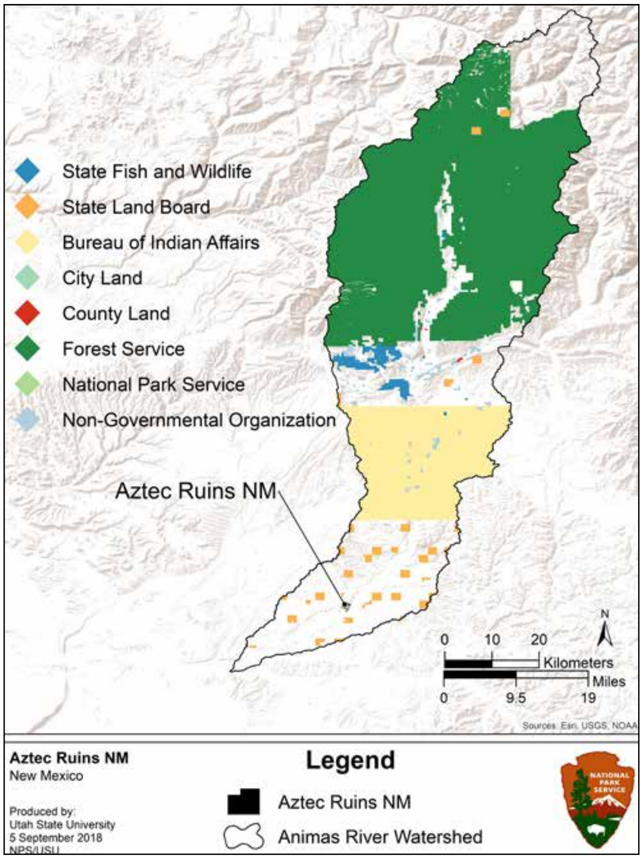


Figure 34. Land management entities in the Animas River watershed.

uses that diminish water quantity; pending water rights; and management of surrounding lands. Because Aztec Ruins NM is a small monument, it may be more heavily influenced by management practices outside its boundaries than would larger parks or monuments. Monument staff have no control of groundwater resources and surface water rights is an ongoing issue.

In 2014, monument staff requested assistance from the NPS Water Resources Division to determine water rights for several land parcels acquired since 1990 (NPS 2014). While some of these parcels have water rights, the rights were adjudicated for uses and areas that are not beneficial to the monument (NPS 2014). In other parcels, it is not clear to monument staff what water rights, if any, exist for these areas, yet native-plant restoration hinges on access to adequate water resources (NPS 2014). Changes in the amount and timing of monsoon precipitation, lowering of the groundwater table, and increased temperatures could also impede restoration efforts.

In the arid southwestern U.S., water is a rare and limited resource. Despite limited availability, demands on water resources in New Mexico have grown. At the same time, winter snowpack, which recharges aquifers and supplies water flow in streams, has

Table 26. Summary of water resources indicators, measures, and condition rationale.

Indicators	Measures	Condition/Trend/ Confidence	Rationale for Condition
Groundwater	Depth to Groundwater (m)	Terrace: dashed circle (unknown); Riparian: green circle	Because historic groundwater levels for the upland terrace zone are unknown, the condition is unknown. However, groundwater levels at three of the six locations in this zone have been stable since 2005 with slight but significant declines in the three remaining locations. Groundwater data for the two wells located in the riparian zone indicate good conditions for maintaining cottonwoods and willows at all life stages. Trends in riparian depth to groundwater could not be determined with only two years of data, and conflicting data for the Terrace zone resulted in an unknown trend.
Surface Water Quantity	Animas River Discharge (cfs)	green circle	The highest discharge occurred on 24 May 2004 with 8,490 cfs and the lowest discharge occurred on 10 August 2018 at 5.4 cfs, although this latter value is provisional. There were zero no-flow days from 2002 through early March 2019. From 2006 to 2018, mean annual discharged declined, but overall there was no significant trend in discharge over time.
	Farmers Ditch Discharge (cfs)	dashed circle (unknown)	Because Farmers Ditch receives water from the Animas River, discharge there mirrors that of the river. The manually controlled ditch flows from March or April through November depending on the water needs of downstream users. To date, there are no data on how the ditch influences soil erosion or other natural processes in the monument.
Protected Area of the Animas River Watershed	Proportion of Watershed Protected	yellow circle	Approximately 59% of the classified areas in the Animas River watershed is considered GAP status 3, or lands that are managed for multiple uses ranging from low intensity (e.g., logging) to high intensity (e.g., mining). Many of these lands are managed by the U.S. Forest Service.

Table 26 continued. ***Summary of water resources indicators, measures, and condition rationale.***

Indicators	Measures	Condition/Trend/ Confidence	Rationale for Condition
Overall Condition	Summary of All Measures		Although local data indicate depth to groundwater and stream flow are good for maintaining riparian trees and shrubs, the overall watershed is largely unprotected with extractive uses possible in many areas. Although groundwater in the terrace zone is consistent with that observed in San Juan Basin from 1970 to 2010, there are no data to determine historic groundwater conditions.

declined (Carroll and Willman 2015). Demands on surface water coupled with declines in snowpack have led to a greater reliance on groundwater in the state (Carroll and Willman 2015). In the San Juan Basin, most agricultural demands are met by surface water, but surface water and groundwater are interconnected with the former slowly replenishing the latter. If water demands continue to increase, groundwater storage will eventually decline. However, the relationship between surface water and groundwater for the watershed surrounding the monument is unknown (Carroll and Willman 2015).

Water diverted into Farmers and other ditches reduces flows in the Animas River, taking sediments and nutrients that would otherwise be deposited on the floodplain in the monument downstream, which alters natural hydrological and erosional processes (NPS 2012a). Farmers Ditch artificially raises the groundwater table, at least when water is flowing through the unlined canal (Filippone and Martin 2014). The ditch also interrupts surface water flow between the uplands in the northern part of the monument and the floodplain (NPS 2012a). A study of groundwater/surface water interactions along the Animas River found that the majority of water that recharges the shallow water aquifer comes from irrigation ditches (Newton et al. 2017). Groundwater levels also change naturally with the seasons and with proximity to the Animas River.

One study found that all wells, regardless of distance to the river, exhibited little change from January to March and the greatest amount of change from March to June (Timmons et al. 2016). From August to January there was an intermediate amount of change. Additionally, wells farther from the river exhibited greater fluctuations in groundwater levels compared to wells closer to the river (Timmons et al. 2016). This is because wells closer to the river are shallower and near the level of the river, whereas wells farther from the river are deeper and more dependent on changes in irrigation (Timmons et al. 2016).

Despite elevated groundwater levels during certain times of the year, several changes in management practices have improved groundwater resources at the monument. Historically, irrigation of the Abrams property and the orchard raised groundwater levels, which was a concern regarding the structural integrity of the ruins; however, Filippone and Martin (2014) found no evidence to suggest that groundwater levels from 2005 to 2012 were the cause of high soil moisture at the West Ruins complex area. Although there is not a study that addresses how the ditch influences water resources and soil erosion in the monument, the vegetation management and cultural landscape preservation maintenance plan notes that there is a dirt maintenance road that runs along the ditch, which contributes to soil loss and the spread of non-native plants (NPS 2012a).

An assessment of the Colorado portion of the Animas River watershed found that soil loss and erosion control, water quality and quantity, and non-native plants were the primary long-range resource concerns (USDA 2010). Water quality is impaired for certain stretches of the river. For example, a stretch of the Animas River from Estes Arroyo in New Mexico just south of the monument to the border of Colorado was listed as impaired for *Escherichia. coli*, phosphorus, temperature, and turbidity during the 2016 monitoring cycle (NPS WRD 2018).

In 2013 and 2014, the San Juan Watershed Group (SJWG), the San Juan Soil and Water Conservation Project, and the Animas Watershed Partnership initiated a fecal bacteria tracking project along the Animas River (SJWG et al. 2015). The goal was to identify the animal source(s) of bacteria and where the bacteria originates along the river. The group found that human waste and the waste of ruminants were the most significant contributors of fecal contamination in the river (SJWG et al. 2015). Birds were also a contributor.

The stretch of river sampled near Aztec Ruins NM was found to be fourth out of five sites in the number of samples testing positive for *E. coli* (SJWG et al. 2015). Improper handling of manure, grazing on irrigated fields and in riparian areas, and direct access of ruminants to the river are all possible contributors to *E. coli* exceedences. Human sources of *E. coli* include illegal septic tanks, leaking sewer pipes, illegal dumping, wastewater treatment plants, and outdoor defecation (SJWG et al. 2015).

In 2015, the release of contaminated, impounded water from the abandoned Gold King Mine in Silverton, Colorado was accidentally triggered by an Environmental Protection Agency work crew (New Mexico Surface Water Quality Bureau [NMSWQB] 2018a). The spill resulted in a spike in lead, arsenic, and copper concentrations. Monitoring at hundreds of locations along the Animas River and San Juan River indicated that by the end of 2016, however, these heavy metals had been flushed downstream (NMWRRI2018). But over the last century, tailings from hundreds of other mines in the region have and continue to threaten water quality as they drain directly into the Animas River. The most recent water quality report for impaired streams lists several reaches of the Animas River in New Mexico as impaired due to temperature, *E. coli*, phosphorus, turbidity, and nutrient loads (NMSWQB 2018b).

Farmers Ditch. Photo Credit: © K. Struthers.

According the monument's foundation document, possible opportunities for mediation of threats to the monument's water resources are to collaborate with local and state governments to manage water resources sustainably, continue vegetation restoration strategies within the monument, and to maintain water rights for native plant restoration (NPS 2015a). Not only are NPS staff pursuing these strategies, but the Animas Watershed Partnership (AWP) has developed a strategic action plan that will help further these objectives throughout the entire watershed (AWP 2014).

Sources of Expertise

Assessment author is Lisa Baril, biologist and science writer, at Utah State University. Stephen Monroe, a retired NPS hydrologist, provided all groundwater and Farmers Ditch discharge data included in this assessment, as well a review of earlier drafts. Additional subject matter expert reviewers for this assessment are listed in Appendix A.

Geology

Background and Importance

Interpreting the geologic history of an area is important for understanding the soils, landforms, and natural processes that occur on the landscape today. In the case of cultural National Park System units such as Aztec Ruins National Monument (NM), geologic history is also integral to understanding an area's cultural history. The Ancestral Puebloans, who occupied the region from the late 1000s to the late 1200s, left behind many structures and artifacts of cultural significance to both present-day Native Americans and visitors to the monument, and these artifacts and structures have deep connections to the geology of the region (NPS 2015a).

Stones from the 60-million-year-old Nacimiento Formation were used to construct the walls of the Great Kiva, West Ruin, East Ruins and other structures in the monument (KellerLynn 2016). The Nacimiento Formation is the bedrock that underlies the monument and is composed of sedimentary rocks that include claystone, shale, siltstone, and sandstone (KellerLynn 2016). In the monument, the Nacimiento Formation can be as thick as 525 m (1,720 ft) and is exposed in only a few places, such as the deep drainages on the North Mesa where erosional forces have worn down the rock layers above (KellerLynn 2016). The Ancestral Puebloans excavated blocks of Nacimiento bedrock from quarries located a few kilometers outside the monument, perhaps because of the lack of exposure of this rock type nearby. The different colors found in the Nacimiento Formation, which reflect grain size, were used to add a decorative touch to the pueblos, such as the distinctive green band added to the walls of the West Ruin (KellerLynn 2016). However, the Ancestral Puebloans covered these decorative details with mud plaster to protect the structures from wind and water.

The Nacimiento Formation is overlain by Quaternary alluvial sediments ranging from 12 to 30 m (40-100 ft) thick (KellerLynn 2016). These valley-fill alluvial sediments were deposited by Pleistocene glaciers that originated in the headwaters of the Animas River in southern Colorado north of the monument. Above this layer is a thin fine-grained alluvium from more local floodplain deposits (KellerLynn 2016). Upland soils, as mapped by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), are dominated by the Haplargids-Blackston-Torriorthents complex with smaller areas dominated by Avalon sandy loam (USDA NRCS 2018, Salas et al. 2009). The morphologically complex terraces in the area represent hundreds of thousands of years of glacial and fluvial activity. The modern floodplain formed after the last glaciation ended (KellerLynn 2016).

The West Ruin in Aztec Ruins NM. Photo Credit: © L. Baril.

Data and Methods

The selected indicators and measures were chosen to assess anthropogenic impacts to geologic features in the monument since human-caused impacts have the potential for management action, although we recognize that natural forces of erosion also affect geologic resources. The indicators are disturbed lands; known deterioration or loss of integral geologic, paleontologic, or cultural features; and seismic activity.

We used the Abandonded Mineral Lands (AML) prioritization ranking as a measure of the disturbed lands indicator. AML information for Aztec Ruins NM were available in the NPS AML report, a comprehensive inventory and assessment of AML sites in the National Park System (Burghardt et al. 2014). Burghardt et al. (2014) listed criteria used to prioritize AML features for remedial action. Each site was assigned rankings for hazards, access, resource significance, and resource impacts. The hazard and access elements were assigned numeric rankings between 0 and 5 (low to high) by the NPS AML Program based on the presence of identifiable characteristics, such as a highwall which is a vertical wall formed from excavation into a hillside (hazard element), or the AML site being accessible by a road leading to it (access element). The resource significance and resource impact rankings had possible values of 0, 2 or 4 for low, medium and high. The National Park Service (NPS) prioritization system for sites that need mitigation was based on the severity of public safety hazard and the level of impact on park resources (Burghardt et al. 2014). Sites with a hazard level of at least 3, or a resource impact level of 4, are assigned as high priority. Medium priority AML have either a hazard level or resource impact level of 2. All other AML features are considered low priority.

For the second measure of disturbed lands, we describe the number and status of oil and gas well pads in the immediate vicinity and within the boundaries of the monument based on an Excel file provided by the NPS Geologic Resources Division (GRD) on 23 February 2018, which included the location and status of wells in the area. We also include information reported in the geologic resources inventory report on the concerns of park staff regarding area wells (KellerLynn 2016).

To assess the condition of known deterioration or loss of integral geologic, paleontologic, or cultural features, we relied on a single measure (proximate anthropogenic impacts) based on a vibration study and a summary of reported incidents at the monument. We also considered including reported damage to paleontological resources (fossils) in the monument. However, according to Tweet et al. (2009) and KellerLynn (2016), no fossils have been documented in the monument except those associated with cultural resources (Tweet et al. 2009). Any paleontological resources would likely occur in the Nacimiento Formation, which holds fossils elsewhere but is rarely exposed in the monument (Tweet et al. 2009). Because of the lack of documentation of fossils in the monument, we did not consider this aspect of the measure further.

King and King (1994) conducted a vibration study to determine what frequencies the ruins are sensitive to, how far sources of vibrations have to be to protect structures, and how much vibratory energy is transferred to the structures from normal daily activities (King and King 1994). In 1994 nine points were located at 0 to 3 m (0-10 ft) from the monument's south boundary (3 points), 9 to 12 m (30-40 ft) from the south boundary (3 points), and 52 to 55 m (170-180 ft) from the south boundary (3 points). Fifty readings were made at each location (see King and King 1994 for more details).

Reported incidents (e.g., trespassing, damage to resources) at the monument were obtained for the period October 2013 through September 2018. The summary was provided by Jeffrey Gardner, Chief Ranger, Aztec Ruins NM/Chaco Culture National Historical Park on 14 December 2018 via an e-mail message to the assessment author. Although the document also included instances of trespass for June 2005 through March 2012, reports were not consistently made during this time. We summarized the number and type of incidents in the monument, particularly those that directly or indirectly affected geological and cultural resources.

Finally, the single measure (presence/absence) of the seismic activity measure was assessed using the U.S. Geological Survey's (USGS) Earthquake Catalog (USGS 2018b). We downloaded the locations of ≥2.5 magnitude (micro) earthquakes that occurred within an 80-km (50-mile) radius of the monument from 1 January 2000 to 1 December 2018 (USGS 2018b). We included data for natural earthquakes as well as seismic events that were human caused by selecting the following search terms: anthropogenic, blasting, explosion, acoustic noise, and sonic booms. The various earthquake magnitudes and class descriptions identified by the Incorporated Research Institutions for Seismology (IRIS 2018) range from micro (<3) to great (≥8). Damage from earthquakes does not usually occur at a magnitude less than 4 or 5 (light to moderate), but factors such as soil type, distance from the earthquake, and sensitivity of a feature also determine whether damage occurs (USGS 2018b).

Reference Conditions

Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the four measures (Table 27). Indicators, measures, and reference conditions were initially developed by the assessment author and then revised at the NRCA scoping meeting on 24 April 2018.

Condition and Trend

Because of the scant data available to assess this resource, trend for all four measures is unknown.

For the disturbed lands indicator, Burghardt et al. (2014), reported that there is one AML feature in the monument, and that site has been mitigated with no other mitigations required. The more recent geologic inventory resources report cites two oil and gas wells that have been abandoned and reclaimed (KellerLynn 2016). Reclamation is the act of restoring the disturbed area by planting native grasses and other vegetation. Because both abandoned wells have been reclaimed, the condition is good. Confidence in the condition rating is high.

The second measure of disturbed lands shows that there are a total of six oil and gas wells in and around the monument according to data provided by the NPS GRD and Aztec Ruins staff (Figure 35), two of which have been abandoned and reclaimed as described in the previous measure. Four of the wells are active, three of which are located within the monument. The direct impacts these wells have had or are having on geologic resources in the monument have not been studied, but in the geologic resources inventory report, oil and gas development and production was listed as a top management priority (KellerLynn 2016). In 2005, there was a spill and recovery at one of the wells in the monument (NPS, A. Adams, Chief of Resources, email communication, 5 March 2019). Private mineral ownership and undeveloped gas resources under the monument could result in additional drilling. Drilling outside the monument will probably continue into the future since the San Juan Basin is one of the most productive oil and gas regions in the nation (KellerLynn

Table 27. Reference conditions used to assess geology at Aztec Ruins NM.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Disturbed Lands	Abandoned Mineral Lands Prioritization Ranking	AML sites requiring mitigation are ranked as low priority or there are no sites requiring mitigation.	At least one AML site requiring mitigation is ranked as medium priority.	At least one AML site requiring mitigation is ranked as high priority.
	Oil and Gas Development and Production	There are no concerns or issues for geological and cultural resources with respect to oil and gas development.	None of the issues or concerns raised would have a major impact on geological and cultural resources with respect to oil and gas development.	At least one issue or concern regarding resource extraction would have major impacts on geological and cultural resources with respect to oil and gas development.
Known Deterioration or Loss of Integral Geologic, Paleontological, or Cultural Features	Proximate Anthropogenic Impacts	No known incidences of vandalism, graffiti, off-trail travel, or other incidents that have led to damage of resources.	There have been a small number of vandalism, graffiti, off-trail travel, or other incidents that have led to damage of resources but none that require mitigation.	There have been one or more incidents of vandalism, graffiti, off-trail travel, or other incidents that have led to or will lead to damage of resources that require mitigation.
Seismic Activity	Presence/Absence	No earthquakes have occurred in the vicinity of the monument or the monument is not in a seismically active zone.	Earthquakes have occurred in the vicinity of the monument or the monument is within a seismically active zone.	Earthquakes have occurred in the monument's vicinity or the monument is in an actively seismic zone. Further, the occurrence of earthquakes appears to be at a moderate to high level in either frequency or magnitude

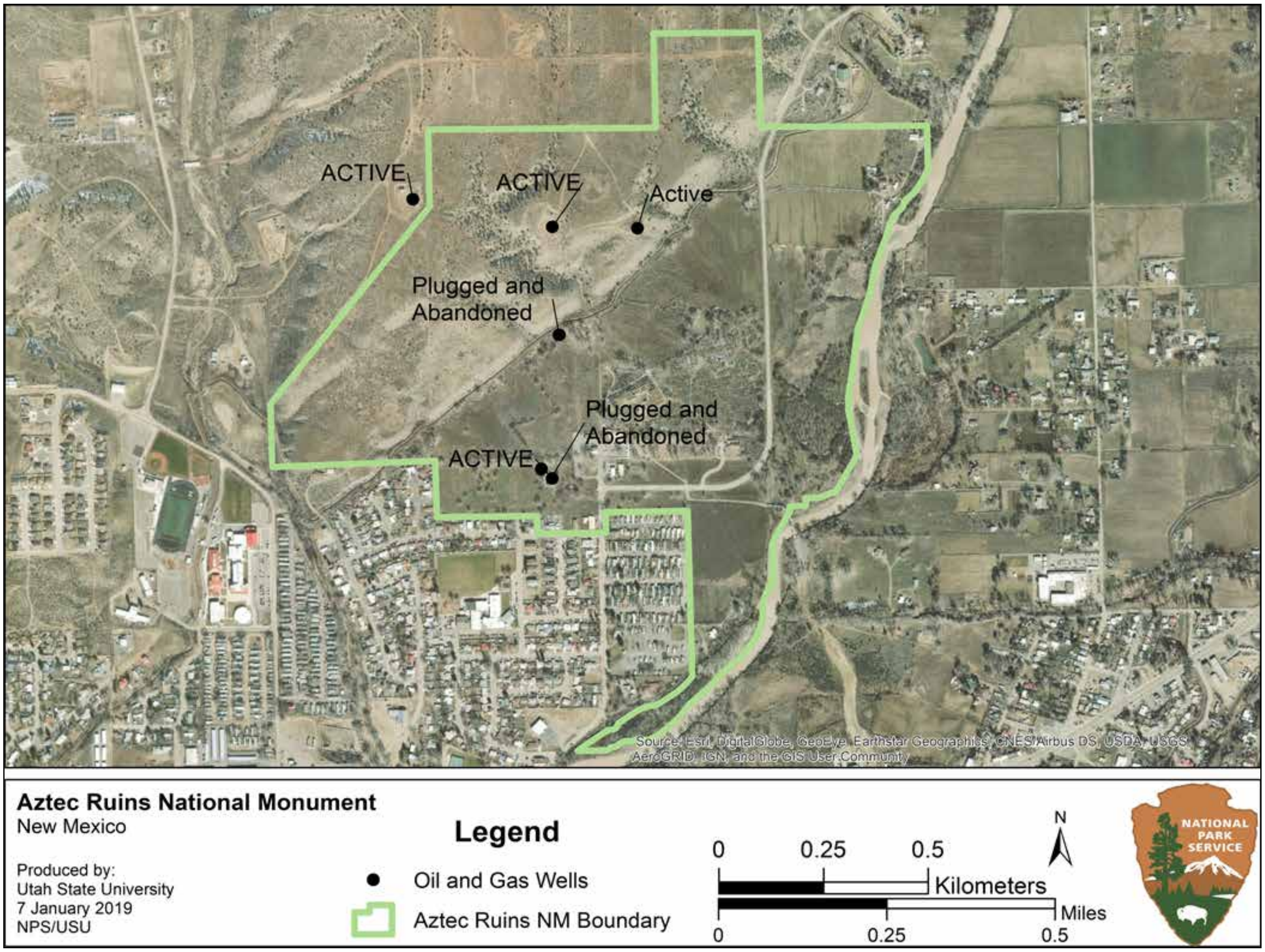


Figure 35. Well locations in and around Aztec Ruins NM.

2016). Potential concerns include groundwater and surface water contamination; erosion and siltation; introduction of non-native plants; and impairment of the viewshed, night sky, and soundscape (KellerLynn 2016).

On 4 November 2016, the 1978 service-wide regulations governing oil and gas rights in national parks (i.e., 9B regulations) were updated and strengthened to protect natural resources on NPS lands (Department of Interior National Park Service 2016). The 2016 amendments removed the $200,000 cap on compensation provided to parks for natural resource damage caused by drilling operations, brought more than 300 oil and gas wells on NPS lands under NPS management, and entitled the NPS to compensation for drilling that occurs outside NPS boundaries but that affects NPS resources. In January 2017 however, the House of Representatives introduced Joint Resolution 46, which seeks to nullify the 2016 amendments (H.J.R. 46, 2017).

Finally, hydraulic fracturing ("fracking"), although currently not allowed in national parks, may cause significant damage to the monument's cultural structures from vibrations produced by fracking itself or by the transportation of heavy equipment in and out of the monument (KellerLynn 2016). KellerLynn (2016) also noted that there is no known safe distance at which sensitive cultural features would be protected from this disturbance. For these reasons, this measure is of significant concern to geologic resources in the monument. Confidence in the condition rating is low due to the numerous uncertainties and lack of formal study regarding this issue.

During the vibration study used to assess the proximate anthropogenic impacts to important features, King and King (1994) found that the ruins were sensitive to vibrations in the 6 to 20 Hz bandwidth, but especially within the 7 to 12 Hz bandwidth. Maintenance road traffic fell within this range. Vehicles of one or more tons (~2,000 lbs) within 15 m (50 ft) of the ruins may cause damage. All other (smaller) vehicles may cause damage at less than 6 m (20 ft). Traffic on the boundary roads did not induce vibrations significant enough to impact the ruins but may cause issues in the future if the East Ruins are ever excavated. While the authors found that the ruins are protected from these sound sources, other sources, including low-flying aircraft (e.g., helicopters within 300 ft [91 m]) or the occasional large and loud vehicle, especially on a nearby road that is not well-maintained (e.g., potholes) could cause vibration disturbances to the ruins. Also, because the monument is located within city limits, construction projects nearby could also cause issues. Unfortunately, there are no current data with which to evaluate the effects of vibrations on monument structures, other than seismic activity, which is described in the next measure.

According to the trespassing summary, resource degradation has grown since the 2014 completion of the pedestrian footbridge over the Animas River, which connects the town of Aztec, New Mexico to the national monument. Prior to fiscal year (FY) 2013, 11 incidents of looting, damage, off-trail travel, off-road vehicle traffic, and a campsite were reported. These incidents occurred from 27 June 2005 to 16 March 2012. In FY 2013, there were 13 reported incidents, 25 incidents in FY 2014, 22 incidents in FY 2015, 42 incidents in FY 2016, 34 incidents in FY 2017, and 11 incidents in FY 2018.

These data represent minimum estimates of activity because not all instances of damage, and especially looting, are discovered. Although not all incidents reported directly damaged geological or cultural resources, the vast majority of them were related to resource damage of this type, including off-road vehicles, off-trail foot traffic, collection piles, and defacement of ruins. The monument's location adjacent to the city of Aztec, New Mexico; extensive housing development surrounding the southern boundary of the monument; the pedestrian bridge linking downtown to the monument; and lack of a dedicated full-time law enforcement ranger all contribute to destruction of resources there. The high number of incidents and looting and/or damage of any kind to the structures and artifacts warrants significant concern. Confidence is medium because the number of incidents represents a minimum, yet incidents of looting and vandalism were among the most common activities reported, which was a common activity historically as well. Geologist, Dr. John S. Newberry, reported in 1859 that the site was well preserved, but over the next 50 years, looting was common (Lister and Lister 1990). Looting was reduced but not eliminated when the site became privately owned in 1889 (Lister and Lister 1990), and formal protection against looting occurred in 1923 when the site was designated a national monument (NPS 2015a).

The presence/absence measure of the seismic activity indicator revealed that since 1 January 2000, only one seismic incident was reported within the 80-km (50-mi) radius of the monument. The incident was the result of a mining explosion that occurred on 21 February 2014, which triggered a 2.7 magnitude earthquake. The explosion occurred 63.5 km (39.5 mi) southwest of the monument. These results suggest that earthquakes due to natural or man-made causes are relatively rare in the area. In the San Juan Basin, injection well sites are not associated with seismicity as in other areas such as central Oklahoma (Weingarten et al. 2018), despite this region being one of the most prolific natural gas producing regions in the U.S. While there are many concerns with respect to the effects of oil and gas development on natural resources in the monument, seismic activity does not appear to be one of them. Therefore, the condition is good. Confidence in the condition rating is medium because these events are unpredictable.

