National Park Service
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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Chaco Culture National Historical Park

Natural Resource Report NPS/CHCU/NRR—2021/2304

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Natural Resource Condition Assessment

Chaco Culture National Historical Park

Natural Resource Report NPS/CHCU/NRR—2021/2304

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Washington Support Office, Denver Service Center Planning Division, provides documentation about current conditions of important park natural resources through a spatially explicit, multidisciplinary synthesis of existing scientific data and knowledge. The workshop for Chaco Culture National Historical Park (CHCU) NRCA was held on 28–30 November 2017.

Chaco Culture National Historical Park (CHCU or Chaco Canyon) was originally established as a national monument in 1907 by President Theodore Roosevelt. Designated a national historical park in 1980, these lands were recognized as a national park unit because of the impressive Puebloan archaeological ruins built between 850 and 1140 BCE (Lekson 2015). Encompassing over 34,000 acres and containing at least 4,000 archeological sites, 26 southwestern Native American tribes are culturally affiliated with CHCU (NPS 2015a).

Because CHCU is a non-urban park, current and future threats are primarily associated with increased oil and gas exploration activities on BLM, Navajo Nation, and private lands adjacent to the park. Additionally, increased visitation and issues associated with growing population centers at considerable distances from the park's boundary are also contributing to the deteriorating conditions of indicators identified as significant and moderate concern. Acoustic environment was rated as "significant concern", which is due to aircraft, vehicular traffic, the CHCU Visitor Center generator, other unidentified low frequency humming sounds, and people. As visitation increases, the condition of the acoustic environment will be further eroded – unless efforts are ultimately taken to limit the number of vehicles on park roads. Air quality and night skies will continue to be challenged by the growing population centers of Farmington, Albuquerque, and Santa Fe, New Mexico. Unless these population centers address air and light pollution, improving these conditions at CHCU will be beyond the park's control. Given that gas and oil exploration activities are on the rise; these activities may also negatively impact these conditions of these resources. Importantly, water quality of the Gallup Sandstone aquifer is considered of moderate concern, but the future quality and human use of this groundwater source is challenged by oil and gas exploration activities within the Mancos Shale and Gallup Sandstone formations. These formations are interbedded, and any directional drilling, hydraulic fracturing, or wellbore stimulations within this formation adjacent to the park boundary could negatively impact CHCU's sole drinking water source.

Eleven natural resources (with 34 indicators) were identified and grouped into three broad categories: landscape-scale, supporting environment (i.e., physical resources), and biological integrity. The latter included chapters on wildlife and vegetation. This NRCA includes an assessment of condition and trend for key resources determined by assessing multiple indicators for each focal resource (Chapter 4). A summary is provided for each resource category below. Most indicators were identified as currently in good condition (13 indicators) or unknown/ data deficient warranting moderate concern (13). The most significantly impacted resources included air quality and the acoustic environment. Ozone effects on vegetation health were of significant concern, yet the trend could not be determined due to lack of long term data; additionally, the condition for "reduction in listening area" is deteriorating due to an increase in anthropogenic activities. Six indicators were identified as “moderate concern”. For trend not determined due to lack of long-term data, these include the geospatial sound model, ozone effects on human health, deposition of wet nitrogen, and aquifer water quality. Additionally, the condition for haze index of air quality was identified as improving. All condition and trend information is displayed per indicator in Tables E-1 through E-6. A detailed discussion of each indicator is provided in Chapter 4.

Table E-1. Condition, trend, and level of confidence categories used in the NRCA assessment process.

Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	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

Table E-2. Example indicator symbols and descriptions of how to interpret them in WCS tables.

Symbol Example	Verbal Description
	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.

Table E-3. Summary of resources identified to warrant “significant concern”. Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), deteriorating (downward arrow), or unknown (no arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

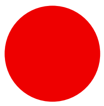
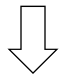
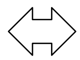
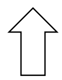
Condition	Trend	Resource	Indicator
 **Resource Warrants Significant Concern**	Unknown/ Indeterminate/ Not applicable	Air quality	Ozone: Vegetation health
		Acoustic environment	Reduction in listening area
		None	N/A
		None	N/A

Table E-4. Summary of resources identified to warrant “moderate concern”. Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), deteriorating (downward arrow), or unknown (no arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

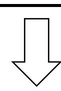
Condition	Trend	Resource	Indicator
Resource Warrants Moderate Concern	Unknown/ Indeterminate/ Not applicable	Acoustic environment	Geospatial sound model
	Unknown/ Indeterminate/ Not applicable	Air quality	Ozone: Human health
	Unknown/ Indeterminate/ Not applicable	Air quality	Deposition: Wet nitrogen
	Unknown/ Indeterminate/ Not applicable	Hydrogeology	Aquifer water quality
		Riparian	Alluvial groundwater level
		Air quality	Haze index

Table E-5. Summary of resources identified as in “good condition”. Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), deteriorating (downward arrow), or unknown (no arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

Condition	Trend	Resource	Indicator
Resource is in Good Condition	Unknown/ Indeterminate/ Not applicable	Air quality	Deposition: Wet sulfur
	Unknown/ Indeterminate/ Not applicable	Soils	Piping and instability of archaeological sites
	Unknown/ Indeterminate/ Not applicable	Wildlife	Amphibians: Species richness
	Unknown/ Indeterminate/ Not applicable	Wildlife	Reptiles: Species richness
	⇩	Acoustic environment	Mean time audible
	⇔	Viewshed	Scenic Inventory Value
	⇔	Night Sky	Zenith limiting magnitude
	⇔	Night Sky	Bortle sky classification
	⇔	Night Sky	Zenith sky brightness
	⇔	Soils	Erosion: Livestock grazing
	⇔	Soils	Erosion: Chaco Wash
	⇔	Wildlife	Elk: Occurrence and distribution
	⇔	Wildlife	Elk: Population size
	⇔	Wildlife	Bats: Species richness

Table E-6. Summary of resources identified as condition "unknown" or "indeterminate". Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), deteriorating (downward arrow), or unknown (no arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

Condition	Trend	Resource	Indicator
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	Unknown/ Indeterminate/ Not applicable	Soils	Erosion: Tamarisk loss due to tamarisk beetle
	Unknown/ Indeterminate/ Not applicable	Riparian & springs	Native riparian composition and structure
	Unknown/ Indeterminate/ Not applicable	Riparian & springs/ Vegetation	Tamarisk occurrence and distribution
	Unknown/ Indeterminate/ Not applicable	Riparian & springs	Sensitive spring ecosystems
	Unknown/ Indeterminate/ Not applicable	Riparian & springs	Aquatic invertebrate communities
	Unknown/ Indeterminate/ Not applicable	Riparian & springs	Surface water quality
	Unknown/ Indeterminate/ Not applicable	Riparian & springs	Stream flow (Chaco River)
	Unknown/ Indeterminate/ Not applicable	Vegetation	Distributions of other invasive alien plant species
	Unknown/ Indeterminate/ Not applicable	Wildlife	Mule deer: Occurrence & population size
	Unknown/ Indeterminate/ Not applicable	Wildlife	Bats: Summer roost occurrence
	Unknown/ Indeterminate/ Not applicable	Wildlife	Bats: Hibernacula roost occurrence
	Unknown/ Indeterminate/ Not applicable	Wildlife	Amphibians: Habitat extent

Chapter 1. NRCA Background Information

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

> ***NRCAs Strive to Provide…***
> - *Credible condition reporting for a subset of important park natural resources and indicators*
> - *Useful condition summaries by broader resource categories or topics, and by park areas*

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

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

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

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[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.

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.

Important NRCA Success Factors

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

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an 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.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

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

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.

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[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.

Chapter 2. Introduction and Resource Setting

In this document, Chaco Culture National Historical Park is referred to as CHCU, “Chaco Canyon”, or “the park” (Fig. 2-1).

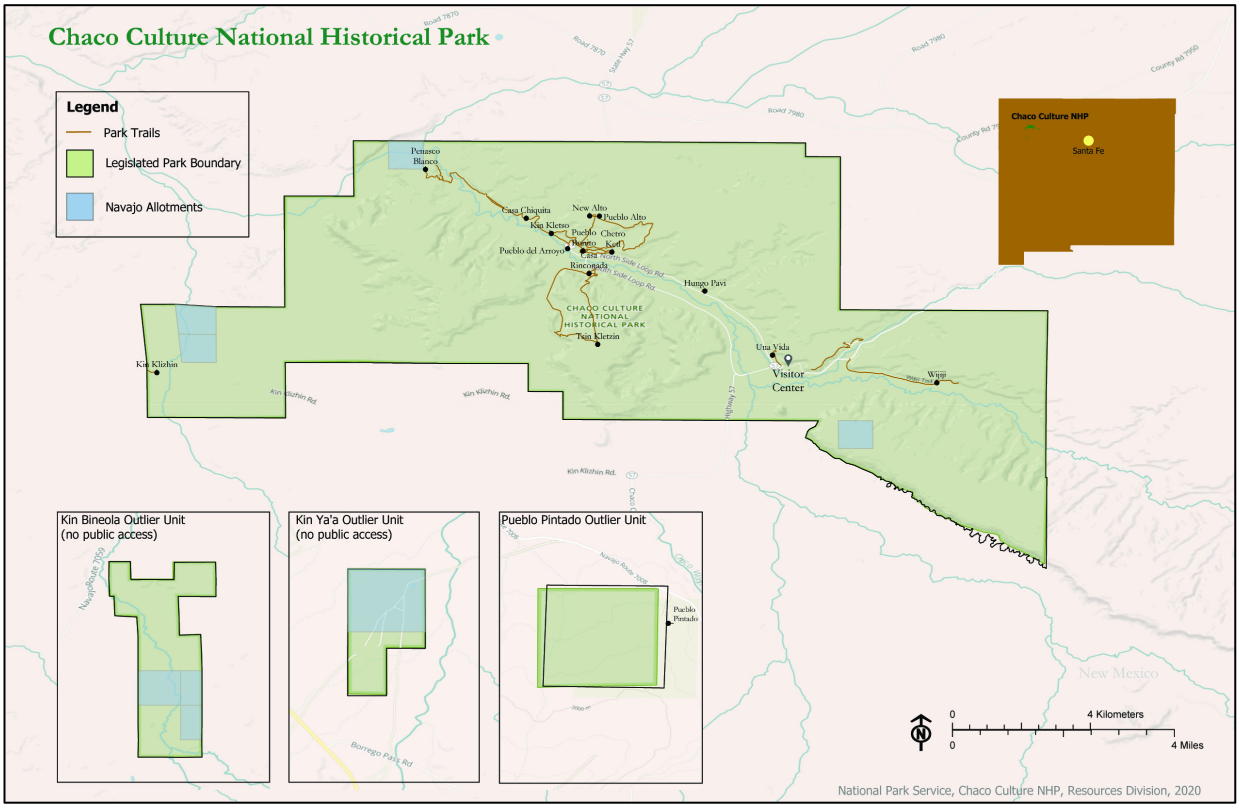


Figure 2-1. CHCU with the current park boundary presented (NPS, Intermountain Region, Geographic Resources, Denver, CO).

2.1. Introduction

2.1.1. Enabling Legislation

The area encompassing Chaco Canyon was designated a national monument by President Theodore Roosevelt in 1907 (NPS 2015a). In 1980, it became Chaco Culture National Historical Park in recognition of its 50,000-square-mile area of influence (NPS 2015a). The catalyst for its designation as a national monument, and ultimately national park, was its impressive Puebloan archaeological ruins built between 850 and 1140 BCE (Lekson 2015). Encompassing over 34,000 acres and containing at least 4,000 archeological sites, 26 southwestern Native American tribes are culturally affiliated with CHCU (NPS 2015a).

2.1.2. Geographic Setting

Located in northeastern New Mexico, the park is situated in the center of the San Juan Basin (refer to Section 2.2.1 for more information). Average elevation of the park is 1,829 m (6,000 ft; de la Torre, 2003). Chaco Canyon is the most prominent geological feature, which drains from the southeast to northwest morphing from the Chaco Wash to the Chaco River.

Population

The area surrounding Chaco Canyon is sparsely populated. Native American lands occur nearly adjacent to the park with Navajo Nation lands distributed throughout northwestern New Mexico, and the Jicarilla Apache Nation lands to the east. Surrounding human populations outside reservation lands include Farmington, New Mexico (population 45,582) 47 mi (76 km) to the north, Gallup, NM (population 22,105) 57 mi (92 km) to the south by southwest, and Santa Fe, NM (population 83,847) 111 mi (180 km) to the east (USCB 2020). The Navajo Nation has a population of roughly 350,000 people distributed across 27,413 sq mi (71,000 km^2).

Climate

The climate of the U.S. Southwest is most influenced by its location between the mid-latitude and subtropical atmospheric circulation regimes. This creates the typical southwestern climate of dry, sunny days (low annual precipitation) and warmer temperatures year round. Monsoonal-driven precipitation occurs from July through September and originates in the Pacific Ocean and the Gulf of Mexico. November through March brings winter precipitation following an eastern storm track from the Pacific Ocean (Sheppard et al. 2002).

The Colorado Plateau, which is where the park is situated, is an arid region characterized by irregular rainfall, periods of drought, warm to hot growing seasons, and long winters with freezing temperatures (Davey et al. 2006; refer to Section 2.2.1 for more information). Due to the immensity of this geographic area and the variation in topography, the climate conditions vary within the southern Colorado Plateau are influenced by both elevation and latitude.

Weather and climatic conditions have been monitored at CHCU since 1909. The Western Regional Climate Center (wrcc.dri.edu) has monitored data from weather station 291647 since 1961. The following information on climate is represents a combination of manual measurements and a datalogging weather station.

Temperature

Average monthly air temperatures ranged from 28° F (2.2° C) in January to 72.8° F (22.7° C) in July; average winter temperature is 30.1° F (1.1° C), while average summer temperature is 69.9° F (19.4° C; Figure 2.1.2-1). Daily extremes ranged from −37° F (−38.3° C) on 07 January 1971, to 104º F (40° C) on 26 July 1979 (Table 2.1.2-1; WRCC, 2020).

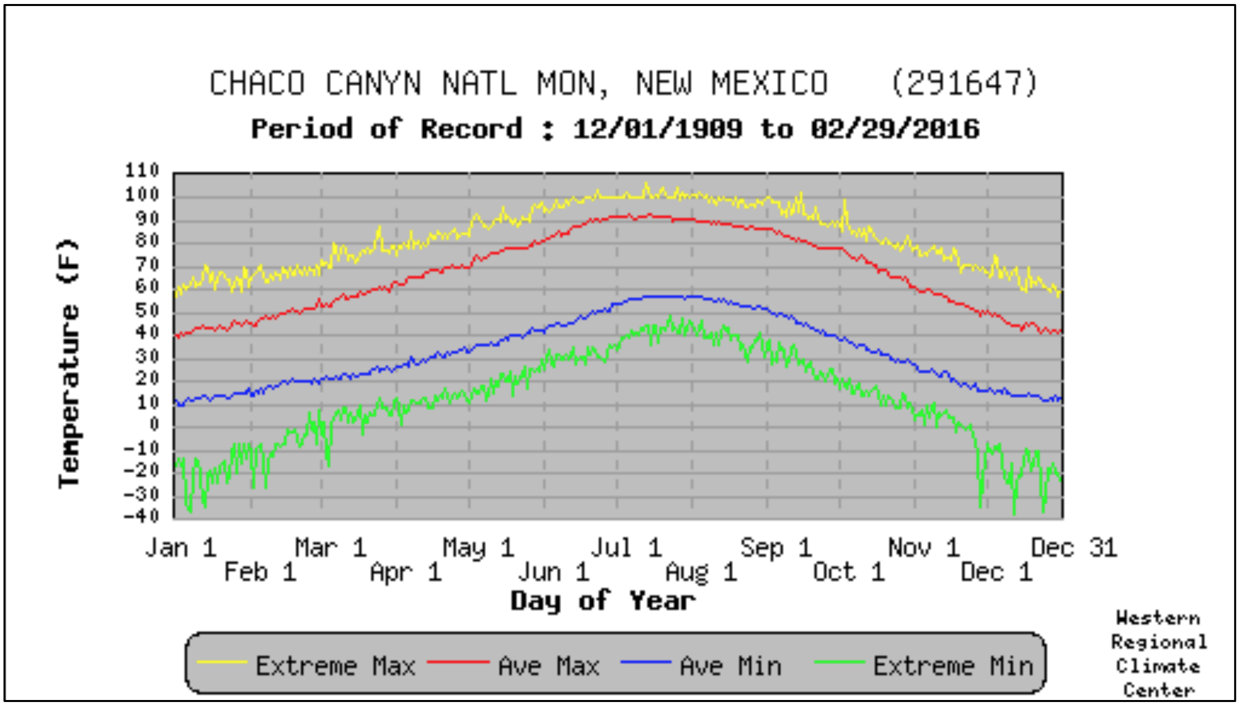


Figure 2.1.2-1. Monthly average temperature (°F) from 12 December 1909 through 29 February 2016, Chaco Culture National Historical Park, New Mexico (NPS Western Regional Climate Center).