Overall Condition, Threats, and Data Gaps

We used three indicators and four measures to assess the condition of geology at Aztec Ruins NM (summarized in Table 28). In this assessment, all measures were assigned medium or low confidence. This is because the data used to determine condition were not specifically collected to assess geology and because there are no studies directly related to geology or cultural feature damage in the monument, except for the vibration study from 1994. Trends could not be determined for any of the four measures. Therefore, the overall trend is unknown. Given the measures used in this assessment, the most damage occurs as the result of local threats like oil and gas development in and around the monument, and vandalism and removal of artifacts within the monument. Earthquakes and AML lands were considered in good condition. However, there are many uncertainties because there are no studies or continued monitoring of this resource type

Table 28. Summary of geology indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Disturbed Lands	Abandoned Mineral Lands Prioritization Ranking		There are two AML features in the monument, both of which have been mitigated.
	Oil and Gas Development and Production		There are a total of six oil and gas wells in and around the monument, two of which have been abandoned and reclaimed as described in the previous measure. Four of the wells are active, three of which are located within the monument. The remaining well is inactive but has not been reclaimed. Issues related to oil and gas development include damage to soils; contamination of groundwater and surface water; introduction of non-native plants; changes to 9B regulations; erosion; and interference with dark night skies, soundscape, and viewsheds.
Known Deterioration or Loss of Integral Geological, Paleontological, or Cultural Features	Proximate Anthropogenic Impacts		Prior to fiscal year (FY) 2013, 11 incidents of looting, damage, off-trail travel, off-road vehicle traffic, and a campsite were reported. These incidents occurred from 27 June 2005 to 16 March 2012. In FY 2013, there were 13 reported incidents, 25 incidents in FY 2014, 22 incidents in FY 2015, 42 incidents in FY 2016, 34 incidents in FY 2017, and 11 incidents in FY 2018, many of which were related to vandalism, off-trail use, off-trail traffic, removal of artifacts, defacement of ruins, and other activities.
Seismic Activity	Presence/ Absence		Only one seismic event (21 February 2014) was recorded between 1 January 2000-2018. This was a human-caused event of a 2.7 magnitude. This micro earthquake occurred ~64 km (~40 mi) southwest of the monument. Given the low magnitude, distance of occurrence, and rarity of seismic activity, earthquakes do not represent a significant threat to cultural or geologic resources in the monument.
Overall Condition and Trend	Summary of All Measures		Given the measures used in this assessment, the most damage to geologic resources occurs as the result of local threats like oil and gas development in an around the monument and vandalism and removal of artifacts within the monument. Earthquakes and AML lands were considered in good condition. However, there are many uncertainties because other than the 1994 vibration study, there are no additional studies or continued monitoring of this resource type in the monument.

in the monument. The overall condition is of moderate concern with medium confidence.

The major threats identified by NPS staff during the scoping meeting were essentially the measures included in this assessment: seismic activity, extractive uses, and disturbances associated with oil and gas wells. KellerLynn (2016) provides an excellent and thorough description of threats to geologic resources in the monument, which we summarize here. As previously mentioned, the San Juan Basin is one of the most productive oil and gas regions in North America (KellerLynn 2016). Any increase in activity associated with these well or new well developments has the potential to affect cultural and geologic resources. Outside of the monument, current oil and gas production (including fracking) has the potential to contaminate groundwater and surface water; cause erosion and siltation; introduce non-native plants; impair wildlife habitat; and interfere with dark night skies, the viewshed, and soundscape (KellerLynn 2016). A related threat is the potential for changes to 9B regulations. As mentioned, fracking does not occur in the monument but is a growing method being used in the San Juan Basin. Although Weingarten et al. (2018) did not find an association between fracking and seismic activity in the San Juan Basin, there are numerous other threats related to this method, including water contamination, reduction of streamflow and groundwater availability, air pollution, and excess dust among other concerns (KellerLynn 2016).

Also of concern is the proximity of development surrounding the monument in addition to nearby access roads. The proximity and accessibility of the monument makes it more convenient for looting and disturbance of cultural and geologic features to occur. There is also an unfinished subdivision located upslope of the monument. If the subdivision is completed, activities there could lead to increased erosion into the monument (KellerLynn 2016). Construction vehicles on nearby development may also cause damaging vibrations to the cultural resources. Irrigation of lawns could also lead to a higher groundwater table, and high groundwater levels could affect the stability of the ruins (Filippone and Martin 2014). Near surface water conditions are locally elevated, causing some issues with the western side of the West Ruin complex (KellerLynn 2016). Local subsidence, especially near the East Ruin, is also cause for concern since it can cause cracking in the walls. The cause of subsidence in this area is unknown but may be the result of changes in groundwater levels since irrigation of recently acquired lands was terminated (KellerLynn 2016). Coal-bed methane extraction in the San Juan Basin also causes regional but minor subsidence, but this is apparently unlikely to affect the monument (KellerLynn 2016).

Lastly, piping, or the removal of soils as a result of percolating subsurface water is of concern. Soil pipes are evident along the banks of the Animas River, which could lead to erosion of the streambank and loss of cultural features. However, Ancestral Puebloans may have created soil pipes to build kivas, which means that they could have cultural significance (KellerLynn 2016).

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Upland Vegetation and Soils

Background and Importance

The National Park Service's (NPS) Southern Colorado Plateau Inventory and Monitoring Network (SCPN) monitors upland vegetation and soils across 10 of its 19 network parks, including Aztec Ruins National Monument (NM), to better understand current condition and patterns of change over time (DeCoster et al. 2012). Upland vegetation was selected as a vital sign because upland ecosystems comprise the majority of land area across parks in the network (>85%) (DeCoster et al. 2012). Soil was also identified as a vital sign because erosion is a significant threat to many dryland ecosystems and can cause destabilization of archeological resources. Unlike in other areas where fire plays an important role in determining vegetation types, in the dryland ecosystems of the Colorado Plateau, soils are the primary driver of plant community composition (Miller 2005). Monitoring vegetation and soils together can help scientists recognize subtle shifts in ecosystem structure and function.

Uplands in Aztec Ruins NM are located in the western side of the monument on what is known as the North Mesa (NPS 2012a, Salas et al. 2009). Upland vegetation on the North Mesa overlies un-excavated ruins that overlooks the West Ruin site and the town of Aztec, New Mexico (Salas et al. 2009). Upland soils, as mapped by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), are dominated by the Haplargids-Blackston-Torriorthents complex with smaller areas dominated by Avalon sandy loam (USDA NRCS 2018, Salas et al. 2009). These well-drained, moderately permeable soils support big basin big sagebrush (*Artemisia tridentata*) with an herbaceous layer of James' galleta (*Pleuraphis jamesii*), broom snakeweed (*Gutierrezia sarothrae*), catseye (*Cryptantha* spp.), globemallow (*Sphaeralcea* spp.), and pepperweed (*Lepidium* spp.) (Salas et al. 2009). These soils also support Utah juniper (*Juniperus osteosperma*) and one-seed juniper (*Juniperus monosperma*) woodlands in the drainages, as well as fourwing saltbush (*Atriplex canescens*) shrublands dominated by an understory of Indian ricegrass (*Achnatherum hymenoides*) (Salas et al. 2009).

Data and Methods

This assessment is based on three indicators (erosion hazard, community composition and structure, and non-native plants) with a total of nine measures. Data were collected as part of SCPN's upland vegetation monitoring program (DeCoster et al. 2012). We also used data from a 2008 non-native plant inventory (Korb 2010). The SCPN established six plots in what the NRCS describes as the Limy ecological site, which represents nearly the entire upland area (DeCoster and Swan 2009). Ecological site descriptions are based on soil survey data, historical plant community

Upland vegetation in Aztec Ruins NM. Photo Credit: NPS.

type, disturbance regime, and other factors (USDA NRCS 2018). The Limy ecological site occurs on river terraces, plateaus, and mesas (Sylvester and Wright 2003). Slopes are generally 0 to 8%, but river terrace slopes may be as steep as 40% (Sylvester and Wright 2003).

Plots were 52 x 50-m (171 x 164 ft) with three, 50-m (164-ft) transects that were established 25 m (82 ft) apart (NPS, M. Swan, botanist, comments to draft assessment, 18 December 2018). Five nested, 10 m^2 (108 ft^2) quadrats were placed along each of the three transects in which cover of all herbaceous and shrub species, cover of functional plant categories (e.g., perennial grass), basal gap cover, cover of soil surface features, and non-native plant frequency were recorded. Tree canopy cover was recorded along the three line transects. The first round of sampling occurred in 2008 and the second round of sampling occurred during 2016. For brevity, we provide a brief description of each measure and why it is important rather than specific sampling details. A detailed description of the protocol can be found in DeCoster et al. (2012). The six SCPN plots and vegetation associations in the uplands are shown in Figure 36.

The first measure of erosion hazard is the cover of bare ground and undifferentiated soil crust. The amount of bare ground is a measure of erosion potential since most soil loss occurs in unprotected bare patches (DeCoster et al. 2012). As the amount of bare ground increases, the velocity of surface water flow and erosion due to wind also increases. Vegetation, biological soil crusts, litter, and rock cover help protect against rapid soil loss. We included undifferentiated crust, which includes physical and light cyanobacteria, because these cover types may also contribute to erosion. Cover was estimated using the mid-points of the 12 cover classes listed in Table 29.

The second measure of erosion hazard is the cover of biological soil crusts (BSC). BSCs are comprised of cyanobacteria, lichen, and moss (DeCoster et al. 2012). Soil crusts provide key ecosystem services by increasing resistance to erosion, increasing infiltration, contributing organic matter to soils, and

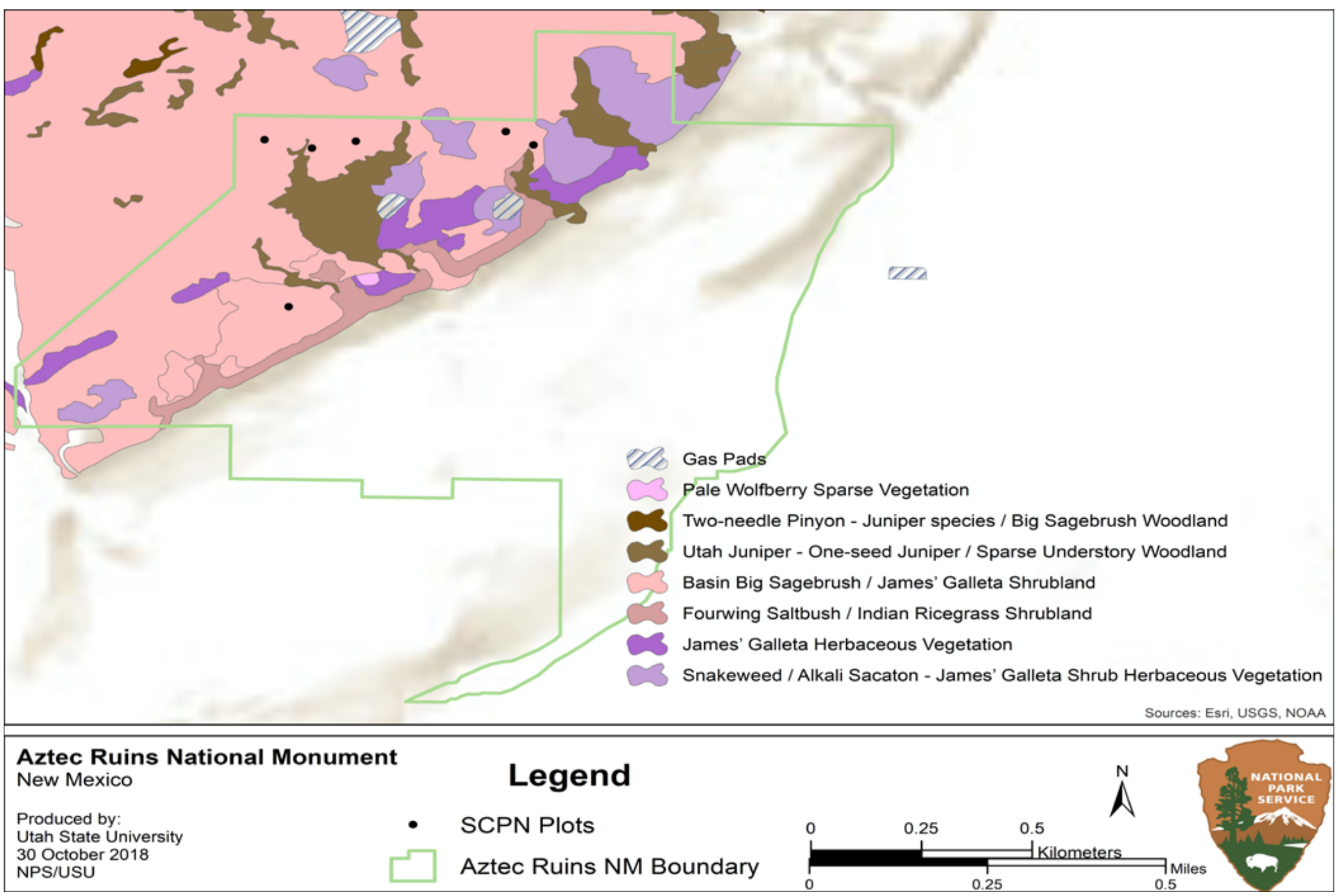


Figure 36. **Upland vegetation and the six plots established by SCPN. Source: NPS vegetation mapping project (Salas et al. 2009).**

Table 29. Summary of the 12 classes used by the SCPN to estimate bare ground, biological soil crust, and non-native species cover.

Cover Class	Cover (%)	Cover Class	Cover (%)
1	< 0.1	7	10 to < 15
2	0.1 to < 0.5	8	15 to < 25
3	0.5 to < 1	9	25 to < 35
4	1 to < 2	10	35 to < 50
5	2 to < 5	11	50 to < 75
6	5 to < 10	12	75 to 100

by fixing atmospheric nitrogen that can then be used by vascular plants (Miller 2005). BSCs can also inhibit the establishment of annual plants, which includes some of the most invasive non-native plants such as cheatgrass (*Bromus tectorum*) (Miller 2005). As with bare ground cover, BSC cover was estimated using the mid-points of the 12 cover classes listed in Table 29.

The third measure of erosion hazard is soil aggregate stability (without overhead cover). This measure refers to the ability of soil particles to hold together when exposed to disturbances (DeCoster et al. 2012). Soil aggregate stability was classified on a scale ranging from 1 (least stable) to 6 (most stable) (Herrick et al. 2005). Soil stability depends on soil texture, with sandy soils exhibiting less stability than clay soils. Of the six plots sampled, four are described as having sandy loam soils, while the other two have clay loam soils. Data were collected following a modified approach to Herrick et al. (2005) (DeCoster et al. 2012). Soil aggregate stability was collected at 18 points per plot, but not all sample points were without a perennial plant canopy. As a result, we reported the average soil stability in two ways. The first was to average the samples without a canopy cover within a plot and then average those values over the six plots (n = 6). The second was to average all samples without a perennial plant canopy cover regardless of plot. This resulted in a sample size of 69 in 2008 and 57 in 2016. Soil stability was summarized without perennial cover because plants generally increase soil stability through their root structure and by mitigating raindrop impact through canopy cover (Chaudhary et al. 2009), and our primary objective with this measure was to determine soil stability without these confounding factors.

The fourth and final measure of erosion hazard is the percent of basal gaps between perennial plants. Basal gap refers to the amount of bare ground between perennial plant bases (DeCoster et al. 2012). Basal gap size is an important measure of runoff and water erosion potential, whereby large gaps indicate higher erosion potential than small gaps. For each of the three transects within the six plots, we determined the total number of gaps in each of three size classes. The three size classes were as follows: <50 cm (<20 in), 51 to 100 cm (20 to 39 in), and >100 cm (> 39 in). We then determined the proportion of gaps within the three size classes that comprised the total length of the transect, which was 50 m (164 ft). We then averaged these values by plot and then over all six plots. The result was the proportion of transect length by gap size in 2008 and 2016.

Tree cover is the first of three measures of community composition and structure. Tree cover was collected in 2016 only. Using the line-intercept method, canopy cover of all trees, regardless of height, was recorded along each of the three transects in all six plots (DeCoster et al. 2012). The natural vegetation of upland habitat in Aztec Ruins NM is dominated by shrublands with scattered patches of grasslands (Salas et al. 2009). Although junipers are native to the area, they occur mostly in drainages, and encroachment onto mesas may suggest a shift in ecosystem structure and composition (Miller 2005).

Perennial grass cover is the second measure of community composition and structure. Cover of perennial grasses can help stabilize soils, reduce erosion, and hold soil moisture. As with bare ground and BSCs, cover was estimated using the mid-points of the 12 cover classes listed in Table 29.

Finally, mean native species richness is the third measure of community composition and structure. Richness was calculated as mean number of native species across the six plots and is the simplest measure of diversity. We also reported the total number of native species observed across the six plots, although the condition for this measure was based on mean richness.

The two measures of non-native plants include frequency and cover. Frequency is used as a way to monitor the spread of exotic species over time and is defined as the proportion of non-native plants averaged over 15, 10-m^2 (108 ft^2) quadrats within each plot. In all, there were 90 quadrats in which non-native plant frequency was determined. In addition to SCPN monitoring, we also included the results of a 2008 exotic plants inventory (Korb 2010). In the inventory, a grid of approximately 2 ha (5 ac) cells was applied to the entire monument in a Geographic Information System (GIS). Each cell was then classified into one of six habitat/land use types, including uplands. In the uplands, there were 22 grid cells (Korb 2010). Each cell was then surveyed for non-native plants along a 50-m-long (164-ft), 4-m-wide (13-ft) belt transect placed diagonally across each cell. The remainder of the grid cell was surveyed to identify any additional non-native species that were not found on the belt transect. Overall frequency was calculated as the proportion of grid cells that contained at least one non-native species and the proportion of belt transects that contained at least one non-native species. Frequency for individual species was also calculated for the belt transects.

Percent cover is the second measure of non-native plants and represents the extent over which exotic species occur. In the SCPN plots, cover was estimated using the mid-points of the 12 cover classes listed in Table 29. We reported total non-native cover and cover by species averaged over all six plots. In addition to the SCPN data, we also used inventory data provided in Korb (2010). Along each belt transect described for the previous measure, observers estimated cover by non-native species using the following cover classes developed by Young et al. (2007) as cited in Korb (2010): 1=less than 0.1% foliar cover, 2 = 0.1 to 1%, 3 = 1 to 5%, 4 = 5 to 10%, 5 = 10 to 25%, 6 = 25 to 50%, and 7 = 50 to 100%. The authors provided an estimate of total cover averaged over all belt transects in the uplands as well as average cover by species.

The North Mesa. Photo Credit: © L. Baril.

Reference Conditions

Reference conditions are described for resources in good, moderate concern, and significant concern conditions for the nine measures (Table 30). Initial reference conditions were developed by the assessment author based on SCPN data and the NRCS ecological site description (Sylvester and Wright 2003). Measures and reference conditions were then modified by natural resources staff at SCPN and Aztec Ruins NM. We did not develop reference conditions for BSC cover because there is wide variation in the published literature depending on disturbance regime, aridity, elevation, vascular plant cover, non-native plant cover, and many other factors (Miller et al. 2013 and Freund 2015).

Table 30. Reference conditions used to assess upland vegetation and soils in Aztec Ruins NM.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Erosion Hazard	Bare Ground and Undifferentiated Soil Crust Cover (%)	< 42%	42-77%	>77%
	Biological Soil Crust Cover (%)	None	None	None
	Soil Aggregate Stability Class (no Perennial Plant Canopy)	≥ 4	3.0 - 3.9	< 3
	Basal Gap Between Perennials (%)	Gaps < 50 cm comprise at least 25% of the transect length and gaps > 100 cm comprise less than 50% of the transect length.	Gaps <50 cm comprise less than 25% of transect length or gaps > 100 cm comprise between 50% and 85% of transect length.	Gaps > 100 cm comprise more than 85% of the transect length.
Community Composition and Structure	Tree Cover (%)	< 5%	5-20%	> 20%
	Perennial Grass Cover (%)	> 3%	1-3%	< 1%
	Mean Native Species Richness	> 12	6 - 12	< 6
Non-Native Plants	Frequency (%)	<30%	30-60%	>60%
	Cover (%)	<10%	10-79%	>80%

Condition and Trend

For the following nine measures, trend could not be determined because this assessment includes only two rounds of sampling and because there was high interannual variability the data. High variability reduces statistical power and the probability of detecting differences between means. High interannual variability, partially the result of the small sample size, also reduced our confidence in the overall condition ratings to either low or medium.

Bare ground cover with undifferentiated crust (a measure of erosion hazard) across the six plots averaged 10.58% in 2008 and 13.73% in 2016, while undifferentiated soil crust represented 60.04% in 2008 and 57.56% in 2016. Together, these values exceed 70% in both years, which is considered moderate concern condition. Although the standard deviations for bare ground cover were high, the standard deviations for undifferentiated soil crust were low. Confidence in the condition rating is medium.

BSC cover (a measure of erosion hazard) averaged 0.58% in 2008 and 1.43% in 2016 (Table 31). Of the three components of BSC, cyanobacteria exhibited the highest cover in 2008 (0.33%) and moss exhibited the highest cover in 2016 (0.82%). Since no reference conditions were developed for this measure, the condition is unknown and confidence is low.

In both 2008 and 2016, soil aggregate stability (a measure of erosion hazard) averaged between 3.42 and 3.93 (Table 32). These values indicate moderate soil stability and are within the moderate concern condition rating. Confidence in the condition rating is low because the standard deviations were large enough to make the condition rating somewhat uncertain (i.e., standard deviations of the means included both good and significant concern reference condition values).

In 2008 and 2016, transects were comprised primarily of basal gaps (a measure of erosion hazard) greater than 100 cm (39 in) (Figure 37). This value was slightly greater in 2016 (81%) than in 2008 (75%). Gaps less than 50 cm (20 in) represented only about 8% and 5% of total transect length in 2008 and 2016, respectively. Transects were comprised of 13% and 8% of gaps within the 50 to 100 cm (20 to 39 in) range. Based on reference conditions, this measure is of moderate concern condition. Confidence in the condition rating is low because of the small number of plots sampled and because large gaps may be normal for this community type.

Tree cover (a measure of community composition and structure) averaged 3.8% in 2016, but the standard deviation was 3.2%, which is high given the mean value (Table 33). As a result, the condition was rated good, but confidence in the condition rating is low because the standard deviation across the six plots was nearly as large as the mean. It should also be noted that most plots extended at least partially into the drainages. Plots necessarily included drainages because of the size of plots relative to the sampling frame area. Drainages are where pinyon-juniper woodlands are most dense. Therefore, tree cover in upland plots may have been overestimated (NPS, J. DeCoster, plant ecologist, comments to draft assessment, 28 November 2018).

Perennial grass cover, the second measure of community composition and structure, averaged 2.69% in 2008 and 6.79% in 2016 (Table 33). These values indicate moderate concern condition in 2008 and good condition in 2016. As with other measures, the variation was high so confidence in the condition rating is low.

The third measure of community composition and structure (native species richness), across the six plots averaged 26.2 species in 2008, with a total of 44 species (Table 33). In 2016, native species richness averaged slightly less at 23.5 species across the six

Table 31. Biological soil crust cover in Aztec Ruins NM.

Measures	Type	2008 Mean (SD)	2016 Mean (SD)
Biological Soil Crust Cover (%)	Cyanobacteria	0.33 (0.36)	0.53 (0.58)
	Moss	0.25 (0.37)	0.82 (1.15)
	Lichen	0 (0)	0.08 (0.09)
	Total	0.58 (0.37)	1.43 (0.61)

Table 32. Bare ground cover and soil aggregate stability in Aztec Ruins NM.

Measures	2008 Mean (SD)	2016 Mean (SD)
Bare Ground Cover (%)	10.58 (9.92)	13.73 (17.72)
Undifferentiated Soil Crust (%)	60.04 (6.6)	57.56 (14.8)
Soil Aggregate Stability of Plots (class)	3.49 (0.52)	3.85 (1.06)
Soil Aggregate Stability of Samples (class)	3.42 (1.06)	3.93 (1.72)

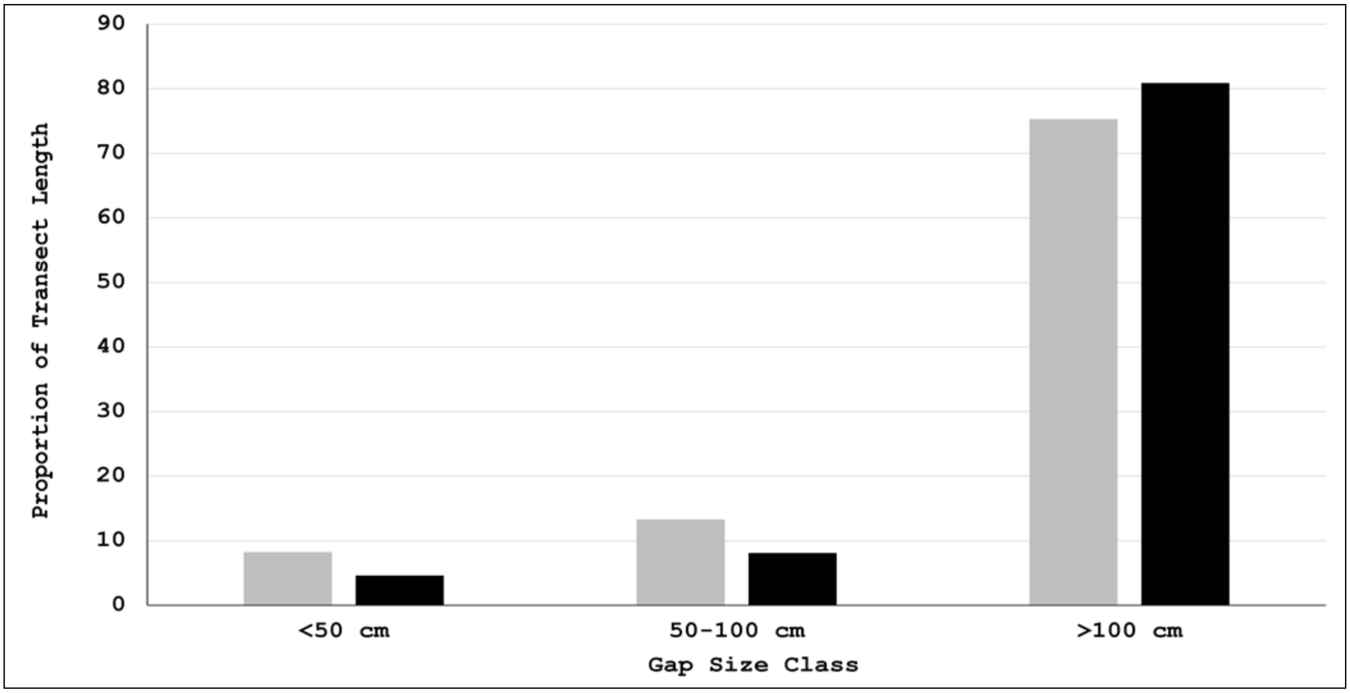


Figure 37. **Proportion of basal gaps within three size classes by plot in 2016.**

Table 33. Tree cover, perennial grass cover, and native species richness in Aztec Ruins NM.

Functional Group	2008 Mean (SD)	2016 Mean (SD)
Tree Cover (%)	No Data	3.8 (3.2)
Perennial Grass Cover (%)	2.69 (1.15)	6.79 (4.93)
Mean Native Species Richness	26.2 (2.8)	23.5 (3.5)

plots, with a total of 46 species. Big sagebrush, rose heath (*Chaetopappa ericoides*), western tansymustard (*Descurainia pinnata*), squirreltail (*Elymus elymoides*), and broom snakeweed were among the most commonly detected species. Based on these results, native species richness is good. Confidence in the condition rating is medium because of the small number of plots sampled.

In assessing the frequency of non-native plants, five species were encountered across the six plots in 2008 (Table 34). These were cheatgrass, redstem stork's bill (*Erodium cicutarium*), prickly lettuce (*Lactuca serriola*), prickly Russian thistle (*Salsola tragus*), and tall tumblemustard (*Sisymbrium altissimum*). Frequency averaged 77.78% across the 90 qaudrats, with cheatgrass representing the most frequently encountered species.

In 2016, prickly lettuce was not recorded, but two additional species were encountered for a total of six species (Table 34). These were saltlover (*Halogeton glomeratus*) and desert madwort (*Alyssum desertorum*). Frequency averaged 90% across the 90 quadrats, a decline in cheatgrass and tall tumblemustard between the two years and a greater frequency of redstem stork's bill and prickly Russian thistle.

In the 2008 non-native plant inventory, upland grid cells exhibited the lowest number of species per belt transect (6.1 species) and grid cell (2.5 species) of all land use types in the monument, but there were 20 total non-native species in the uplands. Ten of the 20 species were only encountered in grid cells and not in belt transects (Table 35). Twenty-one of the 22 grid cells (95%) contained at least one non-native species. Individual species frequency on belt transects varied from 91% for cheatgrass to 5% for Russian knapweed (*Acroptilon repens*), colonial bentgrass (*Agrostis capillaris*), and prickly lettuce (Table 36). Based on the high frequency of non-native plants in both studies, the condition warrants significant concern. Confidence is medium because of the small number of plots sampled by SCPN and the age of data included in the non-native plant inventory.

Across the six SCPN plots, total non-native plant cover averaged 0.63% in 2008 and 2.08% in 2016 (Table 34). Only one species exhibited at least 1% cover (saltlover). Most species exhibited less than

Table 34. Non-native plant frequency and cover in Aztec Ruins NM.

Scientific Name	Common Name*	2008		2016	
		% Frequency	% Cover	% Frequency	% Cover
Alyssum desertorum	Desert madwort	0	0	21	0.03
Bromus tectorum	Cheatgrass	74	0.31	42	0.07
Erodium cicutarium	Redstem stork's bill	13	0.02	46	0.51
Halogeton glomeratus	Saltlover	0	0	32	1.07
Lactuca serriola	Prickly lettuce	2	<0.01	0	0
Salsola tragus	Prickly Russian thistle	24	0.25	66	0.45
Sisymbrium altissimum	Tall tumblemustard	21	0.04	9	0.01
Total	–	77.78	0.63	90.00	2.08

*Common names may differ depending on source document.