Table 2.1.2-1. Period of record general climate summary for temperature at station (291647) CHACO CANYON NATL MON, 1909 to 2011. Table updated on Oct 31, 2012. For monthly and annual means, thresholds, and sums: months with 5 or more missing days are not considered; years with 1 or more missing months are not considered (WRCC 2020).

Period of Record [1]	Monthly Averages			Daily Extremes				Monthly Extremes				Max. Temp		Min. Temp	
	Max. (°F)	Min. (°F)	Mean (°F)	High (°F)	Date	Low (°F)	Date	Highest Mean (°F)	Year	Lowest Mean (°F)	Year	≥ 90°F (# Days)	≤ 32°F (# Days)	≤ 32°F (# Days)	≤ 0°F (# Days)
January	43.3	12.8	28.0	69	1/29/1986	−37	1/07/1971	36.7	1956	18.2	1963	0.0	3.6	29.8	4.4
February	48.6	18.1	33.5	70	2/20/1972	−26	2/07/1989	40.4	1957	24.2	1964	0.0	1.2	26.4	1.2
March	56.9	22.8	39.9	85	3/25/1981	−17	3/04/1971	45.4	1989	33.9	1964	0.0	0.2	26.9	0.1
April	66.6	29.4	48.1	86	4/25/1996	1	4/03/1981	54.2	1954	42.0	1970	0.0	0.0	19.0	0.0
May	76.2	37.8	57.0	97	5/31/2002	10	5/01/1962	62.9	1996	49.0	2005	0.5	0.0	7.7	0.0
June	86.5	46.7	66.7	103	6/23/1981	25	6/01/1971	70.9	1974	60.7	1965	10.2	0.0	0.9	0.0
July	90.4	55.2	72.8	104	7/26/1979	33	7/01/1968	76.7	1951	68.2	1983	18.8	0.0	0.0	0.0
August	87.4	53.4	70.4	101	8/01/1949	28	8/24/1968	73.9	1995	66.7	1965	10.5	0.0	0.0	0.0
September	80.8	44.6	62.6	102	9/15/1922	19	9/29/1974	67.5	1949	57.3	1965	1.8	0.0	2.0	0.0
October	69.1	32.0	50.4	98	10/03/1922	7	10/31/1989	59.5	1950	45.7	1970	0.0	0.0	16.2	0.0
November	54.8	20.9	37.8	77	11/02/1952	−35	11/28/1976	42.2	1949	31.5	1992	0.0	0.4	26.5	0.3
December	44.1	13.1	28.7	74	12/04/1939	−38	12/12/1961	36.2	2010	19.0	1990	0.0	3.5	29.5	3.8
Annual	67.1	32.3	49.7	104	7/26/1979	−38	12/12/1961	51.4	1996	46.5	1964	41.8	8.8	184.9	9.7
Winter (Dec, Jan, Feb)	45.4	14.7	30.1	74	12/04/1939	−38	12/12/1961	34.9	1978	23.9	1964	0.0	8.2	85.7	9.3
Spring (Mar, Apr, May)	66.6	30.0	48.3	97	5/31/2002	−17	3/04/1971	52.4	1989	44.3	1964	0.5	0.2	53.6	0.1
Summer (Jun, Jul, Aug)	88.1	51.8	69.9	104	7/26/1979	25	6/01/1971	72.6	1922	65.9	1965	39.4	0.0	0.9	0.0
Fall (Sep, Oct, Nov)	68.2	32.5	50.3	102	9/15/1922	−35	11/28/1976	54.5	1950	47.0	1961	1.9	0.4	44.7	0.3

[1] Seasons are climatological not calendar seasons.

Precipitation

CHCU receives precipitation from both summer monsoons and winter storms with more precipitation during summer than winter. Regionally, average precipitation on the Colorado Plateau is 10 to 35 inches (25.4 to 88.9 cm) per year (Figure 2.1.2-2A). Mean annual precipitation is 8.78 inches (22.3 cm; 1922–2006) with August the wettest month (1.33 in; 3.4 cm) and June the driest (0.42 in; 1.7 cm) (Table 2.1.2-2; Figure 2.1.2-2B; WRCC 2020) with an average annual snowfall of 14.6 inches (37.1 cm; Table 2.1.2-2; WRCC 2020).

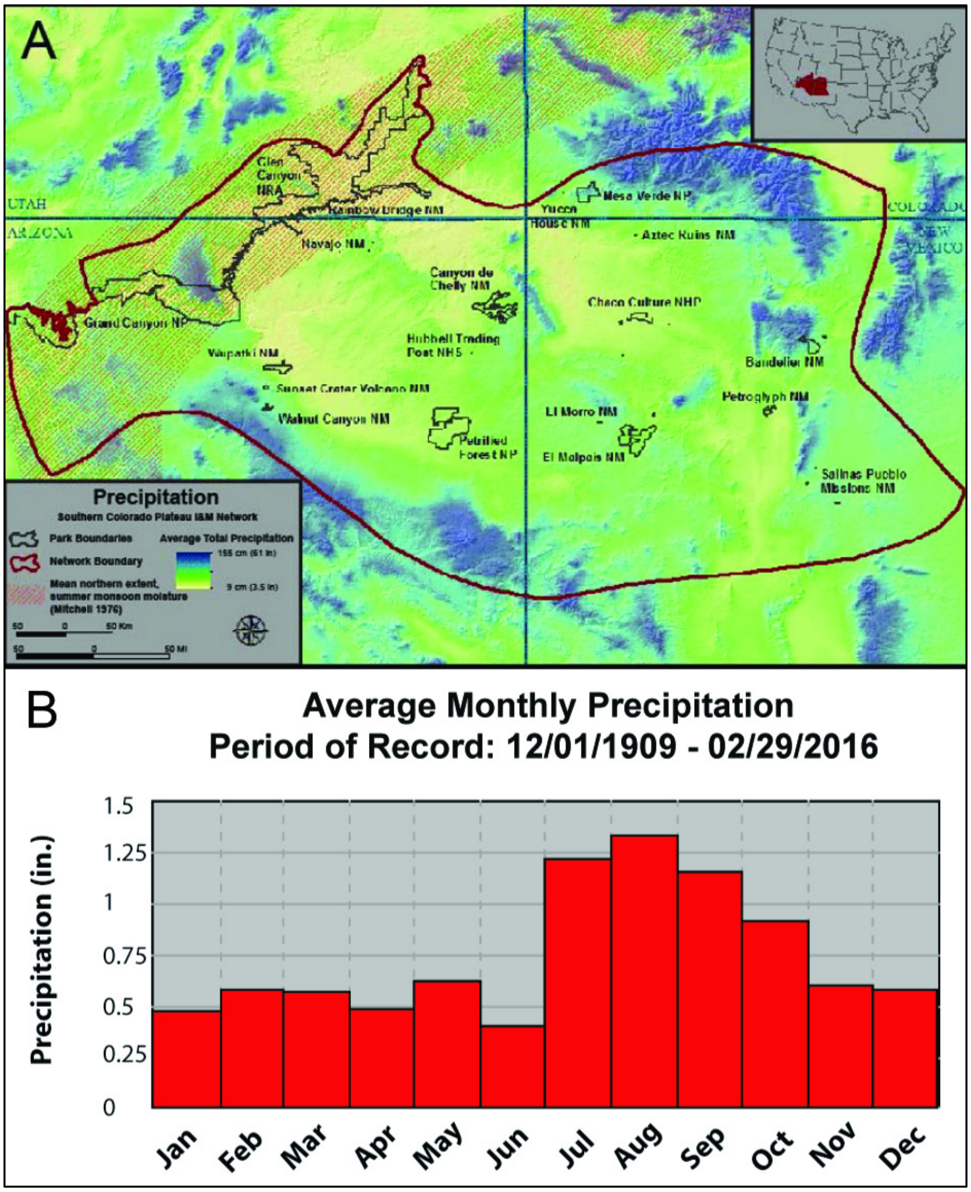


Figure 2.1.2-2. (A) Precipitation gradient model produced by NPS Southern Colorado Plateau Inventory and Monitoring Network for the southern Colorado Plateau, U.S. (B) Average monthly precipitation from on-site monitoring (weather station #291647) from 12/01/1909 through 02/29/2016, NPS Western Regional Climate Center for Chaco Culture National Historical Park, NM.

Table 2.1.2-2. Period of record general climate summary for precipitation at station (291647) CHACO CANYON NATL MON, 1909 to 2011. Table updated on Oct 31, 2012. For monthly and annual means, thresholds, and sums: months with 5 or more missing days are not considered; years with 1 or more missing months are not considered (WRCC 2020).

Period of Record [1]	Precipitation											Total Snowfall		
	Mean (in.)	High (in.)	Year	Low (in.)	Year	1 Day Max. (in.)	1 Day Max. (Date)	≥ 0.01 in. (# Days).	≥ 0.10 in. (# Days).	≥ 0.50 in. (# Days).	≥ 1.00 in. (# Days).	Mean (in.)	High (in.)	Year
January	0.48	1.87	1989	0.00	1933	1.02	1/24/1989	4	2	0	0	3.6	11.5	1987
February	0.56	2.68	2005	0.00	1933	1.01	2/2/1982	4	2	0	0	3.1	11.6	1986
March	0.53	3.17	2000	0.00	1913	1.10	3/31/2000	4	2	0	0	1.8	17.0	1973
April	0.48	2.49	2004	0.00	1923	0.91	4/1/1949	3	1	0	0	0.7	12.0	1949
May	0.59	3.03	1941	0.00	1910	2.23	5/26/1982	4	2	0	0	0.0	1.5	1953
June	0.42	2.19	1991	0.00	1923	0.76	6/9/2009	3	1	0	0	0.0	0.0	1910
July	1.18	3.99	1998	0.04	1993	2.26	7/27/1998	7	3	1	0	0.0	0.0	1910
August	1.33	3.35	1947	0.06	1950	1.33	8/22/1947	8	4	1	0	0.0	0.0	1912
September	1.10	4.15	1941	0.00	1912	2.80	9/12/1982	5	3	1	0	0.0	0.6	1951
October	0.92	5.88	1972	0.00	1922	1.60	10/22/1969	5	3	0	0	0.3	10.0	1972
November	0.58	3.29	1986	0.00	1912	1.56	11/4/1986	4	2	0	0	1.5	15.1	1952
December	0.61	3.90	1961	0.00	1912	0.74	12/23/1945	4	2	0	0	3.7	13.5	1967
Annual	8.78	15.12	1986	3.35	1950	2.80	9/12/1982	55	27	3	1	14.8	30.8	1964
Winter (Dec, Jan, Feb)	1.65	5.50	1941	0.05	1950	1.02	1/24/1989	12	6	0	0	10.4	26.9	2010
Spring (Mar, Apr, May)	1.60	4.59	1982	0.05	1996	2.23	5/26/1982	11	5	1	0	2.5	19.5	1973
Summer (Jun, Jul, Aug)	2.94	6.05	1967	0.67	1942	2.26	7/27/1998	18	9	1	0	0.0	0.0	1923
Fall (Sep, Oct, Nov)	2.60	7.26	1972	0.17	1912	2.80	9/12/1982	14	7	1	0	1.9	15.1	1952

[1] Seasons are climatological not calendar seasons.

2.1.3. Visitation Statistics

Monthly visitation data for Chaco Canyon are available for January 1976 through December 2019 (NPS 2020a). Total number of visitors per year ranged from 29,917 (in 2013) to 113,336 (in 1997). The highest number of visitors for a given year (47,342 visitors), for which data are available, was in 2019. Although there is substantial monthly variation by year, the month of May received the highest average number of visitors over the recorded period with 8,574 visitants.

2.2. Natural Resources

A summary of CHCU natural resources is provided here and represents an overview of the national park's resources. Assessments are presented in Chapter 4.

2.2.1. Ecological Units and Watersheds

<u>Ecological Units</u>

Chaco Canyon is located in the Colorado Plateau ecoregion subunit, which encompasses the highlands of northern Arizona, southern-southeastern Utah, southwestern Colorado and northwestern New Mexico (TNC 2002). The park falls within the Arizona-New Mexico Plateau ecoregion (TNC 2002). This region covers the southernmost 26% of the Colorado Plateau (TNC 2002). Major landforms consist of plateau, canyons, hills, and valley plains with semi-desert grassland at lower elevations gradating to pinyon-juniper woodlands at higher elevations (TNC 2002).

<u>Watershed Units</u>

Chaco Canyon is located within the San Juan structural basin, which includes the northwestern corner of New Mexico, the southwestern most extent of Colorado, the southeastern corner of Utah and a narrow strip of eastern-most Arizona (Kernodle 1996). There are three watersheds within this basin. The park occurs within the Upper Colorado watershed, which includes most of northwestern-most New Mexico and southwestern-most Colorado (USGS 1987). The watershed extends across 25,241 km^2 (9,743 sq mi).

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

In addition to NPS staff input, the NPS' Washington (WASO) level programs guided the selection of key natural resources for this condition assessment. This included Southern Colorado Plateau Inventory and Monitoring (I&M) Network (SCPN) Program, the Natural Resource Stewardship and Science Directorate's (NRSS) Air Resources Division (ARD) for air quality, and the Natural Sounds and Night Skies Program (NSNSD) for the soundscape and night sky sections.

<u>Southern Colorado Plateau Inventory and Monitoring Program</u>

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 2011a). 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 2011a).

To facilitate this effort, 270 parks with significant natural resources were organized into 32 regional networks. CHCU is part of the SCPN, which includes 18 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.

Park Planning Reports

Natural Resource Condition Assessments

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

Figure 2.3.1-1. Flow diagram emphasizing how information and data from both NRCAs and other sources are used in developing a resource stewardship strategy (NPS 2015b).

Foundation Document

Foundation Documents describe a park's purpose and significance and identify fundamental and other important park resources and values. While a resource management plan does exist for the park (NPS 1988), it is over 30 years old. The Foundation Document, which was completed for Chaco Canyon in 2015 (NPS 2015a), is the most current park planning document and was used to identify several of the focal elements of this NRCA.

State of the Park

A State of the Park report is intended for non-technical audiences and summarizes key findings of park conditions and management issues, highlighting recent park accomplishments and activities. NRCA condition findings are used in developing this report. Chapter 5 details a condition summary for the natural resources assessed in this NRCA.

Resource Stewardship Strategy

A Resource Stewardship Strategy (RSS) uses past and current resource conditions to identify potential management targets or objectives by developing comprehensive strategies using all available reports and data sources including NRCAs. National Parks are encouraged to develop an RSS as part of the park management planning process. Indicators of resource condition, both natural and cultural, are selected by the park. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. A Resource Stewardship Strategy for the park commence in summer 2019 and its projected completion is the fall of 2020.

2.3.2. Status of Supporting Science

Available data, reports and published papers varied depending upon the resource topic. The existing data used to assess condition of each indicator and/or to develop reference conditions are described in each of the Chapter 4 assessments. Extensive collaboration was provided by SCPN I&M, university researchers and other scientists. Additional Washington level programs, including Natural Sounds and Night Skies, Air Resources, and the Geologic Resources Divisions were also consulted and contributed significantly to the park's condition assessments.

Chapter 3. Study Scoping and Design

Chaco Culture National Historical Park Natural Resource Condition Assessment (NRCA) was coordinated by the National Park Service (NPS), Intermountain Region Office (IMR; now| NPS Regional Office, Serving Interior Regions 6, 7 & 8), Northern Arizona University (NAU), and the Colorado Plateau Cooperative Ecosystem Studies Unit (CESU) through Task Agreement, P15AC01073.