Table 35. Non-native plants found in grid cells but not on belt transects in 2008 at Aztec Ruins NM.

Scientific Name	Common Name*
Alopecurus pratensis	Meadow foxtail
Bromus inermis	Smooth brome
Cirsium arvense	Canadian thistle
Convolvulus arvensis	European bindweed
Descurainia sophia	Flaxweed tansymustard
Kochia scoparia	Common kochia
Melilotus officinalis	Yellow sweetclover
Onopordum acanthium	Scotch thistle
Rumex crispus	Curly dock
Tamarix chinensis	Saltcedar

*Common names may differ depending on source document.

0.5% cover. In the non-native plant inventory, Korb (2010) reported ten non-native plant species along upland belt transects (Table 36). As with SCPN data, grid cell cover by species was generally low and did not exceed 0.5% except for two species (cheatgrass at 1.13% and redstem stork's bill at 1.28%). Total average cover in the upland grid cells was 2.8%.

The overall cover values for 2008 and 2016 SCPN plots fall within the moderate concern condition rating. Cover for the grid cells falls within the significant concern condition rating, but only by 0.03%. Therefore, we assigned an overall condition rating of moderate concern for upland non-native plant cover. Confidence in the condition rating is medium because of the small number of plots sampled and the age of the data included in the non-native plant inventory.

Table 36. Frequency and cover of non-native species found in the 2008 belt transects in Aztec Ruins NM.

Scientific Name	Common Name*	Frequency (%)	Cover (%)
Acroptilon repens	Russian knapweed	5	<0.01
Agrostis capillaris	Colonial bentgrass	5	<0.01
Alyssum desertorum	Desert alyssum	27	0.01
Bromus tectorum	Cheatgrass	91	1.13
Erodium cicutarium	Filaree	27	1.28
Hordeum marinum	Mediterranean barley	18	0.01
Lactuca serriola	Prickly lettuce	5	<0.01
Salsola tragus	Russian thistle	27	0.01
Sisymbrium altissimum	Tumble mustard	41	0.38
Tragopogon dubius	Common salsify	9	0.01

*Common names may differ depending on source document.

Overall Condition, Threats, and Data Gaps

We used three indicators and nine measures (Table 37) to assess the condition of upland vegetation and soils in Aztec Ruins NM. Measures with high confidence generally weigh more heavily into the overall condition rating than measures with medium or low confidence. In this assessment, measures were assigned medium and low confidence as a result of high variability in the means, which was likely due to the small sample size, and the small sample size even though variation may have been small (or in some cases not reported). The sample size (i.e., 6 plots) was necessarily small because of the small area over which uplands in the monument occur. The SCPN protocol was developed to be used

Table 37. Summary of upland vegetation and soils indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Erosion Hazard	Bare Ground and Undifferentiated Soil Crust Cover		Bare ground cover averaged 10.58% in 2008 and 13.73% in 2016. Undifferentiated soil crust cover averaged 60.04% in 2008 and 57.56% in 2016. Although variation was high for bare ground, it was relatively low for undifferentiated soil crust cover.
	Biological Soil Crust Cover		BSC cover averaged 0.58% in 2008 and 1.43% in 2016. The low cover of BSC could be due to compressional disturbances such as human foot traffic and animals, but the expected cover in sagebrush communities is highly variable and is unknown for the monument.
	Soil Aggregate Stability		Average soil aggregate stability ranged from 3.42 to 3.93, which indicates moderate soil stability, but the standard deviation of the means, which ranged from 0.52 to 1.72, also included good or significant concern reference condition values.
	Basal Gap Between Perennials		In 2008 and 2016, transects were comprised primarily of gaps greater than 100 cm (39 in) . This value was slightly greater in 2016 (81%) than in 2008 (75%). Gaps less than 50 cm (20 in) represented only about 8% and 5% of total transect length in 2008 and 2016, respectively. Transects were comprised of 13% and 8% of gaps within the 50 to 100 cm (20 to 39 in) range.
Community Composition and Structure	Tree Cover		In 2016, tree cover averaged 3.8%, but the standard deviation was 3.2, which indicates high variability.
	Perennial Grass Cover		Perennial grass cover averaged 2.69% in 2008 and 6.79% in 2016. The standard deviations, which were 1.15 and 4.63, respectively, indicate high variability in the means.
	Mean Native Species Richness		A total of 44 native species were documented in 2008, while 46 native species were documented in 2016. Native species richness averaged 26.2 in 2008 and 23.5 species in 2016.
Non-native Plants	Frequency		A total of seven non-native species were documented in SCPN plots (five in 2008 and six in 2016). Quadrat frequency was 78% in 2008 and 90% in 2016. Cheatgrass and prickly Russian thistle were two of the most common non-native species. In grid cells, 20 non-native species were detected, 10 of which were detected in the grid cells but not on belt transects. Of the 22 grid cells, 21 contained at least one non-native species with an average of ~3 species per grid cell (95%).
	Cover		Although extent of non-native species was high, cover was relatively low. In 2008, cover averaged 0.63% and in 2016 cover averaged 2.08%. Cover on belt transects did not exceed 0.5% for any given species except for two (cheatgrass at 1.13% and redstem stork's bill at 1.28%). Total average cover in the upland belt transects was 2.8%. However, given the low cover of plants in general, even low cover of non-native species is concerning.
Overall Condition	Summary of All Measures		Native species richness was high, bare ground cover was low, and non-native plants represent a relatively small proportion of the total plant cover. However, at least 21 species of non-native plants occur in the uplands, some which (e.g., cheatgrass) are widespread. Cover for most non-native plants was relatively low, but even at low levels, non-native species may alter native plant communities.

for all SCPN parks, which means that smaller units may be undersampled (DeCoster and Swan 2009, DeCoster et al. 2012). Based on these factors, we assigned an overall condition rating of moderate concern with medium confidence. Trend could not be determined based on two rounds of sampling. The primary key uncertainty is the high variability in measures observed in the SCPN plots.

Non-native plants have been cited as one of the most significant threats to native vegetation in the monument (Korb 2010, NPS 2012a, NPS 2015a). Between the six SCPN plots and the grid cells, 21 non-native plant species are confirmed for the uplands. Although only seven species were documented in SCPN over both years of sampling, the 2008 exotic plant survey found 20 non-native plants in the uplands (57 species across the entire monument) (Korb 2010). All but one species (saltlover) in SCPN plots were also found in upland grid cells (Korb 2010). Saltlover was first documented in 2016, which suggests that this species may be a relatively recent arrival.

Although the non-native plant inventory included the entire upland area, some species may have been missed because average annual precipitation during the 2008 water year (WY, 1 October to 30 September) was similar to the 30-year average (1971-2000) (Climate Analyzer 2019), and many non-native annuals are more prevalent during years of above average precipitation (Prevey 2013). More study is needed to determine the factors influencing non-native species richness, frequency, and cover in the monument.

Preventing the establishment of non-native species is difficult to achieve anywhere, especially in small, urban units such as Aztec Ruins NM. But maintaining healthy native plant communities by avoiding management actions that encourage invasion, coupled with annual monitoring and control, can be effective for minimizing the establishment and spread of non-native species (Korb 2010). To our knowledge, annual monitoring of non-native plants in the uplands has not occurred since the initial 2008 inventory. Although the NPS Exotic Plant Management Team (EPMT) visits the monument annually to control non-native plants, the team targets the riparian area and areas around the West Ruin (unpublished GIS data provided by the EPMT) because these areas were found to be the most invaded (i.e., riparian) and sensitive (i.e., core cultural area) places in the monument (Korb 2010, NPS 2012a). No control occurs in the uplands.

Non-native plants can spread through a variety of pathways, including roads, river corridors, trails, human foot traffic, and dispersal by mammals and wind. Although there is no public access to the uplands, there is a dirt road that provides access to two gas wells (NPS 2012a). Activities associated with the two gas well pads may contribute to the introduction and dispersal of non-native species and to the disturbance of native species (NPS 2012a). Furthermore, a land parcel adjacent to the North Mesa may become a housing development, which could lead to further disturbances, including increased runoff and soil erosion (NPS 2012a, NPS 2015a).

On a broader scale, changes to the climate, such as increasing levels of atmospheric CO_2, increasing soil and air temperatures, and altered patterns of precipitation "are likely to affect physiological processes and competitive relationships of vascular plants, nutrient cycles, hydrologic processes, and disturbance regimes—all of which have the potential to greatly alter the structure and functioning of dryland ecosystems" (Miller 2005). However, there is a great deal of uncertainty regarding the outcomes of climate change on ecosystems. In addition wet deposition of nitrogen and sulfur, along with high ozone levels, may also pose a threat to the monument's vegetation (refer to air quality assessment for details).

Hypotheses regarding the potential trajectory of dryland ecosystems on the Colorado Plateau include four alternative states. The alternative states are 1) a woody-dominated state, 2) a system that becomes a monoculture of a single non-native species such as cheatgrass, 3) a system that is comprised mostly of non-native annuals, or 4) a severely eroded state whereby soil resources are lost or redistributed (Miller 2005). These hypothetical outcomes for existing natural systems, were based on currently observed trajectories of change on the Colorado Plateau (Miller 2005). Susceptibility to these alternative states depends on exposure, resistance, and resilience to the processes driving change (Miller 2005). The data used in this assessment do not indicate a shift toward a woody-dominated state nor to a highly eroded state. However, the frequency of non-native species may indicate a shift toward one of the non-native plant communities outlined in Miller (2005).

According to the 2012 vegetation management and cultural landscape preservation maintenance plan, the desired future condition of uplands includes healthy native vegetation, limited presence of non-native species, healthy soil crust cover, and the absence of the gas pads and associated infrastructure (NPS 2012a). The primary data gap is the lack of non-native plant surveys following the initial inventory in 2008. Although the SCPN plots will be monitored on a 5-6 year basis, non-native plant richness was underestimated using these methods. A targeted survey and a control program that includes uplands would help to mitigate non-native plants in the monument.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Birds

Background and Importance

Hundreds of species of birds occur in the American Southwest, as do some of the best birdwatching opportunities. Birdwatching is a popular, longstanding recreational pastime in the United States and forms the basis of a large and sustainable industry (Sekercioglu 2002). Birds are a highly visible component of many ecosystems and are considered good indicators of ecosystem health because they can respond quickly to changes in resource and environmental conditions (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). Like other wildlife, birds are also inherently valuable. Only a few studies of birds at Aztec Ruins National Monument (NM) have been conducted. Prior to the early 2000s, birds in the monument had not been surveyed at all; however, a checklist for the monument was compiled in 1992 (Johnson et al. 2007). The list contained 74 species, but details on how the list was developed were not reported (Johnson et al. 2007). The only, and most recent, standardized inventory of birds at Aztec Ruins NM was conducted by the U.S. Geological Survey (USGS) Biological Resources Division in 2001-2002 (i.e., Johnson et al. 2007). Johnson et al. (2007) conducted surveys mainly during the breeding season, but also during the winter. No comprehensive avian inventories or monitoring at the monument have been conducted since the 2001-2002 Johnson et al. (2007) work, although there have been annual National Audubon Society (NAS) Christmas Bird Counts (CBC) as well as observations by park personnel and visitors.

Data and Methods

For this limited assessment, we used one indicator (species occurrence) with a single measure (presence/absence), focusing on which bird species have been observed at the national monument by four survey/observation efforts. For each survey/observation effort, we included a brief description of methods. Scientific names mentioned in tables throughout this assessment are provided in Appendix C for brevity.

The most comprehensive survey effort to date was conducted by the USGS in 2001 and 2002 (Johnson et al. 2007). Eleven standard point count stations were established across four habitat types in the monument. The four habitat types were riparian, riparian-shrubland, shrubland, and agricultural (i.e., orchard). Stations were placed at least 250 m (820 ft) apart. Each station was surveyed four times from mid-May to mid-July of 2001. In 2002, observers used the area-search method rather than point counts. In

The white-crowned sparrow is one of the most common native bird species in Aztec Ruins NM. Photo Credit: © R. Shantz.

the area search method, two teams of two observers surveyed birds across half the park so that the entire park was surveyed in one morning. These surveys were repeated three times during the breeding season but individual species were not reported by habitat type. Additional surveys for yellow-billed cuckoos (*Coccyzus americanus*) were conducted three times during 2002. At the time of these surveys, the yellow-billed cuckoo was a candidate species for listing under the U. S. Fish and Wildlife Service's (USFWS) Endangered Species Act (USFWS 2018). In 2014 the yellow-billed cuckoo was listed as federally threatened by the USFWS (USFWS 2018). Lastly, non-breeding (winter) area search surveys were conducted on 21 December 2001 and 11 February 2002 (Johnson et al. 2007).

The second survey effort was the annual Christmas Bird Count (CBC) conducted by National Audubon Society volunteers. CBC surveys in and around the monument were conducted on one day (24-hr period) between 14-22 December from 1996 to 2014, excluding 2008 and 2013. After 2014, Aztec Ruins NM was dropped from the count circle because the goal of the CBC is to maximize diversity and the habitat types found in the monument were surveyed elsewhere in the count circle (J. Rees, CBC participant, e-mail message, 10 October 2018). The total count circle is a 24-km (15-mi) diameter area (NAS 2014), but only those birds reported as occurring in the monument were included in this assessment. We summarized species by total abundance and number of years recorded. Raw CBC data are provided in Appendix C. CBC data were provided by Janet Rees via e-mail on 24 June 2018.

The third data source included observations reported in eBird, which is a an online checklist program that was launched in 2002 by the Cornell Lab of Ornithology and National Audubon Society (eBird 2018a). eBird reports on the occurrence (presence or absence) of bird species, as well as other information, using data from checklists provided by recreational and professional bird watchers. A cumulative list of bird species was available for Aztec Ruins NM based on observations from a number of individuals (eBird 2018b). eBird data for the national monument spans the years 1982 to mid–September 2018. We obtained the list of birds reported for the monument on 3 October 2018 (eBird 2018b).

The fourth resource we used was comprised of incidental observations from two sources. The first source was the Aztec Ruins NM wildlife observations database. These data were accessed during the NRCA scoping meeting on 25 April 2018. We scanned the database for bird species submitted that were not included in NPSpecies (NPS 2018a). NPSpecies vets and documents the occurrence of wildlife and plants by NPS unit and is typically updated using past surveys, such as those described in this assessment, and expert opinion. The list is included in Appendix C along with additional species reported by other survey/observations efforts described in this assessment.

The second source of incidental observations were those reported by J. Rees for 6-7 May 2009, 12 May 2012, 17 July 2014, and 22 July 2014. These observations were submitted to the assessment author via e-mail on 24 June 2018. Observations in 2009 and 2012 were made by J. Rees and one other individual, and the 2014 observations were made by David Strawn, an NPS intern, J. Rees, and one other individual (J. Rees, email message, 27 June 2018). Surveys in 2014 were arranged by Dana Hawkins, natural resource program lead at Aztec Ruins NM, in preparation for invasive plant removals along the Animas River (J. Rees, email message, 27 June 2018). The surveys were intended to document any threatened and endangered species that may occur in the riparian area.

To put these results in context, we compared the NPSpecies list, which is based on the abovementioned studies and data sources, to the checklist of birds for San Juan County, New Mexico. The San Juan County bird checklist was developed based on sightings provided by the Four Corners Bird Club, eBird reports, Audubon Field Notes, New Mexico Ornithological Society Field Notes, and the observations of private citizens (Reeves 2016). Using the two lists, we determined what proportion of birds reported for San Juan County, New Mexico occur in Aztec Ruins NM. We excluded rare, accidental, or historical species from the San Juan County checklist because these species are not regular occurrences in the county.

Finally, we included a list of species of concern for those considered "present" in NPSpecies. The species of concern list was derived from the New Mexico Department of Game and Fish (NMDGF) State Wildlife Action Plan (NMSWAP) for the Colorado Plateaus ecoregion, which is where the monument is located (NMDGF 2016). We also included species listed as threatened or endangered by the USFWS that have been reported for the monument (USFWS 2018).

Reference Conditions

No reference conditions for condition status were developed for this resource topic because no two similar studies or surveys to compare species occurrence exist (e.g., to examine changes in species occurrence over time), and no comparable recent information is available.

Condition and Trend

Johnson et al. (2007) reported a total of 68 species across all habitat types and survey methods during the breeding seasons of 2001 and 2002 (Table 38). During the 2001 point count surveys, 42 species were documented across the four habitat types. Species richness was similar between riparian (30 species) and mixed shrubland/riparian (31 species) habitat. Twenty species were observed in agricultural habitat and 14 species were recorded in shrubland habitat. Twenty-six of the 68 species were observed through incidental observations and area searches; however, habitat was not recorded for these observations.

During Johnson et al's. (2007) winter surveys, 27 species were reported (18 in 2001 and 22 in 2002), two of which were not observed during the breeding season (Table 39). The two species were loggerhead shrike (*Lanius ludovicianus*) and hairy woodpecker (*Picoides villosus*). Over all surveys during the two years, three non-native species were reported. These were the house sparrow (*Passer domesticus*), ring-necked

Loggerhead shrike. Photo Credit: © R. Shantz.

Table 38. Bird species observed at Aztec Ruins NM by habitat type during 2001 and 2002.

Species	Habitat Type
American crow	Not Reported
American kestrel	A,M
American robin	A,R,M
Ash-throated flycatcher	A,M
Barn swallow	A,M
Bewick's wren	A,R,M
Black-billed magpie	A,R,S,M
Black-capped chickadee	A,R,M
Black-chinned hummingbird	A,R,S,M
Black-crowned night heron	Not Reported
Black-headed grosbeak	A,R,S,M
Black-throated sparrow	M
Blue grosbeak	Not Reported
Brewer's blackbird	Not Reported
Brewer's sparrow	Not Reported
Brown-headed cowbird	A,R,M
Bullock's oriole	A,R,S,M
Canada goose	A,R
Cassin's kingbird	A,R
Chipping sparrow	Not Reported
Cliff swallow	R,S,M
Common nighthawk	Not Reported
Common raven	A,M
Common yellowthroat	R
Eastern meadowlark	R
European starling	A,R,S,M
Evening grosbeak	Not Reported
Gambel's quail	S,M
Great horned owl	Not Reported
Greater roadrunner	R
House finch	A,R,S,M
House sparrow	M
Juniper titmouse	Not Reported
Killdeer	A,R,M
Ladder-backed woodpecker	Not Reported
Lark sparrow	S,M
Lazuli bunting	A,R,M
Lesser goldfinch	A,R
Mallard	R,M
Mountain chickadee	Not Reported
Mourning dove	R,S,M
Northern flicker	R

* A = agriculture, S = shrubland, R = riparian, M = mixed shrubland/riparian, and Not Reported = birds were observed during area searches in 2002 and associated habitat type was not noted in this method.

Source: Johnson et al. (2007).

Table 38 continued. ***Bird species observed at Aztec Ruins NM by habitat type during 2001 and 2002.***

Species	Habitat Type
Northern mockingbird	Not Reported
Northern rough-winged swallow	R,M
Pinyon jay	Not Reported
Prairie falcon	Not Reported
Red-necked phalarope	Not Reported
Red-tailed hawk	Not Reported
Red-winged blackbird	R
Ring-necked pheasant	R,M
Say's phoebe	Not Reported
Spotted sandpiper	R
Spotted towhee	Not Reported
Turkey vulture	S
Violet-green swallow	S,M
Virginia's warbler	Not Reported
Western bluebird	M
Western kingbird	S,M
Western meadowlark	A,R,S,M
Western tanager	Not Reported
Western wood-pewee	R
White-breasted nuthatch	Not Reported
White-crowned sparrow	Not Reported
Wilson's warbler	Not Reported
Woodhouse's scrub jay	Not Reported
Yellow warbler	R,M
Yellow-billed cuckoo	R
Yellow-rumped warbler	Not Reported
Total richness	68

* A = agriculture, S = shrubland, R = riparian, M = mixed shrubland/riparian, and Not Reported = birds were observed during area searches in 2002 and associated habitat type was not noted in this method.

Source: Johnson et al. (2007).

Table 39. Bird species observed during USGS winter surveys at Aztec Ruins NM during 2001 and 2002.

Species	2001	2002
American goldfinch	X	X
American robin	X	X
Black-billed magpie	X	X
Black-capped chickadee	–	X
Canada goose	X	X
Cedar waxwing	–	X
Common raven	X	X
Dark-eyed junco	X	X
European starling	X	X
Gambel's quail	X	X
Great blue heron	–	X
Hairy woodpecker	–	X
House finch	X	X
House sparrow	X	X
Juniper titmouse	X	–
Loggerhead shrike	X	–
Mallard	X	X
Mountain bluebird	year not provided	year not provided
Northern flicker	X	X
Red-tailed hawk	–	X
Ruby-crowned kinglet	–	X
Sharp-shinned hawk	X	–
Song sparrow	X	X
Townsend's solitaire	–	X
White-breasted nuthatch	X	–
White-crowned sparrow	X	X
Yellow-rumped warbler	–	X
Richness	18	22

Source: Johnson et al. (2007).

pheasant (*Phasianus colchicus*), and European starling (*Sturnus vulgaris*). Rock pigeons (*Columba livia*) are considered "probably present" by NPSpecies but were not reported by Johnson et al. (2007).

During the National Audubon CBC surveys, a total of 41 species and 1,738 individuals were reported over the 17-year period (Table 40). Annual species richness ranged from seven to 16 species with an average of 11 species observed per year (annual data are included in Appendix C). All but one species (Eurasian collared-dove [*Streptopelia decaocto*]) was listed by NPSpecies. Eurasian collared-doves are non-native and were not observed until 2009. Nor were Eurasian collared-doves reported by Johnson et al. (2007). This suggests that this species is a relatively recent arrival. Only six individuals were recorded over three CBC surveys (2009, 2012, 2014). The other non-native species reported were house sparrow and European starling. Non-native European starlings were by far the most abundant species observed with 593 individuals and observations made during each of the 17 years of surveys. Starlings were followed in abundance by 238 Canada geese (*Branta canadensis*), 221 dark-eyed juncos (*Junco hyemalis*), and 121 white-crowned sparrows (*Zonotrichia leucophrys*).

Table 40. Bird species observed at Aztec Ruins NM during Christmas Bird Count surveys (1996-2014).

Species	Years Observed	Total Abundance
American goldfinch	1	3
American kestrel	2	2
American robin	10	37
Bald eagle	3	3
Bewick's wren	2	2
Black-billed magpie	15	81
Black-capped chickadee	3	7
Brown creeper	4	7
Bushtit	3	22
Canada goose	6	238
Cedar waxwing	2	37
Common raven	4	8
Dark-eyed junco	15	221
Downy woodpecker	3	3
Eurasian collared-dove	3	6
European starling	17	593
Evening grosbeak	1	1
Gambel's quail	3	40
Great blue heron	1	2
Great horned owl	1	1
House finch	8	50
House sparrow	5	21
Killdeer	1	1
Lesser goldfinch	1	4
Mountain bluebird	3	58
Mountain chickadee	2	3
Mourning dove	1	1
Northern flicker	13	60
Prairie falcon	2	2
Red-tailed hawk	9	16
Red-winged blackbird	1	4
Ruby-crowned kinglet	3	4
Say's phoebe	1	1
Sharp-shinned hawk	2	2
Song sparrow	5	9
Spotted towhee	3	3
Townsend's solitaire	4	7
Western bluebird	6	43
White-breasted nuthatch	7	8
White-crowned sparrow	8	121
Yellow-rumped warbler	4	6
Total richness/abundance	41	1,738

Source: CBC data provided by Janet Rees.

Four species reported during CBC surveys were listed as "probably present" by NPSpecies, which indicates that they have not been confirmed for the monument. The four species are bald eagle (*Haliaeetus leucocephalus*), brown creeper (*Certhia americana*), bushtit (*Psaltriparus minimus*), and downy woodpecker (*Picoides pubescens*). Four species reported during winter by Johnson et al. (2007) were not reported during CBC surveys despite the longer span of the latter effort. The four species were: hairy woodpecker, juniper titmouse (*Baeolophus ridgwayi*), loggerhead shrike, and mallard (*Anas platyrhynchos*).

The eBird list for the monument included 78 species across 22 checklists (eBird 2018b, Appendix C). The checklists were submitted between 1982 and mid-September 2018, with the bulk of the checklists submitted between 2014 and 2018. Seven species listed by eBird have not been reported for the monument and are not listed in NPSpecies, including olive-sided flycatcher (Contopus cooperi), tree swallow (Tachycineta bicolor), and willow flycatcher (Empidonax traillii) (Table 41).

Observations in the monument's wildlife database included reports of a spotted owl (*Strix occidentalis*), scaled quail (*Callipepla squamata*), Cooper's hawk (*Accipiter cooperii*), wild turkey (*Meleagris gallopavo*), common goldeneye (*Bucephala clangula*), and osprey (*Pandion haliaetus*) (Table 41). None of these species are included in NPSpecies. In addition, sharp-shinned hawk (*Accipiter striatus*), bushtit (*Psaltriparus minimus*), and hairy woodpecker were observed in May 2009 and July 2014 as reported by J. Rees. All three species had only been previously reported during the CBC surveys. Rees also reported a black phoebe (*Sayornis nigricans*) in July 2014, and plumbeous vireo (*Vireo plumbeus*), orange-crowned warbler (*Oreothlypis celata*), and a blue-gray gnatcatcher (*Polioptila caerulea*) in May 2009. The black phoebe is not listed by NPspecies and the remaining three species are listed as "probably present." The 13 species listed in Table 41 have not been validated for the monument. Detailed documentation for each of these species is required before they can be added to NPSpecies. Although some of these reports may be errors in identification, all 13 species listed in Table 41 have been reported in San Juan County.

The comparison between the NPSpecies bird list and the San Juan County bird list revealed that 44% (112)

Table 41. Bird species reportedly observed at Aztec Ruins NM but not listed in NPSpecies.

Species	San Juan County Bird Checklist Status
Black phoebe[1]	Uncommon to accidental
Common goldeneye[2]	Rare to uncommon
Cooper's hawk[2,3]	Uncommon to common
Eurasian collared-dove[3,4]	Abundant
Olive-sided flycatcher[3]	Occasional to uncommon
Osprey[2]	Occasional to common
Scaled quail[2]	Uncommon
Spotted owl[2]	Accidental
Tree swallow[3]	Rare to common
White-throated sparrow[3]	Occasional
White-winged dove[3]	Uncommon
Wild turkey[2]	Uncommon
Willow flycatcher[3]	Uncommon

[1] J. Rees

[2] Aztec Ruins NM wildlife observations database.

[3] eBird (2018a).

[4] CBC.

of the regularly occuring birds in the county were also listed for the monument. A total of 375 species appear on the San Juan County bird list, excluding hybrids. Of these, 254 species are considered abundant, common, uncommon, or occasional. Note that some of the species listed as rare, accidental, or historical on the San Juan County bird list were also listed by NPSpecies. According to NPSpecies, 120 birds are "present", "probably present", or "under review" in the monument.

Finally, thirteen species that are considered species of concern for the State of New Mexico have been reported for Aztec Ruins NM (Table 42). Nine of these species are listed as "present" by NPSpecies. Only one species confirmed for the monument (yellow-billed cuckoo) occurs on the USFWS List of Threatened and Endangered Wildlife and Plants (USFWS 2018). A single yellow-billed cuckoo was observed in 2001, which prompted follow-up surveys in 2002; however, no cuckoos were documented during follow-up surveys (Johnson et al. 2007). The only other report of a yellow-billed cuckoo occurred on 26 May 2009 as reported in eBird (eBird 2018b).

Two additional species of conservation concern are listed as "probably present" by NPSpecies. These two species are the olive-sided flycatcher and the spotted owl. The Mexican spotted owl (*Strix occidentalis lucida*) is listed as federally threatened (USFWS 2018), while the olive-sided flycatcher is listed as a species of concern for the State of New Mexico (NMDGF 2016). If the owl report is accurate, it is almost certainly the Mexican subspecies. Lastly, the southwestern subspecies of the willow flycatcher (*Empidonax traillii extimus*) is listed as endangered (USFWS 2018), and a willow flycatcher was reported on eBird, but the observer did not indicate that this was the southwestern subspecies. Therefore, this species was not included in Table 42.

Overall Condition, Threats, and Data Gaps

We could not assess the overall condition of birds at Aztec Ruins NM because of the limited data available (Table 43). However, this assessment compiles all known information regarding birds in the monument. Based on these data, some changes to NPSpecies may be required provided the sightings can be verified. Although species composition is relatively well documented for the monument, abundance is less certain. Additionally, species presence, even in high numbers, does not necessarily indicate a healthy population. Breeding surveys that attempt to determine nesting success would provide a more complete understanding of bird communities in the monument. Because of the monument's small size, birds may be surveyed relatively rapidly, especially if designed to document presence/absence only. But

Table 42. Bird species of conservation concern that do or may occur at Aztec Ruins NM.