The NRCA process was a collaborative effort between Chaco Culture National Historical Park staff, SCPN staff, IMR NRCA Coordinator, the NRCA project management from Northern Arizona University, Flagstaff (NAU) and several subject matter experts across the intermountain west. Mark Meyer, NRSS Air Resources Division, Fort Collins, Colorado was the content matter expert for viewshed. Dr. Li-Wei Hung, NRSS Natural Sounds and Night Skies Division, Fort Collins, Colorado was the content matter expert for night skies. For the acoustic landscape, Emma Brown, NRSS Natural Sounds and Night Skies Division, Fort Collins, Colorado, provided valuable comments and direction. Ksienya Taylor, NRSS Air Resources Division provided guidance and reviewed the air quality chapter. Phillip Palmer, CHCU Facilities, Don Weeks, IMR Natural Resources Division, National Park Service, Lakewood, Colorado, and Stephen A. Monroe, SCPN provided technical guidance regarding hydrogeology. Dana Hawkins, CHCU Natural Resources Division provided guidance with the soils section. Stacy Stumpf and Stephen A. Monroe, SCPN I&M, and Dana Hawkins, CHCU, reviewed and improved the content for the riparian section. Megan Swan, botanist with SCPN, provided insightful comments that improved the vegetation sections. Kristen Philbrook, regional wildlife biologist, IMR Natural Resources Division, Lakewood, Colorado reviewed the ungulate section. Esther Nelson, wildlife biologist for USDA Forest Service Region 3, provided a review of the reptiles and amphibians section.

3.1. Preliminary Scoping

Preliminary scoping for Chaco Canyon began in February 2016. A draft list of natural resource topics based on the "key [natural] resources and values" identified in the park's Foundation Document (NPS 2015a) was developed and then submitted to Aron Adams at CHCU and Phyllis Pineda Bovin, National Park Service Intermountain Region NRCA coordinator. Pineda Bovin and the author (JJW) then coordinated with CHCU staff to schedule the workshop and obtain all relevant reports and datasets. Park officials then compiled reports and data sets pertaining to the preliminary list of natural resources and provided these materials to Judson Wynne.

The workshop was held over a three-day period from 28 through 30 November 2017 at Chaco Culture National Historical Park headquarters, New Mexico. The initial list of natural resource topics was reviewed, discussed, and refined by scoping workshop attendees (Aron Adams, Dana Hawkins CHCU; Megan Swan, SCPN; Phyllis Pineda Bovin, NPS IMR; and, J. Judson Wynne, NAU). Through discussions, participants finalized the draft indicators, measures, and reference conditions for each resource topic. Some topics were omitted, and some key resources were identified and selected as focal resources for the condition assessment. Additional data sets and reports were identified and incorporated into the revised assessment summary. Park staff also identified important concerns, issues/ stressors, and data gaps for each natural resource topic.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

CHCU NRCA utilizes an assessment framework adapted from “The State of the Nation’s Ecosystems 2008: Measuring the Lands, Waters, and Living Resources of the United States”, by the H. John Heinz III Center for Science, Economics and the Environment. This framework was endorsed by the National NRCA Program as an appropriate framework for listing resource components, indicators/ measures, and resource conditions.

NRCAs represent an assessment of key natural resource topics identified as important to the park of interest. For CHCU’s NRCA, 11 focal resources were selected for assessment (Tables 3.2.1-1 to 3.2.1-3.). Although it does not include every natural resource at the park, the natural resources and processes identified were of greatest significance to park staff at the time of this effort.

Reference conditions were identified with the intent of providing a benchmark to the current condition of each indicator/ measure, which could then be compared to existing research. When a quantifiable reference for a given measure was not feasible, an attempt was made to include a qualitative reference and/ or assessment to best interpret current resource condition.

Table 3.2.1-1. Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report.

Resource Group	Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
I. Landscape Condition Context	Viewshed	Scenic Inventory Value	• Scenic Inventory Value • Visibility	Current threats include haze from neighboring power-plant and metropolitan areas, sand/dust emitted from dry washes during high wind events, and smoke due to seasonal wildfires. Increased oil and gas exploration/ extraction adjacent to the park may ultimately adversely affect viewshed quality.	Data was collected in 2014 with the report published in 2016. Thus, the dataset is fairly current; however, the dataset was insufficient to establish a trend.
	Night Sky	Sky glow	• Zenith Limiting Magnitude • Bortle Dark Sky Scale • Zenith Sky Brightness	Light domes of Gallup and Albuquerque may ultimately impinge upon the dark sky rating of CHCU. Additionally, the low expense and energy efficiency of LED lighting has made these bulbs quite attractive for outdoor lighting.	Data collected sporadically from 2001 through 2019.
	Acoustic Environment	Sound level	• Mean time audible (noise) • Reduction in listening area • Geospatial L_{50} impact model	Primary sources of anthropogenic noise were aircraft, vehicular traffic, the CHCU Visitor Center generator, and people. As oil and gas exploration continue to expand closer to the boundary of CHCU, these operations will likely intensify anthropogenic noise.	Additional work into effects of anthropogenic noise on wildlife is needed. Monitoring the effects of oil and gas exploration/ expansion should also be considered.

Table 3.2.1-1 (continued). Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report.

Resource Group	Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
II. Supporting Environment	Air Quality	• Visibility • Ozone • Wet Deposition	• Haze Index • Human health • Vegetation health • Wet Nitrogen deposition • Wet Sulfur deposition	Global climate change; increasing dust due to drier conditions.	Onsite air quality monitoring stations have been collecting data since 2017; given the increase in oil and gas exploration and extraction operations surrounding the park, continued air quality monitoring will be vital. Importantly, continued nitrogen compound monitoring for early detection of elevated levels that may adversely affect CHCU ecosystems; Support for monitoring air quality during wildfire events and other times when haze is problematic; Management direction and planning efforts emphasizing efforts to protect air quality, scenic views, and resources sensitive to air pollution; Identification of sensitive resources, and future air quality needs, and research and monitoring (in consultation with NPS-ARD and the Regional Air Resources Coordinator); Monitoring of eight ozone-sensitive native plants (two of which are biological indicator species for ozone) – as determined by CHCU personnel; Predictions of future trends in air pollution, as well as the future dominant sources of pollution.
	Hydrogeology	Aquifer (well-house) water quality	Alluvial water quality	Hydraulic fracturing or wellbore stimulation activities within the Mancos Shale adjacent to the park boundary could contaminate the parks only reliable potable water source.	A USGS-led three-year assessment of potential risk of groundwater contamination at CHCU has entered its final year. These results may be useful in underscoring the present conditions and threats to the parks only water source.

Table 3.2.1-1 (continued). Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report.

Resource Group	Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
II. Supporting Environment (continued)	Soils	Soil quality	• Erosion due to livestock grazing • Erosion of Chaco Wash • Piping	Piping remains a treat to the Pueblo del Arroyo.	Another assessment should be conducted to ascertain whether other sites are at risk due to piping and whether the treat posed to Pueblo del Arroyo has intensified. This will inform park officials whether mitigation strategies are warranted.
	Riparian Zones & Springs	Riparian habitat	• Native riparian composition and structure • Tamarisk distribution • Sensitive spring ecosystems • Aquatic invertebrate community • Water quality • Stream Flow	The primary threats are lack of cottonwood reproduction and recruitment, and increased temperatures and drought conditions due to climate change.	Cottonwood trees are not producing seeds and thus progeny for new recruitment is lacking; with the change in tamarisk distribution and no recruitment of new cottonwood trees, research is needed to address this potentially dramatic change in riparian habitat. Alternatively, a program to restore native riparian habitat should be explored. Additional studies on aquatic invertebrates should be conducted to determine community composition both within all CHCU water bodies including Chaco River and Wijiji Spring. Water quality analyses were conducted 26 years ago and based on sampled collected between 43 to 26 years ago, while data collected on Chaco River stream flow is 16 to 40 years old; monitoring programs for both water quality and stream flow should be considered.

Table 3.2.1-1 (continued). Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report.

Resource Group	Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
II. Supporting Environment (continued)	Riparian Zones & Springs	Alluvial groundwater levels	Alluvial groundwater levels	Groundwater levels were monitored over a 10 year period (2007–2017). A declining trend is anticipated, which is expected to adversely affect riparian zones (Soles and Monroe 2021).	Groundwater levels are 8 to ~11 meters below the floodplain, which is at least partially responsible for cottonwood decline (Soles and Monroe 2021).

Table 3.2.1-2. Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report continued.

Resource Group	Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
III. Biological Integrity Vegetation	Invasive alien plant species	• Tamarisk occurrence in Chaco River/Wash	• Tamarisk occurrence in Chaco River/Wash	None.	Information on tamarisk occurrence/ presence is 16 years old. While it is likely the tamarisk beetle will ultimately reduce coverage of tamarisk, this has not been quantified.
	Invasive alien plant species	• Other invasive alien plant species	• Other invasive alien plant species	Climate change may result in greater instability of native vegetation communities enabling invasive alien plant species to become established.	Information on invasive alien plant species is 16 years old.

Table 3.2.1-3. Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report continued.

Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
Ungulate occurrence and population sizes	• Elk • Mule deer	• Occurrence • Population size	–	Elk management identified as a natural resource priority; however, active management is presently lacking. Populations should be monitored more frequently than annually. No information is available on mule deer within the park. Information is lacking on herd movement of both elk and mule deer, as well as how future oil and gas exploration activities may affect movements of these animals.
Bats	• Species richness • Habitat	• Species richness • Summer roost habitat (maternity, bachelor, and night roosts) • Winter roosts (hibernacula)	Increased drought conditions associated with climate change; westward advance of white-nose syndrome.	Species known to occur within the park is well-documented. However, no information is available on where bats within the park roost during summer and winter.
Reptiles & amphibians	• Species richness • Habitat	• Amphibian richness • Reptile richness • Amphibian habitat	Drought and other disturbance events to standing water and edge habitats; climate change. Expansion of oil and gas exploration may also threaten populations on adjacent BLM and Navajo land potentially isolating park populations. Changes in the hydrology of Chaco Wash due to drought or land use practices outside CHCU may affect the availability of amphibian breeding sites.	Lack of documentation on long-term impacts of the aforementioned anthropogenic impacts is not well-documented.

Table 3.2.1-3 (continued). Chaco Culture National Historical Park Natural Resource Condition Assessment framework based on Heinz Center's, The State of the Nation's Ecosystems (2008) report continued.

Focal Resources	Indicators	Measures	Threats / Stressors	Data Gaps
Invertebrates	• Invertebrate species richness	• Invertebrate species richness	Climate change and intensified oil and gas exploration adjacent to park lands may adversely affect invertebrate populations – especially those whose reproductive activities are timed with availability of perennial/intermittent water sources.	No terrestrial invertebrate surveys have been conducted; thus, the potential is high for new species discoveries.

3.2.2. Reporting Areas

National Park

The primary focus of the reporting area was within CHCU's legislative boundary. However, given most natural resources do not follow geopolitical boundaries, analyses often encompassed areas beyond the park boundary.

Landscape-scale

Natural resources assessed at the landscape level included viewshed, night sky, soundscape, and hydrogeology. Viewshed data was provided by the NPS Air Resources Division. Data and reports for the night sky and soundscape assessments were provided by the NPS Natural Sounds and Night Skies Division. Guidance on the hydrogeology section was provided by CHCU.

3.3. General Approach and Methods

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

3.3.1. Background and Importance

This section provides a summary on the resource, and a discussion of its relevance using existing data, publications reports, as well as descriptions developed by park staff and various planning documents.

3.3.2. Data and Methods

This section details the existing datasets and methodologies employed to evaluate the indicators and measures for each resource.

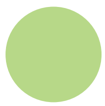
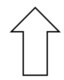
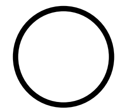
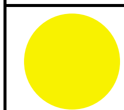
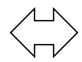
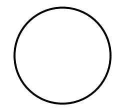
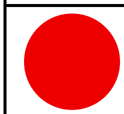
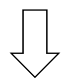
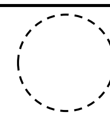
3.3.3. Reference Conditions

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

3.3.4. Condition and Trend

This section provides a discussion of the condition and trend, if available, for each indicator/measure based on each reference condition(s). Condition icons were presented in a standard format consistent with State of the Park reporting (NPS 2012) and serve as visual representations of condition/trend/ level of confidence for each measure evaluated. Table 3.3-1 shows the condition/ trend/confidence level scorecard used to describe each condition within the assessment.

Table 3.3-1. Condition, trend, and level of confidence categories used in the NRCA assessment process.

Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	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

<u>Summary Table</u>
Circle colors convey resource condition. Red circles signify a resource is of significant concern, yellow signify moderate condition, while green circles indicate a measure is in good condition. A circle without any color is associated with the low confidence symbol—dashed line—signifies insufficient information to make a statement about condition; therefore, condition is unknown.

Arrows within the circles indicate the indicator/ measure's trend. An upward pointing arrow represents the measure is improving, double pointing arrows denote the measure's condition is currently unchanging, and a downward pointing arrow indicates that the measure's condition is deteriorating. No arrow indicates an unknown trend.

Level of confidence ranges from high to low and is symbolized by the border around the condition circle. Bold heavy black line around the circle indicates high confidence; thin back line is indicative of medium confidence, while a dashed line signifies low confidence. Key uncertainties and resource threats are provided in the condition and trend discussion section for each resource assessment.

3.3.5. Sources of Expertise
Names of individuals who were consulted and/or provided a review are listed in this section, along with the writer's name that drafted the assessment.

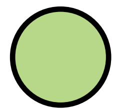
3.3.6. Literature Cited
This section lists all of the referenced sources for the assessment.

Chapter 4. Natural Resource Conditions

4.1. Viewshed

A summary of all assessed conditions for viewshed is provided in Table 4.1-1.

Table 4.1-1. Condition assessment summary for viewshed, Chaco Culture National Historical Park, New Mexico.

Indicator/ Measure	**Description**	**Condition Status/Trend**	**Summary**
Scenic Inventory Value	92% of the views were rated as “High” or “Very High” (Meyer et al., 2016).		Most evaluated sites (92%) received the highest score; data collected in 2014 (Meyer et al., 2016); thus, confidence is relatively high; not enough data to establish trend.

4.1.1. Background and Importance

The Organic Act of 1916, which established the national park system and the NPS, states that the mission of the Service is “to conserve the scenery…and wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.” This direction is further amplified in the 2006 NPS Management Policies, which mention scenic views in several chapters and includes them in the definition of “natural resources” (Chapter 4, Introduction, p. 36). The policies call for the protection of all park resources in a proactive, collaborative manner as an “integral part of larger regional environments” (Chapter 1, 1.6 p. 13). To assist parks in this effort NPS has developed a visual resource program that includes inventory and analysis tools to better inform management decisions for protecting scenic views.

At CHCU, providing a rich cultural experience of the mostly undisturbed, natural landscape is a vital component of the visitors’ experience. Historically, the Chacoan region extended westward from the Rio Grande river, south and west of the Lower Colorado River and northward through southeastern most Utah and the southwestern corner of Colorado (Lekson 2006). CHCU is recognized for its expansive views of Native American Pueblo complexes, which were built and occupied from 850 to 1140 CE and were seemingly constructed largely to compliment the towering mesas and treeless deserts (Lekson 2006). Among the most popular scenic views in the park are Pueblo Bonito, Casa Rinconada, Penasco Blanco (NE and SW), Hungo Pavi, Pueblo del Arroyo, Pueblo Alto, Visitor Center Entry, Una Vida Greathouse, and Pueblo Bonito Overlook (from the mesa). The ability to experience these views offers park visitors numerous opportunities for inspiration, solitude, and connection with both the rich prehistoric past and present ecosystems.

Protection of scenery will become increasingly challenging given the pressures of human population growth, increased resource demands, and development throughout the American West. Threats that may degrade scenery important to the visitor experience include the infrastructure associated with oil and mineral exploration and development. Air pollution may also adversely affect how visitors experience landscapes by reducing the clarity of the air. **Section 4.4** (Air Quality) discusses air pollutants and their associated documented background levels.

Where development is proposed within shared viewsheds, the NPS has an opportunity to engage in local, regional, and national regulatory and planning processes. Engaging with others to advance park protection is also consistent with the direction of the 2006 NPS Management Policies. Within the NPS Management Policies, Section 1.6 on Cooperative Conservation Policies Beyond Park Boundaries instructs parks to work cooperatively with others to anticipate, avoid and resolve potential conflicts; protects park resources and values; provides for enjoyment; and, addresses mutual interests in the quality of life of community residents, including matter such as compatible economic development and resource and environmental protection (NPS 2006). Information about existing visual resources, the level of visitation to park viewpoints, and the potential for changes in the visual setting to alter the visitor experience can inform external planning and development proposals and may help protect park scenic views.