Species	NPSpecies Occurrence
Bald eagle	Probably Present
Cassin's finch	Probably Present
Common nighthawk	Present
Evening grosbeak	Present
Juniper titmouse	Present
Loggerhead shrike	Present
Mountain bluebird	Present
Olive-sided flycatcher	Not Listed
Pinyon jay	Present
Spotted owl	Not Listed
Virginia's warbler	Present
Western bluebird	Present
Yellow-billed cuckoo	Present

Table 43. Summary of bird indicators, measures, and condition rationale.

Indicator	Measure	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence		A total of 133 species have been reported for the monument, 120 of which appear on the official NPSpecies list. Of the most likely bird species to occur in San Juan County, New Mexico, 112 (44%) occur in the monument. There are at least nine species of concern confirmed for the monument, including the federally threatened yellow-billed cuckoo, although sightings of this species are rare.
Overall Condition	Summary of All Measures		The limited amount of data coupled with the age of the only comprehensive survey for the monument precluded assigning a condition for birds. Nevertheless, this assessment reveals relatively high species richness given the small size of the monument and location within an urban area. The proximity to the Animas River increases the monument's species richness since riparian vegetation provides one of the most important habitat types in the arid southwest. Key uncertainties include current abundance and breeding success of birds, particularly those of conservation concern.

studying nesting success takes a large amount of time (months) and a large crew and can only be done well for certain species (S. Hejl, Research Coordinator, National Park Service, draft condition assessment review comment, 12 February 2019).

Migratory and other bird species face threats throughout their ranges, 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 bird species, and many of these species are experiencing population declines because of increased threats within their range (USFWS 2016). Also, across the U.S., free-ranging domestic cats (*Felis catus*) may be responsible for as many as 2.4 billion bird deaths each year (Wildlife Society 2011, Loss et al. 2013). Although neither the domestic cat or dog (*Canis lupus familiaris*) appear on the NPSpecies list (NPS 2018a), the proximity to the urban area of the City of Aztec, NM and the housing development directly adjacent to the monument suggest that these species have the potential to occur in the monument. In fact, according to the wildlife observations database for the monument, house cats have been recorded by the monument's game camera on at least two occasions. The monument's website also briefly mentions that feral dogs, cats, and domestic rabbits are found at the monument and survive by depredating native species (NPS 2015e). Also, the effects of nest parasitism by brown-headed cowbirds (*Molothrus ater*) on nesting birds, especially riparian species, are well documented (Lowther 1993, Lorenza and Sealy 1999). While the brownheaded cowbird is native, it can still have devastating effects on nesting success for open-cup nesting species, such as vireos and warblers (Banks and Martin 2001).

Because of the monument's small size, edge effects such as non-native species encroachment may be high. Five human-adapted non-native bird species have been observed in the monument. While the specific effects of these introduced species on native birds in the monument is unknown, some of them likely compete with native birds for nesting habitat, food, and other resources as they do in other areas (Cabe 1993, Lowther and Cink 2006, Romagosa 2012, Lowther and Johnston 2014).

In addition to habitat loss and non-native species, climate change may be the biggest threat to bird species in and around the monument. In a joint study by the National Park Service and the National Audubon Society, researchers found that among all NPS units included in the study, Aztec Ruins falls within an intermediate range of projected change by 2050 (Shuurman and Wu 2018). Under the high (current) emissions scenario established by the Intergovernmental Panel on Climate Change, the monument's summer climate is expected to improve for nine species, worsen for five species, and remain stable for 19 species (Figure 38). Fifteen species are projected to be extirpated from the monument, including black-capped chickadee (*Poecile atricapillus*) and American robin (*Turdus migratorius*) (Schuurman and Wu 2018). On the other hand, the summer climate may become suitable for 23 species that are not currently known to occur there, including cactus wren (*Campylorhynchus brunneicapillus*) and black-tailed gnatcatcher (*Polioptila melanura*). In winter, climate suitability is expected to improve for 10 species, remain stable for 14 species, and become worse for five species (Schuurman and Wu 2018). Three species may become locally extirpated during winter, while conditions may become suitable for 40 species not currently known to occur in the monument (Schuurman and Wu 2018).

Of the species of conservation concern that do or may occur in the monument, conditions are likely to improve or remain stable for the loggerhead shrike and western bluebird (*Sialia mexicana*) (Schuurman and Wu 2018). In contrast, conditions during summer are projected to worsen for the pinyon jay (*Gymnorhinus cyanocephalus*) and may even preclude mountain bluebird (*Sialia currucoides*) (Schuurman and Wu 2018). Similarly, conditions may preclude the occurrence of bald eagles in the monument. Interestingly, non-native species in the monument are not expected to benefit from a changing climate (Schuurman and Wu 2018). The overall potential turnover rate by 2050, which is based on the projected proportions of colonizations and extirpations, was estimated to be 0.23 in summer and 0.21 in winter, with 1.0 indicating complete turnover and 0 indicating no turnover (Shuurman and Wu 2018). These projections suggest an approximate 25% shift in the monument's bird community if current emissions do not improve. Even under a low emissions, best-case scenario, bird species composition is still expected to change, although to a lesser degree.

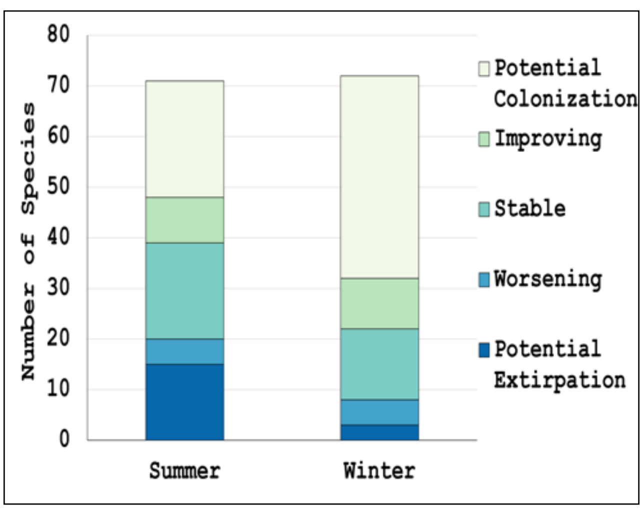


Figure 38. Projected changes in climate suitability for birds at Aztec Ruins NM by season for the high (current) emissions pathway (Shurmann and Wu 2018).

These predictions are based solely on changes in temperature and precipitation, but shifts in birds' future ranges will also be influenced by changes in vegetation composition and structure, and the availability and abundance of key food resources (Kissling et al. 2010, Martin and Maron 2012, Zellweger et al. 2017). This is complicated by the fact that birds are arriving on spring breeding grounds and laying eggs earlier than in the past (Crick et al. 1997, Usui et al. 2016). Shifts in life history characteristics may help birds adapt to a changing climate but only if they are aligned with changes in resources that matter to birds (Møller et al. 2008). While highly mobile species may keep pace with climate change (e.g., birds, flying insects), other species on which birds depend (e.g., some plants) may not (Visser 2008). Ultimately, the interaction between climate change and the various components of the biotic system will determine future ranges of birds, plants, and other wildlife (Schmitz et al. 2003). Current habitat restoration efforts along the Animas River may help mitigate some of these projected changes, including providing habitat for species that may colonize the monument in the future.

Changing climate has and will continue to have profound influence on native species and ecosystems. Continued observations submitted to eBird as well as observations submitted directly to NPS staff at the monument will help managers understand how climate change is affecting the bird community.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Mammals

Background and Importance

Mammals depend on plants for cover and forage, and plant community structure and composition influence mammal species abundance and distribution. The health, distribution, and diversity of mammals that utilize the Animas River area and other habitat types in the monument is important to the monument and surrounding region because mammals serve as both predators and prey, seed dispersers, and grazers. Mammals that frequently occur on the Colorado Plateau include several species of deer mice and white-footed mice (*Peromyscus* spp.), a few species of ground squirrel (Sciurids), three species of lagomorphs (hares and rabbits), and deer and elk (Cervids) (Bogan et al. 2007). Carnivores are generally not common on the plateau, partly because of their large territory size compared to herbivores but also because of habitat loss and fragmentation (Bogan et al. 2007). Mammals in general exhibit wide variation in territory size depending on the species (e.g., larger mammals require more area than smaller mammals) and the distribution of and access to resources. This assessment describes the mammals found in the monument and those that potentially occur in the monument.

Data and Methods

To assess the condition of mammals at Aztec Ruins National Monument (NM) we used one indicator, species occurrence, with a total of three measures. The three measures are: presence/absence, species nativity, and species of conservation concern. For a complete list of species known to occur in or that probably occur in the monument, we relied on the NPSpecies list of mammals (NPS 2018a). NPSpecies is a database that relies on previously published surveys, such as those included in this assessment, and expert opinion, to maintain a record of the presence or potential presence of species in lands managed by the NPS. The NPSpecies list also serves as a reference, especially to highlight potential data gaps of unconfirmed but species expected to occur within national parks and monuments, although the list is not exhaustive but represents a thorough literature review, which informed the initial list of the monument's baseline inventory.

We assessed the first measure (presence/absence) of mammals in the monument using baseline inventory data conducted from 2001 to 2003 (Bogan et al. 2007). The inventory was part of a regional effort to document mammals in eight Arizona, Colorado, and New Mexico national parks and monuments within the NPS's Southern Colorado Plateau Inventory and Monitoring Network (SCPN). In 2001, Bogan et al. (2007) surveyed small mammals using random and targeted searches and trapping. In 2002, the

A Gunnison's prairie dog. Photo Credit: © R. Shantz.

effort focused on species-rich groups to maximize the number of species documented, and in 2003, a few species suspected of being missed during other surveys were targeted during occasional, brief visits. Additionally, any opportunistic observations of mammals were noted. Below is a brief description of the methods used for the different groups of mammals.

Small mammals include mostly ground-based rodents (e.g., mice, rats, and shrews). Small terrestrial mammals were trapped using Havahart®, Sherman®, and Tomahawk® live traps, in addition to pitfall arrays, and snap traps. Traps were arranged along traplines placed to sample the monument's major habitat types (Bogan et al. 2007).

Bats were inventoried using mist nets and acoustic surveys. Nets were opened after sunset and monitored until activity declined. Echolocation calls were recorded and analyzed to identify species. Mist nests and acoustic recording devices were deployed along the irrigation ditch and at the Great Kiva (Bogan et al. 2007).

Carnivores were surveyed using track-scat surveys, live-trapping (using Havahart® or Tomahawk® traps for smaller predators such as weasels), and spot-lighting techniques. Track-scat surveys entailed searching suspected high-use areas and areas where tracks are most visible, including along the ditch and riparian area, in sandy soils, and around areas of human refuse (Bogan et al. 2007).

We supplemented the 2001-2003 inventory data with information included in the monument's wildlife observations database (NPS unpublished data). The wildlife observations database included wildlife cards submitted by visitors and monument staff from 2002 to 2015 in addition to species recorded by wildlife cameras. Wildlife cameras were placed in the riparian area, near Farmers Ditch, at the East Ruins, and on the North Mesa during 2015 and 2016.

We used non-native species as the second measure of species occurrence. The non-native mammal species present at the monument were listed by NPSpecies (NPS 2018a). If any non-native species was identified, it was evaluated for its impact(s) to native species, especially those of conservation concern.

Lastly, we used species of conservation concern as the third measure of species occurrence. We compared the monument's list of 'present' species to the U.S. Fish and Wildlife Service's (USFWS) list of endangered and threatened mammals that are known to occur in New Mexico (USFWS 2018). We also reviewed species listed in the New Mexico State Wildlife Action Plan (NMSWAP) as those of greatest conservation need (New Mexico Department of Game and Fish [NMDGF] 2016). We included only those species listed for the Colorado Plateau ecoregion, which includes Aztec Ruins NM. Each of the listed species was placed into one of five categories as follows: I (immediate priority), H (limited habitat), S (susceptible), D (data needed), and F (federally listed). In addition, the reason(s) for inclusion in one of the five categories was based on five criteria as follows: De (declining), Di (disjunct population), E (endemic), K (keystone species), and V (vulnerable) (NMDGF 2016).

Finally, we summarized the results of a Gunnison's prairie dog (*Cynomys gunnisoni*) study conducted in the monument during 2003 (Terracon 2003). The Gunnison's prairie dog has declined by 90% throughout its range, which encompasses the four corners area of Colorado, New Mexico, Arizona, and Utah (NMDGF 2006). Habitat loss, introduced diseases, and eradication efforts by humans are the primary causes for the decline. Prairie dogs, however, represent an important link in the ecosystem, serving as prey for foxes, badgers, hawks, and the federally endangered black-footed ferret (*Mustela*

Kit fox vixen and pups. Photo Credit: © R. Shantz.

nigripes); contributing to nutrient cycling through waste products, which enhances forage quality for large herbivores; and by creating burrows that serve as habitat for other species such as burrowing owls (*Athene cunicularia*) (NMDGF 2006).

In the early 2000s, NPS staff at Aztec Ruins NM observed an increase in the population of prairie dogs in the monument (Terracon 2003). The observation sparked concern regarding the effects of burrowing prairie dogs on cultural resources. To determine the population size and distribution of prairie dogs at the monument, observers mapped the extent of their colony, counted the number of individuals within the colony, and used line transects to determine the number of active and inactive burrows. Although this study was conducted for a single season (2003) more than 10 years ago, the data provide a baseline for comparing to future studies.

Reference Conditions

Reference conditions for the three measures are shown in Table 44 and are described for resources in good, moderate concern, and significant concern conditions. Reference conditions were developed by NRCA staff.

Condition and Trend

NPSpecies lists 68 species of mammal, 36 (53%) of which are considered 'present' (Table 45). Twelve species are considered 'probably present' and the remaining 20 species are 'unconfirmed.' Bogan et al. (2007) documented 33 species of mammal during 2001 to 2003. An additional two species of rodent were on the NPSpecies list as possible that were not encountered during Bogan et al. (2007). The two species are the Hopi chipmunk (*Neotamias rufus*) and the white-footed mouse (*Peromyscus leucopus*). The Hopi chipmunk is listed as 'unconfirmed' and the white-footed mouse is listed as 'present.'

Species from six orders are known to occur in or may occur in the monument. The three shrew species have not been confirmed (order Insectivora), but based on range maps, these species may inhabit the monument (Bogan et al. 2007). During the 2001-2003 study, the western harvest mouse (*Reithrodontomys megalotis*) was the most abundant small mammal captured, followed closely by the non-native house mouse (*Mus musculus*). The deer mouse (*Peromyscus maniculatus*) was the third most commonly trapped species. Northern grasshopper mouse (*Onychomys leucogaster*), desert cottontail (*Sylvilagus audubonii*), and brush mouse (*Peromyscus boylii*) were the three least commonly captured small mammal species. Notably, the study team captured a meadow vole (*Microtus pennsylvanicus*) in 2003, which belongs to an isolated and disjunct population that occurs in mesic habitats in the region and was not expected to occur in the monument. Of the larger mammals, the coyote (*Canis latrans*) was most frequently encountered.

Table 44. Reference conditions used to assess mammals.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/Absence	All or nearly all of the species recorded during early surveys/observations in the monument were recorded during later surveys.	Several species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the monument).	A substantial number of species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the monument).
	Species Nativity	Non-native species are absent.	Non-native species are present but are limited by habitat type and/or do not outcompete or negatively impact native species.	Non-native species are widespread, indicating available habitat, and outcompete or negatively impact native species.
	Species of Conservation Concern	A moderate to substantial number of species of conservation concern occur in the monument, which indicates that the NPS unit provides the correct type of habitat for these species and contributes to their conservation.	A small number of species of conservation concern occur in the monument, and the monument provides the correct type of habitat.	No species identified as species of conservation concern occur in the monument due to lack of habitat.

Table 45. Mammal species that are present or may occur at Aztec Ruins NM.

Order	Common Name	Scientific Name	Brogan et al. (2007)	NPS Wildlife Observations	NPSpecies Occurrence (NPS 2018a)
Insectivora	Crawford's gray shrew	*Notiosorex crawfordi*	–	–	Probably Present
	Dwarf shrew	*Sorex nanus*	–	–	Unconfirmed
	Merriam's shrew	*Sorex merriami*	–	–	Unconfirmed
Chiroptera	Allen's big-eared bat	*Idionycteris phyllotis*	X	–	Probably Present
	Big brown bat	*Eptesicus fuscus*	X	2005	Present
	Big free-tailed bat	Nyctinomops macrotis	X	–	Present
	California myotis	*Myotis californicus*	X	–	Present
	Fringed myotis	*Myotis thysanodes*	–	–	Unconfirmed
	Hoary bat	*Lasiurus cinereus*	–	–	Probably Present
	Little brown myotis	*Myotis lucifugus*	X	–	Present
	Long-eared myotis	*Myotis evotis*	–	–	Unconfirmed
	Long-legged myotis	*Myotis volans*	–	–	Probably Present
	Mexican free-tailed bat	*Tadarida brasiliensis*	X	–	Present
	Pallid bat	*Antrozous pallidus*	X	–	Present
	Silver-haired bat	*Lasionycteris noctivagans*	–	–	Probably Present
	Spotted bat[1]	*Euderma maculatum*	X	2002	Present
	Townsend's big-eared bat[1]	*Corynorhinus townsendii*	–	–	Present
	Western pipistrelle	*Pipistrellus hesperus*	–	–	Probably Present
	Western small-footed bat	*Myotis ciliolabrum*	X	–	Present
	Yuma myotis	*Myotis yumanensis*	X	–	Present
Lagomorpha	Black-tailed jackrabbit	*Lepus californicus*	–	2016	Present
	Desert cottontail	*Sylvilagus audubonii*	X	2015, 2016	Present
	Mountain cottontail	*Sylvilagus nuttallii*	–	–	Unconfirmed
Rodentia	American beaver	*Castor canadensis*	X	2014	Present
	Botta's pocket gopher	*Thomomys bottae*	X	–	Present
	Brush mouse	*Peromyscus boylii*	X	–	Present
	Canyon mouse	*Peromyscus crinitus*	–	–	Unconfirmed
	Colorado chipmunk	*Tamias quadrivittatus*	–	–	Unconfirmed
	Deer mouse	*Peromyscus maniculatus*	X	–	Present
	Gunnison's prairie dog[1]	*Cynomys gunnisoni*	X	–	Present
	Hopi chipmunk	*Neotamias rufus*	–	–	Unconfirmed
	House mouse[2]	*Mus musculus*	X	–	Present
	Meadow vole	*Microtus pennsylvanicus*	X	–	Present
	Mexican woodrat	*Neotoma mexicana*	–	–	Unconfirmed
	Muskrat	*Ondatra zibethicus*	X	–	Present
	Northern grasshopper mouse	*Onychomys leucogaster*	X	–	Present
	Ord's kangaroo rat	*Dipodomys ordii*	X	–	Probably Present
	Pinyon mouse	*Peromyscus truei*	X	–	Present
	Plains pocket mouse	*Perognathus flavescens*	–	–	Probably Present
	Porcupine	*Erethizon dorsatum*	–	2002, 2015	Present
	Rock squirrel	*Spermophilus variegatus*	X	2015, 2016	Present
	Silky pocket mouse	*Perognathus flavus*	X	–	Present

Note: X = species present.

[1] Species of conservation concern (NMDGF 2016).

[2] Non-native species.

[3] Observed in the monument in 2017 and 2018.

Table 45 continued. Mammal species that are present or may occur at Aztec Ruins NN.

Order	Common Name	Scientific Name	Brogan et al. (2007)	NPS Wildlife Observations	NPSpecies Occurrence (NPS 2018a)
Rodentia *continued*	Spotted ground squirrel	*Spermophilus spilosoma*	–	–	Probably Present
	Stephen's woodrat	*Neotoma stephensi*	–	–	Unconfirmed
	Western harvest mouse	*Reithrodontomys megalotis*	X	–	Present
	White-footed mouse	*Peromyscus leucopus*	–	–	Present
	White-tailed antelope squirrel	*Ammospermophilus leucurus*	–	–	Probably Present
	White-throated woodrat	*Neotoma albigula*	X	–	Present
Carnivora	American Badger	*Taxidea taxus*	X	–	Present
	American black bear	*Ursus americanus*	–	–	Unconfirmed[3]
	American mink[1]	*Mustela vison*	–	–	Unconfirmed
	Black-footed ferret	*Mustela nigripes*	–	–	Unconfirmed
	Bobcat	*Lynx rufus*	X	2002, 2016	Present
	Coyote	*Canis latrans*	X	2002, 2005, 2015, 2016	Present
	House cat[2]	*Felis catus*	–	2015	Not Listed
	Gray fox	*Urocyon cinereoargenteus*	–	2015	Probably Present
	Gray wolf[1]	*Canis lupus*	–	–	Unconfirmed
	Grizzly bear	*Ursus arctos*	–	–	Unconfirmed
	Kit fox	*Vulpes macrotis*	–	–	Unconfirmed
	Long-tailed weasel	*Mustela frenata*	–	–	Probably Present
	Mountain lion	*Puma concolor*	–	2015	Unconfirmed
	Raccoon	*Procyon lotor*	X	2016	Present
	Red fox	*Vulpes vulpes*	–	–	Present
	Ringtail	*Bassariscus astutus*	–	–	Unconfirmed
	Striped skunk	*Mephitis mephitis*	X	2002, 2015, 2016	Present
	Western spotted skunk	*Spilogale gracilis*	X	–	Present
Artiodactyla	Elk	*Cervus elaphus*	–	2007	Unconfirmed
	Mule deer	*Odocoileus hemionus*	X	2016	Present
	Pronghorn	*Antilocapra americana*	–	–	Unconfirmed

Note: X = species present.

[1] Species of conservation concern (NMDGF 2016).

[2] Non-native species.

[3] Observed in the monument in 2017 and 2018.

Bogan et al. (2007) listed an additional 33 species as potentially occurring in the monument based on range maps and other reports but speculated that this list was too inclusive. The species accumulation curve based on Bogan et al.'s (2007) survey efforts shows that about 35 species of mammal occur in the monument, which is about the number of species documented by Bogan et al. (2007) and listed as 'present' in NPSpecies (2018a). Based on Bogan et al. (2007), it appears that most mammal species that occur in the monument have been documented. However, there were a few notable new species reported in the wildlife observations database.

A total of 39 observations of 15 native species were included in the wildlife observations database, including two species listed as 'unconfirmed' by NPSpecies. The two 'unconfirmed species were the mountain lion (*Puma concolor*) and elk (*Cervus elaphus*). An adult female elk was observed on 5 August

2007 at the back of the orchard, and mountain lion tracks were observed at the East Ruin on 4 February 2015. Additionally, black bears (*Ursus americanus*) have been seen in the monument in 2017 and 2018 in the East Ruin and riparian area (D. Hawkins, pers. comm. 5 March 2019) and in nearby Farmington, New Mexico in 2017 according to a local newspaper (Farmington Daily Times 2017). While informative, these observations are inadequate for comparing to the inventory data. However, Stegner et al. (2017) found that other than a few large carnivores, the Colorado Plateau mammal populations in national parks are very similar now to 100 years ago. Based on information described above, the monument's mammal presence/absence measure trend in the condition is unknown, but given the relatively high diversity of mammals observed in the monument overall, the condition is good. Because of the age of the inventory data and infrequent wildlife sighting reports, confidence is medium.

For the non-native species measure, only one, the house mouse, was listed by NPSpecies. It was also one of the most commonly trapped species during the 2001-2003 inventory. In addition, the house cat (*Felis catus*) was photographed in 2015 on two separate occasions according to the wildlife observation database (NPS unpublished data). Game cameras at both Farmers Ditch and the riparian area recorded a house cat on 21 November 2015 and 10 December 2015, respectively. No feral dogs (*Canis familiaris*) have been documented in the monument.

Although there are no studies of how domestic cats or house mice have specifically affected the monument's wildlife, their presence in other areas has caused substantial disturbance to native species. Throughout the U.S., free-ranging domestic cats may be responsible for more than one billion bird deaths each year (Loss et al. 2013). For small mammals, the predation rate from domestic cats is much higher, ranging between 6.3 and 22.3 billion deaths annually (Loss et al. 2013). There are few studies that address the effects of house mice on native mammal populations, but the studies available show that mice transmit disease (Wittmer and Pitt 2012) and alter trophic interactions (Strong and Leroux 2014). While information on the influence of house mice on native mammals is limited (Doherty et al. 2016), their tendency to occupy developed areas and agricultural fields may reduce their influence on native species. For these reasons, the condition is of moderate concern. However, the current trend is unknown and the confidence level is low since there are no monument-specific studies.

For the species of conservation concern measure, the NMSWAP lists seven mammals of concern in the Colorado Plateau ecoregion, five of which were listed by NPSpecies (Table 46). But only the two bat species and the Gunnison's prairie dog are confirmed for the monument. Neither the American mink (*Mustela vison*) nor the Mexican wolf (*Canis lupus baileyi*) has been documented there. Although only three of the five species listed as those of conservation concern for the Colorado Plateau ecoregion have been documented in the monument, we consider the condition for this measure to be good because the monument is outside the current range of the remaining two species. The American mink is extirpated from New Mexico, although the species historically occurred in San Juan County (BISON-M 2019), and northern New Mexico is outside of the Mexican wolf's historic range, including the range expansion area identified by the USFWS (Heffelfinger et al. 2017). For these reasons, the condition is good, but confidence in the condition rating is medium because mammals have not been surveyed since 2001 to 2003. The other two species not listed in NPSpecies for the monument include the river otter (*Lontra canadensis*) and the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*).

Table 46. Species of conservation concern listed in NPSpecies.

Common Name	Scientific Name	Category	Reason to Include
Spotted bat[1]	*Euderma maculatum*	Susceptible	Vulnerable
Townsend's big-eared bat[1]	*Corynorhinus townsendii*	Susceptible	Vulnerable
Gunnison's prairie dog[1]	*Cynomys gunnisoni*	Immediate priority	Declining, Vulnerable, Keystone species
American mink[2]	*Mustela vison*	Immediate priority	Vulnerable
Mexican wolf[2]	*Canis lupus baileyi*	Federally listed as endangered	Declining, Vulnerable, Keystone species

Source: NMDGF (2016).

[1] Considered 'present' by NPSpecies.

[2] Considered 'unconfirmed' by NPSpecies.

In 2003, the size of the prairie dog colony at Aztec Ruins NM was estimated at about 5.1 ha (12.6 ac) (Terracon 2003). The colony was located in roughly the center of the monument with Farmers Ditch forming the western boundary and the ruins forming the southern boundary (Terracon 2003). At the time of the survey, the greatest activity occurred in the northeast portion of the colony; however, there were numerous burrows ("too many to count") in the remainder of the colony area (Terracon 2003).

The highly active northeast corner was divided into two subplots, which were surveyed intensively for three days each. The authors estimated that at least 72 individual occurred across these two subplots, which corresponds to a density of 30.9 individuals/ha (12.5 individuals/ac). The authors concluded that this density was somewhat high for the species and speculated that the high density may have been an artifact of late season surveys (i.e., prior to the dispersal of young) and/or limited habitat availability along the boundary of the monument that potentially prevented dispersal.

Across the two subplots, there were 156 active burrows and 44 inactive burrows for a density of 67.0 active burrows/ha (27.1 active burrows/ac). In addition to the main area of activity, six active burrows were found in the orchard and four active burrows were found in the excavated portion of the ruins. Although there are no current estimates of prairie dogs in the monument, the general management plan states that none were known to exist there as of the report's publication in 2010 (NPS 2010c). Although this species is sometimes considered a nuisance, the NMSWAP states that the prairie dog requires immediate conservation priority due to its declining population, vulnerability to a variety of threats, and its role as a keystone species (NMDGF 2016).

Overall Condition, Threats, and Data Gaps

To assess the condition of mammals at Aztec Ruins NM, we used one indicator with three measures, which are summarized in Table 47. Because of the lack of repeat surveys at the monument and limited recent data, the overall condition and trend are unknown. Because of the unknown condition, confidence is low. There have even been recent sightings and tracks of large mammals in the monument, such as elk and mountain lion. Key uncertainties are whether species listed as 'probably present' actually occur in the monument and whether species observed during the inventory continue to occur in the monument.

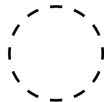
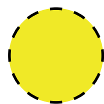
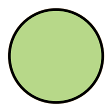
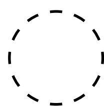
Most native mammals are susceptible to human development, harassment, habitat loss, poor water quality, and human-influenced mortality. Medium-to large-sized mammals are more prone to stressors related to an accumulation of human activity because their home ranges most likely surpass the monument where ideal habitat is limited. Due to the limited distance of small mammals' home ranges, which most likely confines this group of mammals, monument staff has greater control of eliminating stressors that reside within the monument's boundaries, although some of these native species may be considered a nuisance where they occur in archeological sites (e.g., prairie dogs).

Nuisance species may cause damage to archeological resources by digging holes in soil and displacing artifacts. Where they occur near buildings, they may cause structural damage. However, the extent to which this has occurred, if it all, has not been evaluated at the monument. There also is the potential for a prairie dog plague outbreak, which threatens human health and the health of other mammals; however, the potential for an outbreak in the monument has not been evaluated.

Increased development and settlement of humans surrounding the monument can stress native mammals through wildlife corridor displacement, habitat loss and fragmentation, and restricted access to resources. The Animas River likely serves as a wildlife corridor for at least some mammals. While seven species of small- and mid-sized carnivores are present in the monument (e.g., foxes, coyotes, badgers, skunks), almost all of the large carnivores are absent, except mountain lion tracks were observed in 2015 and black bears have been sighted in the monument and nearby. Of all the large carnivores listed by NPSpecies, these are the most likely species to pass through the monument given their current ranges. Black bears are widely distributed in the state, including in San Juan County (Costello et al. 2001), and, according to the state's wildlife information system, mountain lions are rare but present in San Juan County (BISON-M 2019).

While grizzly bears once occurred in New Mexico, they have been extirpated from that state since 1930 (Frey and Yates 1996), and the nearest population occurs in

Table 47. Summary of mammal indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence		NPSpecies lists 68 species of mammal, 36 (53%) of which are considered 'present.' The 2001-2003 inventory documented 33 of those species. Additional observations have been made since the baseline inventory effort. Although nearly all mammal species have likely been documented, there are several species that may have historically occurred in the monument. Despite its small size, the monument supports about half of all species known to occur in similar habitat in San Juan County. The data, however, were collected more than 10 years ago and there are not recent studies to compare the inventory results to.
	Species Nativity		Two non-native species occur in the monument. These are the house mouse and domestic cat. While studies have shown that these two species, particularly the house cat, can negatively affect mammals, there are no monument-specific studies.
	Species of Conservation Concern		Seven species were listed as those of conservation concern in the NMSWAP, five of which were also listed by NPSpecies. Three of the five species are confirmed for the monument, but the Mexican gray wolf and the American mink are not. Mink is extirpated from the state and the monument is outside both the historical range of the Mexican gray wolf.
Overall Condition	Summary of All Measures		Overall, the mammal community, at least as observed from 2001 to 2003, is diverse. There have even been recent sightings and tracks of large mammals in the monument, such as elk, bear, and mountain lion. A key uncertainty is whether species listed as 'probably present' actually occur in the monument. The two non-native species may have substantial negative consequences for native mammals, but this has not been studied to date. Because the monument is small, larger mammals need to include areas outside the monument to meet their resource needs, but habitat fragmentation and human development may limit their ranges. However, there are no current data on mammal presence/ absence in the monument.

northwestern Wyoming in the Greater Yellowstone Ecosystem, hundreds of miles to the north (USFWS 2019a). While the current range of the Mexican wolf is much closer to the monument, it is restricted to areas south of Albuquerque, New Mexico (USFWS 2019b). Although wolves are capable of traveling long distances, they face many obstacles to dispersal, including connectivity issues and persecution by humans (USFWS 2017).

According to New Mexico's wildlife information system, a total of 72 native species of mammal are known to occur in San Juan County (BISON-M 2019). This figure only considers species that occupy similar habitats to that which occurs in Aztec Ruins NM. The database allows users to select habitat types within a particular county to develop wildlife lists. Given that Aztec Ruins NM has confirmed at least 35 native species (38 if including mountain lion, elk, and bear) but represents <0.01% of the area of San Juan County, mammalian diversity in the monument is fairly high (52.8% of the 72 species listed for similar habitat types in San Juan County). Furthermore, while we restricted habitat types to those that occur in the monument, the wide range in where some habitat types occur (e.g., mountains vs. lowland riparian areas), some species were included on the San Juan County list that the monument would not be expected to support (e.g., Canada lynx [*Lynx canadensis*]).

The largest data gap is the lack of follow-up monitoring. While the 2001-2003 inventory serves as a baseline, repeat surveys are necessary to detect changes over time and to evaluate the current condition. Wildlife camera traps strategically placed in known or suspected corridors, such as riparian areas, are an excellent and inexpensive way to document medium and large mammals over the long term. Small mammals generally require more effort to survey.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Herpetofauna

Background and Importance

Aztec Ruins National Monument (NM) is located adjacent to the town of Aztec, New Mexico in San Juan County along 1.6 km (1.0 mi) of the Animas River— a tributary of the San Juan River. Another water resource at Aztec Ruins NM is Farmers Ditch, which is an irrigation canal that transverses the monument. Both the river and canal provide habitat for water-based amphibians and reptiles, collectively referred to as herpetofauna. However, the monument is largely comprised of upland habitat and formerly cultivated fields, which provides habitat for terrestrial-based herpetofauna species as well.

Herpetofauna constitute an important part of the food web. They serve as prey for many animals, including mammals, birds, and other herpetofauna. They are beneficial for pest control too in that they consume insects and other invertebrates and species traditionally considered to be pests to the agriculture industry, such as mice, rats, squirrels, starlings, and more. They also serve as important trophic links and facilitators of energy flow. Amphibians, in particular, are good indicators of wetland ecosystem health. They are sensitive to a variety of threats due to their permeable skin and complex life histories, thus, can serve as early indicators of ecosystem change when monitored over time.

Data and Methods

In 2000, the National Park Service's (NPS) Southern Colorado Plateau Inventory & Monitoring Network (SCPN) developed a species inventory plan for 19 parks within its network. Aztec Ruins NM was one of those parks for which baseline inventories were conducted. Between 2001 and 2003, 103-person hours were spent on herpetofaunal inventories at the monument, with the overall goals of documenting at least 90% of the species present, identifying park-specific species of special concern, and, recommending actions for creating an effective monitoring program (Persons and Nowak 2006). Due to the monument's small size, a stratified random sampling design could not be employed. Instead, non-random 1-ha (2.5-ac) time-area constrained search plots were established and surveyed, along with general and nighttime road driving surveys to detect species. Prior to the Persons and Nowak (2006) survey, no known comprehensive survey for amphibians and reptiles occurred at Aztec Ruins NM.

To assess the overall condition of reptiles and amphibians at Aztec Ruins NM, we used one indicator, species occurrence, with a total of three measures: species presence/absence, species nativity, and species of conservation concern.

Eastern collared lizard at Aztec Ruins NM. Photo Credit: NPS.

To evaluate the species presence/absence measure, we needed more than one survey to compare/contrast recorded species, providing a crude comparison of persistence over time. Unfortunately, as of 2018, early 2019, only one herpetofauna survey has been conducted at the monument. So instead, we discuss the species recorded by Persons and Nowak (2006) in addition to species that may occur in San Juan County using the Biota Information System of New Mexico (BISON-M) (2019) database and at Aztec Ruins NM using the monument's NPSpecies list of probably present and unconfirmed herpetofauna (NPS 2018a).

NPSpecies is a database that is maintained by the NPS and relies on previously published surveys, such as those included in this assessment, and expert opinion, to maintain a record of the presence or potential presence of species in national parks and monuments. The NPSpecies list also serves as a reference, especially to highlight potential data gaps of unconfirmed, but probable, species expected to occur within the monument but that weren't observed during the baseline inventory.

The BISON-M (2019) database for San Juan County, New Mexico lists the reptiles and amphibians that have been recorded throughout the county. We use this list to cross-reference the monument's probable and unconfirmed species, along with additional species that have been recorded in the county but are not listed in the monument's NPSpecies database. Amphibian and reptile scientific names from all sources were updated following the standard English names of amphibians and reptiles of North America north of Mexico, Eighth edition (SSAR 2017).

In general, non-native 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 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 non-native invasive species. To determine species nativity, we used the NPSpecies 'nativeness' designation (NPS 2018a). If any of the species recorded at the monument were non-native amphibian or reptile species, they were evaluated for impact(s) to native species, especially those of conservation concern.

In New Mexico, wildlife species are designated as threatened and endangered under the New Mexico Wildlife Conservation Act (NMDGF 2018). For each endangered or threatened species, the NMDGF develops a recovery plan. The Biota Information System of New Mexico (BISON-M), a database of all vertebrate species in New Mexico, including federally threatened and endangered species, is maintained (BISON-M 2019). BISON-M also includes Species of Greatest Conservation Need (SGCN) that have been designated for New Mexico. We cross-referenced the monument's list of present herpetofauna species to those listed for the state of New Mexico to determine if any species are of conservation concern.

Reference Conditions

Reference conditions for the three species occurrence measures are listed in Table 48 and are described for resources in good, moderate concern, and significant concern conditions.

Condition and Trend

Table 49 lists the 12 herpetofauna species (two amphibians and 10 reptiles) that have been observed at Aztec Ruins NM. According to NPSpecies (NPS 2018a), an additional three species of amphibians and three species of reptiles are probably present. Also three species of amphibians and 11 species of reptiles remain unconfirmed (NPS 2018a). Persons and Nowak (2006) note that the region was experiencing extreme drought conditions during the 2001-2003 baseline inventory, very likely affecting the high number of undetected species. The inventory completeness was estimated at 57% and a follow-up survey during more favorable weather conditions will likely increase the number of observed amphibians and reptiles at the monument.

Persons and Nowak's (2006) general survey method resulted in the highest number of detections of all species except for three, sagebrush lizard (*Sceloporus graciosus*), striped whipsnake (*Coluber taeniatus*), and the prairie rattlesnake (*Crotalus viridis*), which were primarily observed during the time-area constrained searches (Persons and Nowak 2006). The plateau striped whipsnake (*Aspidoscelis velox*) accounted for 48% of all sightings. The next most sighted species was the eastern collared lizard, accounting for 12.6% of all sightings. The remaining 10 species accounted for less than 10% of the sightings each (Persons and Nowak 2006).

Table 48. Reference conditions used to assess herpetofauna.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Species Presence /Absence	All or nearly all of the species recorded during early surveys/ observations in the monument were recorded during later surveys or additional species were observed during later surveys.	Several species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the monument).	A substantial number of species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the monument).
	Species Nativity	Non-native species are absent. If they are present, they are limited by habitat type and/or are not known to outcompete or negatively impact native species.	Non-native species are present but are limited by habitat type and/or do not outcompete or negatively impact native species.	Non-native species are widespread, indicating available habitat, and are known to outcompete or negatively impact native species.
	Species of Conservation Concern	A moderate to substantial number of species of conservation concern occur in the monument, which indicates that the NPS unit provides important habitat for these species and contributes to their conservation.	A low number of species of conservation concern occur in the monument.	No species identified as species of conservation concern occur in the monument.

Table 49. Amphibian and reptile species recorded at Aztec Ruins NM during baseline inventory.

Group	Common Name	Scientific Name	Conservation Status
Amphibians	Western chorus frog	*Pseudacris triseriata*	N/A
	Woodhouse's toad	*Anaxyrus woodhousii*	Natural Heritage NM State Rank, S5, which is demonstrably secure
Reptiles	Bull or gopher snake	*Pituophis catenifer*	Natural Heritage NM State Rank, S5, which is demonstrably secure
	Eastern collared lizard	*Crotaphytus collaris*	Identified as a species of greatest conservation need in the Comprehensive Wildlife Conservation Strategy for New Mexico (NMDGF 2006)
	Eastern fence lizard	*Sceloporus undulatus*	N/A
	Painted turtle*	*Chrysemys p. picta*	Natural Heritage NM State Rank, S4, which is apparently secure and a species of greatest conservation need in the Comprehensive Wildlife Conservation Strategy for New Mexico (NMDGF 2006)
	Plateau striped whiptail	*Aspidoscelis velox*	Natural Heritage NM State Rank, S5, which is demonstrably secure
	Prairie rattlesnake	*Crotalus viridis*	Natural Heritage NM State Rank, S5, which is demonstrably secure
	Sagebrush lizard	*Sceloporus graciosus*	Natural Heritage NM State Rank, S4, which is apparently secure
	Striped whipsnake	*Coluber taeniatus*	Natural Heritage NM State Rank, S5, which is demonstrably secure
	Western whiptail	*Aspidoscelis tigris*	Natural Heritage NM State Rank, S3, which is rare or uncommon
	Western terrestrial gartersnake	*Thamnophis elegans*	Natural Heritage NM State Rank, S5, which is demonstrably secure

* Species was collected during a different effort other than Persons and Nowak (2006).

Sources: Persons and Nowak (2006) and BISON-M (2019).

Because only one herpetofauna survey has been conducted at the monument, we cannot compare presence/absence of species over time, resulting in an unknown condition and trend. Instead we provide a comparison of the species listed as probably present or unconfirmed on the monument's NPSpecies list (2018a) to the San Juan County herpetofauna species list (BISON-M 2019). These species are listed in Table 50.

A total of 27 species (seven amphibians and 20 reptiles) have yet to be confirmed as present at the monument. This includes six species listed as highly probable by Persons and Nowak (2006) that also occur in San Juan County, and five species listed as medium probability that all occur in San Juan County as well. Focusing a new survey effort on these more likely species would almost double the number of amphibians and reptiles present at the monument. An additional nine species were ranked as low probability of occurring at the monument, seven of which are present in San Juan County. And finally, BISON-M (2019) listed an additional seven species (one frog, one turtle, two lizards, and three snakes) as occurring throughout the county, but these seven are not listed on the monument's NPSpecies list (NPS 2018a).

The monument's General Management Plan (NPS 2010c) states that the acquired property to the north of Farmers Ditch may contain a number of snake species

Table 50. Amphibian and reptile species at Aztec Ruins NM that have yet to be confirmed.

Group	Common Name	Scientific Name	San Juan County, New Mexico (BIOTA-M 2019)	NPSpecies Occurrence (2018a)	Persons and Nowak (2006) Probability Rank
Amphibians	American bullfrog	*Lithobates catesbeianus*	X	Unconfirmed	Low
	Boreal chorus frog	*Pseudacris maculata*	X*	N/A	N/A
	Eastern tiger salamander	*Ambystoma tigrinum*	X	Probably Present	High
	New Mexican spadefoot	*Spea multiplicata*	X	Probably Present	High
	Northern leopard frog	*Lithobates pipiens*	X	Unconfirmed	Low
	Plains spadefoot	*Spea bombifrons*	X	Probably Present	High
	Red-spotted toad	*Anaxyrus punctatus*	X	Unconfirmed	Low
Reptiles	Black-necked gartersnake	*Thamnophis cyrtopsis*	X	Unconfirmed	Medium
	California kingsnake	*Lampropeltis californiae*	X*	N/A	N/A
	Chihuahuan nightsnake	*Hypsiglena jani*	X*	N/A	N/A
	Common kingsnake	*Lampropeltis getula*	–	Unconfirmed	Low
	Common lesser earless lizard	*Holbrookia maculata*	X	Unconfirmed	Medium
	Common side-blotched lizard	*Uta stansburiana*	X	Unconfirmed	Medium
	Desert spiny lizard	*Sceloporus magister*	X*	N/A	N/A
	Glossy snake	*Arizona elegans*	X	Probably Present	High
	Hernandez's short-horned lizard	*Phrynosoma hernandesi*	X	Probably Present	High
	Little striped whiptail	*Aspidoscelis inornata*	X	Unconfirmed	Low
	Long-nosed leopard lizard	*Gambelia wislizenii*	X	Unconfirmed	Low
	Milksnake	*Lampropeltis gentilis*	X*	N/A	N/A
	Milksnake	*Lampropeltis triangulum*	X	Unconfirmed	Medium
	Nightsnake	*Hypsiglena chlorophaea*	X	Probably Present	High
	North American racer	*Coluber constrictor*	X	Unconfirmed	Low
	Ornate tree lizard	*Urosaurus ornatus*	X	Unconfirmed	Low
	Plains hog-nosed Snake	*Heterodon nasicus*	X	Unconfirmed	Medium
	Plateau fence lizard	*Sceloporus tristichus*	X*	N/A	N/A
	Ring-necked snake	*Diadophis punctatus*	–	Unconfirmed	Low
	Sonora mud turtle	*Kinosternon sonoriense*	X*	N/A	N/A

* These species are not likely to occur in the monument even though they are listed for San Juan County, New Mexico.

Note: X = Species observed in San Juan County, New Mexico.

that have yet to be recorded as present at the monument. NatureServe's (2018) online species database shows distribution maps for five of the species that are listed for San Juan County in BISON-M (2019) (but are not listed on the monument's NPSpecies list) and while two of the five are present within the county, they are not known to occur within the Animas watershed #14080104, thus are not expected to be present at the monument.

The remaining two species, milksnake (*Lampropeltis gentilis*) and Chihuahuan nightsnake (*Hypsiglena jani*) were both recorded as occurring in San Juan County by Degenhardt et al. (1996) while only Painter (1991) recorded the milksnake as occurring in the county. BISON-M (2019) indicates these are the only documented occurrences of these species in San Juan County and considers the Chihuahuan nightsnake as extant in New Mexico (BISON-M 2019). Thus, it's also unlikely that these two species are present at the monument, reducing the possibility of identifying additional species to 20, but most likely less due to the high number of low probability species.

According to the monument's NPSpecies (NPS 2018a) nativeness designation, all species that have been observed in the monument during the baseline inventory are native. As a result, condition is good, with an unknown trend. The confidence level is low due to the initial survey occurring 16-18 years ago.

Of the 12 herpetofauna species observed at the monument, two, the eastern collared lizard (*Crotaphytus collaris*) and the painted turtle (*Chrysemys p. picta*) are identified as SGCN in New Mexico's Comprehensive Wildlife Conservation Strategy (NMDGF 2006). Neither species have state or federal protection status. NMDGF (2006) indicates that the painted turtle is associated with perennial tank habitats in New Mexico. Also, areas where water tables have been lowered, declines in the number of turtles has occurred. Additionally, due to habitat modifications, the painted turtle no longer occupies the Chama and Jemez Rivers (NMDGF 2006). Factors that have led to the decline of eastern collared lizard, as cited by NMDGF (2006), include extensive urbanization, agricultural development and associated pesticides and herbicides, invasion of non-native grasses (i.e., cheatgrass (*Bromus tectorum*)), pet trade, and the oil/gas industry opening roads thus increasing access to habitat. While the eastern collared lizard was listed as common in the monument during the Persons and Nowak (2006) survey, the factors identified by NMDGF (2006) as contributing to the species decline are relevant to Aztec Ruins NM, but at present, it's unknown whether these stressors have reduced the monument's population.

While only two species are listed as SGCN in New Mexico, the monument likely provides protected habitat for additional species of conservation concern. However, without a more complete and current inventory to document these species, we rate the current condition and trend for this measure as unknown.

Overall Condition, Threats, and Data Gaps

To assess the condition of herpetofauna at the national monument, we used one indicator, with three measures (Table 51). We consider the overall condition and trend of amphibians and reptiles to be unknown without a repeat survey to compare current conditions. A key uncertainty is that many species likely went undetected due to the persistent drought that was impacting the region during the baseline inventory.

Herpetofauna species are susceptible to changes in water resources, habitat loss and fragmentation, introduction of exotic species, pollution, roadkill and disease. While terrestrial herpetofauna typically reflect a higher diversity and have a larger habitat area, water-dependent species are restricted to aquatic habitats. As habitat specialists, changes in aquatic systems have substantial effects on riparian species. Many invasive and exotic species are able to adapt to new areas through corridors such as roads and waterways. While non-native species, such as the American bullfrog (*Lithobates catesbeianus*) and crayfish (*Oronectes* spp.) are known to have major negative effects on native herpetofaunal populations, they have yet to be observed at the monument. Where crayfishes and bullfrogs are abundant, leopard frogs are rare or not present (Fernandez and Rosen 1996). In addition, the direct elimination by humans and increased collection for scientific and personal interest has negative effects on herpetofauna populations. The viability of water flow and quality could become a problem in response to climate change, with changes in sedimentation, especially caused by erosion after flooding and drought events. In response to the 2015 Gold King Mine spill, U.S. Environmental Protection Agency

Table 51. Summary of herpetofauna indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Species Presence / Absence		Only 12 species of amphibians and reptiles have been recorded at the monument, which occurred 16-18 years ago. Without more recent data to compare herpetofauna presence, the current condition and trend are unknown.
	Species Nativity		No non-native species has been observed at the monument, resulting in a good condition rating, but without a more recent survey to compare presence/absence data, confidence in the rating is low. Trend is unknown.
	Species of Conservation Concern		Two species observed at the monument are listed as species of conservation concern in New Mexico. Without an additional survey to document the presence of these two species and likely others during non-drought conditions, we do not know the current condition or trend of this measure.
Overall Condition	Summary of All Measures		Based on the lack of repeatable surveys to determine presence/absence of native species, including species of conservation concern and non-native species, the overall condition and trend for amphibians and reptiles at the monument are unknown.

scientists sampled water, sediment, and biological data from river segments impacted by the plume (USEPA 2018). Rivers sampled included the Animas River near Silverton, Colorado to its confluence with the San Juan River in Farmington New Mexico, and the San Juan River from the Animas confluence to Lake Powell in Utah (USEPA 2018). While no herpetofauna were evaluated, fish were shown to have accumulated metals when first sampled after the spill. Metal levels declined to background conditions when samples were collected again the following spring and human health advisories were never issued. However, differences in sampling methods across states and between partner agencies confounded the comparison of results (USEPA 2018).

On a broader scale, the average annual precipitation amount that falls within the Animas watershed decreases from north to south from a high of 139.7 cm (55 in) to a low of approximately 22.9 - 27.9 cm (9-11 in) per year in the region of Aztec Ruins NM (USDA 2010). USDA (2010) also indicates that droughts are common throughout the watershed region, resulting in lower streamflows and increasing flood severity, which in turn, may reduce the abundance of habitat for all water-dependent species.

Sources of Expertise

The assessment was authored by Kim Struthers, with Utah State University.

Sunset over Aztec Ruins National Monument. Photo Credit: © Bettymaya Foott.

Discussion

Nine of Aztec Ruins National Monument's (NM) natural resources were evaluated to determine current conditions. Most of the resources are considered to be in condition states of moderate concern, with the exception of the wildlife focal resources whose conditions are largely unknown (Table 52). Because no two surveys have been conducted at the monument for birds, mammals, or herpetofauna, condition statuses could not be assigned.

The management of the natural resources at Aztec Ruins NM is guided by the vegetation management plan/environmental assessment (NPS 2012a). The plan divides the monument into eight management units that correspond to vegetation zones (Figure 39). The zones are demarcated by dominant vegetation compositions and are closely linked to the monument's cultural landscapes (NPS 2012a). Four of these zones, (1) Uplands and Slopes (referred to as Uplands), (2) Old Fields and Cultivated Lands, (3) Riparian and Floodplain, and (4) Farmers Ditch correspond to several of the focal resources evaluated in this NRCA report. The natural resource conditions within each of the four zones will be discussed in light of current condition findings, and using the 2012 conditions and the desired future conditions (DFCs) described in the plan for each zone. If possible, potential 'next steps' for management consideration will also be discussed. The fifth management zone, Orchards, will

Ranger taking night sky measurements at Aztec Ruins NM. Photo Credit: © Bettymaya Foott.

Table 52. Natural resource condition summary for Aztec Ruins NM.

Resource	Overall Condition
Viewshed	
Night Sky	
Air Quality	
Water Resources	
Geology	
Upland Vegetation	
Birds	
Mammals	
Herpetofauna	

also be discussed due to the 2013 restoration effort undertaken by monument staff, restoring it to a more natural landscape.

The remaining three management zones, Core Cultural Area, Aztec Ruins Historic District Landscape, and Park Developed Areas, are excluded from this chapter since they are primarily focused on cultural and recreational resources. However, the Ancient Aztec Community prehistoric community (referred to as the Ancient Aztec Landscape) and the Aztec Ruins Historic District Landscape 2012 conditions will be included in each of the five natural resource-based management zones, if available.

The Uplands Vegetation Management Zone occupies the northwestern portion of the monument, upslope of Farmers Ditch. It is referred to as the "North Mesa," which overlies un-excavated ruins, overlooking the West Ruin site (in the Core Cultural Management Zone) and the town of Aztec, New Mexico. The North Mesa Archeological District is located entirely in the Uplands zone and includes a "complex series of sites with both residential and public architecture that date to A.D. 1050-1300" (NPS 2012a). The District is currently listed on the State Register of Cultural Properties and contains sites that are eligible for listing on the National Register of Historic Places (NPS 2012a).

The dominant vegetation in the Uplands zone includes woodlands, shrublands, and an herbaceous understory, along with juniper woodlands growing in drainages. The soils are well-drained and moderately permeable and the topography influenced placement of prehistoric structures and features that included earthen and cobble berms, terrace platforms or pedestals, swales, and roadways (NPS 2012a). The 2012 plan identified resource conditions for the Uplands zone, which included low vegetation diversity, cheatgrass (*Bromus tectorum*) establishment, and the recent presence of cryptobiotic crusts. Condition information reported in NPS (2012) cited the presence of potholes and visual intrusions such as power poles/lines, gas/oil extraction equipment and associated impacts such as access road development, old homesite, barbed wire, etc.

The plan's DFCs for the Uplands zone identified a diversity of native plants, with minimal non-native invasive plant presence; occurrence of cryptobiotic soil crusts; no visual intrusions or social trails; and that additional features such as signs or structures be compatible with the cultural landscape.

Of the measures evaluated in this report, nine vegetation and soils measures, two viewshed measures, one air quality measure, and one geology measure pertain to the Uplands Vegetation Management Zone. As shown in Table 53, current condition statuses for half of the measures warrant moderate concern, with the frequency of non-native plants and active oil and gas well impacts warranting significant concern. It appears that the native species composition and community is improving based on the data collected by the National Park Service (NPS) Southern Colorado

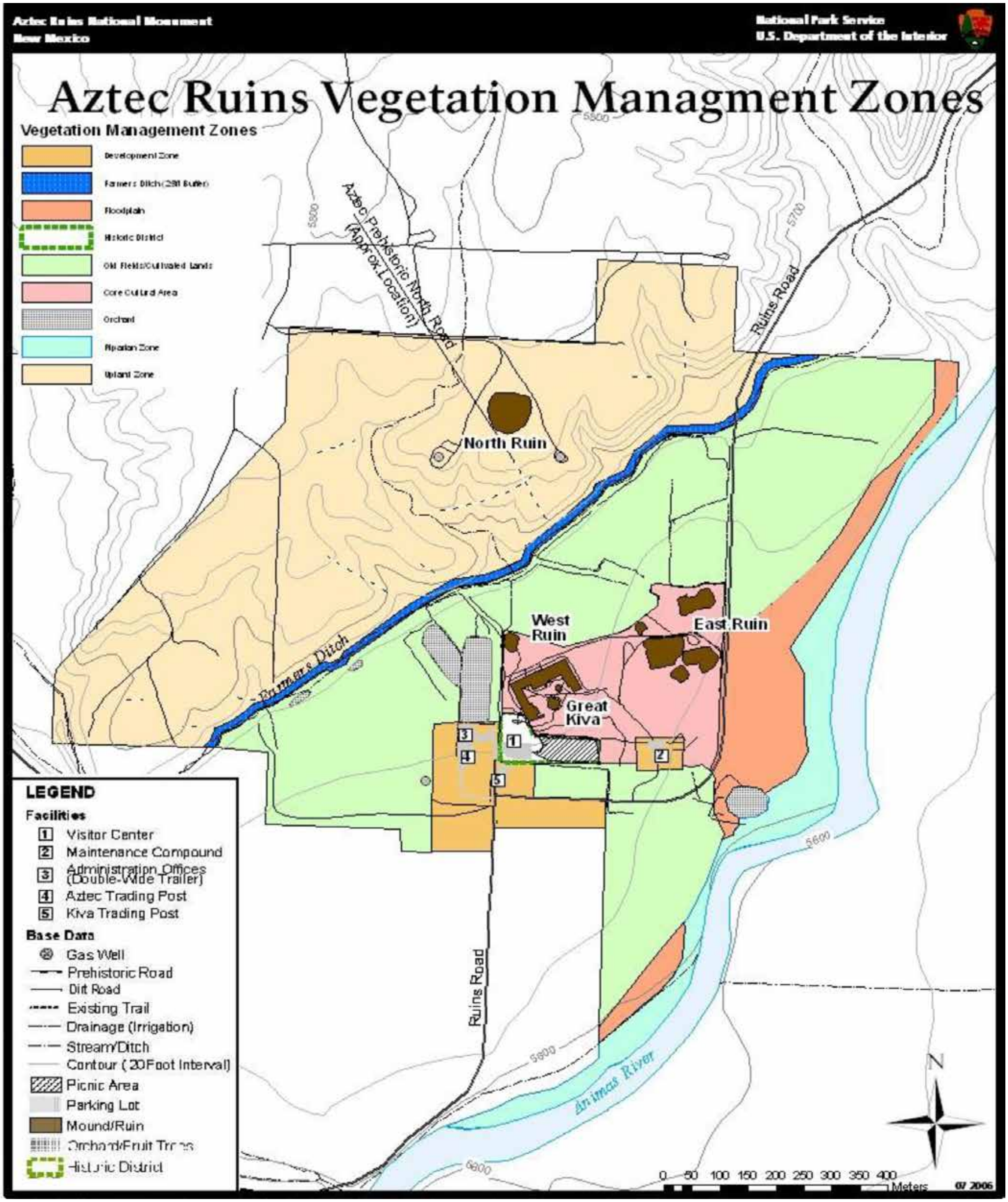


Figure 39. Vegetation management zones at Aztec Ruins NM. Figure Credit: NPS (2012).