4.1.2. Reference Conditions

In June 2014, CHCU conducted a visual resource inventory (VRI) at the park. During the inventory, 26 views that represent a cross section of park visitor experiences, landscape types, and level of visitation. The selection process was based upon the following general criteria: (1) *critical inventory priority* – highly valued views by either visitor experience or under immediate threat from a proposed development project or changes in land management; (2) *moderate priority* – views not likely to change in near future, but may change eventually due to future land management development decisions; and, (3) *low priority* – views currently somewhat protected from visual intrusions.

Views were assessed for scenic quality and view importance. Scenic quality rating factors include landscape character integrity, vividness, and visual harmony. The ratings result in a score ranging from highest (A) to lowest (E) indicating the relative scenic quality of the view. View importance rating factors include viewpoint importance, viewed landscape importance, and viewer concern. The ratings result in a score ranging from highest (1) to lowest (5) indicating the relative value of the view to the park and its visitors. The visual resource inventory results for each view can be summarized using a scenic inventory value (SIV), which combines scenic quality and view importance using the matrix below (Table 4.1.2-1). The SIV scale ranges from very high (VH) to very low (VL).

Table 4.1.2-1. Scenic inventory value matrix ranking system with scenic quality (scored A through E; columns) and visitor importance (scored 1 through 5; rows). Overall conservation value for each vista relative to other inventoried views is classified using the matrix as very high (VH), high (H), moderate (M), low (L) or very low (VL). Refer to NPS (2018a).

Scenic Quality	View Importance Rating				
	1	2	3	4	5
A	VH	VH	VH	H	M
B	VH	VH	H	M	L
C	H	H	M	L	L
D	H	M	L	VL	VL
E	M	L	VL	VL	VL

Indicators & Measures

Indicator
Visibility

Measure
Scenic Inventory Value

4.1.3. Condition and Trend

The current condition of visual resources at CHCU is "good" (refer to Table 4.1.3-1). Based on the inventory conducted at the park, 92% (24 of 26) of the views have a SIV of "high" or "very high" (Meyer et al. 2016; Table 4.1.3-2). Most views received high scenic quality ratings of either an "A" (16 views) or a "B" (9 views), and one view rated "C". View importance rating was as follows: "1" (2 views), "2" (9 views), "3" (9 views), and "4" (6 views). At all viewpoints, visitor attention was focused on archaeological, natural, or the combined landscape with multiple focal points dispersed across the landscape.

Discussion of trends is generally not recommended by the NPS Visual Resources Program because there were no previous inventories or other documented sources that could be used to reasonably identify trends in landscape changes at CHCU (M. Meyers, pers. comm. 2018). The park may be able to identify trends as they establish baseline inventories and monitor changes over time.

Table 4.1.3-1. Criteria to evaluate overall condition of visual resources based upon the best available data (NPS 2018a).

Category	Criteria
Good	75% or more views have a Scenic Inventory Value (SIV) of very high or high
Good/Fair	50% to 74% views have a SIV of very high or high
Fair	25% to 49% of views have a SIV of very high or high
Fair/Poor	50% to 74% of views have a SIV of moderate, low, or very low
Poor	75% or more views have a SIV of moderate, low, or very low

Table 4.1.3-2. Twenty-six popular scenic views monitored at Chaco Culture National Historical Park, New Mexico. Scenic quality scored from "A" (highest) to "E" (lowest); however, only one site was ranked as a "C." View importance is typically ranked from 1 through 5 with 1 being highest and 5 the lowest; however, in this case, the lowest rank was a 4. Scenic inventory value is categorized as very high (VH), high (H) and moderate (M), from Meyer et al. (2016).

View Name	Scenic Quality	View Importance	Scenic Inventory Value
Casa Rinconada	A	1	VH
Pueblo Bonito (Threatening Rock)	A	1	VH
Penasco Blanco NE	A	2	VH
Penasco Blanco SW	A	2	VH
Hungo Pavi	A	2	VH
Pueblo del Arroyo	A	2	VH
Pueblo Alto	A	2	VH
Visitor Center Entry	B	2	VH
Una Vida Greathouse	B	2	VH
Pueblo Bonito Overlook (on mesa)	B	2	VH
Kin Kletso	B	2	VH
Fajada View Overlook	A	3	VH
Tsin Kletzin	A	3	VH
Pueblo Pintado	A	3	VH
Kin Klizhin	A	3	VH
Ki Bieola	A	3	VH
Campground Trail	A	4	H
Verizon Hill	A	4	H
South Gap	A	4	H
Shabik'eschee	A	4	H
Petroglyph Trail	B	3	H
Wijiji	B	3	H
Pueblo Pintado Plaza	B	3	H
South Entrance	B	4	M
Kin Ya'a	B	4	M
Gallo Campground	C	3	M

Threats and Issues

Future threats to the viewshed may include general development outside park boundaries. There are numerous threats to viewshed from outside the park. These include haze from neighboring power-plant and major metropolitan areas, sand/dust emitted from dry washes during high wind events, and smoke from seasonal wildfires (typically April through July). However, park personnel indicate that in recent years, reduced visibility due to wildfire smoke can occur through September (D. Hawkins, pers. comm. 2020). Potential projects may include fracking and wind farm development, and telecommunications tower construction on adjacent non-park lands.

CHCU is surrounded by a combination of Navajo tribal lands, New Mexico state lands and Bureau of Land Management federal inholdings (Fig. 4.1.3-1). Depending upon market forces and the landholder management objectives, these lands may be subject to mineral and oil exploration and potential development in the future (e.g., Engler et al. 2014; BLM 2015, 2020).

Depending on the location of future oil and mineral developments, as well natural landscape features (e.g., mesas) that may obviate these unnatural structures from the viewshed, the quality of some of the 26 popular views may be degraded in the future.

Additionally, construction, drilling, and production activities associated with oil and gas exploration on adjacent lands could adversely affect the surrounding visual landscape and the visitor experience by introducing visual intrusions into an otherwise mostly intact landscape (NPS 2020b). Thus, the potential effects to park resources would include the degradation of scenic quality and views important to not just tribal communities and park visitors.

Data Gaps

CHCU conducted a baseline assessment of 26 park views identified as important to park visitors and management. Additional views could be considered for inventory to provide a comprehensive dataset for the park. Inventory data may be used for developing scenery management and conservation strategies to better protect the desirable visual characteristics of popular scenic views. No inventory repeat interval is required – however, an assessment every 7 to 10 years would allow the park to monitor change over time and adjust management accordingly (M. Meyer, pers. comm. 2018).

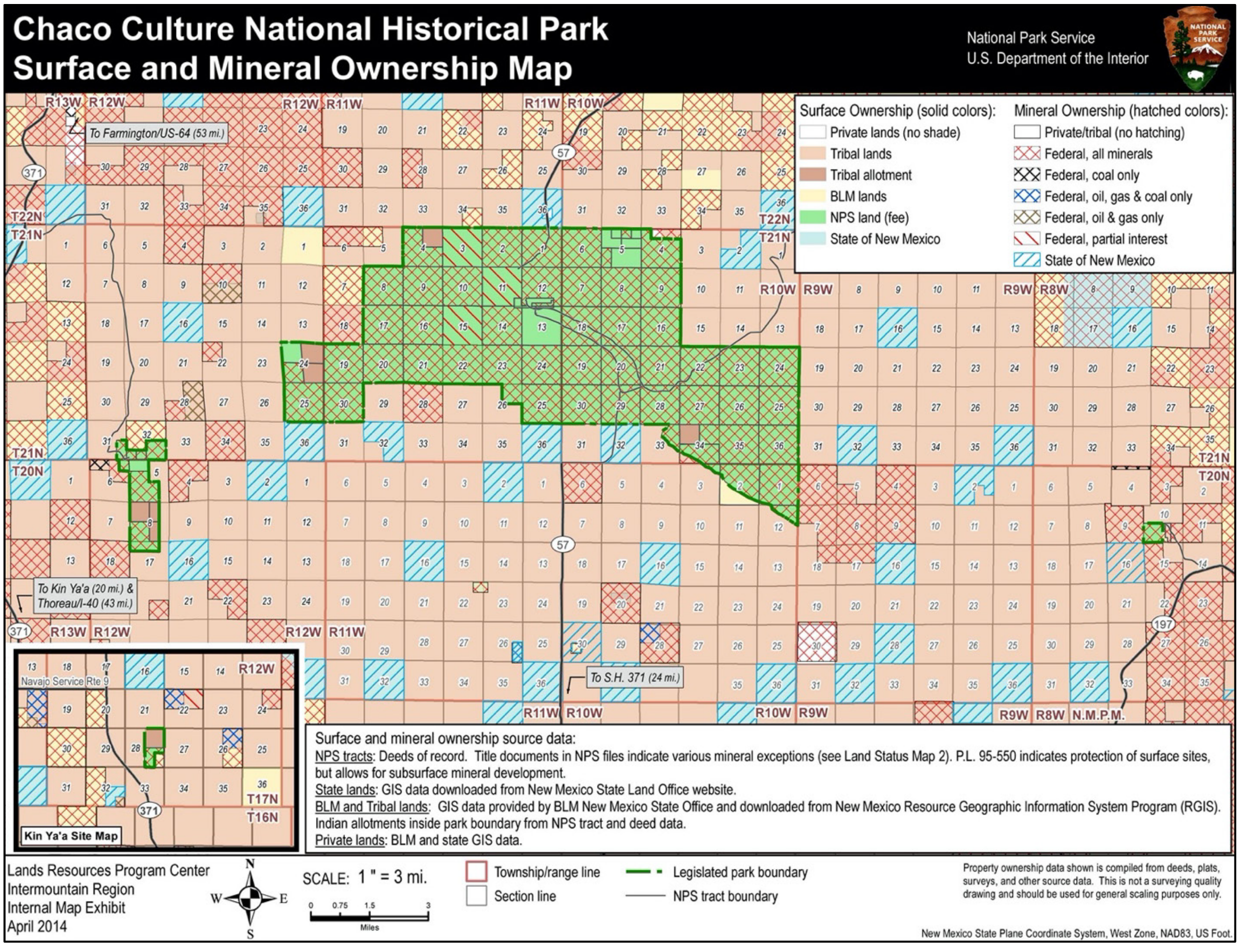


Figure 4.1.3-1. Land ownership of parcels surrounding Chaco Culture National Historical Park, New Mexico (Lands Resources Program Center, NPS).

Chaco Canyon could also establish a photo-monitoring program at its most important scenic views. Expanding upon the work of Meyer et al. (2016), which included the 26 most important views, a future monitoring program could include seasonal acquisition of both photographic images, as well as transmissometer measurements (refer to Binkley et al., 1997). Transmissometer data may be used to calculate both visibility distances and light extinction coefficients (see Binkley et al., 1997). These data may also be used to support scenery management and conservation strategies.

Finally, to comprehensively evaluate and ultimately monitor visual resources conditions, the following should be considered, which combine both VRI and threats.

- Specific popular scenic views of interest and their respective scenic quality and view importance ratings;
- Quantify potential future impacts and their implications to the visual landscapes and specific views; and,

- Identify strategies and activities to better protect the desirable visual characteristics of popular scenic views.

Confidence Level of Data

The degree of confidence is relatively high given that the measurements were collected within the last five years (in 2014; Meyer et al. 2016). As mentioned above, these data should be collected every 7 to 10 years (M. Meyer, pers. comm. 2018).

4.1.4. Sources of Expertise

Mark Meyer, Air Resources Division, National Park Service, Fort Collins, Colorado.

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. Note that the measures and methods used for assessing the condition of viewshed in this report predate current measures and methods recommended by the NPS. For current information and methodology, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/ or contact the NPS at visual_resources@nps.gov.

4.2. Night Sky

A summary of all assessed conditions for night sky is provided in Table 4.2-1.

Table 4.2-1. Condition assessment summary for night skies, Chaco Culture National Historical Park, New Mexico.

Measures	Description	Condition Status/Trend	Summary
Zenith limiting magnitude (ZLM)	Based upon 2000–2016 data (NPS 2018b), ZLM was 7.0.		ZLM is 7.0 under most conditions, light domes of surrounding cities diminish Milky Way at the horizon and skyglow is exacerbated when cloudy or atmospheric aerosols (e.g. dust, soot) is present (NPS 2019c) ZLM data were collected on nine nights between 2001 and 2016; thus, confidence in current condition is high.
Bortle sky classification	Class 3: rural sky, based on the visibility of astronomical objects.		Data were collected between 2001 and 2016; however, given there were only nine observations over the 15 year period, no trend is possible.
Zenith sky brightness	ZSB ranged from 21.72 to 22.23 mag arcsec^{-2} between 2001 and 2016; in 2016, ZSB was 21.91 mag arcsec^{-2} (NPS 2018b).		Data captured from sky quality measurement sites were collected and reported from four sites over a 15 year period (for a total of 9 observations over that period); no trend is possible.

4.2.1. Background and Importance

Nighttime views and environments are considered one of the critical features protected by the National Park Service (NPS 2019a). Importantly, the natural photic environment, unencumbered by light pollution, is critical to ecosystem function, as well as providing both natural aesthetic and experiential qualities to park visitors (Moore et al. 2013). Underscored by the NPS Natural Sounds and Night Skies Division (NSNSD), nighttime views are distinguished both as a lightscape (the human perception of the nighttime scene, including both the night sky and the faintly illuminated terrain), and the photic environment (the totality of light at night at all wavelengths; Moore et al. 2013). The importance of dark night skies is evidenced by the fact that 31 national parks have stargazing programs; of these, the International Dark-Sky Association (IDA) has recognized 18 parks as "dark sky destinations" and many have night skies programs (NPS 2019a).

Numerous negative effects to ecological systems and human health are associated with light pollution (i.e., light glare, light trespass, and artificial sky glow). Animal movements, feeding, breeding, hibernation, and even dormancy have evolved to respond to diurnal, seasonal and lunar changes in natural ambient light. For example, Hölker et al. (2010a) estimate at least 28% of all vertebrates and more than 60% of all invertebrates globally are nocturnal. Plants have also evolved to respond to varying light levels for flowering, growth, and even direction of growth (RCEP, 2009; Hölker et al. 2010a). Thus, as light pollution alters the natural cycle of light and dark, natural patterns of resource use by animals and plants will likely be disrupted – negatively effecting both ecological structure and function (Gaston et al. 2013).

Humans are also negatively affected by the artificially illuminated night. Evidence suggests that prolonged exposure to light at night negatively affects sleep quality, which results in more frequent arousals, and suppressed pineal melatonin production and secretion (Cho et al. 2013). Importantly, as melatonin is an anti-carcinogenic hormone, lower levels in blood may reduce resistance to the growth of some cancers (Pauley 2004; Bullough et al. 2006; Haim et al. 2010; Garcia-Saenz et al. 2018). Thus, NPS lands with natural dark sky and proper in-park lighting can provide benefits for visitors to enjoy the natural illumination cycle.

Over the past 60 years, night skies globally have been rapidly transformed by light pollution at an approximate 6% per year increase (Smith 2009; Hölker et al. 2010b). Today, more than 80% of the planet and 99% of the human populations of U.S. and Europe persist under artificial sky glow (Falchi et al. 2016). Because of this, the importance of star filled night skies have gone from a normal occurrence to a novelty globally. Thus, for most visitors, a night sky largely absent of light pollution and illuminated by starlight enhances both solitude and the notion of wilderness.

In 2013, Chaco Canyon was certified as an International Dark Sky park. CHCU remains relatively insulated from the sky glow effects of major cities. However, the main impacts include the light domes from Albuquerque, Bloomfield, Crownpoint, Farmington, Gallup, Grants, Rio Rancho, and Santa Fe. These light domes were observable along the horizon with a few exceeding the brightness of the Milky Way. Additionally, glare sources from oil and gas development sites are observable along the north and east horizons.

Additionally, while the artificial sky brightness interactive map of Falchi et al. (2016; Fig. 4.2.1-1) and CIRES (2018) differs slightly from the findings of the CHCU NPS Night Skies Team, it is still useful as a tool to highlight the current and future impediments in maintaining unencumbered night skies (Fig. 4.2.1-2).