Plateau Inventory and Monitoring Network (SCPN) staff from six, upland vegetation study plots. With future monitoring occurring every 5-6 years, the data may suggest trends in vegetation.

The primary threats in the Uplands zone are from non-native invasive plants, visual intrusions, and oil and gas extractive operations, which negatively affect both invasive plants and the views. Potential considerations for improving conditions in the Uplands zone include engaging the local community to preserve marque views (such as from the Aztec Trail System - create viewshed waysides), requesting additional help from Exotic Plant Management Team (EPMT) crews to conduct annual rapid assessments (possibly control), and evaluating types of vegetation most adapted to viewshed screening and climate changes, especially heat and drought tolerant species. Currently, monument staff are working towards burying power lines and removing poles to improve the viewshed condition to be more compatible with the Ancient Aztec Landscape.

The vegetation management unit adjacent to the Uplands zone is Farmers Ditch (Table 54). Farmers Ditch bisects the monument along a northeast to southwest line and separates the Uplands from the Old Fields and Cultivated Lands Vegetation Management Zone. Water flow in Farmers Ditch is manually controlled by the New Mexico Office of the State Engineer/Interstate Stream Commission, depending on the needs of downstream users (Filippone and Martin 2014). It also supplies water to the monument's picnic area and garden, and historically supported

Table 53. Aztec Ruins NM Uplands Vegetation Management Zone's current and desired conditions.

Uplands and Soils Management Zone	Natural/Cultural Resource Conditions Described in NPS (2012)	Desired Resource Condition Described in NPS (2012)	Current NRCA Conditions (2018)	Management Considerations/ Highlights
There are six, long-term vegetation and soil study plots monitored by the Southern Colorado Plateau Inventory & Monitoring Network every 5-6 years. The Ancient Aztec Landscape is in good condition and stable.	Low native vegetation diversity due to overgrazing Cheatgrass established Energy extraction impacts Visual intrusions Social trails, abandoned well site, old homesite, barbed wire present Potholes present Newly established crypto-biotic crusts Ancient Aztec Landscape: stable cultural resources with mostly native vegetation	Healthy, robust, viable, self-sustaining Upper Sonoran life zone Minimal non-native plants Preservation of Chacoan landscape Healthy occurrence of cryptobiotic soil crusts No visual intrusions Archeological sites and Ancient Aztec Landscape in good condition with no potholes or active erosion No social trails Signs and structures are compatible with cultural landscape	Native species community/composition (tree/grass cover, native species richness) Erosion hazard (includes soil crusts) Non-native plants (frequency and cover) Conspicuous of non-contributing features Development Haze Three active oil/gas wells (1 outside park)	The primary stressors in the Uplands zone are invasive plants, visual intrusions, and extractive uses. Consider establishing a viewshed partnership with local community to preserve marque views. Consider strategic vegetation restoration activities that screen current or existing development(s). Consider native plants that are more adapted to warmer and drier conditions. Annually monitor uplands for new plant invasions for rapid removal prior to establishment. Monument staff are working towards improving the scenic view condition.

an orchard until 2009 when irrigation was discontinued (Filippone and Martin 2014).

Only one NRCA measure pertained to the Farmers Ditch vegetation unit, which was discharge. Vegetation, including non-native plants, is not monitored along the ditch/access road and cut vegetation can remain on-site after being cleared (NPS 2012a). The primary threats in this zone include invasive plants and the alteration of the hydrology between the Uplands, Old Fields/Cultivated Lands, and the Floodplain/Riparian zones. Since Farmers Ditch is culturally significant and determined eligible for the National Register of Historic Places, the hydrologic disruption between the uplands and Animas River will likely remain.

Some management considerations include reconsidering the watering practices at the picnic grounds and garden, especially as precipitation is expected to decrease and to monitor and eradicate newly established non-native plants, enlisting the help of the EPMT crew.

The vegetation zones situated to the east of Farmers Ditch include the Old Fields and Cultivated Lands and Orchards (Table 55). These zones consist of old pasture and remnants of pear and apple trees. Most of the area is

Farmers Ditch and access road at Aztec Ruins NM. Photo Credit: © Kim Struthers.

cleared due to former agricultural activities and homesites (NPS 2012a). The associated structures that remain are ineligible for the National Register, although there are certain cultural sites and features that may be eligible as they pertain to the Ancient Aztec Landscape (NPS 2012a). Similar to

Table 54. Aztec Ruins NM Farmers Ditch Vegetation Management Zone's current and desired conditions.

Farmers Ditch Management Zone	Natural/Cultural Resource Conditions Described in NPS (2012)	Desired Resource Condition Described in NPS (2012)	Current NRCA Conditions (2018)	Management Considerations/Highlights
Historic Farmers Ditch is determined eligible for the National Register.	Disturbed soils Access road along ditch Piles of cleared vegetation Non-native vegetation is dominant. Hydrologically interrupts surface water flow from uplands to river	Native vegetation is dominant. No new non-native populations are established. Control and contain weeds as feasible Remove vegetation piles Signs and structures are compatible with cultural landscape.	Farmers Ditch Discharge	The primary stressors in the Farmers Ditch zone are invasive plants and alteration of hydrologic regime. Annually monitor along access road for new plant invasions for rapid removal prior to establishment. Develop Standard Operating Procedure protocol for cleared vegetation removal to limit the spread of non-native plants. Reconsider watering the picnic area and garden. Instead, develop interpretive information about climate change and impacts to decreasing water resources, showcasing proactive management practices.

Table 55. Aztec Ruins NM Old Fields and Cultivated Lands and Orchards Vegetation Management Zones' current and desired conditions.

Management Zone	Natural/Cultural Resource Conditions Described in NPS (2012)	Desired Resource Condition Described in NPS (2012)	Current NRCA Conditions (2018)	Management Considerations/ Highlights
Old Fields and Cultivated Lands	Dominated by non-native species Lack of native vegetation Subsurface cultural deposits disturbed by prairie dogs Non-contributing (developed) features exist Deteriorated condition of wood fencing, corrals, and buildings Lack of healthy agricultural crops Ancient Aztec Landscape Historic Vernacular Landscape	A more natural landscape compatible with the Ancient Aztec Landscape Open shrubland with native grasses and forbs Non-natives prioritized for impacts and controlled Irrigation ditches don't interrupt surface water flow Visual impacts minimized Signs and structures are compatible with cultural landscape.	Presence of Gunnison's prairie dog was reported based on a 2003 (single year) survey. No condition was assigned.	Need to weigh management actions between cultural, natural, and adjacent land use significance to supporting prairie dogs. Prioritize viewshed impacts as observed from other vantage point locations for prioritizing the removal of non-contributing features and structures. Prioritize areas for vegetation restoration and non-native invasive plant removal. Include consideration of irrigation ditches, in restoration approach. If possible, request establishment of SCPN plots to help with restoration efforts, especially since the old fields and orchards occupy a rather large area within the monument.
Orchards	Unmaintained pear and apple orchards Irrigation is altering vegetation.	A natural appearing Ancient Aztec landscape Open shrubland with grasses and forbs	None	Irrigation from Farmers Ditch to water the trees was discontinued in 2009. Orchard trees were removed in 2013.

Farmers Ditch, vegetation is not monitored in these zones, although the majority of orchard trees were removed in 2013. Furthermore, orchard tree irrigation from Farmers Ditch was discontinued in 2009, highlighting the monument's management actions to restore landscapes to more environmentally-preferred conditions. The presence of the Gunnison's prairie dog (*Cynomys gunnisoni*) represents an interdisciplinary resource issue that requires consideration of managing for cultural versus natural resources due to its ability to disturb subsurface cultural artifacts. The removal of structures throughout the Old Fields and Cultivated Lands Management Zone could be prioritized based on vantage points along the Aztec Trail System or other designated marque view vantage points throughout the monument. With the removal of the orchard trees, the DFC of a "more natural landscape compatible with the Ancient Aztec Landscape"has improved since 2013.

The remaining zones discussed in this chapter are the Floodplain and Riparian (Table 56). These are situated along the Animas River adjacent to the Old Fields and Cultivated Lands zone. Monument staff are actively working with EMPT crews to restore the riparian habitat within the park and to serve as a community model. Riparian areas are usually the most productive habitats, especially in arid environments, due to the presence of water— both ground and surface. The current condition of groundwater in the riparian zone indicate that the depth to groundwater is sufficient to support all growth stages of cottonwoods (*Populus* spp.) and willows (*Salix* spp.).

The Aztec Trail System pedestrian bridge links the town of Aztec, New Mexico to the national monument along the riparian corridor. Additionally, monument staff have reported the return of bald eagles (*Haliaeetus leucocephalus*) to the area, indicating improving conditions. However, 59% of the Animas River watershed is classified for multiple uses, which can range from low to high intensity activities.

The primary threats in the Floodplain and Riparian Vegetation Management Zones include non-native invasive plants (although monument staff have a robust restoration program underway to address this issue), hydrologic interruption of Farmers Ditch, agricultural runoff, pending water rights and associated irrigation, drought conditions due to global warming, and adjacent development(s).

Since these two zones are quite productive, establishing permanent, long-term vegetation and soil study plots that are routinely monitored would provide monument staff with data to inform continued, future management actions. Additionally, rapid assessments to determine presence of wildlife would address data gaps for amphibians, reptiles, birds, and mammals. Other parks within the National Park System have been successful at photo-documenting the presence of medium to large-sized mammals using relatively inexpensive remote-sensing cameras. Protocols using remote cameras for monitoring amphibians and reptiles are currently being developed and may be applicable to the monument's future monitoring and management efforts.

Table 56. Aztec Ruins NM Floodplain and Riparian Vegetation Management Zones' current and desired conditions.

Management Zone	Natural/Cultural Resource Conditions Described in NPS (2012)	Desired Resource Condition Described in NPS (2012)	Current NRCA Conditions (2018)	Management Considerations/ Highlights
Floodplain Riparian	Dominant overstory consists of Russian olive (*Elaegnus angustifolia*), box elder (*Acer negundo*), tamarisk *Tamarix* spp.), and to lesser extent cottonwood (*Populus* spp.). Understory vegetation is a mixture of willows (*Salix* spp.), western wheat grass (*Pascopyrum smithii*), and a variety of non-native species, including maple (*Acer* spp.) trees and cultivars. Non-natives out-compete native species for limited resources. Historic fencing and building remnants	Natural functioning and sustainable processes exist Mixed aged native species of box elder, ash, and cottonwood dominate Floodplain vegetation is dominated by native willows, native grasses, and riparian forbs. Tamarisk and Russian olive are not displacing native species. Vegetative/watershed restoration demonstration area serves as a model for neighbors. Vegetation compatible with Ancient Aztec Landscape is emphasized. Signs and structures are compatible with cultural landscape.	Depth to groundwater Animas River discharge Proportion of protected watershed	A concentrated effort to remove non-native invasive plants, thereby restoring the riparian vegetation has been undertaken by monument and EPMT staffs. This may be the most biologically significant zone due to the presence of water. Consider adding long-term vegetation study plots. Consider viewshed management as observed from the pedestrian bridge. Consider focused wildlife monitoring in this zone to inform conditions of birds, mammals, amphibians, and reptiles.

Literature Cited

Abatzoglou, J. T. and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences 113: 11770-11775. Available at: http://www.pnas.org/content/113/42/11770 (access 24 August 2018).

Allen, E. B., L. E. Rao, R. J. Steers, A. Bytnerowicz, and M. E. Fenn. 2009. Impacts of atmospheric nitrogen deposition on vegetation and soils in Joshua Tree National Park. Pages 78–100 in R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller, editors. The Mojave Desert: Ecosystem processes and sustainability. University of Nevada Press, Las Vegas, Nevada. Available at: https://www.fs.usda.gov/treesearch/pubs/37082 (accessed 24 August 2018).

American Ornithological Society (AOS). 2018. Checklist of North and Middle American birds. Available at: http://www.americanornithology.org/content/checklist-north-and-middle-american-birds (accessed 3 October 2018).

Animas Watershed Partnership (AWP) Steering Committee. 2014. Animas Watershed Partnership strategic action plan 2013 through 2016. Available at: http://animaswatershedpartnership.org/wp-content/uploads/2016/11/Animas-Watershed-PartnershipStrategic-Plan-Final-2014.pdf (accessed 10 September 2018).

Banks, A. J. and T. E. Martin. 2001. Host activity and the risk of nest parasitism by brown-headed cowbirds. Behavioral Ecology 12: 31-40. Available at: https://academic.oup.com/beheco/article/12/1/31/392369 (accessed 3 March 2009).

Baron, J. S., C. T. Driscoll, J. L. Stoddard, and E. E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive U.S. lakes. Bioscience. American Institute of Biological Sciences, 61:602-613. Available at: https://academic.oup.com/bioscience/article/61/8/602/337131 (accessed 24 August 2018).

Bell, M. D. In Review. Ozone Sensitive Plant Species on National Park Service and U.S. Fish and Wildlife Service Lands: An Update to Results from the 2003 Baltimore Ozone Workshop. Natural Resource Report NPS/NRARD/NRR-X/Y. Available at: https://irma.nps.gov/NPSpecies/Reports/Systemwide/Ozone-Sensitive%20Species%20in%20a%20Park (accessed 24 August 2018).

Bibby, C. J, N. D. Burgess, D. A. Hill, and S. Mustoe. 2000. Bird census techniques. Second ed. London: Academic Press.

Biota Information System of New Mexico (BISON-M). 2019. BISON-M home page. Available at: http://www.bison-m.org (accessed 11 January 2019).

Bogan, M. A., K. Geluso, S. Haymond, and E. W. Valdez. 2007. Mammal Inventories for Eight National Parks in the Southern Colorado Plateau Network. Natural Resource Technical Report NPS/SCPN/NRTR-2007/054. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/650869 (accessed 30 April 2018).

Brush, R. O. and Palmer, J. F. 1979. Measuring the impact of urbanization on scenic quality: land use change in the northeast. In: Elsner, Gary H., and Richard C. Smardon, technical coordinators. 1979. Proceedings of our national landscape: a conference on applied techniques for analysis and management of the visual resource [Incline Village, Nev., April 23-25, 1979]. Gen. Tech. Rep. PSW-GTR-35. Berkeley, CA. Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture: p. 358. Available at: https://www.fs.fed.us/psw/publications/documents/psw_gtr035/psw_gtr035_08_brush.pdf (accessed 5 July 2018).

Bryce, S. A., R. M. Hughes, and P. R. Kaufmann. 2002. Development of a bird integrity index: Using bird assemblages as indicators of riparian condition. Environmental Management 30:294–310. Available at: https://pdfs.semanticscholar.org/9ada/9eac7c0698695ae41484567ae1154cc5bbeb.pdf (accessed 9 October 2018).

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of biological populations. Oxford, U.K.: Oxford University Press.

Bureau of Land Management (BLM). 2016. Visual Resource Management. U.S. Department of the Interior, Bureau of Land Management. Washington, DC. Available at: https://www.blm.gov/programs/recreation/recreation-programs/visual-resource-management (accessed 6 July 2017).

Burghardt, J. E., E. S. Norby, and H. S. Pranger, II. 2014. Abandoned mineral lands in the National Park System—comprehensive inventory and assessment. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2014/906. National Park Service, Fort Collins, Colorado. Available at: https://www.nps.gov/subjects/abandonedminerallands/upload/NPS_AML-IandA-Report_Septermber2014_screen.pdf (accessed 7 January 2018).

Cabe, P. R. 1993. European Starling (Sturnus vulgaris), The Birds of North America (P. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology. Available at: https://birdsna.org/Species-Account/bna/species/eurstaDOI: 10.2173/bna.48 (accessed 8 October 2018).

Canterbury, G. E., T. E. Martin, D. R. Petit, L. J. Petit, and D. F. Bradford. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conservation Biology 14:544–558. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conservation Biology 14:544–558. Available at: https://www.umt.edu/mcwru/documents/Martin_Publications/Reprint574.pdf (accessed 8 October 2018).

Carles, L. J., I. L. Barrio, and J. Vicente de Lucio. 1999. Sound influence on landscape values. Landscape and Urban Planning 43:191-200. Available at: https://ac.els-cdn.com/S0169204698001121/1-s2.0-S0169204698001121-main.pdf?_tid=db9a3788-c9d0-49df-bc29-fa115ad3d80e&acdnat=1530830332_6d15f1cea9bfbe41ec65e32e5f95be18 (accessed 5 July 2018).

Carroll, K. C. and S. E. Willman. 2015. New Mexico statewide water assessment. Plant and Environmental Sciences Department and Water Science and Management graduate program, New Mexico State University. New Mexico Water Resource Institute. Available at: https://nmwrri.nmsu.edu/wp-content/SWWA/Reports/Roach/June%202015%20FINAL/Report.pdf (accessed 26 February 2019).

Chaudhary, V. B., M. A. Bowker, T. E. O'Dell, J. B. Grace, A. E. Redman, M. C. Rillig, and N. C. Johnson. 2009. Untangling the biological contributions to soil stability in semiarid shrublands. Ecological Applications 19: 110-122. Available at: https://www.jstor.org/stable/pdf/27645952.pdf?casa_token=sM6bvKMvpqEAAAAA:t7iroPPtmrLhEVKkzYDtjccR5sU1NsqFeXiDQhS0Xrf-A-AH8m4b5TUPlqbKmUJVDcr9G44e00MZICRRwbG-v0jwPOgt19lrbsUK14AyDc7tpbL9ilJf (accessed 7 February 2019).

Chen, W. and J. D. Olden. 2017. Designing flows to resolve human and environmental water needs in a dam-regulated river. Nature Communications, article # 2158. Available at: https://www.nature.com/articles/s41467-017-02226-4 (accessed 23 April 2019).

Climate Analyzer. 2019. Aztec Ruins National Monument. Available at: http://hfour.mtercek.webfactional.com/graphers/arbit_30dep.py?station=aztecruins&year1=2008&title=Aztec%20Ruins%20National%20Monument&norm_per=1971_2000&year2=2019&month1=1&month2=12&ann_avg_only=true&mode=water_year (accessed 7 February 2019).

Colorado Plateau Dark Sky Cooperative (CPDSC). 2018. Maps. Available at: https://cpdarkskies.org (accessed 14 May 2018).

Costello, C. M., D. E. Jones, K. A. G. Hammond, R. M. Inman, K. H. Inman, B. C. Thompson, R. A. Deitner, and H. B. Quuigley. 2001. A study of black bear ecology in New Mexico with models for population dynamics and habitat suitability. New Mexico Department of Game and Fish. Available at: http://www.wildlife.state.nm.us/download/hunting/species/bear/publications/

New-Mexico-Black-Bear-Study-Costello-et-al-2001%20.pdf (accessed 6 February 2019).

Crick, H. Q. P., C. Dudley, D. E. Glue, and D. L. Thomson. 1997. UK birds are laying eggs earlier. Nature 388,526. Available at: https://academic.oup.com/bioscience/article/53/12/1199/302301 (accessed 5 March 2019).

DeCoster, J. K., and M. C. Swan. 2009. Integrated upland vegetation and soils monitoring for Aztec Ruins National Monument: 2008 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2009/014. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/148350 (accessed 7 November 2018).

DeCoster, James K., Chris L. Lauver, Mark E. Miller, Jodi R. Norris, Allison E. C. Snyder, Megan C. Swan, Lisa P. Thomas, and Dana L. Witwicki. 2012. Integrated upland monitoring protocol for the Southern Colorado Plateau Network. Natural Resource Report NPS/SCPN/NRR–2012/577. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/456615 (accessed 7 November 2018).

Degenhardt, Painter, and Price. 1996. Amphibians and Reptiles of New Mexico. UNM Press, Albuquerque, NM. 431 pp. as cited in BIOTA-M (2019).

Department of Interior, National Park Service (DOI NPS). 2016. General Provisions and Non-Federal Oil and Gas Rights. Federal Register 81 (214). 4 November 2016. Available at: https://www.govinfo.gov/content/pkg/FR-2016-11-04/pdf/2016-26489.pdf (accessed 7 January 2018).

Doherty, T. S., A. S. Glen, D. G. Nimmo, E. G. Ritchie, and C. R. Dickman. 2016. Invasive predators and global biodiversity loss. Proceedings of the National Academy of Sciences 113: 11261-11265. Available at: https://www.pnas.org/content/113/40/11261 (accessed 6 February 2019).

Duriscoe, D., C. B. Luginbuhl, and C. A. Moore. 2007. Measuring night sky brightness with a wide-field CCD camera. Publications of the Astronomical Society of the Pacific 119:192-213.

Duriscoe, D. M. 2013. Measuring anthropogenic sky glow using a natural sky brightness model. Mon. Not. R. Astron. Soc. 125:1370-1382. Available at: https://irma.nps.gov/DataStore/DownloadFile/465763 (accessed 15 May 2018).

Duriscoe, D. 2016. Photometric indicators of visual night sky quality derived from all-sky brightness maps. Journal of Quantitative Spectroscopy and Radiative Transfer 181: 33-45.

E&S Environmental Chemistry, Inc. 2009. Nitrogen screening project - sensitive vegetation. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2170016 (accessed 24 August 2018).

eBird. 2018a. About eBird: Global tools for birders, critical data for science. Available at: http://ebird.org/content/ebird/about/. (accessed 8 October 2018).

eBird. 2018b. eBird checklist for Aztec Ruins National Monument. Ithaca, New York. Available at: https://ebird.org/hotspot/L734141. (accessed 3 October 2018).

ESRI. 2016. Using viewshed and observer points for visibility analysis. Available at: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/using-viewshed-and-observer-points-for-visibility.htm (accessed 12 July 2018).

Farmington Daily Times. 2017 (21 September). NM Game & Fish: Bears search for food in urban areas. Available at: https://www.daily-times.com/story/news/local/2017/09/21/nm-game-fish-bears-search-food-urban-areas/686833001/ (accessed 6 February 2019).

Fernandez, P. J., and P. C. Rosen. 1996. Final report: effects of the introduced crayfish *Orconectes virilis* on native aquatic herpetofauna in Arizona. Submitted to Arizona Game and Fish Department, Heritage Fund, Phoenix, AZ.

Filippone, C. and L. Martin. 2014. Aztec Ruins Monument hydrology study and mitigation plan final report: geology, soils, and groundwater section. Colorado Plateau Ecosystem Studies Unit. National Park Service.

Fowler, D., J. A. Pyle, J. A. Raven, and M. A. Sutton. 2013. The global nitrogen cycle in the twenty-first century: Introduction. Philosophical Transactions of the Royal Society B: Biological Sciences, 368(1621), 20130165. Available at: http://doi.org/10.1098/rstb.2013.0165 (accessed 24 August 2018).

Frankenberg, C., A. K. Thorpe, D. R. Thompson, G. Hulley, E. A. Kort, N. Vance, J. Borchardt, T. Krings, K. Gerilowski, C. Sweeney, S. Conley, B. D. Bue, A. D. Aubrey, S. Hook, and R. O Greene. 2016. Available at: http://www.pnas.org/content/early/2016/08/10/1605617113.full (accessed 14 May 2018).

Frey, J. K. and T. L. Yates. 1996. Mammalian diversity in New Mexico. New Mexico Journal of Science 36:4-37. Available at: http://web.nmsu.edu/~jfrey/19%20Frey%20and%20Yates%201996%20Mammalian%20Diversity%20NMJS.pdf (accessed 7 February 2019).

Freund, S. 2015. Biological soil crust cover and richness in two Great Basin vegetation zones. Master's Thesis. University of Nevada, Reno, Nevada. Available at: https://scholarworks.unr.edu/bitstream/handle/11714/2674/Freund_unr_0139M_11953.pdf?sequence=1&isAllowed=y (accessed 11 February 2019).

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Ch. 20: Southwest, in J. M. Melillo, T. C. Richmond, and G. W. Yohe, eds. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 462-486. doi:10.7930/J08G8HMN. Available at: http://nca2014.globalchange.gov/report/regions/southwest%0D (accessed 29, April 2018).

Gobster, P. H. 1999. An ecological aesthetic for forest Johnson, G. W., J. D. Anderson, and D. Godwin. 2008. A guidebook for the Blue Ridge Parkway Scenery Conservation System. Draft. National Park Service, Asheville, North Carolina. Available at: https://www.nrs.fs.fed.us/pubs/jrnl/1999/nc_1999_Gobster_001.pdf (accessed 5 July 2018).

Han, K. T. 2010. An exploration of relationships among responses to natural scenes: Scenic beauty, preference and restoration. Environment and Behavior 42:243-270. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.882.5743&rep=rep1&type=pdf (accessed 3 September 2018).

Hannum, C. 2012. Biological assessment: Animas River pedestrian bridge at Aztec Ruins National Monument. San Juan County, New Mexico - District 5. Parametrix. Albuquerque, New Mexico. Available at: http://www.aztecnm.gov/plans/pedbridge-bioassessment.pdf (accessed 15 July 2018).

Hardaker, C. 2004. The hexagon, the solstice, and the kiva. [Special issue of Symmetry: Culture and Science]. Symmetry in Ethnomathematics, 12(1-2), 167-183. Budapest, Hungary: International Symmetry Foundation. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.179.2823&rep=rep1&type=pdf (accessed 14 May 2018).

Heffelfinger, J. R., R. M. Nowak, and D. Paetkau. 2017. Clarifying historical range to aid recovery of the Mexican wolf. The Journal of Wildlife Management 81: 766-777. Available at: https://wildlife.onlinelibrary.wiley.com/doi/epdf/10.1002/jwmg.21252 (accessed 6 February 2019).

Herrick, J. E., J. W. Van Zee, K. M. Havstad, J. M. Burkett, and W. G. Whitford. 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume II: Design, supplementary methods and interpretation. USDA-ARS Jornada Experimental Range, Las Cruces, New Mexico. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044179.pdf (accessed 7 November 2018).

Hetherington, J., T.C. Daniel. and T.C. Brown. 1993. Is motion more important than it sounds?: The medium of presentation in environmental perception research. J. Environmental Psychology. 13: 283-291.

House of Representatives Joint Resolution 46 (H.J.R. 46). 2017. Available at: https://www.congress.gov/bill/115th-congress/house-joint-resolution/46/text (accessed 7 January 2019).

Hughes, J. D. 1993. Great kivas of the American Southwest. Architecture and Behavior 9: 177-190. Available at: https://lasur.epfl.ch/files/content/sites/lasur2/files/Images/stories/editions_du_lasur_pdf/AC/AC%20Vol%209%20No.2/HUGHES.pdf (accessed 14 May 2018).

Incorporated Research Institutions for Seismology (IRIS). 2018. Earthquake magnitude descriptions. Available at: https://ds.iris.edu/ds/support/faq/52/how-do-i-interpret-magnitudes-and-magnitude-types/ (accessed 7 January 2019).

Inouye, R.S. 2006. Effects of shrub removal and nitrogen addition on soil moisture in sagebrush steppe. Journal of Arid Environments. 65: 604–618.

Johnson, G. W., J. D. Anderson, and D. Godwin. 2008. A guidebook for the Blue Ridge Parkway Scenery Conservation Haas G.E., and T.J. Wakefield. 1998. National parks and the American public: a summary report of the National Parks Conservation Association, conducted by Colorado State University, Fort Collins, Colorado.

Johnson M. J., J. A. Holmes, M. A. Stuart, and J. Lynn. 2007. Avian inventories for six national parks in the Southern Colorado Plateau Network. Natural Resource Technical Report NPS/SCPN/NRTR–2007/047. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/464492 (accessed 2 October 2018).

Kaltenborn, B. P. and T. Bjerke. 2002. Associations between environmental value orientations and landscape preferences. Landscape and Urban Planning 59:1-11. Available at: https://ac.els-cdn.com/S0169204601002432/1-s2.0-S0169204601002432-main.pdf?_tid=89c687e3-6bfb-4617-8ad8-8d7efb67a1f8&acdnat=1530828329_db6c0b2e07a444376c8b0abe1c15b2cd (accessed 5 July 2018).

Kaplan, R. and S. Kaplan. 1989. The experience of nature: A Psychological Perspective. Cambridge University Press, Cambridge, UK.

Kearney, A. R., G. A. Bradley, C. H. Petrich, R. Kaplan, S. Kaplan, and D. Simpson-Colebank. 2008. Public perception as support for scenic quality regulation in a nationally treasured landscape. Landscape and Urban Planning 87:117-128. Available at: https://ac.els-cdn.com/S0169204608000819/1-s2.0-S0169204608000819-main.pdf?_tid=e581bcc6-712a-425b-84d6-8bf743193a38&acdnat=1530827814_0eeffcfc5d7207cbd79fc97fc65505d6 (accessed 5 July 2018).

Keiser, D., G. Lade, and I. Rudik. 2018. Air pollution and visitation at U.S. national parks. Science Advances eaat1616. Available at: http://advances.sciencemag.org/content/advances/4/7/eaat1613.full.pdf (accessed 28 August 2018).

KellerLynn, K. 2016. Aztec Ruins National Monument: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2016/1245. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/552675 (accessed 7 January 2019).

King, K. and E. King. 1994. Vibration investigation of archaeological structures, Aztec Ruins National Monument, New Mexico. K. King, consultant. Lakewood, Colorado.