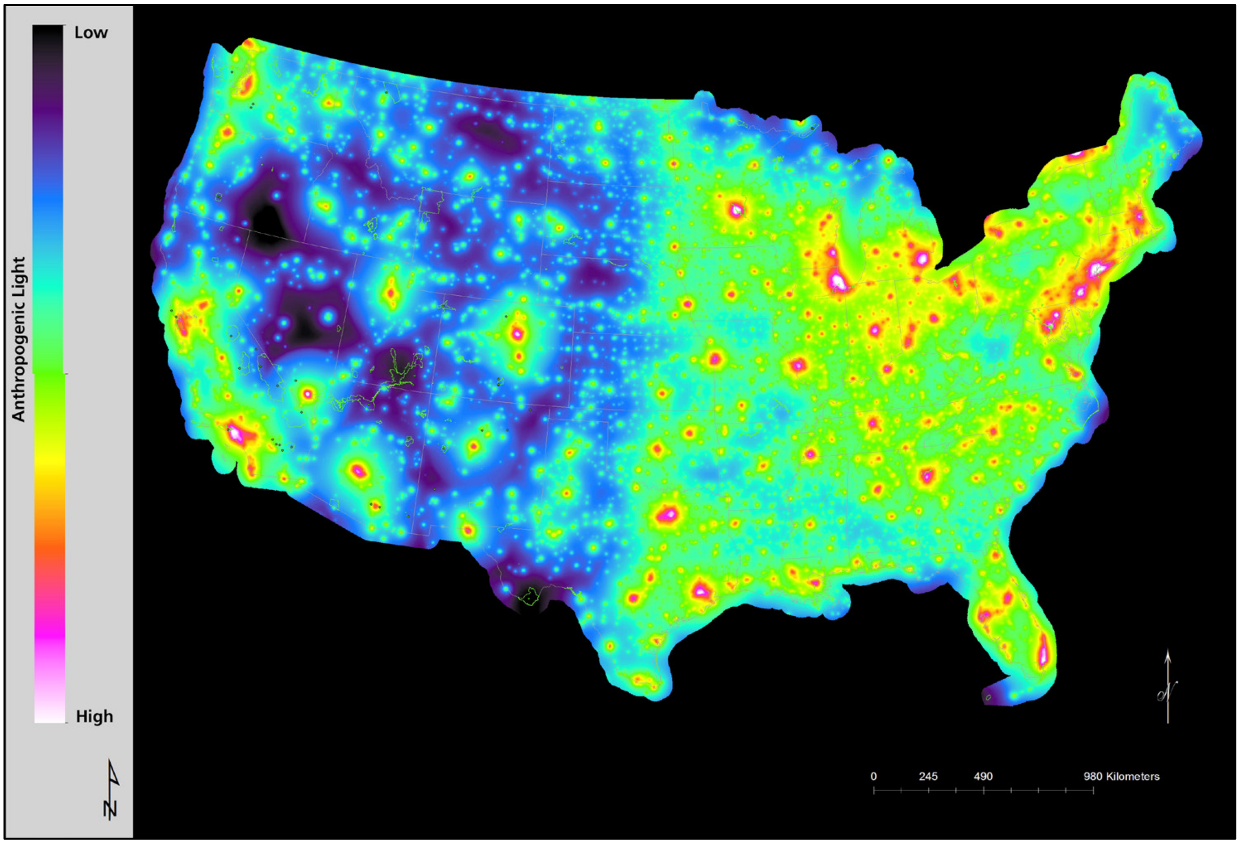


Figure 4.2.1-1. Artificial sky brightness map (of zenith sky brightness) of the United States based upon Falchi et al. (2016) and CIRES (2018).

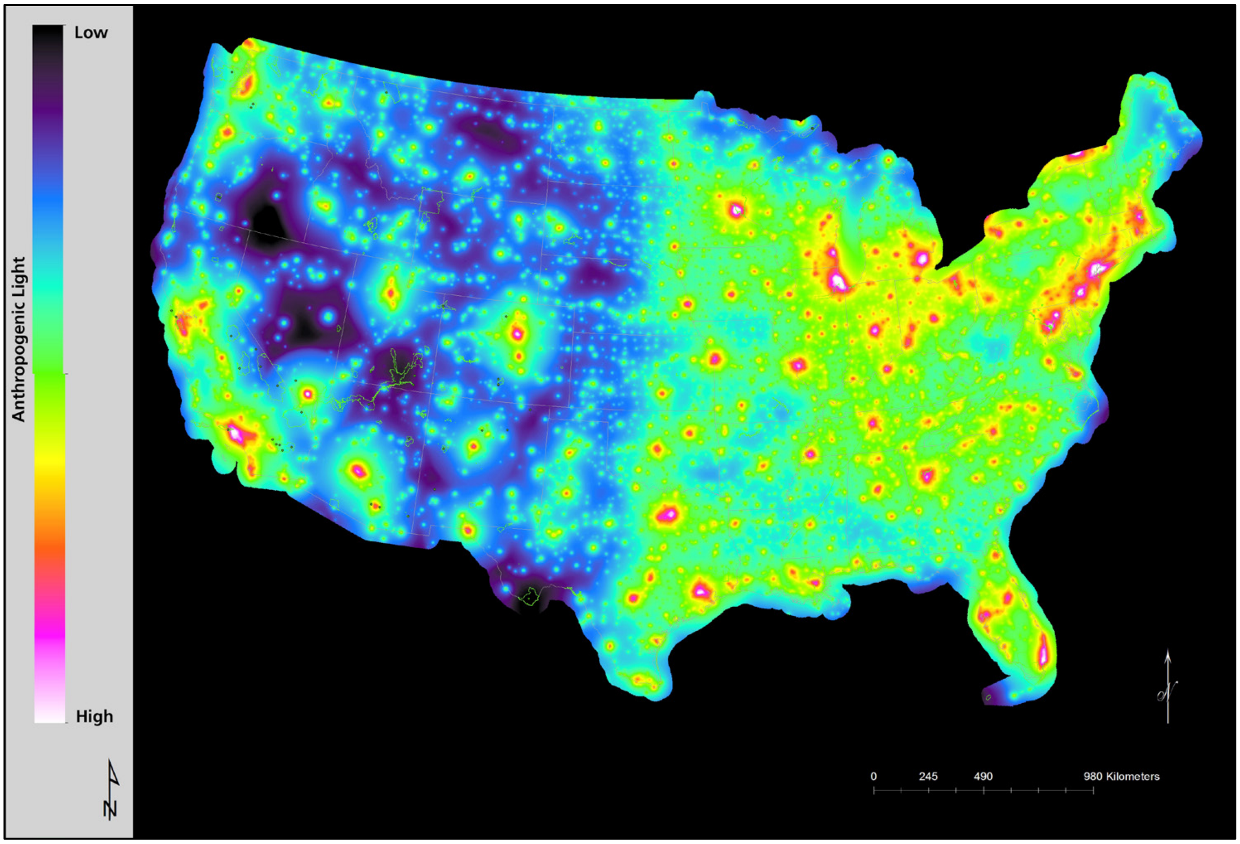


Figure 4.2.1-2. Artificial sky brightness map of the United States based upon Falchi et al. (2016) and CIRES (2018).

4.2.2. Data and Methods

Night sky measurements were collected using photographic equipment configured by the NPS Night Skies Program. They system consisted of a commercial lens, a V-band filter, and a charge-couple device camera. A filter was used to permit visible light pass through and allow the detected signal to closely represent what human eyes can see based on our spectral sensitivity. Because each image has limited field of view, a number of images was required to attain coverage of the entire sky. A robotic mount was employed to automatically position the camera for each image. Each image set takes up to 40 minutes to complete, depending on the specific system used and the exposure time. To minimize the amount of sun and moon light, data are collected when the sun is more than 18° below the horizon, and when the moon also is below the horizon. The weather conditions required for data collection are clear nights with almost no cloud cover. Summary of data collected from 2001 through 2016 are provided in Table 4.2.2-1.

Table 4.2.2-1. Summary information for measurement sites, elevation, and coordinates, as well as Zenith Limiting Magnitude, Bortle Class, and Zenith Brightness (in mag/arcsec2). Numbers (#) is used to relate measurements to the cameras used: (1–3) Apogee, (4) IMG1, (5,6) IMG2, (7) ML4, and (8–9) ML3, Chaco Culture National Historical Park, New Mexico (from NPS 2018b).

#	Date	Location	Elevation	Latitude	Longitude	Limiting Magnitude	Bortle Class	Zenith Brightness
1	10/13/01	Water Tank	1955	36.03153	−107.90854	6.8	3	21.72
2	1/28/03	Water Tank	–	–	–	–	–	21.96
3	1/30/03	Water Tank	–	–	–	–	–	21.86
4	3/10/05	Water Tank	–	–	–	–	–	21.76
5	5/29/08	Water Tank	–	–	–	7	3	22.21
6	5/30/08	Water Tank	–	–	–	7	3	22.23
7	5/31/13	Gallo Cuesta	2006	36.04025	−107.90461	7.1	3	21.87
8	5/8/14	Pueblo Alto	1965	36.07018	−107.95522	7.1	–	21.84
9	9/23/16	Kin Kletso	1905	36.06547	−107.96900	–	3	21.91

To visually represent the region surrounding CHCU, an artificial sky brightness interactive map of Falchi et al. (2016; Fig. 4.2.2-1) and the NPS all-sky light pollution ratio (ALR) map (NPS 2018c; Figure 2) to highlight the current and future impediments in maintaining unencumbered night skies were used. Falchi et al. (2016) map only shows the zenith sky brightness, which means they only consider the brightness of the sky overhead and not the brightness over the whole sky. The zenith is usually the darkest part of the sky, so the average brightness over the entire sky usually is higher than the zenith brightness. Thus, this figure and the associated values are a conservative model for representing the extent of skyglow. The NPS ALR map shows the brightness averaged over the entire sky and is thus a better representation of the overall sky brightness condition (NPS 2018c).

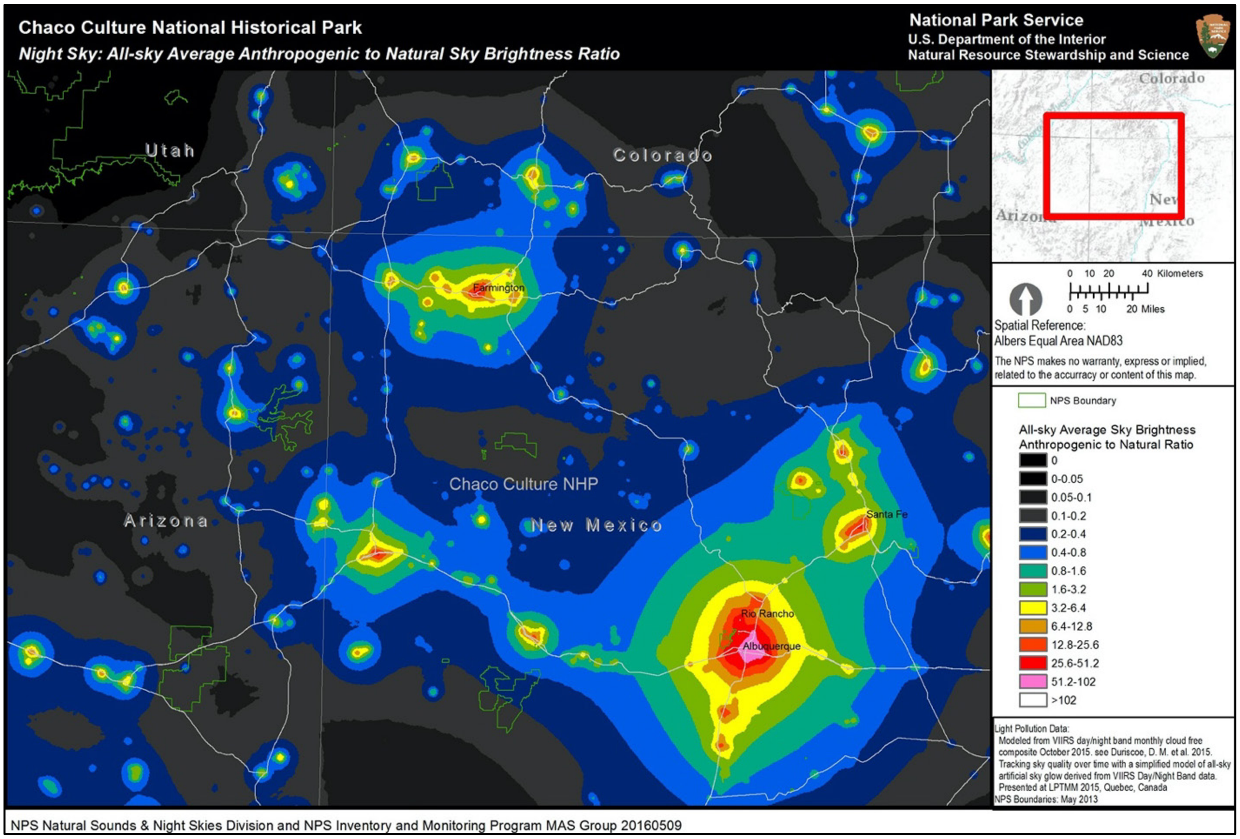


Figure 4.2.2-1. Regional view of all-sky light pollution ratio caused by cities at proximity to CHCU. Refer to the map legend for the brightness of anthropogenic to natural light ratio (NPS 2018c).

Indicators & Measures

Indicator
Sky glow
Measure
Zenith Limiting Magnitude

Zenith limiting magnitude (ZLM) is the faintest stars than can be observed visually without optical aid (naked eye) near the zenith or darkest part of the sky (Duriscoe 2015). A ZLM of 6.6 is considered near pristine under average conditions, while 7.0 is achievable under good observing conditions and with proper dark adaptation of the eye; a number lower than 6.3 usually indicates significantly degraded sky quality (Duriscoe 2015). Based upon five of six measurements taken from the water tank between 2001 and 2016 (e.g., Fig. 4.2.2-2), CHCU ZLM ranges from 6.8 to 7.1; (NPS 2018b); the average values is 7.0, which is considered good viewing conditions (NPS 2018c). One measurement, for 23 September 2016, was not collected.

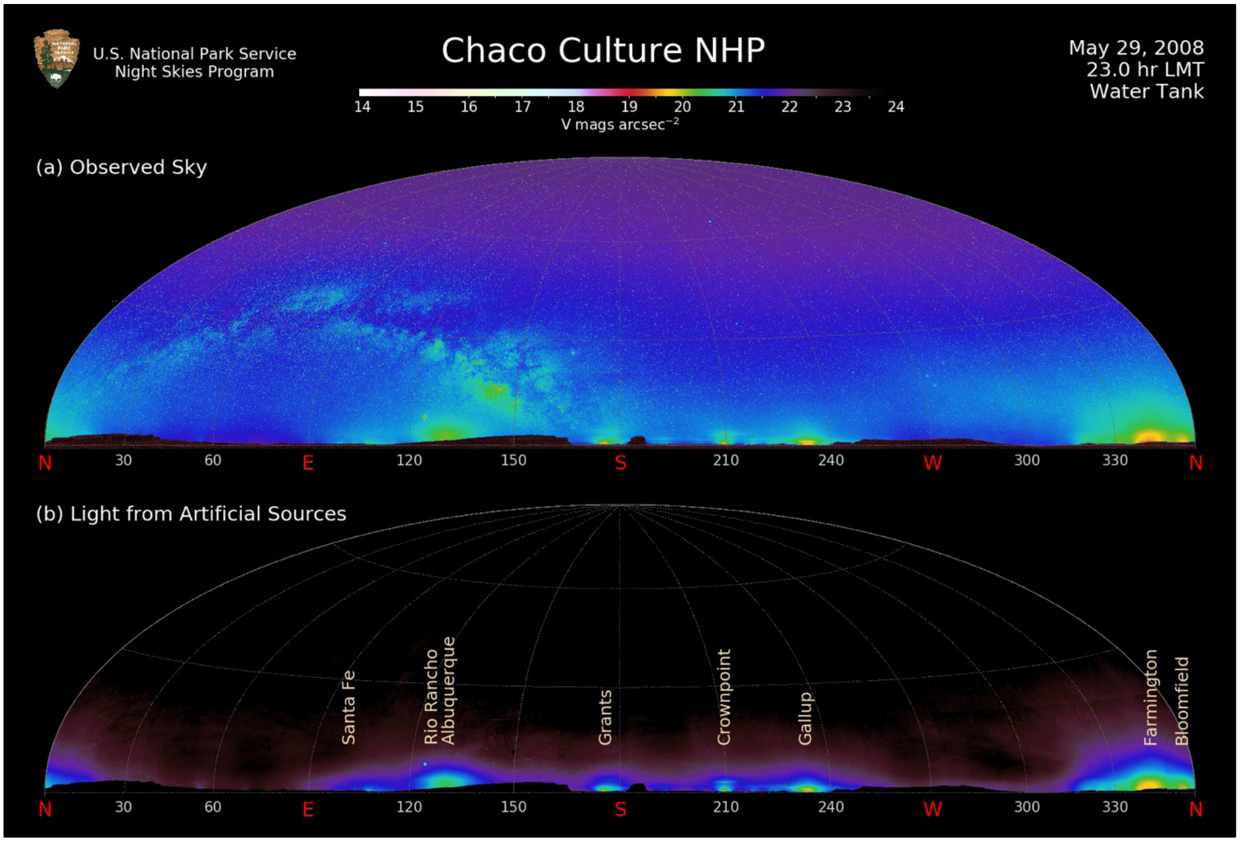


Figure 4.2.2-2. 360° Panoramic image of natural and anthropogenic light sources, water tank, approximately 740 m NNE of the Visitor Center, Chaco Culture National Historical Park, New Mexico, 29 May 2008 (NPS Night Skies Program).

Indicator
Sky glow

Measure
Bortle Sky Classification

The Bortle Dark Sky scale was developed to evaluate the quality of the night sky for stargazing (refer to Appendix 1, Bortle 2001). Consisting of nine classes, the scale uses a number of objects observable at night including zodiacal light, gegenschein, zodiacal band, and galaxy M33 to assign the class rating (Bortle 2001). Using this system, the NPS Night Skies Team rated CHCU's night skies at Class 3; this classification was based upon five of six measurements taken from 2001 to 2016 at the water tank monitoring site (NPS 2018b). All measurements fell within rural skies (Class 3) classification. Data for 08 May 2014 was not reported.

Indicator
Sky glow

Measure
Zenith Sky Brightness

To evaluate sky brightness, the NPS dark sky team applied horizontal illuminance, maximum vertical illuminance, zenith brightness, percentage of lost stars, and all-sky light pollution ratio (ALR; NPS 2018b). Of the nine measurements collected across four sampling sites (from 2001 through 2016), all sky quality meter reading were 21.72 mag arcsec^{-2} or higher (NPS 2018b). Aimed at the zenith, the camera captured data in magnitudes per square arc-second (mag arcsec^{-2}; NPS 2018b).

4.2.3. Condition and Trend

Night sky condition is considered "good" with a trend of "unknown" and likely to be "changing" (Table 4.2-1). Currently, CHCU maintains the top third category (i.e., #3 or "rural skies") on the Bortal (2001) sky brightness scale. New Mexico has experienced flat to negative population growth over roughly the past five years and the human population in the northern region has actually decreased by 1.2% between 2010 and 2015 (NMDWS 2017).

Threats, Issues, and Data Gaps

Threats

Oil and gas exploration and potential extraction activities on adjacent non-park lands may produce additional sources of light pollution. The ability to view the stars, constellations, and the dark spaces in between, is important to area Native American tribal cultures. As CHCU's interpretative programs emphasize the importance of the night sky to both the Ancestral Puebloans and their living descendants, it is important for the park retain a sense of remoteness where dark skies largely unimpeded by light pollution (NPS 2020b).

Issues

Over time, the light domes of Gallup and Albuquerque may ultimately impinge upon the dark sky rating of CHCU. Current and future oil and gas exploration activities are also expected to reduce dark sky quality. Another source of local light pollution are LED lights. Given the low expense and energy efficiency, these bulbs quite attractive for outdoor lighting. Unfortunately, LED lights are often high lumens, which can contribute significantly to light pollution in rural communities (Falchi et al. 2011). All of these issues should be closely monitored to help reduce the artificial sky glow and impacts optimal dark sky conditions at CHCU.

The park can take immediate steps to reduce the impacts of outdoor lighting. To do this, the following sustainable outdoor lighting principles should be considered: (i) light only if needed, and only when needed; (ii) light only where it is needed; (iii) use warm-white or amber light; (iv) use the minimum amount of light needed; and, (v) use energy-efficient and lights (NPS 2016a). Additionally, in areas infrequently used, yet necessary for safety, motion detecting on-switches with a timer will further limit within park light pollution.

Data Gaps

Data used to assess the park was based on a varying number of measurements per indicator. For both zenith limiting magnitude and Bortle classification, one measurement was taken in 2001, two in 2008, and two measurements in 2013 and 2014; nine measurements were taken from 2001 through 2019 for zenith brightness (NPS 2018b; Table 4.2-2). Given that data collection was reported sporadic, this is considered to be a data gap. Thus, our overall confidence in this dataset is "medium."

Moreover, as oil and gas exploration activities may increase adjacent to CHCU lands, it will be increasingly important for the park to monitor the potential impacts of these activities on dark sky quality.

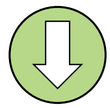
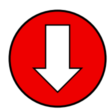
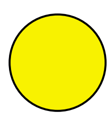
4.2.4. Sources of Expertise

Li-Wei Hung, Natural Sounds and Night Skies Division, Ft. Collins, Colorado

4.3. Acoustic Environment

A summary of all assessed conditions for acoustic environment is provided in Table 4.3-1.

Table 4.3-1. Condition assessment summary for the acoustic environment, Chaco Culture National Historical Park, New Mexico.

Indicator	**Description**	**Condition Status/Trend**	**Summary**
Mean time audible (noise)	The two frontcountry sites (Visitor Center and Downtown Chaco) were 60.3 and 45.6%, respectively (Nelson 2015).		Below 35% is considered a "good" reference condition (NPS 2014b, Lynch et al. 2011). No moderate and significant concern levels have been established by NPS. Based upon the limited amount of data collected, 05 May–18 June 2014 for approximately 10 days each site), no trend can be established. Additionally, the data is ~5 years old and from one observational window, data quality is considered low.
Reduction in listening area (difference between human and natural ambient sounds)	The two backcountry sites (Kin Klizhin and Pueblo Alto) revealed nearly 50% reduction in listening area during the day. Sound levels at the frontcountry "Visitor Center" site for nighttime monitoring reported a 37% reduction in listening area. For the two frontcountry sites, there was over 75% reduction in listening area.		Percent reduction in listening area is due to within-park sources. Oil and gas exploration continues to expand towards the park boundary and noise associated with this activity is likely to intensify. Data collected is ~5 years old, thus, confidence is medium.
Geospatial sound model (LA_{50} impact)	Mean impact modeled at 2.1 decibels (dB); the minimum to maximum ranges from 2.2 dB in areas with the least impact to 8.8 dB in areas with greatest impact (Nelson 2015).		The average value (2.1 dB) warrants "moderate" concern. The minimum (2.2 dB) and maximum (8.8 dB) impact values range from "moderate" to "significant concern" (NPS 2014b; Nelson 2015). No trend is possible given the nature of the dataset. Confidence is medium as this model was generated using data from five years ago.

4.3.1. Background and Importance

The natural soundscape (or acoustic environment) is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies (§ 4.9) require the NPS to preserve the park's acoustic environment and restore it, when degraded, to the natural condition wherever possible. Additionally, NPS is required to prevent or minimize degradation of the natural acoustic environment from noise (i.e., inappropriate/undesirable human-caused sound). Although the management policies currently refer to the term *soundscape* as “the totality of the perceived acoustical environment” (Turina et al. 2013) that occur in a park, it may be further described as the total amount of ambient noise in an area, measured in terms of frequency and amplitude (decibels; Ambrose and Burson 2004). From a management perspective, acoustic environment is a combination of both what humans and other species may aurally perceive. The physical sound resources (i.e., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location are referred to as the *acoustic environment*, while the human perception of that *acoustic environment* is defined as the *soundscape*. Clarifying this distinction will allow managers to create objectives for safeguarding both the *acoustic environment* and the *visitor experience*.

NPS has been working for several decades to establish baseline conditions, as well as to develop measuring and monitoring methods for acoustic environments in national parks (Miller 2008). Their efforts have been geared towards visitor experiences (Miller 2008; Lynch et al. 2011) with relatively few studies examining the impacts of anthropogenic noise on wildlife populations (Barber et al. 2011; Brown et al. 2012; Francis and Barber 2013; Buxton et al. 2017). Other studies have shown the negative impacts of human-generated noise on birds (Dooling and Popper 2007; Habib et al. 2007; Slabbekoorn and Ripmeester 2008; Francis et al. 2009; Francis et al. 2011a), bats (Schaub et al. 2008), rodents (Shier et al. 2012), frogs (Barber et al. 2010; Bee and Swanson 2007), and invertebrates (Morley et al. 2014). Although 120 different studies have examined the impacts of noise on wildlife populations, ~43% focused on the effects of environmental and transportation noise on vocal behavior (Shannon et al. 2016).

The effects of noise on wildlife is very complex and varies by species and taxa. Unfortunately, there have been no comprehensive efforts to examine the effects of all potential noise sources on wildlife (Shannon et al. 2016). However, roads and energy development facilities are known to negative impact wildlife (Barber et al. 2011; Newman et al. 2014). Road noise can alter animal behavior, movement patterns, ability to find prey, and breeding processes (Reijnen and Foppen 2006; Bee and Swanson 2007; Barber et al. 2011; Siemers and Schaub 2011), while noises associated with energy development are often incessant and have been associated with increased levels of chronic stress on animals near these sites (Bayne et al. 2008; Barber et al. 2009; Francis et al. 2011b; Blickley et al. 2012; Souther et al. 2014). Some species are capable of adapting to long-term anthropogenic noise sources in their environment, while others cannot (Barber et al. 2010). Research further suggests that given the complex nature of sounds and that impacts at individual and population scales may affect organisms at the ecosystem and process levels, ambient and pulsed noise levels perceived by wildlife should be examined and addressed at multiple spatial and temporal scales (Slabbekoorn and Halfwerk 2009; Barber et al. 2011; Dumyahn and Pijanowski 2011a, 2011b). For example, an increase of 4 decibels (dB) in the median background sound pressure level represents a reduction in listening area for wildlife and visitors of 60% (Wood 2015). If a predator can hear a potential prey animal in an area of 100 square feet in a setting with natural ambient sounds, that animal’s ability to hear would be reduced to 40 square feet if the median background sound pressure level was increased by 4 dB. Park visitors would experience similar reductions in their ability to hear natural sounds, which would affect their park experience.

Aircraft noise intrusions include air tour (fixed wing aircraft and helicopters), commercial general aviation, military, and other aircraft sounds (NPS 2018d). These acoustic disruptions are linked to negative health effects on humans (Morrell et al. 1997; Hygge et al. 2002; Jarup et al. 2008). Additionally, aircraft overflights have been shown to disturb behavior and alter time budgets of harlequin ducks (*Histrionicus histrionicus*; Goudie 2006) and mountain goats (*Oreamnos americanus*; Goldstein et al. 2005), while aircraft noise simulations evoked escape behaviors of nesting bridled (*Sterna anaethetus*) and crested (*S. bergii*) terns (Brown 1990).

4.3.2. Data and Methods

<u>Acoustic Monitoring</u>

Acoustic monitoring was conducted from 05 May through 18 June 2014 at four acoustical monitoring systems (for approximately 10 days each site; Fig. 4.3.2-1). Using two Larson Davis 831 sound level meters, natural ambient sound levels were estimated and all audible anthropogenic sound sources were identified (Nelson 2015). Continuous, one-second, A-weighted sound levels and their associated one-third octave-band un-weighted spectrum from 20 to 20,000 Hz acoustic data were collected. To obtain daytime and nighttime datasets, data were collected continuously, then day and night periods (0700 to 1900 hr and 1900 to 0700 hr) were analyzed to identify trends in daily variation. To calculate the "percentage of time audible", we used the percentages calculated for percentage of all aircraft and other audible human noise for both summer and winter. For a general measure representative of broad changes that can account for the reduction in listening area, we used the LA_{50} metric, which represents the median sound level during a specified period, and includes energy generated by all sound sources, both natural and anthropogenic. This metric represents the sound level exceeded 50 percent of a specific time period. For example, for a dataset representing 50 samples (or data points) within a measurement period, the samples are sorted from highest sound level to lowest sound level with the twenty-fifth sound level (or the median) as the 50th-percentile.

In general and as expected, the backcountry was characterized by less anthropogenic noise than the frontcountry. At the backcountry monitoring site, sound was primarily natural (wind gusts and through vegetation) but included aircraft and motor-related (including the Visitor Center generator and more-distant unidentified low frequency humming noises; Nelson 2015). The frontcountry monitoring site was characterized primarily by visitor-related (vehicles on the Administrative Road and the parking lot, and voices) noise with the occasional aircraft and Visitor Center generator were also audible (Nelson 2015).

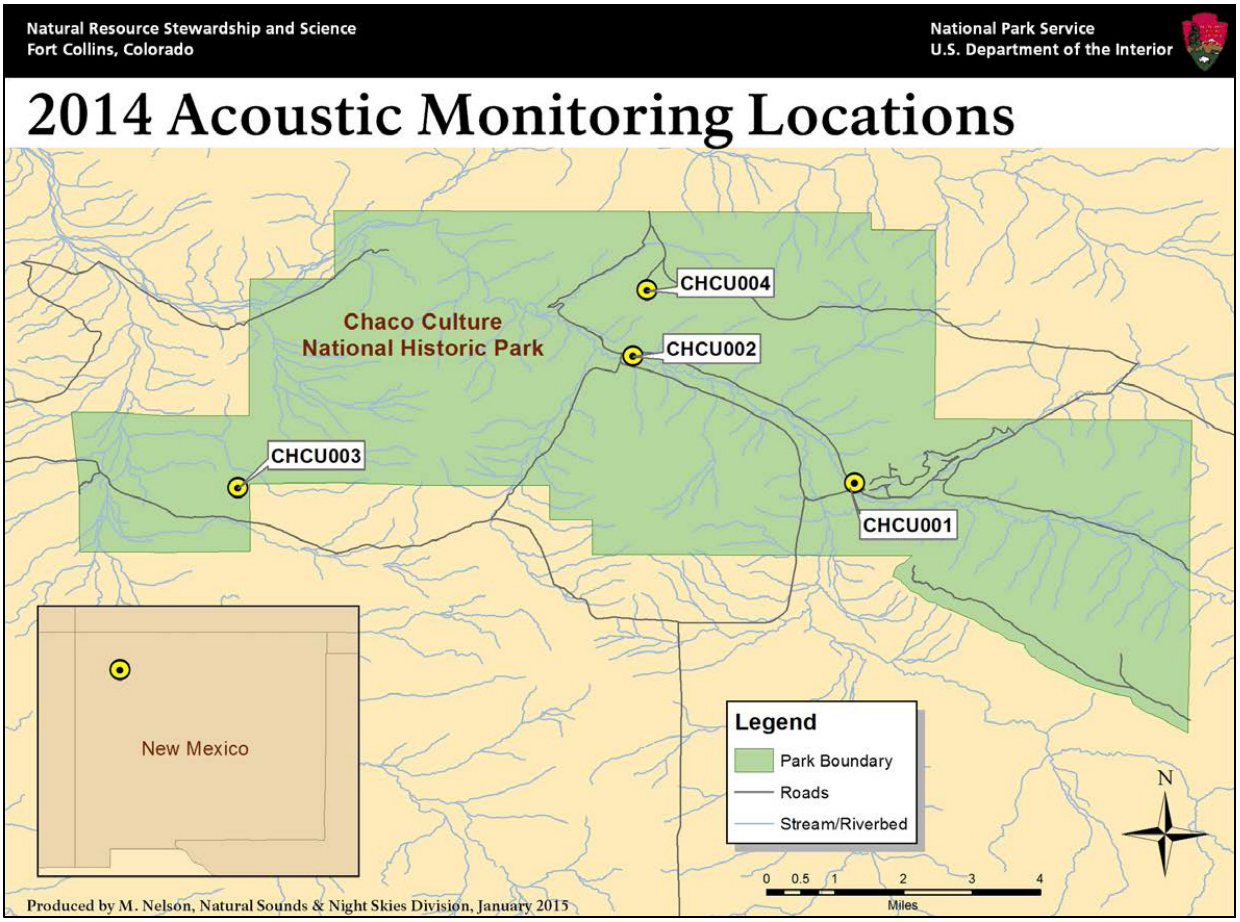


Figure 4.3.2-1. Locations of acoustic monitoring stations, Chaco Culture National Historical Park, New Mexico (from Nelson 2015).

<u>Air Tours</u>

There are a maximum of 147 tours are permitted each year to fly over the park per interim operating authority (IOA, the annual limit of tours; Lignell 2018). The number of actual air tour flights ranged from 49 to 76 per year over the past five years (NPS 2013, 2014b, 2015b, 2016b; Lignell 2017; Table 4.3.2-1).