Kinney, P. L. 2008. Climate change, air quality, and human health. American Journal of Preventative Medicine 35: 459-467. Available at: http://www.ajpmonline.org/article/S0749-3797(08)00690-9/abstract (accessed 24 August 2018).

Kissling, W. D., R. Field, H. Korntheuer, U. Heyder, and K. Böhning-Gaese. 2010. Philosophical Transactions of the Royal Society B 365: 2035-2045. Available at: https://royalsocietypublishing.org/doi/pdf/10.1098/rstb.2010.0008 (accessed 5 March 2019).

Korb, J. E. 2010. Inventory of exotic plant species occurring in Aztec Ruins National Monument. Natural Resource Technical Report NPS/SCPN/NRTR—2010/300. National Park Service, Fort

Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/148349 (accessed 7 November 2018).

Kray, J. A., D. J. Cooper, and J. S. Sanderson. 2012. Groundwater use by native plants in response to changes in precipitation in an intermountain basin. Journal of Arid Environments 83: 25-34.

Kunkel, K. E, L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional climate trends and scenarios for the U.S. national climate assessment. Part 5. Climate of the Southwest U.S. National Oceanic and Atmospheric Administration, Technical Report NESDIS 142-5, Washington, DC. Available at: https://www.ncdc.noaa.gov/news/us-regional-climate-trends-and-scenarios (accessed 29 April 2018).

Lister, R. H. and F. C. Lister. 1990. Aztec Ruins National Monument, administrative history of an archaeological preserve. Southwest Cultural Resources Center, Southwest Region, National Park Service. Santa Fe, New Mexico. Available at: http://www.npshistory.com/publications/azru/adhi.pdf (accessed 7 January 2018).

Longcore, T. and C. Rich. 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2: 191-198. Available at: https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/1540-9295%282004%29002%5B0191%3AELP%5D2.0.CO%3B2 (accessed 15 May 2018).

Lorenza, J. C. and S. G. Sealy. 1999. A meta-analysis of the impact of parasitism by the brown-headed cowbird on its hosts. Studies in Avian Biology 18: 241-253. Available at: https://sora.unm.edu/sites/default/files/SAB_018_1999%20P241-253_A%20Meta-Analysis%20of%20the%20Impact%20of%20Parasitism%20by%20the%20Brown-Headed%20Cowbird%20on%20Its%20Hosts_Janice%20C.%20Lorenzana%2C%20Spencer%20G.%20Sealy.pdf (accessed 5 March 2019).

Loss, S.R., T. Will, and P.P Marra. 2013. The impact of free-ranging domestic cats on wildlife of the United States. Nature Communications 4, Article 1396, doi:10.1038/ncomms2380. Available at: https://www.nature.com/articles/ncomms2380.pdf (accessed 19 October 2018).

Lowther, P. E. 1993. Brown-headed cowbird (*Molothrus ater*), version 2.0. The Birds of North America (A. F. Poole and F. B. Gill, editors). Cornell Lab of Ornithology, Ithaca, NY, USA. Available at: https://doi.org/10.2173/bna.47 (accessed 5 March 2019).

Lowther, P. E. and C. L. Cink. 2006. House sparrow (*Passer domesticus*), version 2.0. The Birds of North America (P. G. Rodewald, editor). Cornell Lab of Ornithology, Ithaca, New York, USA. Available at: https://doi.org/10.2173/bna.12 (accessed 8 October 2018).

Lowther, P. E. and R. F. Johnston. 2014. Rock pigeon (*Columba livia*), version 2.0. The Birds of North America (P. G. Rodewald, editor). Cornell Lab of Ornithology, Ithaca, New York, USA. Available at: https://doi.org/10.2173/bna.13 (accessed 18 November 2017).

Martin, T. E. and J. L. Maron. 2012. Climate impacts on bird and plant communities from altered animal-plant interactions. Nature Climate Change. DOI: 10.1038/NCLIMATE1348. Available at: http://klamathconservation.org/docs/martinmaron2012.pdf (accessed 5 March 2019).

Miller, M. E. 2005. The structure and functioning of dryland ecosystems—conceptual models to inform long-term ecological monitoring: U.S. Geological Survey Scientific Investigations Report 2005-5197, 73 p. Available at: https://pubs.usgs.gov/sir/2005/5197/pdf/SIR-5197.pdf (accessed 7 November 2018).

Miller, R.F., J. C. Chambers, D. A. Pyke, F. B. Pierson, and C. J. Williams. 2013. A review of fire effects and soils in the Great Basin region: response and ecological site characteristics. U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-308. Available at: https://www.researchgate.net/publication/259077988_A_review_of_fire_effects_on_vegetation_and_soils_ in_the_Great_Basin_region_Response_and_site_characteristics (accessed 11 February 2019).

Møller, A. P., D. Rubolini, and E. Lehikoinen. 2008. Proceedings of the National Academy of Sciences 105: 16195-16200. Available at: https://www.pnas.org/content/pnas/105/42/16195.full.pdf (accessed 5 March 2019).

Monahan, W. B. and N. A. Fisichelli. 2014. Recent climate change exposure of Aztec Ruins National Monument. Available at: https://irma.nps.gov/DataStore/DownloadFile/496787 (accessed 24 August 2018).

Monahan, W. B., J. E. Gross, L. K. Svancara, and T. Philippi. 2012. A guide to interpreting NPScape data and analyses. Natural Resource Technical Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/interpguide.cfm (accessed 8 May, 2017).

Moore, C. A., J. M. White, and F. Turina. 2013. Recommended indicators of night sky quality for NPS state of the park reports, interim guidance. Natural Sounds and Night Skies Division, WASO-Natural Resource Stewardship and Science. July 10, 2013.

National Aeronautics and Space Administration (NASA). 2018. NASA day/night band product. Available at: http://viirsland.gsfc.nasa.gov (accessed 15 February 2018).

National Atmospheric Deposition Program (NRSP-3) (NADP). 2018a. NADP Program Office, Wisconsin State Laboratory of Hygiene, 465 Henry Mall, Madison, WI 53706. Available at: http://nadp.slh.wisc.edu/data/animaps.aspx (accessed 27 February 2019).

National Atmospheric Deposition Program (NRSP-3) (NADP). 2018b. NADP Program Office, Wisconsin State Laboratory of Hygiene, 465 Henry Mall, Madison, WI 53706. Available at: http://nadp.slh.wisc.edu/amon/ (accessed 27 7 February 2019).

National Audubon Society (NAS). 2014. Christmas Bird Count compiler's manual. Available at: http://docs.audubon.org/sites/default/files/documents/compilers_manual_oct_2014_0.pdf (accessed 2 October 2018).

National Park Service (NPS). 2002. Cultural landscapes inventory, 1998, revised 2002. Aztec Ruins historic district. Aztec Ruins National Monument. Aztec, New Mexico.

National Park Service (NPS). 2004. Natural Resource Management Reference Manual #77. Available at: http://www.nature.nps.gov/rm77/(accessed 29 April 2018).

National Park Service (NPS). 2005. NPS ecological monitoring framework. Available at: https://www.nps.gov/orgs/1439/nrca-framework.htm#framework (accessed 29 April 2018).

National Park Service (NPS). 2006. Management Policies 2006: The guide to managing the National Park System. Washington, D.C. 180 pp. Available at: https://www.nps.gov/policy/mp/Index2006.htm (accessed 24 August 2018).

National Park Service (NPS). 2010a. Standard NRCA report outline – annotated version 3.1. 5p. Available at: https://www.nps.gov/orgs/1439/upload/NRCA_Report_Outline_annotated_ver3-1_508.pdf (accessed 29 April 2018).

National Park Service (NPS). 2010b. Stargazing in parks. NPS Natural Resource Program Center Air Resources Division Night Sky Program. Available at: http://npshistory.com/publications/sound/stargazing.pdf (accessed 15 February 2018).

National Park Service (NPS). 2010c. General management plan for Aztec Ruins National Monument, New Mexico.

National Park Service (NPS). 2011. Program brief: Inventory and monitoring program. U.S. Department of the Interior, National Park Service, Natural Resource Program Center, Inventory and Monitoring Division, Fort Collins, Colorado.

National Park Service (NPS). 2012a. Vegetation management and cultural landscape preservation maintenance plan/environmental assessment. 143 pp.

National Park Service (NPS). 2012b. A call to action: preparing for a second century of stewardship and engagement. Washington, D.C. Available at: https://www.nps.gov/calltoaction/ (accessed 29 April 2018).

National Park Service (NPS). 2014. Technical assistance request. Unpublished document. Aztec Ruins National Monument.

National Park Service (NPS). 2015a. Foundation document. Aztec Ruins National Monument, New Mexico. 36 pp.

National Park Service (NPS). 2015b. NPScape standard operating procedure: roads measure – road density, distance from roads, and area without roads. Version 2015-04-23. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/521765 (accessed 1 March 2019).

National Park Service (NPS). 2015c. NPScape standard operating procedure: housing measure – current and projected housing density. Version 2015-04-14. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/521103 (accessed 12 July 2018).

National Park Service (NPS). 2015d. NPScape standard operating procedure: conservation status measure – protected area and ownership/governance. Version 2014-01-06. National Park Service, Natural Resource Stewardship and Science. Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/521469 (accessed 12 July 2018).

National Park Service (NPS). 2015e. Environmental factors. Available at: https://www.nps.gov/azru/learn/nature/environmentalfactors.htm (accessed 21 February 2019).

National Park Service (NPS). 2016. NPScape: monitoring landscape dynamics of U.S. National Parks. Natural Resource Program Center, Inventory and Monitoring Division. Fort Collins, Colorado. Available at: http://science.nature.nps.gov/im/monitor/npscape/(accessed 5 July 2018).

National Park Service (NPS). 2018a. NPSpecies list. Available at: https://irma.nps.gov/NPSpecies/ (accessed 29 April 2018).

National Park Service (NPS). 2018b. Aztec Ruins National Monument, New Mexico. Available at: http://www.nps.gov/azru/index.htm. (accessed 29 April 2018).

National Park Service (NPS). 2018c. Integrated resource management applications: IRMA portal. Available at: https://irma.nps.gov/App/ (accessed 29 April 2018).

National Park Service (NPS). 2018d. Natural Resource Stewardship and Science Directorate. Available at: https://nature.nps.gov/aboutus.cfm (29 April 2018).

National Park Service Air Resources Division (NPS ARD). 2002. Air quality in the national parks, second edition. Lakewood, Colorado. Available at: https://nature.nps.gov/air/Pubs/pdf/aqNps/aqnps.pdf (accessed 24 August 2018).

National Park Service Air Resources Division (NPS ARD). 2003. Air atlas summary tables for I&M parks. Available at: http://www.nature.nps.gov/air/Permits/ARIS/networks/docs/SummariesAirAtlasRevised11072003.pdf (accessed 24 August 2018).

National Park Service Air Resources Division (NPS ARD). 2005. Redesignation of clean air areas. Available at: http://www.nature.nps.gov/air/Regs/redesig.cfm (accessed 31 January 2018).

National Park Service Air Resources Division (NPS ARD). 2010. Air quality in national parks: 2009 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2010/266. National Park Service, Denver, Colorado. Available at: https://www.nature.nps.gov/air/pubs/pdf/gpra/AQ_Trends_In_Parks_2009_Final_Web.pdf (accessed 2 February 2018).

National Park Service Air Resources Division (NPS ARD). 2018a. Clean Air Act and regulations. Available at: http://www.nature.nps.gov/air/Regs/cleanAir.cfm (accessed 16 August 2018).

National Park Service Air Resources Division (NPS ARD). 2018b. Ozone effects on human health. Available at: https://www.nps.gov/subjects/air/humanhealth-ozone.htm (accessed 16 August 2018).

National Park Service Air Resources Division (NPS ARD). 2018c. Ozone effects on plants. Available at: https://www.nps.gov/subjects/air/nature-ozone.htm (accessed 16 August 2018).

National Park Service Air Resources Division (NPS ARD). 2018d. Mercury and toxics in nature. Available at: https://www.nps.gov/subjects/air/nature-toxics.htm (accessed 16 August 2018).

National Park Service Air Resources Division (NPS ARD). 2018e. Guidance for evaluating air quality in Natural Resource Condition Assessments. National Park Service, Denver, Colorado.

National Park Service Air Resources Division (NPS ARD). 2018f. Air quality conditions and trends by NPS units: Aztec Ruins NM. National Park Service. Denver, CO. Available at: https://www.nps.gov/subjects/air/park-conditions-trends.htm (accessed 31 January 2018).

National Park Service Air Resources Division (NPS ARD). 2018g. Mercury/toxics data and information for Aztec Ruins NM, provided by Jim Cheatham, NPS Air Resources Division, to Lisa Baril, Utah State University, via email on 2 February 2018.

National Park Service Air Resources Division (NPS ARD). 2018h. Where does air pollution come from? Available at: https://www.nps.gov/subjects/air/sources.htm (accessed 4 January 2019).

National Park Service Natural Sounds and Night Skies Division (NPS NSNSD). 2016. Night sky monitoring report metrics and glossary of terms. Available at: https://www.nps.gov/subjects/nightskies/skydata.htm (accessed 17 June 2018).

National Park Service Natural Sounds and Night Skies Division (NPS NSNSD). 2018. Natural Sounds and Night Skies Division. Available at: https://www.nps.gov/orgs/1050/index.htm (accessed 21 June 2018).

National Park Service (NPS) Southern Colorado Plateau Network (SCPN). 2018. Natural resources at Aztec Ruins National Monument. Available at: https://www.nps.gov/im/scpn/azru.htm (accessed 29 April 2018).

National Park Service (NPS) Public Use Statistics Office. 2019. NPS visitor use statistics. Annual park visitation (all years). Available at: https://irma.nps.gov/Stats/Reports/ReportList (accessed 28 April 2019).

National Park Service (NPS) Water Resources Division (WRD). 2018. Hydrographic impairment statistics for Aztec Ruins National Monument. Available at: https://www.nature.nps.gov/water/HIS/parkreport.cfm (accessed 10 September 2018).

NatureServe. 2018. Explorer online database. Available at: http://explorer.natureserve.org/aboutd.htm(accessed 1 February 2019).

New Mexico Department of Game and Fish (NMDGF). 2006. Comprehensive Wildlife Conservation Strategy for New Mexico. New Mexico Department of Game and Fish. Santa Fe, New Mexico. 526 pp + appendices.

New Mexico Department of Game and Fish (NMDGF). 2016. State wildlife action plan for New Mexico. New Mexico Department of Game and Fish. Sante Fe, New Mexico. Available at: http://www.wildlife.state.nm.us/download/conservation/swap/New-Mexico-State-Wildlife-Action-Plan-SWAP-Final-2017.pdf (accessed 8 October 2018).

New Mexico Department of Game and Fish (NMDGF). 2018. Threatened & endangered species. 2018 biennial review. Available at: http://www.wildlife.state.nm.us/conservation/wildlife-species-information/threatened-and-endangered-species/ (accessed 1 February 2019).

New Mexico Office of the State Engineer/Interstate Stream Commission (NMOSE). 2011. Real-time water measurement information system, Farmer's Irrigation. Available at: http://meas.ose.state.nm.us/site.jsp?id=72&status=Y&type=S&dist=5&basin=Animas%20River (accessed 3 March 2019).

New Mexico State Historic Preservation Division (NMHPD). 2012. Listed state and national register properties by name. Available at: http://www.nmhistoricpreservation.org/assets/files/registers/2012%20Report_%20Section%201_%20Arranged%20by%20Name.pdf (accessed 12 July 2018).

New Mexico Surface Water Quality Bureau (NMSWQB). 2018a. Gold King Mine water spill long-term monitoring plan. Available at: https://www.env.nm.gov/wp-content/uploads/2016/01/GKM-Long-Term-Monitoring-Plan-for-2017-Final_5-5-2017.pdf (accessed 10 September 2018).

New Mexico Surface Water Quality Bureau (NMSWQB). 2018b. Available at: 2018-2010 state of New Mexico Clean Water Act Secion 303(d)/Section 305(b) integrated report. Available at: https://www.env.nm.gov/wp-content/uploads/2018/03/2018-2020-EPA-approved-IR.pdf (accessed 4 March 2019).

New Mexico Water Resources Research Institute (NMWRRI). 2018. Notes from the 2nd annual conference on environmental conditions of the Animas and San Juan watersheds with emphasis on Gold King Mine and other mine waste issues. Available at: https://nmwrri.nmsu.edu/notes-from-the-2nd-annual-conference-on-environmental-conditions-of-the-animas-and-san-juan-watersheds-with-emphasis-on-gold-king-mine-and-other-mine-waste-issues-continued/ (accessed 26 February 2019).

Newton, B. T., E. Mamer, and S. Timmons. 2017. Hydrogeology and geochemistry of the Animas River alluvial aquifer after the Gold King Mine Spill, San Juan County, New Mexico. New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico. Available at: https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=592 (accessed 23 April 2019).

O'Connor, Z. 2008. Facade colour and aesthetic response: examining patterns of response within the context of urban design and planning in Sydney, University of Sydney: Sydney, Austraila. Available at: https://core.ac.uk/download/pdf/41232383.pdf (accessed 3 September 2018).

O'Connor, Z. 2009. Facade colour and judgements about building size. In D. Smith, P. Green-Armytage, M. A. Pope, and N. Harkness (Eds.) AIC 2009: Proceedings of the 11th Congress of the International Colour Association, Sydney. Available at: https://aic-color.org/page-18077 (accessed 5 July 2018).

Painter, C. W. 1991. Amphibians and Reptiles of New Mexico Distribution by County, From dBase III+ Data Base of Museum Collection Records. Endangered Species Program. New Mexico Department of Game and Fish as cited in BIOTA-M (2019).

Persons, T.B., and E.M. Nowak. 2006. Inventory of amphibians and reptiles in Southern Colorado Plateau National Parks: U.S. Geological Survey, Southwest Biological Science Center, Colorado Plateau Research Station, Open File Report 2006-1132. 186 p. Available at: https://irma.nps.gov/DataStore/Reference/Profile/599076 (accessed 30 April 2018).

Porter, E., and A. Wondrak-Biel. 2011. Air quality monitoring protocol and standard operating procedures for the Sonoran Desert, Southern Plains, and Chihuahuan Desert networks. Version 2.00. Natural Resource Report NPS/SODN/NRTR—2011/390. National Park Service, Fort Collins, Colorado. Available at: https://www.nps.gov/articles/air-quality-monitoring-in-southwest-networks.htm (accessed 24 August 2018).

Prein, A. F., G. J. Holland, R. M. Rasmussen, M. P. Clark, and M. R. Tye. 2016. Running dry: the U.S. Southwest's drift into a drier climate. Geophysical Research Letters 43: 1-8. Available at: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2015GL066727 (accessed 29 April 2018).

Prevey, J. S, 2013. Precipitation change in a semi-arid grassland: plant community responses and management strategies. Ecology & Evolutionary Biology Graduate Theses & Dissertations. Available at: https://scholar.colorado.edu/ebio_gradetds/50 (accessed 7 February 2019).

Rao, L.E., E.B. Allen, and T. Meixner. 2010. Risk-based determination of critical nitrogen deposition loads for fire spread in southern California deserts. Ecological Applications 20:1320–1335.

Ratcliff, F. 1972. Contour and contrast. Scientific American 226: 91-101.

Reeves, T. 2016. Checklist and photographic guide for the birds of San Juan County, New Mexico. Available at: http://www.aztecnm.com/aztec/wildlife/BirdOfSanJuanCounty.pdf (accessed 8 October 2018).

Ribe, R. G. 2005. Aesthetic perceptions of green-tree retention harvests in vista views: The interaction of cut level, retention pattern, and harvest shape. Landscape and Urban Planning 73:277-293. Available at: https://ac.els-cdn.com/S0169204604000970/1-s2.0-S0169204604000970-main.pdf?_tid=8184b46c-593d-42b0-a6b3-efaf22e9115c&acdnat=1530830056_f6188eeeade305c480269efa47551ed7 (accessed 5 July 2018).

Romagosa, C. M.. 2012. Eurasian collared-dove (*Streptopelia decaocto*), version 2.0. The Birds of North America (P. G. Rodewald, editor). Cornell Lab of Ornithology, Ithaca, New York, USA. Available at: https://doi.org/10.2173/bna.630 (accessed 18 November 2017).

Royal Commission on Environmental Pollution. 2009. Artificial light in the environment. The Stationery Office Limited, London. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228832/9780108508547.pdf.pdf (accessed 15 May 2018).

Ryan, R. L. 2006. Comparing the attitudes of local residents, planners, and developers about preserving rural character in New England. Landscape and Urban Planning 75: 5-22.

Salas, D. E., D. Wegner, and L. Floyd-Hanna. 2009. Vegetation mapping and classification report: Aztec Ruins National Monument. Natural Resource Technical Report NPS/SCPN/NRTR—2009/244. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/569663 (accessed 7 November 2018).

San Juan Watershed Group (SJWG), San Juan Soil and Water Conservation Project, and the Animas Watershed Partnership. 2015. San Juan Basin bacteria source tracking project. Available at: http://animaswatershedpartnership.org/wp-content/uploads/2015/10/MST-Results.AWP-Spring-Forum_reduced-1.pdf (accessed 22 April 2019).

Schauman, S. 1979. The countryside visual resource. In Proceedings of our national landscape: a conference on applied techniques for analysis and management of the visual resource, General Technical Report PSW-35, Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkely, California. Available at: https://www.fs.fed.us/psw/publications/documents/psw_gtr035/psw_gtr035_fm.pdf (accessed 5 July 2018).

Schmitz, O. J., E. Post, C. E. Burns, and K. M. Johnson. 2003. Ecosystem responses to global climate change: moving beyond color mapping. BioScience 53: 1199-1205. Available at: https://academic.oup.com/bioscience/article/53/12/1199/302301 (accessed 5 March 2019).

Schwinning, S., B.I. Starr, N.J. Wojcik, M.E. Miller, J.E. Ehleringer, and R.L. Sanford. 2005. Effects of nitrogen deposition on an arid grassland in the Colorado plateau cold desert. Rangeland Ecology and Management. 58: 565–574.

Schuurman, G. and J. Wu. 2018. Birds and climate change: Aztec Ruins National Monument. Available at: https://www.nps.gov/subjects/climatechange/upload/AZRU_2018_Birds_-_CC_508Compliant.pdf (accessed 8 October 2018).

Sekercioglu, C. H. 2002. Impacts of birdwatching on human and avian communities. Environmental Conservation 29:282–289.

Selin, N.E. 2009. Global biogeochemical cycling of mercury: a review. Annual Review of Environment and Resources 34:43.

Sheibley, R. W., M. Enache, P. W. Swarzenski, P. W. Moran, and J. R. Foreman, 2014. Nitrogen deposition effects on diatom communities in lakes from three national parks in Washington State. Water, Air, & Soil Pollution 225:1857. Available at: https://link.springer.com/article/10.1007/s11270-013-1857-x (accessed 24 August 2018).

Sheppard, S. R. J. 2001. Beyond visual resource management: Emerging theories of an ecological aesthetic and visible stewardship. In Sheppard, S. R. J. and H. W. Harshaw, Eds., Forests and Landscapes: Linking Ecology, Sustainability and Aesthetics. CABI Publishing, New York.

Society for the Study of Amphibians and Reptiles (SSAR). 2017. Scientific and standard English names of amphibians and reptiles of North America north of Mexico, with comments regarding confidence in our understanding. 8th edition. Available at: https://www.asih.org/sites/default/files/documents/resources/scientific_and_standard_english_names_na_herps_2017.pdf (accessed 28 January 2019).

Stegner, M.A., D.S. Karp, A.J. Rominger, and E.A. Hadly. 2017. Can protected areas really maintain mammalian diversity? Insights from a nestedness analysis of the Colorado Plateau. Biological Conservation 209: 546-553.

Stephens, D. B. and Associates, Inc. 2017. City of Farmington water system source water protection plan, public water system # 102-24. Available at: http://www.fmtn.org/DocumentCenter/View/13657/Draft---COF-Water-System-Source-Water-Protection-Plan?bidId= (accessed 22 April 2019).

Stromberg, J. C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6: 113-131. Available at: http://www.azwater.gov/AzDWR/SurfaceWater/Adjudications/documents/SRP13121-SRP13140.pdf (accessed 26 February 2019).

Stromberg, J. C. 2013. Root patterns and hydrogeomorphic niches of riparian plants in the American Southwest. Journal of Arid Environments 94: 1-9.

Strong, J. S. and S. J. Leroux. 2014. Impact of non-native terrestrial mammals on the structure of the terrestrial mammal food web of Newfoundland, Canada. PLoS ONE 9: e106264. doi:10.1371/journal.pone.0106264. Available at: https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0106264&type=printable (accessed 6 February 2019).

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Southern Colorado Plateau Network (SCPN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/372. National Park Service, Denver, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/428452 (accessed 4 January 2019).

Sullivan, T. J., T. C. McDonnell, G. T. McPherson, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: Southern Colorado Plateau Network (SCPN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/330. National Park Service, Denver, Colorado. Available at: https://irma.nps.gov/DataStore/DownloadFile/425475 (accessed 4 January 2019).

Sylvester, D. and E. Wright. 2003. United States Department of Agriculture Natural Resources Conservation Service ecological site description, ID: R037XA003NM. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_067718.pdf (accessed 7 November 2018).

Taylor, K. A. 2017. National Park Service air quality analysis methods: August 2017. Natural Resource Report NPS/NRSS/ARD/NRR—2017/1490. National Park Service, Fort Collins, Colorado. Available at: https://www.nature.nps.gov/air/data/products/methods.cfm (accessed 24 August 2018).

Terracon. 2003. Population survey and site assessment of Gunnison's prairie dogs: Aztec Ruins National Monument. Flora Vista, New Mexico.

Theobald, D.M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10:32. Available at: http://www.tetonwyo.org/compplan/LDRUpdate/RuralAreas/Additional%20Resources/Theobald2005.pdf (accessed 12 July 2018).

Thomas, L.P., M.N. Hendrie (editor), C.L. Lauver, S.A. Monroe, N.J. Tancreto, S.L. Garman, M.E. Miller. 2006. Vital Signs Monitoring Plan for the Southern Colorado Plateau Network. Natural Resource Report NPS/SCPN/NRR-2006/002. National Park Service, Southern Colorado Plateau Network, Northern Arizona University, Flagstaff, Arizona. Available at: https://science.nature.nps.gov/im/units/scpn/publications.cfm?tab=4 (accessed 30 April 2018).

Timmons, S., E. Mamer, and C. Pokorny. 2016. Groundwater monitoring along the Animas River, New Mexico: summary of groundwater hydraulics and chemistry from August 2015 to June 2016. New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico. Available at: https://geoinfo.nmt.edu/resources/water/amp/brochures/FTR_Animas_River_Sept_2016_LR.pdf (accessed 23 April 2019).

Tweet, J. S., V. L. Santucci, J. P. Kenworthy, and A. L. Mims. 2009. Paleontological resource inventory and monitoring—Southern Colorado Plateau Network. Natural Resource Technical Report NPS/NRPC/NRTR—2009/245. National Park Service, Fort Collins, Colorado.

U.S. Census. Bureau. 2010. Rural America. Available at: https://storymaps.geo.census.gov/arcgis/apps/MapSeries/index.html?appid=9e459da9327b4c7e9a1248cb65ad942a (accessed 12 July 2018).

U.S. Census Bureau. 2017. TIGER/Line Shapefiles: Roads. Available at: https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2016&layergroup=Roads (accessed 5 July 2018).

U.S. Census Bureau. 2018. Quick facts Aztec city, New Mexico; San Juan County, New Mexico; United States. Available at: https://www.census.gov/quickfacts/fact/table/azteccitynewmexico,sanjuancountynewmexico,US/PST045217 (accessed April 29, 2018).

U.S. Department of Agriculture (USDA). 2010. Animas watershed Hydrologic Unit Code 14080104 rapid assessment.

U.S. Department of Agriculture (USDA). 2018. Geospatial data gateway. Available at: https://datagateway.nrcs.usda.gov/ (accessed 5 September 2018).

U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCA). 2018. Web soil survey. Available at: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed 7 November 2018).

U.S. Environmental Protection Agency (USEPA). 2014. Policy assessment for the review of the ozone national ambient air quality standards. EPA-452/R-14-006. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Available at: http://www.epa.gov/ttn/naaqs/standards/ozone/data/20140829pa.pdf (accessed 249 August 2018).

U.S. Environmental Protection Agency (USEPA). 2016. National ambient air quality standards (NAAQS). Available at: https://www.epa.gov/criteria-air-pollutants/naaqs-table (accessed 24 August 2018).

U.S. Environmental Protection Agency (USEPA). 2017. Acid rain. Available at: https://www.epa.gov/acidrain/what-acid-rain (accessed 24 August 2018).

U.S. Environmental Protection Agency (USEPA). 2018. Analysis of the Biological Data Collected from the Animas and San Juan Rivers Following the Gold

King Mine Release. U.S. Environmental Protection Agency, Washington, DC, EPA/830/R-18/003, November 2018. Available at: https://www.epa.gov/sites/production/files/2018-11/documents/gkm_bio_report_181129-508-final.pdf (accessed 24 February 2019).