Table 4.3.2-1. Summary of commercial aircraft tours operating over Chaco Culture National Historical Park from 2013 – 2017 (NPS 2013, 2014b, 2015b, 2016b; Lignell 2017).

Year	Number of Tours
2013	68
2014	72
2015	76
2016	58
2017	49

Modeling Landscape-level Acoustic Conditions: The NPS Natural Sounds and Night Skies Division (NSNSD) predicted anthropogenic noise impacts at the landscape scale using the geospatial sound (LA_{50} Impact) model developed by Mennitt et al. (2013). This geospatial sound model predicts A-weighted median sound levels (LA_{50}) to represent average listening conditions, which was based on summer daytime (0700 – 1900 hr). A weighted 1 second sound level measurements. The difference between predicted existing and predicted natural sound levels provides an average of how much anthropogenic noise is increasing the existing sound level above the natural sound level. Sound pressure levels for the continental United States were predicted using actual acoustic measurements combined with explanatory variables including location, climate, land cover, hydrology, wind speed, and proximity to noise sources (roads, railroads, and airports). Predictions were made for daytime impacts during midsummer. Impacts were determined by taking the difference between the "existing" (including anthropogenic noise) and "natural" ambient sounds levels (both variables were predicted by the model). The model employed a 270 meter pixel resolution. Levels in national parks may vary greatly, depending on location, topography, vegetation, biological activity, weather conditions and other factors. For example, the din of a typical suburban area fluctuates between 50 and 60 dB, while the crater of Haleakala National Park is intensely quiet, with levels around 10 dB (Wood 2015). To examine the variation of anthropogenic noise at CHCU, a park-specific impact map was generated from this national geospatial model.

<u>Indicators & Measures</u>

Indicator
Level of anthropogenic noise (metric directly measured)
Measures
Mean time audible

Based upon data from 189 acoustic monitoring sites in 43 national parks, the median percent time audible of anthropogenic noise during daytime hours was 35% (Lynch et al. 2011); however, the data and median percent time audible does not differentiate between urban and non-urban national parks. We used the value provided by Lynch et al. (2011) as the reference condition for "good" if it was ≤ 35% (e.g., McKenna et al. 2016; Table 4.3.2-2). Moderate and significant concern conditions have not been examined or established by the NPS (K. Nuessly, pers. com. 2018); thus, this indicator was not assessed. Using data from CHCU acoustic monitoring sites, only the front country sites exceeded 35% dB; these were 60.3 and 45.6% for the Visitor Center and Downtown Chaco, respectively. (Nelson 2015; Table 4.3.2-3).

Table 4.3.2-2. Reference conditions used to assess measures of sound levels, Chaco Culture National Historical Park, New Mexico. Reference conditions for percent reduction in listening area and geospatial (LA50 impact) model from NPS (2014a).

Indicator	Measure	Good	Moderate	Significant Concern
Sound Pressure Level	% time audible	≤35%	Not established	Not established
	% reduction in listening area (non-urban parks)	Reduced by ≤30% (Difference between sound pressure levels is ≤ 1.5)	Reduced by 30–50% (Difference between sound pressure levels is >1.5 and ≤ 3.0)	Reduced by > 50% (Difference between sound pressure levels is >3.0)
	Geospatial (LA_{50} impact) model, non-urban parks (Mean LA_{50} impact)	Listening area reduced by ≤30% (Difference between sound pressure levels is ≤ 1.5 dB)	Listening area reduced by 30–50% (Difference between sound pressure levels is >1.5 and ≤ 3.0 dB)	Listening area reduced by > 50% (Difference between sound pressure levels is >3.0 dB)

Table 4.3.2-3. Summary of acoustic observer log data for front- and back-country sites from May through June 2014; Mean time audible (over the 24 hr period) in percent of a 24 hour day, Chaco Culture National Historical Park, New Mexico (Nelson 2015).

Acoustic Zone/ Season	Visitor Use	Mean Time Audible (%)
Front-country	High	–
Visitor's Center (CHCU001)	–	60.3*
Downtown Chaco (CHCU002)	–	45.6*
Back-country	Low	–
Kin Klizhin (CHCU003)	–	20.4
Pueblo Alto (CHCU004)	–	23.1

* Indicates exceedance of 35% dB (or what is considered a "good" condition).

Indicator

Level of anthropogenic noise (metric directly measured)

Measures

Reduction in listening area

Listening area is the defined as the area within which an animal may perceive sound. Deviation from natural ambient can be used to identify reductions in listening area and alerting distance. Reduction in listening area quantifies the loss of hearing ability to humans and wildlife as a result of an increase in ambient noise level. Under natural ambient conditions a sound is audible within a certain area around visitors or wildlife. If the background sound pressure level is increased due to a noise event, the area in which the sound is audible decreases. The reduction in listening area is calculated from difference between existing ambient levels (i.e., anthropogenic noise) and natural ambient levels (which exclude anthropogenic sound; NPS 2014b). Barber et al. (2010) quantified these effects and found that seemingly small increases in sound level can have substantial impacts in terms of loss of listening area. From the difference between LA_{50} existing ambient sound, we can determine the percentage reduction in listening area (Barber et al. 2009). The estimated decreases in listening area due to an increase in background sound levels are summarized in Table 4.3.2-4.

Table 4.3.2-4. Increases in background sound pressure level at one decibel (dB) increments with resultant decreases in listening area (NPS 2014b).

Increase in background sound pressure level (dB)	Decrease in listening area
1	21%
2	37%
3	50%
4	60%
5	68%
6	75%
7	80%
8	84%
9	87%
10	90%

During the day, monitoring at the two backcountry sites (Kin Klizhin and Pueblo Alto) revealed nearly 50% reduction in listening area. Sound levels at the frontcountry Visitor Center site for nighttime monitoring reported a 37% reduction in listening area. For the two front-country sites (Visitor Center and Downtown Chaco) there was over 75% reduction in listening area. Refer to Tables 4.3.2-4 and 4.3.2-5.

Table 4.3.2-5. Existing ambient daytime, natural ambient daytime, and percent reduction in listening area (dB) for front- and backcountry sites for summer (05 May through 18 June 2014), Chaco Culture National Historical Park, New Mexico (from Nelson 2015). In the "difference between existing and natural" ambient LA50 column, † indicates levels 21 to ~50% reduction, while ∇ represents a >75% reduction in listening area; both categories are of "significant concern.".

Location	Acoustic Zone/ Season	Median Existing Ambient LA_{50} (dB)		Median Natural Ambient LA_{50} (dB)		Difference between Existing & Natural	
		Day	Night	Day	Night	Day	Night
Front country	Visitor's Center	33.6	20.2	26.6	18.4	∇7.0	†1.8
	Downtown Chaco	30.9	21.0	24.3	19.8	∇6.6	1.2
Backcountry	Kin Klizhin	42.0	21.5	39.6	20.6	†2.4	0.9
	Pueblo Alto	36.8	21.5	34.3	20.5	†2.5	1.0

Indicator
Level of anthropogenic noise (predicted by model)

Measures
Geospatial Sound Model (LA_{50} Impact)

Geospatial sound models are used to provide a spatial understanding of natural and existing ambient in the park. The limitations of the monitoring data are that they provide a spatial and temporal snapshot into the state of the acoustic environment. These conditions may change with spatial and temporal extent. Average values represent the median summer daytime LA_{50} value occurring within the park boundary, and visitors may experience sound levels higher and lower than the average noise impact (LA_{50}). This value is calculated by subtracting the natural ambient from the existing ambient for the maximum values was 8.8 dB above natural conditions in the most impacted areas and 2.2 in the least impacted areas; for overall mean values the difference was 2.1 dB (Table 4.3.2-6). The average value (2.1 dB) warrants “moderate” concern. The minimum (2.2 dB) and maximum (8.8 dB) impact values range from “moderate” to “significant concern” (NPS 2014b; Nelson 2015). No trend is possible given the nature of the dataset. Confidence is medium as this model was generated using data from five years ago. Figure 4.3.2-2 provides the spatial representation of modeled median impact sound levels in the park. Maps for existing and natural acoustic environment condition maps are provided in Appendix B.

Table 4.3.2-6. Minimum, maximum, and median values (in dB) of modeled LA50 measurements, Chaco Culture National Historical Park, New Mexico (NPS 2014b).

Acoustic Environment Condition	Minimum	Maximum	Mean
Existing	24.4	34.9	26.1
Natural	22.3	26.1	24.0
Impact	**2.2**	**8.8**	**2.1**

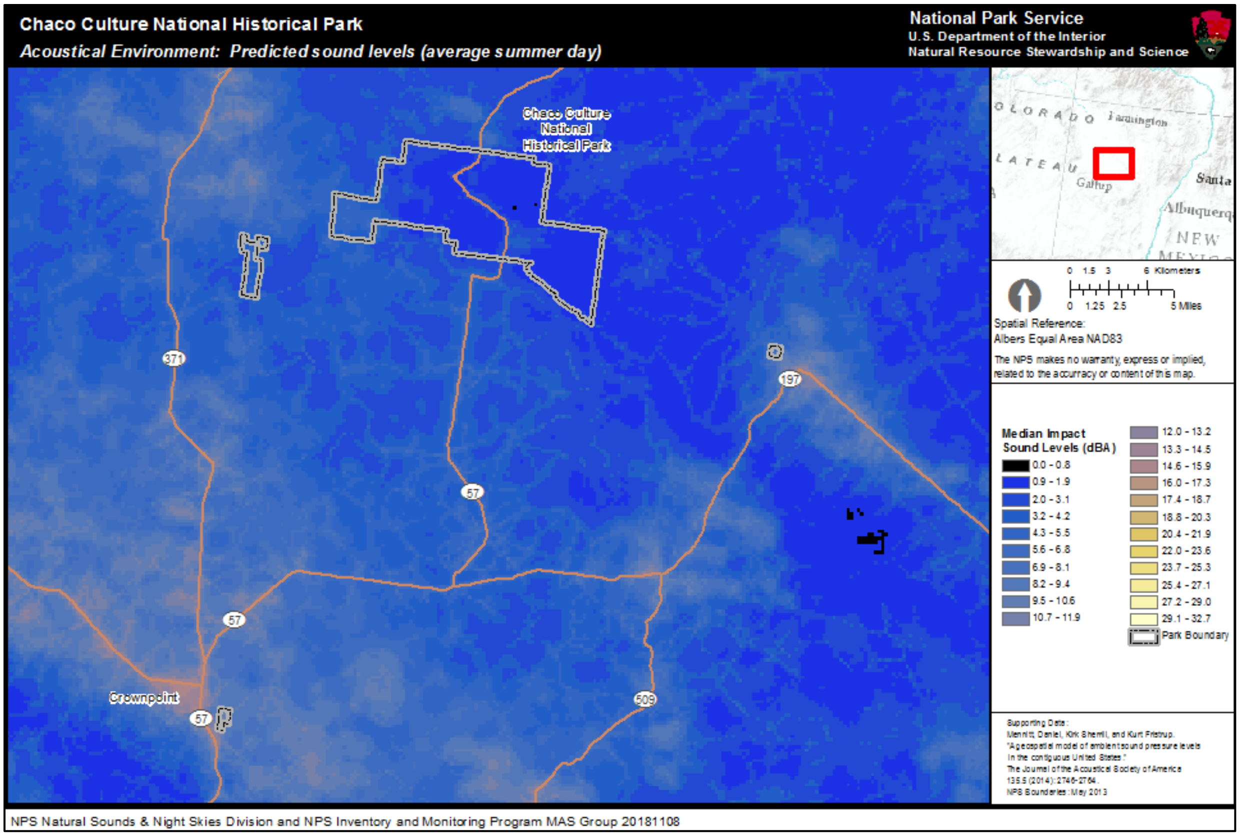


Figure 4.3.2-2. Median sound level impact map generated by the LA50 dB impact map using version 3.2 of the geospatial model, Chaco Culture National Historical Park, New Mexico. Color scale indicates how much anthropogenic noise raises the existing sound levels in a given location (measured in A-weighted decibels, or dB). Black and dark blue colors indicate low impacts while gradating to lighter colors (lighter blue through light yellow) indicate greater impacts (Mennitt et al. 2013).

4.3.3. Reference Conditions

Reference conditions should address the effects of noise on human health and physiology, the effects of noise on wildlife, the effects of noise on the quality of the visitor experience, and finally, how noise impacts the acoustic environment itself (NPS 2014a). Various characteristics may be used to gauge how anthropogenic noise affects the acoustic environment including rate of occurrence, duration, amplitude, pitch, and whether the sound occurs consistently or sporadically. To capture these characteristics, the quality of the acoustic environment is assessed using a number of different metrics including existing ambient and natural ambient sound level (measured in decibels), percent time human-caused noise is audible, and noise free interval. In summary, to develop a complete understanding of a park's acoustic environment, a variety of sound metrics should be considered. This can make selecting one reference condition difficult. For example, if natural ambient sound level was the reference condition, only sound pressure level would be examined and other aspects of the acoustic environment mentioned above would be overlooked.

In cases where on-site measurements have not been gathered or are limited, one may reference meta-analyses of national park monitoring efforts such as those detailed in Mennitt et al. (2013). The mean

LA_{50} impact model compiled data from 291 park monitoring sites across the U.S. and is at least five years old. Because this is a continental model, scale is 270 m resolution. Through this effort, Mennitt et al. (2013) revealed the median daytime existing sound level in national parks is ~31 dB. NPS (2014a) provided further interim guidance for interpretations of this model, which consist of values of ≤ 1.5 dB as representing a "good" condition, between >1.5 and ≤ 3.0 as "moderate", and >3.0 dB as "significant concern."

At CHCU, mean impact is predicted to be 2.2 decibels (dB) and ranges from 0.68 dB in areas with the least impact to 12.16 dB in areas with more impact (Mennitt et al. 2013). Thus, the average impact across the park (with the influence of man-made sounds) is predicted to be 2.2 decibels above the natural ambient sound level.

4.3.4. Condition and Trend

<u>Overall Condition and Trend</u>
Based upon the 2014 data, the most common sources of anthropogenic noise were aircraft, vehicular traffic, the CHCU Visitor Center generator, other unidentified low frequency humming sounds, and people (Nelson 2015).

<u>Level of Confidence</u>
Conditions of the three metrics (percent time audible and percent reduction in listening area; Nelson 2015), and the national geospatial (LA_{50} impact) model were accessed (Mennitt et al. 2013). As data used to derive percent time audible and percent reduction in listening area measures were ~5 years old, collected during one summer season, and oil and gas exploration continues to expand towards the park boundary, confidence is medium.

<u>Emerging Issues</u>
A common source of noise in national parks is transportation (i.e., airplanes, vehicles). Growth in transportation is increasing faster than is the human population (Barber et al. 2010). Between May 1993 and May 2018, traffic on U.S. roadways increased by 29.44 % from 2,269,835 to 3,216,841 vehicle miles (3,652,945 to 5,177,004 km; US DOT 2018). Commercial air tours have fluctuated over the past five years; however, as park visitation increases this may also result in a larger number of air tours. As these noise sources increase throughout the United States, the ability to protect pristine and quiet natural areas becomes more difficult (Mace et al. 2004). As oil and gas exploration continue to expand closer to the boundaries of CHCU, it is likely that noise associated with these operations will intensify and further impact the acoustic environment.

<u>Data Gaps & Needs</u>
With respect to the effects of noise, there is compelling evidence that wildlife can suffer adverse behavioral and physiological changes from noise and other human disturbances, but the ability to translate that evidence into quantitative estimates of impacts is presently limited (NPS 2015b). Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife and the habitats we share. The majority of research on wildlife has focused on acute noise events, so further research needs to be dedicated to chronic noise exposure (Barber et al. 2011). In addition to wildlife, standards have not been developed for assessing the quality of physical sound

resources (the acoustic environment), separate from human or wildlife perception. Scientists are also working to differentiate between impacts to wildlife that result from the noise itself or the presence of the noise source (NPS 2015b).

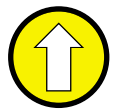
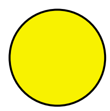
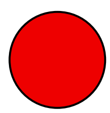
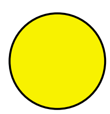
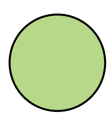
4.3.5. Sources of Expertise

Emma Brown, NPS Natural Sounds and Night Skies Division, Ft. Collins, CO, provided guidance in selecting the measures to access and reviewed this document. Additionally, NSNSD scientists aid NPS park units in managing anthropogenic sounds to best address the various expectations of visitors. They provide technical assistance to parks in the form of acoustic monitoring, data collection and analysis, and in developing acoustical baselines for planning and reporting purposes. For more information, go to https://www.nps.gov/orgs/1050/index.htm.