U.S. Fish and Wildlife Service (USFWS). 2016. Threats to birds, migratory birds mortality- questions and answers. Available at: https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds.php (last accesssed 8 October 2018).

U.S. Fish and Wildlife Service (USFWS). 2017. Mexican wolf recovery plan. First revision. Available at: https://www.fws.gov/southwest/es/mexicanwolf/pdf/2017MexicanWolfRecoveryPlanRevision1Final.pdf (accessed 6 February 2019).

U.S. Fish and Wildlife Service (USFWS). 2018. Listed species believed to or known to occur in New Mexico. Environmental Conservation Online System. Available at: https://ecos.fws.gov/ecp0/reports/species-listed-by-state-report?state=NM&status=listed (accessed 8 October 2018).

U.S. Fish and Wildlife Service (USFWS). 2019a. Grizzly bear (*Ursus arctos horribiis*). Available at: https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=A001 (accessed 6 February 2019).

U.S. Fish and Wildlife Service (USFWS). 2019b. Mexican wolf (*Canis lupus baileyi*). Available at: https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=A00E (accessed 6 February 2019).

U.S. Forest Service (USFS). 1995. Landscape aesthetics: a handbook for scenery management. Agricultural Handbook 710. https://www.fs.fed.us/cdt/carrying_capacity/landscape_aesthetics_handbook_701_no_append.pdf (accessed 5 July 2018).

U.S. Geological Survey (USGS). 2012. A summary of the relationship between GAP Status Codes and IUCN Definitions. Available at: http:// gapanalysis.usgs.gov/blog/iucn-definitions/ (accessed 12 July 2018).

U.S. Geological Survey (USGS). 2014. What is groundwater? Available at: https://pubs.usgs.gov/of/1993/ofr93-643/ (accessed 26 February 2018).

U.S. Geological Survey (USGS). 2015. Predicted surface water methylmercury concentrations in National Park Service Inventory and Monitoring Program Parks. Last modified February 20, 2015. U.S. Geological Survey. Wisconsin Water Science Center, Middleton, WI. Available at: http://wi.water.usgs.gov/mercury/NPSHgMap.html (accessed 24 August 2018).

U.S. Geological Survey (USGS). 2018a. The National Map Viewer. Available at: http://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View#productGroupSearch (accessed 4 July 2018).

U.S. Geological Survey (USGS). 2018b. Earthquake catalog. https://earthquake.usgs.gov/earthquakes/search/ (accessed 7 January 2019).

U.S. Geological Society (USGS). 2019. National Water Information System (NWIS) USGS 09364010 Animas River below Aztec, NM. Available at: https://nwis.waterdata.usgs.gov/nm/nwis/dv?cb_00060=on&format=html&site_no=09364010&referred_module=sw&period=&begin_date=2001-12-17&end_date=2019-03-02 (accessed 3 March 2019.

U.S. Geological Survey (USGS), Gap Analysis Program (GAP). 2016. Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class. Available at: http://gapanalysis.usgs.gov/padus/data/download/ (accessed 12 July 2018).

Usui, Takuji, S. H. M. Butchart, and A. B. Phillimore. 2017. Temporal shifts and temperature sensitivity of avian spring migratory phenology: a phylogenetic meta-analysis. Journal of Animal Ecology 86: 250-261. Available at: https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/1365-2656.12612 (accessed 5 March 2019).

Virden, R. J. and G. J. Walker. 1999. Ethnic/racial and gender variations among meanings given to, and preferences for, the natural environment. Leisure Sciences 21:219-239. Available at: https://www.tandfonline.com/doi/abs/10.1080/014904099273110 (accessed 5 July 2018).

Visser, M. E. 2008. Keeping up with a warming world; assessing the rate of adaptation to climate change. Proceedings of the Royal Society B. 275: 649-659. Available at: https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2007.0997 (accessed 5 March 2019).

Weingarten, M. S. Ge, J. W. Godt, B. A. Bekins, and J. L. Rubinstein. 2018. High-rate injection is associated with the increase in U.S. mid-continent seismicity. Science 348: 1336-1340.

Western Area Power Administration (WAPA). n.d. About WAPA. Available at: https://www.wapa.gov/About/Pages/About.aspx (accessed 8 July 2018).

Wildlife Society, The. 2011. Ecological impacts of feral cats. Two-page fact sheet. Available at: http://www.wildlife.org/policy/fact-sheets (accessed 19 October 2018).

Wittmer, G. W. and W. C. Pitt. 2012. Invasive rodents in the United States: ecology, impacts, and management. Pages 15-20 in J. Blanco. and A. Fernandes, editors. Invasive Species: Threats, Ecological Impacts and Control Methods.Nova Science Publishers, Inc., NY. Available at: https://www.aphis.usda.gov/wildlife_damage/nwrc/publications/14pubs/14-132%20witmer.pdf (accessed 6 February 2019).

Wondrak-Biel, A. 2005. Aesthetic conservation and the National Park Service. Yellowstone Science 13(3):1. Available at: https://www.nps.gov/yell/learn/upload/YS_13_3_sm.pdf (accessed 12 July 2018).

World Atlas. 2019. UNESCO World Heritage Sites in the USA. Available at: https://www.worldatlas.com/articles/unesco-world-heritage-sites-in-the-united-states-of-america.html (accessed 26 February 2019).

Zellweger, F., T. Roth, H. Bugmann, and K. Bollman. 2017. Beta diversity of plants, birds, and butterflies is closely associated with climate and habitat structure. Global Ecology and Biogeography 26: 898-906.

Zube, E. H., J. L. Sell, and J. G. Taylor. 1982. Landscape perception: Research, application, and theory. Landscape Planning 9:1-33. Available at: https://ac.els-cdn.com/0304392482900090/1-s2.0-0304392482900090-main.pdf?_tid=6d3195f1-5542-4b2e-8128-52203e2f7c78&acdnat=1530827676_9d20168d80c9154aac78faaa1e5d698e (accessed 5 July 2018).

Appendix A. Scoping Meeting Participants and Report Reviewers

Table A-1. Scoping meeting participants.

Name	Affiliation and Position Title
Aron Adams	National Park Service Aztec Ruins National Monument, Chief of Resources
Lisa Baril	Utah State University, Wildlife Biologist and Writer/Editor
Phyllis Pineda Bovin	National Park Service Intermountain Region Office, Natural Resource Condition Assessment Coordinator
Mark Brunson	Utah State University, Professor and Principal Investigator
Jim DeCoster	National Park Service Southern Colorado Plateau Inventory and Monitoring Network, Plant Ecologist
Dana Hawkins	National Park Service Aztec Ruins National Monument, Natural Resource Program Lead
Kim Struthers	Utah State University, NRCA Project Coordinator and Writer/Editor

Table A-2. Report reviewers.

Name	Affiliation and Position Title	Section(s) Reviewed or Other Role
Jeff Albright	National Park Service Water Resources Division, Natural Resource Condition Assessment Series Coordinator	Washington-level Program Manager
Phyllis Pineda Bovin	National Park Service Intermountain Region Office, Natural Resource Condition Assessment Coordinator	Regional Program Level Coordinator and Peer Review Manager
Kelly Adams and Todd Wilson	National Park Service, Grants and Contracting Officers	Executed agreements
Fagan Johnson	National Park Service Inventory & Monitoring Division, Web and Report Specialist	Washington-level Publishing and 508 Compliance Review
Alyssa S. McGinnity	Contractor to National Park Service, Managed Business Solutions, a Sealaska Company	Washington-level Publishing and 508 Compliance Review
Dusty Perkins	National Park Service Northern Colorado Plateau Inventory and Monitoring Network, Program Manager	Air Quality, Birds, Mammals, Geology, Water Resources, and Herpetofauna Assessments
Aron Adams	National Park Service Aztec Ruins National Monument, Chief of Resources	Park Resource Expert Reviewer
Dana Hawkins	National Park Service Aztec Ruins National Monument, Natural Resource Program Lead	Park Resource Expert Reviewer
Jim DeCoster	National Park Service Southern Colorado Plateau Inventory and Monitoring Network, Plant Ecologist	Uplands, Geology, and Herpetofauna Assessments
Megan Swan	National Park Service Southern Colorado Plateau Inventory and Monitoring Network, Botanist	Uplands Assessment
Ksienya Taylor	National Park Service Air Resources Division Natural Resource Specialist	Air Quality and Viewshed Assessments
Li-Wei Hung	National Park Service Natural Sounds and Night Skies Division, Night Sky Research Scientist	Night Sky Assessment
Sallie Hejl	National Park Service Desert Southwest Cooperative Ecosystem Studies Unit, Research Coordinator	Birds Assessment
Don Weeks	National Park Service Intermountain Regional Office, Physical Resources Program Manager	Geology Assessment
Tracy Thompson	National Park Service Biological Resource Division, Veterinary Medical Officer	Herpetofauna Assessment
Sharla Stevenson	National Park Service Water Resources Division, Hydrologist	Water Resources Assessment
Stephen Monroe	Northern Arizona University, Senior Research Specialist (retired)	Water Resources Assessment
Stacy Stumpf	National Park Service Southern Colorado Plateau Inventory and Monitoring Network, Aquatic Ecologist	Water Resources Assessment
Amanda Hardy	National Park Service Biological Resources Division, Wildlife Biologist	Mammals Assessment

Appendix B. Viewshed Analysis Steps

The process used to complete Aztec Ruins National Monument's viewshed analyses is listed below.

Downloaded 10 of the 1/3 arc second national elevation dataset (NED) grid (roughly equivalent to a 30 m digital elevation model [DEM]) from U.S. Geological Survey's National Map Viewer (http://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View#productGroupSearch) (USGS 2018a) and created a mosaic dataset. The x and y values for the NED are in arc seconds while the z data are in meters. The DEMs were reprojected into NAD83 Albers Meter to get all data in meters and into a geographic extent that covered the entire area.

Prepared observation point layers for viewshed analyses by importing GPSd points for all vantage point locations selected for viewshed analysis. Exported data to a shapefile. Added field named "OFFSETA" (type = double) to shapefile and set value to an observer height of 1.68 m (~5'6"). ESRI (2016) provides a useful overview of the visibility analysis.

Ran Viewshed Analysis using the Viewshed Tool in ESRI's ArcGIS 10.2, Spatial Analyst Toolbox, ran viewsheds using the following inputs.

- Input raster = 1/3 arc second NED
- Input point observer feature = obs_point.shp.

The rasters were reclassified into visible areas only to create the maps. The area of analysis (AOA) was a 98 km (61 mi) buffer surrounding the monument, reprojected into the Albers Equal Area Conic USGS projection, then overlaid with the NPS NPScape's road, housing, and conservation status tools as described in NPS 2015b,c,d. A text attribute field was added to the AOA for the area of analysis identifier.

Housing (CONUS, Density, SERGoM, 1970 - 2100, Metric Data 9.3 File Geodatabase (Theobald 2005), U.S. Census Bureau 2017 TIGER/Line Shapefiles: Roads) (U.S. Census Bureau 2017), and conservation status (NPS 2015d, USGS GAP 2016) GIS datasets were downloaded from NPScape (NPS 2016) and the USGS GAP (USGS GAP 2016) websites. Standard Operating Procedures for all three tools were followed based on NPScape instructions (NPS 2015b,c,d).

Appendix C. Aztec Ruins NM Bird List

Listed in the table below (Table C-1) are the bird species reported for Aztec Ruins National Monument (NM) according to NPSpecies (NPS 2018a), Johnson et al. (2007), eBird reports (eBird 2018a), birds observed during National Audubon Society Christmas Bird Counts (CBC), and incidental observations made by National Park Service (NPS) and visitors to the monument. Bird species included in the appendix but not listed by any of the efforts were those reported by Janet Rees and/or listed in the monument's wildlife database. Scientific names were updated with the current taxonomy used by the American Ornithological Society (AOS 2018). A total of 133 species are contained in the table, but only the NPSpecies list (120) is certified (i.e., vetted for accuracy). The additional 13 species were reported in eBird, during CBC surveys, and/or via incidental observations by park staff and visitors. Table C-2 lists annual CBC data, which were provided by Janet Rees via e-mail on 24 June 2018.

Table C-1. Bird list for Aztec Ruins NM.

Common Name	Species Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	eBird[2]	USGS[3]	CBC[4]
American coot	*Fulica americana*	Probably Present	–	Breeder	–	–	–
American crow	*Corvus brachyrhynchos*	Present	Common	Breeder	X	X	–
American goldfinch	*Spinus tristis*	Present	Uncommon	Resident	X	–	X
American kestrel	*Falco sparverius*	Present	Common	Breeder	X	X	X
American robin	*Turdus migratorius*	Present	Abundant	Breeder	X	X	X
American wigeon	Anas americana	Under Review	–	Resident	–	–	–
Ash-throated flycatcher	*Myiarchus cinerascens*	Present	Common	Breeder	X	X	–
Bald eagle	*Haliaeetus leucocephalus*	Probably Present	–	Resident	X	–	X
Barn owl	*Tyto alba*	Present	Unknown	Breeder	–	–	–
Barn swallow	*Hirundo rustica*	Present	Uncommon	Breeder	X	X	–
Belted kingfisher	*Megaceryle alcyon*	Probably Present	–	Breeder	–	–	–
Bewick's wren	*Thryomanes bewickii*	Present	Common	Breeder	X	X	X
Black phoebe	*Sayornis nigricans*	Not Listed	–	–	–	–	–
Black-billed magpie	*Pica hudsonia*	Present	Abundant	Breeder	X	X	X
Black-capped chickadee	*Poecile atricapillus*	Present	Common	Breeder	X	X	X
Black-chinned hummingbird	*Archilochus alexandri*	Present	Common	Breeder	X	X	–
Black-crowned night-heron	*Nycticorax nycticorax*	Present	Rare	Breeder	–	X	–
Black-headed grosbeak	*Pheucticus melanocephalus*	Present	Common	Breeder	X	X	–
Black-throated sparrow	*Amphispiza bilineata*	Present	Uncommon	Breeder	–	X	–
Blue grosbeak	*Passerina caerulea*	Present	Common	Breeder	–	X	–
Blue-gray gnatcatcher	*Polioptila caerulea*	Probably Present	–	Breeder	X	–	–
Brewer's blackbird	*Euphagus cyanocephalus*	Present	Uncommon	Breeder	–	X	–
Brewer's sparrow	*Spizella breweri*	Present	Rare	–	X	X	–
Broad-tailed hummingbird	*Selasphorus platycercus*	Probably Present	–	Migratory	X	–	–
Brown creeper	*Certhia americana*	Probably Present	–	Resident	X	–	X
Brown-headed cowbird	*Molothrus ater*	Present	Common	Breeder	X	X	–
Bullock's oriole	*Icterus bullockii*	Present	Common	Breeder	X	X	–
Bushtit	Psaltriparus minimus	Probably Present	–	Breeder	X	–	X

[1] Non-native species.

[2] eBird (2018a).

[3] Johnson et al. (2007).

[4] Christmas Bird Count data provided by J. Rees.

Note: X = species present.

Table C-1 continued. *Bird list for Aztec Ruins NM.*

Common Name	Species Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	eBird[2]	USGS[3]	CBC[4]
Canada goose	*Branta canadensis*	Present	Common	Breeder	X	X	X
Cassin's finch	Haemorhous cassinii	Probably Present	–	–	–	–	–
Cassin's kingbird	*Tyrannus vociferans*	Present	Common	Breeder	X	X	–
Cedar waxwing	*Bombycilla cedrorum*	Present	Uncommon	Resident	X	–	X
Chipping sparrow	*Spizella passerina*	Present	Uncommon	Breeder	X	X	–
Cinnamon teal	*Spatula cyanoptera*	Probably Present	–	Migratory	–	–	–
Cliff swallow	*Petrochelidon pyrrhonota*	Present	Common	Breeder	–	X	–
Common goldeneye	*Bucephala clangula*	Not Listed	–	–	–	–	–
Common merganser	*Mergus merganser*	Probably Present	–	Resident	–	–	–
Common nighthawk	*Chordeiles minor*	Present	Uncommon	Breeder	–	X	–
Common raven	*Corvus corax*	Present	Uncommon	Breeder	X	X	X
Common snipe	*Gallinago gallinago*	Under Review	–	–	–	–	–
Common yellowthroat	*Geothlypis trichas*	Present	Uncommon	Breeder	–	X	–
Cooper's hawk	*Accipiter cooperii*	Not Listed	–	–	X	–	–
Dark-eyed junco	*Junco hyemalis*	Present	Abundant	Resident	X	–	X
Downy woodpecker	*Picoides pubescens*	Probably Present	–	Resident	X	–	X
Eastern meadowlark	*Sturnella magna*	Present	Rare	–	–	X	–
Eurasian collared-dove[1]	*Streptopelia decaocto*	Not Listed	–	–	X	–	X
European starling[1]	*Sturnus vulgaris*	Present	Abundant	Breeder	X	X	X
Evening grosbeak	*Coccothraustes vespertinus*	Present	Rare	Resident	X	X	X
Gambel's quail	*Callipepla gambelii*	Present	Abundant	Breeder	X	X	X
Golden eagle	*Aquila chrysaetos*	Probably Present	–	–	X	–	–
Golden-crowned kinglet	*Regulus satrapa*	Present	Occasional	Migratory	–	–	–
Great blue heron	*Ardea herodias*	Present	Common	–	X	–	X
Great horned owl	*Bubo virginianus*	Present	Uncommon	Breeder	X	X	X
Greater roadrunner	*Geococcyx californianus*	Present	Rare	Resident	–	X	–
Great-tailed grackle	*Quiscalus mexicanus*	Probably Present	–	Breeder	–	–	–
Green-tailed towhee	*Pipilo chlorurus*	Probably Present	–	Migratory	–	–	–
Green-winged teal	*Anas crecca*	Probably Present	–	Resident	–	–	–
Hairy woodpecker	*Picoides villosus*	Present	Uncommon	Resident	X	X	–
Horned lark	*Eremophila alpestris*	Probably Present	–	Breeder	–	–	–
House finch	*Haemorhous mexicanus*	Present	Abundant	Breeder	X	X	X
House sparrow[1]	*Passer domesticus*	Present	Abundant	Breeder	X	X	X
Juniper titmouse	*Baeolophus ridgwayi*	Present	Uncommon	Breeder	–	X	–
Killdeer	*Charadrius vociferus*	Present	Common	Breeder	X	X	X
Ladder-backed woodpecker	*Picoides scalaris*	Present	Rare	Vagrant	–	X	–
Lark sparrow	*Chondestes grammacus*	Present	Common	Breeder	–	X	–
Lazuli bunting	*Passerina amoena*	Present	Uncommon	Breeder	X	X	–
Lesser goldfinch	*Spinus psaltria*	Present	Common	Breeder	X	X	X
Lewis's woodpecker	*Melanerpes lewis*	Probably Present	–	–	X	–	–

[1] Non-native species.

[2] eBird (2018a).

[3] Johnson et al. (2007).

[4] Christmas Bird Count data provided by J. Rees.

Note: X = species present.

Table C-1 continued. Bird list for Aztec Ruins NM.

Common Name	Species Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	eBird[2]	USGS[3]	CBC[4]
Loggerhead shrike	*Lanius ludovicianus*	Present	Common	Breeder	X	X	–
MacGillivray's warbler	*Geothlypis tolmiei*	Probably Present	–	Migratory	–	–	–
Mallard	*Anas platyrhynchos*	Present	Abundant	Breeder	–	X	–
Mountain bluebird	*Sialia currucoides*	Present	Common	Resident	X	–	X
Mountain chickadee	*Poecile gambeli*	Present	Rare	Breeder	–	X	X
Mourning dove	*Zenaida macroura*	Present	Abundant	Breeder	X	X	X
Northern flicker	*Colaptes auratus*	Present	Common	Breeder	X	X	X
Northern harrier	*Circus hudsonius*	Probably Present	–	Resident	X	–	–
Northern mockingbird	*Mimus polyglottos*	Present	Common	Breeder	–	X	–
Northern rough-winged swallow	*Stelgidopteryx serripennis*	Present	Uncommon	Breeder	X	X	–
Northern waterthrush	*Parkesia noveboracensis*	Probably Present	–	Migratory	–	–	–
Olive-sided flycatcher	*Contopus cooperi*	Not Listed	–		X	–	–
Orange-crowned warbler	*Oreothlypis celata*	Probably Present	–	Migratory	X	–	–
Osprey	*Pandion haliaetus*	Not Listed	–	–	–	–	–
Pine siskin	*Spinus pinus*	Present	Uncommon	Resident	X	–	–
Pinyon jay	*Gymnorhinus cyanocephalus*	Present	Common	Breeder	X	X	–
Plumbeous vireo	*Vireo plumbeus*	Probably Present	–	–	–	–	–
Prairie falcon	*Falco mexicanus*	Present	Rare	Breeder	X	X	X
Red-breasted nuthatch	*Sitta canadensis*	Probably Present	–	Resident	–	–	–
Redhead	*Aythya americana*	Probably Present	–	Resident	–	–	–
Red-naped sapsucker	*Sphyrapicus nuchalis*	Probably Present	–	Migratory	X	–	–
Red-necked phalarope	*Phalaropus lobatus*	Present	Rare	Migratory	–	X	–
Red-tailed hawk	*Buteo jamaicensis*	Present	Common	Breeder	X	X	X
Red-winged blackbird	*Agelaius phoeniceus*	Present	Common	Breeder	X	X	X
Ring-necked duck	*Aythya collaris*	Probably Present	–	Resident	–	–	–
Ring-necked pheasant[1]	*Phasianus colchicus*	Present	Common	Breeder	–	X	–
Rock pigeon[1]	*Columba livia*	Probably Present	–	Breeder	X	–	–
Rock wren	*Salpinctes obsoletus*	Probably Present	–	Resident	X	–	–
Ruby-crowned kinglet	*Regulus calendula*	Present	Common	Resident	–	–	X
Rufous hummingbird	*Selasphorus rufus*	Probably Present	–	Migratory	–	–	–
Say's phoebe	*Sayornis saya*	Present	Common	Breeder	X	X	X
Scaled quail	*Callipepla squamata*	Not Listed	–	–	–	–	–
Sharp-shinned hawk	*Accipiter striatus*	Present	Occasional	Resident	–	–	X
Song sparrow	*Melospiza melodia*	Present	Common	Resident	–	–	X
Sora	*Porzana carolina*	Probably Present	–	Breeder	–	–	–
Spotted owl	*Strix occidentalis*	Not Listed	–	–	–	–	–
Spotted sandpiper	*Actitis macularius*	Present	Uncommon	Breeder	–	X	–
Spotted towhee	*Pipilo maculatus*	Present	Rare	Breeder	X	X	X
Townsend's solitaire	*Myadestes townsendi*	Present	Uncommon	Resident	–	–	X

[1] Non-native species.

[2] eBird (2018a).

[3] Johnson et al. (2007).

[4] Christmas Bird Count data provided by J. Rees.

Note: X = species present.

Table C-1 continued. Bird list for Aztec Ruins NM.

Common Name	Species Name	NPSpecies Occurrence	NPSpecies Abundance	NPSpecies Status	eBird[2]	USGS[3]	CBC[4]
Tree swallow	*Tachycineta bicolor*	Not Listed	–	–	X	–	–
Turkey vulture	*Cathartes aura*	Present	Uncommon	Breeder	X	X	–
Violet-green swallow	*Tachycineta thalassina*	Present	Common	Breeder	–	X	–
Virginia rail	*Rallus limicola*	Probably Present	–	Breeder	–	–	–
Virginia's warbler	*Oreothlypis virginiae*	Present	Uncommon	Migratory	X	X	–
Warbling vireo	*Vireo gilvus*	Probably Present	–	Migratory	–	–	–
Western bluebird	*Sialia mexicana*	Present	Common	Migratory	X	X	X
Western kingbird	*Tyrannus verticalis*	Present	Uncommon	Breeder	X	X	–
Western meadowlark	*Sturnella neglecta*	Present	Common	Breeder	X	X	–
Western tanager	*Piranga ludoviciana*	Present	Common	Migratory	X	X	–
Western wood-pewee	*Contopus sordidulus*	Present	Uncommon	Breeder	X	X	–
White-breasted nuthatch	*Sitta carolinensis*	Present	Rare	Breeder	X	X	X
White-crowned sparrow	*Zonotrichia leucophrys*	Present	Abundant	Resident	X	X	X
White-throated sparrow	*Zonotrichia albicollis*	Not Listed	–	–	X	–	–
White-throated swift	*Aeronautes saxatalis*	Probably Present	–	Migratory	–	–	–
White-winged dove	*Zenaida asiatica*	Not Listed	–	–	X	–	–
Wild turkey	*Meleagris gallopavo*	Not Listed	–	–	–	–	–
Willow flycatcher	*Empidonax traillii*	Not Listed	–	–	X	–	–
Wilson's snipe	*Gallinago delicata*	Unconfirmed	–	–	–	–	–
Wilson's warbler	*Cardellina pusilla*	Present	Uncommon	–	X	X	–
Woodhouse's scrub-jay	*Aphelocoma woodhouseii*	Present	Common	Breeder	X	X	–
Yellow warbler	*Setophaga petechia*	Present	Common	–	X	X	–
Yellow-billed cuckoo	*Coccyzus americanus*	Present	Rare	–	X	X	–
Yellow-breasted chat	*Icteria virens*	Probably Present	–	Breeder	X	–	–
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	Probably Present	–	–	–	–	–
Yellow-rumped warbler	*Setophaga coronata*	Present	Common	Breeder	X	X	X

[1] Non-native species.

[2] eBird (2018a).

[3] Johnson et al. (2007).

[4] Christmas Bird Count data provided by J. Rees.

Note: X = species present.

Table C–2. National Audubon Society annual Christmas Bird Count Data for Aztec Ruins NM (1996–2014).

Common Name	96	97	98	99	00	01	02	03	04	05	06	07	09	10	11	12	14
American goldfinch	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–
American kestrel	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–
American robin	3	–	1	8	6	1	–	–	1	–	–	4	1	–	10	2	–
Bald eagle	–	–	–	–	–	–	–	–	–	1	–	1	–	–	1	–	–
Bewick's wren	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Black–billed magpie	1	6	3	5	23	6	2	3	6	–	–	7	1	3	6	3	6
Black–capped chickadee	–	–	–	–	4	–	1	–	–	–	–	–	2	–	–	–	–
Brown creeper	–	–	–	–	–	–	–	–	–	–	–	2	1	1	–	3	–
Bushtit	5	–	–	–	–	–	–	–	–	–	10	–	–	7	–	–	–
Canada goose	51	–	109	51	–	–	–	–	–	–	–	12	7	–	–	–	8
Cedar waxwing	–	–	–	–	–	–	–	–	–	–	–	–	31	–	6	–	–
Common raven	–	–	–	–	–	–	–	4	1	–	–	2	–	–	1	–	–
Dark–eyed junco	6	12	8	1	14	1	–	12	20	–	20	22	36	12	16	19	22
Downy woodpecker	1	–	1	–	–	–	–	–	–	–	–	–	1	–	–	–	–
*Eurasian collared–dove**	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	1	3
*European starling**	87	15	130	20	17	101	5	15	24	8	18	8	1	82	20	36	6
Evening grosbeak	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Gambel's quail	–	2	31	–	–	–	–	–	–	–	–	–	7	–	–	–	–
Great blue heron	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–
Great horned owl	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
House finch	–	3	–	–	23	3	–	4	2	–	1	–	–	–	2	–	12
*House sparrow**	–	4	–	–	4	1	–	–	–	5	–	–	–	–	7	–	–
Killdeer	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Lesser goldfinch	–	–	–	–	–	–	–	–	–	–	4	–	–	–	–	–	–
Mountain bluebird	–	–	–	–	2	–	–	–	–	13	–	–	–	–	43	–	–
Mountain chickadee	1	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–
Mourning dove	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Northern flicker	–	8	4	4	7	3	2	5	3	–	–	4	4	4	7	5	–
Prairie falcon	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–
Red–tailed hawk	–	1	2	1	–	–	–	–	2	–	2	2	2	–	3	1	–
Red–winged blackbird	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ruby–crowned kinglet	–	2	–	–	–	–	1	–	–	–	–	–	–	–	1	–	–
Say's phoebe	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Sharp–shinned hawk	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–
Song sparrow	–	2	2	2	2	–	–	1	–	–	–	–	–	–	–	–	–
Spotted towhee	–	–	–	–	1	–	–	–	1	1	–	–	–	–	–	–	–
Townsend's solitaire	1	–	–	–	1	–	–	–	2	–	–	–	–	–	–	3	–
Western bluebird	–	–	–	–	–	–	–	9	2	9	2	8	13	–	–	–	–
White–breasted nuthatch	–	–	1	–	–	1	–	–	–	–	1	1	2	1	–	1	–
White–crowned sparrow	12	14	11	45	2	–	–	–	–	–	6	8	–	23	–	–	–
Yellow–rumped warbler	–	–	–	–	2	–	1	–	–	–	–	–	–	2	1	–	–

* Non-native species.

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