4.4. Air Quality

A summary of all assessed conditions for air quality is provided in Table 4.4-1.

Table 4.4-1. Condition assessment summary for air quality, Chaco Culture National Historical Park, New Mexico.

Measure	Indicator	Condition Status/Trend	Summary
Visibility	Haze Index		"Moderate concern" based the 2012–2016 estimated visibility on mid-range days of 2.9 deciviews above estimated natural conditions (2.7 deciviews) (NPS 2019b). For 2007–2016, the trend in visibility at CHCU improved both on the 20% clearest and haziest days, resulting in an overall improving visibility trend (IMPROVE Monitor ID: BAND1, NM).
Ozone	Human Health: Annual 4th-Highest daily maximum 8-hour concentration		"Moderate concern" based on the 2012–2016 estimated ozone of 66.3 parts per billion (NPS 2019b).
	Vegetation Health: 3 month Maximum 12 hr W126		"Significant concern" based on 2012–2016 estimated W126 metric of 12.6 parts per million-hours (NPS 2019b).
Deposition	Wet nitrogen deposition		"Moderate concern" based the 2011–2015 estimated wet nitrogen deposition of 0.9 kilograms per hectare per year and a risk assessment that concluded that ecosystems at CHCU may be very highly sensitive to nitrogen-enrichment effects (Sullivan et al. 2011c; Sullivan et al. 2011d).
	Wet sulfur deposition		"Good" condition based on the 2012–2016 estimated wet sulfur deposition of 0.4 kg/ ha/ yr.

4.4.1. Background and Importance

Most visitors who come to national parks expect clean air and clear views. However, air pollution on NPS lands may result in a combination of negative impacts including adverse effects on ecosystems and human health concerns (NPS 2018e), as well as diminished scenic views and visitor experience (NPS 2018e). In addition to safeguards provided by the NPS Organic Act, the Clean Air Act (CAA) provides a national goal "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic or historic value" (USFR 1963). 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.

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 2008). While Chaco Culture National Historical Park (CHCU) is designated as a Class II airshed, the NPS Organic Act and the NPS management policies direct that all units of the National Park System be managed so as to protect resources for the benefit of the current and future generations.

For many parks and monuments, air quality related values may include wilderness character, biodiversity, scenic views, night sky, vegetation, wildlife, soil, and other resources that could be degraded by air pollution. Local and distant air pollutant sources—including power plants, oil and gas development, and the industrial and urban areas of southern California, southern Arizona, and northern Mexico—may degrade air quality at the park. In addition to human caused pollution, sand and dust from dry washes during high winds and smoke from wildfire can contribute to reduced visibility (EPA 2018a).

Air pollutants of concern include nitrogen (N) and sulfur (S) compounds (including nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]), ground-level ozone (O_3) and fine particulates (Sullivan 2016). Potential effects to humans include visibility impairment, and ozone-induced human health problems.

<u>Visibility</u>

Air pollution can create a white or brown haze that affects how well and far we can see. Both particulate matter (e.g. soot and dust) and certain gases and particles in the atmosphere, such as sulfate and nitrate particles, can create haze and reduce visibility (Sullivan 2016). During the night, air-borne particulates reflect and scatter artificial light, increasing the effect of light pollution (NPS 2018e). The CAA established a national goal to return visibility to "natural conditions" in Class I areas and the NPS ARD recommends a visibility benchmark condition for all NPS units, regardless of Class designation, consistent with the Clean Air Act goal (Taylor 2017). Natural visibility conditions are those estimated to exist in a given area in the absence of human-caused visibility impairment (EPA 2003).

<u>Ozone</u>

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NOx) from vehicles, power plants, industry, and fire and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Biel 2011). It is one of the most widespread air pollutants and the major constituent in smog (NPS 2018f). In addition to causing respiratory problems in people, ozone can injure plants. Ozone enters leaves through pores (stomata), where it can kill plant tissues, causing visible injury or reduced survival (NPS 2018f). 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 exists when the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions, particularly adequate soil moisture, foster gas exchange and the uptake of ozone by plants (Kohut 2007).

A risk assessment that considered ozone exposure, soil moisture, and sensitive plant species concluded that the condition at CHCU was "low" (Kohut 2007). Ozone concentrations and cumulative doses at the park are high enough to induce foliar injury to sensitive vegetation under certain conditions (Binkley et al. 1997). While the park's arid conditions often cause plant stomata to close, limiting water loss and ozone uptake, Kohut et al. (2012) reported that within mesic areas, such as along streams and seeps in the Intermountain West, plants may keep stomata open more often resulting in ozone uptake and subsequent injury. There are eight known native ozone-sensitive plants in the park including **Artemisia ludoviciana* (cudweed sagewort), *Mentzelia albicaulis* (white blazingstar), **Populus fremontii* (Fremont's cottonwood), *Salix exigua* (coyote willow), *S. gooddingii* (Gooding's willow), *Prunus virginiana* (chokecherry), *Parthenocissus quinquefolia* (American ivy), *P. vitacea* (Virginia creeper; Kohut 2007, NPS 2019c); species with an * are biological indicators (NPS 2019c).

<u>Nitrogen and Sulfur Deposition</u>
Nitrogen and sulfur compounds in air pollution (e.g., from industry, agriculture, oil, and gas development) can deposit into ecosystems and cause acidification, excess fertilization, and changes in soil and water chemistry that can affect community composition and alter biodiversity (Fowler et al. 2013; Sullivan 2016; NPS 2018g).

Although nitrogen is an essential plant nutrient, surplus levels of atmospheric nitrogen deposition can stress ecosystems. Increases in nitrogen have been found to promote invasions of fast-growing alien plant species of annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and forbs (e.g., Russian thistle [*Salsola tragus*]) at the expense of native species (Brooks 2003; Schwinning et al. 2005; Allen et al. 2009). Expansion of alien grass species can increase fire risk (Rao et al. 2010) with profound implications on biodiversity within non-fire adapted ecosystems. Nitrogen may also decrease water use efficiency in arid land plant groups, such as sagebrush (Inouye 2006). Modeled deposition of nitrogen at CHCU does not exceed critical loads measured by the NPS, refer to NPS-ARD (2019) for more information.

Sulfur, together with nitrogen, can acidify surface waters and soils, which can result in losses in biodiversity, the release of toxic aluminum, and upset balances in nutrient cycling. CHCU ecosystems were identified as having "moderate" sensitivity to acidification effects (Sullivan et al. 2011c; Sullivan et al. 2011d). This rating was based on conditions including steep slope, high elevation headwater streams, and the abundance of surface water and vegetative types expected to be most sensitive to acidification. Surface waters along the Colorado Plateau are well-buffered from acidification, but smaller, intermittent and ephemeral streams may have little opportunity to buffer potentially acidic run-off (Binkley et al. 1997).

Air Quality Standards

Air quality is deteriorated by many forms of pollutants that either occur as primary pollutants, emitted directly from sources such as power plants, vehicles, wildfires, and wind-blown dust, or as secondary pollutants, which result from atmospheric chemical reactions. The CAA requires the U.S. Environmental Protection Agency (EPA) establish National Ambient Air Quality Standards (NAAQS) (USFR 2015) to regulate air pollutants considered harmful to human health and the environment. The two types of NAAQS are primary and secondary, with primary standards establishing limits to protect human health, and secondary standards establishing limits to protect public welfare from air pollution effects including decreased visibility, and damage to animals, crops, vegetation, and buildings.

The NPS Air Resources Division (NPS-ARD) air quality monitoring program uses EPA's NAAQS, natural visibility goals and ecological thresholds as benchmarks to assess visibility, ozone, and atmospheric deposition (Taylor 2017). Additionally, critical loads should also be examined when determining the extent of deposition impacts (i.e., nutrient enrichment) of nitrogen to park resources. A critical load is defined as "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt 1988).

4.4.2. Data and Methods

NPS-ARD uses all available data from NPS, EPA, state, and/or tribal monitoring stations to calculate air quality values. Trends are calculated from data collected over a 10-year period at on-site or nearby representative monitoring stations. For data to be included, it must be at least a six-year dataset and have data for the end year of the reporting period (i.e., a complete annual dataset for year 6). Statistical analyses are used to identify significant trends.

This assessment used methods developed by the NPS Air Resources Division (NPS-ARD) for Natural Resource Condition Assessments (NPS-ARD 2018). Conditions & Trends website (NPS 2019b) provides additional information on visibility, ozone, and nitrogen and sulfur deposition for CHCU. For this assessment, we include three indicators (visibility, ozone level, and N and S deposition) and five measures (haze index, annual 4th-highest 8-hr ozone concentration for human health, 3-month maximum 12-hr W126 for vegetation, sulfur wet deposition and nitrogen wet deposition).

Indicators & Measures

Indicator Visibility **Measures** Haze Index

Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. Visibility is expressed by the haze index in deciviews (dv), which is scored as a zero in pristine conditions and increases as visibility decreases. Haze index is a measure that corresponds to uniform incremental changes in visual perception across the entire range of conditions from pristine to highly impaired (Taylor 2017).

NPS-ARD assesses visibility condition status based on the estimated 5-year average haze index on the mid-range days minus the estimated natural visibility (i.e., those estimated for a given area in the absence of pollution). Mid-range days are where visibility is between the 40th and 60th percentiles. Annual measurements on mid-range days are averaged over a 5-year period at each visibility monitoring site with at least 3-years of complete annual data. Five-year averages are taken across all monitoring locations.

Visibility trends are computed from the annual haze index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the CAA and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. Although this legislation provides special protection for NPS lands designated as Class I designated viewsheds, the NPS applies these metrics to all units of the NPS. If the haze index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating. Otherwise, the Haze Index trend on the 20% haziest days is reported as the overall visibility trend. Monitoring data from the IMPROVE BAND1, NM site (operating since 3/2/1988) were used to determine the 10-year visibility trend at CHCU. This instrument is located approximately 100 miles (~160 km) to the east of CHCU.

Indicator Ozone Level **Measures** Human Health: Annual 4th-highest daily maximum 8-hr Concentration

Aggregated ozone data were acquired from the EPA Air Quality System (AQS) database. Prior to 2012, monitoring data were also obtained from the EPA Clean Air Status and Trends Network (CASTNet) database. Ground-level ozone is calculated using two statistics: 4th-highest daily maximum 8-hour average ozone concentration (human health risk measure), and 3-month maximum 12-hour W126 Index (vegetation health risk measure; Taylor 2017).

Human health risk from ozone trends are evaluated annual 4th-highest 8-hr Concentration values. The primary National Ambient Air Quality Standards (NAAQS) for ground-level ozone was set by the U.S. EPA and is based on human health effects. The 2015 NAAQS for ozone is a 4th-highest daily maximum 8-hour ozone concentration of 70 parts per billion (ppb). 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 at all monitoring sites. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The ozone condition for human health risk at CHCU is the maximum estimated value within the park boundary derived from this national analysis (Taylor 2017).

Human health risk from ozone trends are evaluated annual 4^{th}-highest daily maximum 8-hour average ozone concentration values over a 10-year period. Since the monitor at CHCU (AQS ID: 350450020) has only operated since February 2017, there are not enough monitoring data to compute trends.

Indicator

Ozone Level

Measures

Vegetation Health: 3 month Maximum 12 hr W126

Exposure indices are biologically relevant measures used to quantify plant response to ozone exposure. These measures are better predictors of vegetation response than the metric used for the human health standard. One annual index is the W126, which preferentially weighs the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours (8AM–8PM). The highest 3-month period that occurs from March to September is reported in “parts per million-hours” (ppm-hrs) and is used for vegetation health risk from ozone condition assessments.

Annual 3-month maximum 12-hour W126 index values are averaged over a 5-year period at all monitoring sites with at least 3 years of complete annual data. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for vegetation health risk at CHCU is the maximum value within the park boundary derived from this national analysis.

Vegetation health risk from ozone trends are evaluated annual 3-month maximum 12-hour W126 index values over a 10-year period. Since the monitor at CHCU (AQS ID: 350450020) has only operated since February 2017, there are not enough monitoring data to compute trends.

Indicator
Wet Deposition
Measures
Nitrogen wet deposition & Sulfur wet deposition

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

Wet deposition is used as a surrogate for total deposition (wet plus dry) because wet deposition is the only metric nationally monitored source for nitrogen and sulfur deposition data. Wet deposition values for nitrogen (N) and sulfur (S) from sulfate are expressed as amount of N or S in kilograms deposited over one-hectare area in one year (kg/ha/yr).

For N and S condition assessments, wet deposition was calculated by multiplying nitrogen (from ammonium and nitrate) or sulfur (from sulfate) concentrations in precipitation by a normalized precipitation. Annual wet deposition is averaged over a 5-year period at monitoring sites with at least three years of annual data. National five-year averages were calculated using data from all monitoring locations across the contiguous U.S. For NPS park units, maximum values are estimated from these data, which are then assigned the condition status.

Wet nitrogen and sulfur deposition trends are typically calculated using pollutant concentrations in precipitation (micro equivalents/liter). For CHCU, trends are not available because there is no representative wet deposition monitor.

4.4.3. Reference Conditions

The reference conditions for which current air quality parameters were assessed are identified by NPS-ARD (Taylor 2017) for NRCAs and list in Table 4.4.3-1.

Visibility (Haze Index)

A visibility condition estimate of less than 2 deciviews (dv) above estimated natural conditions is considered "good", estimates ranging between 2 and 8 dv above natural conditions is "moderate concern" and estimates greater than 8 dv above natural conditions is "significant concern." The NPS-ARD uses reference condition ranges to reflect the variation in visibility conditions across the monitoring network (Taylor 2017). Natural visibility conditions are those estimated to exist in a given area in the absence of human-caused visibility impairment. Based upon data from 2012–2016, estimated annual average natural condition on mid-range days equals 2.9 deciviews (dv), above estimated natural conditions (2.7 dv; NPS 2019b), at CHCU.

Level of Ozone: Human Health

Human health ozone condition thresholds are based on the 2015 EPA ozone standard, which is the safe level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 70 ppb (Taylor 2017). The NPS-ARD rates ozone condition as "good" if the ozone concentration is less than or equal to 54 ppb. This is congruent with the updated Air Quality Index breakpoints (Taylor 2017), where "moderate concern" is between 55 and 70 ppb, and "significant concern" when greater than or equal to 71 ppb.

<u>Level of Ozone: Vegetation Health</u>
The W126 condition thresholds are based the EPA's Policy Assessment for the Review of the Ozone NAAQS (Taylor 2017). For W126 values of ≤ 7 ppm-hrs results in tree seedling biomass loss is ≤ 2 % per year in sensitive species, and ≥13 ppm-hrs facilitates tree seedling biomass loss is 4-10 % per year in sensitive species (EPA 2014; Taylor 2017). NPS-ARD identified a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation, which is considered "good", 7-13 ppm-hrs is considered "moderate concern" and >13 ppm-hrs is "significant concern" (Taylor 2017).

<u>Wet Deposition: Nitrogen and Sulfur</u>
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 is 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 and in the Pacific Northwest. 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" (Taylor 2017)(Table 4.4.3-1).

Table 4.4.3-1. NPS-ARD reference conditions (Taylor 2017; NPS-ARD 2018) for both conditions and measures.

Air quality indicator	Significant Concern	Moderate	Good
Visibility (dv)	>8	2–8	< 2
Ozone: Human Health (ppb)	≥ 71	55–70	≤ 54
Ozone: Vegetation Health (ppm-hrs)	>13	7–13	<7
N and S Wet Deposition (kg/ha/yr)	>3	1–3	< 1

4.4.4. Condition and Trend
The values used to determine conditions for all air quality indicators and measures are listed in Table 4.4-1.

<u>Visibility (Haze Index)</u>
Visibility warrants moderate concern. Status is based on the 2012–2016 estimated visibility on mid-range days of 2.9 dv above estimated natural conditions (2.7 dv). For 2007–2016, visibility improved both on the 20% clearest days and haziest days, resulting in an overall improving visibility trend (IMPROVE Monitor ID: BAND1, NM). Confidence in this assessment is high because conditions and trends were based on on-site visibility monitor. In 2016, the clearest days occurred in January and April (Fig. 4.4.4-1), while the haziest days occurred during June and July (Fig. 4.4.4-2); trend lines are provided for both clearest and haziest days (Fig. 4.4.4-3 and Fig 4.4.4-4).

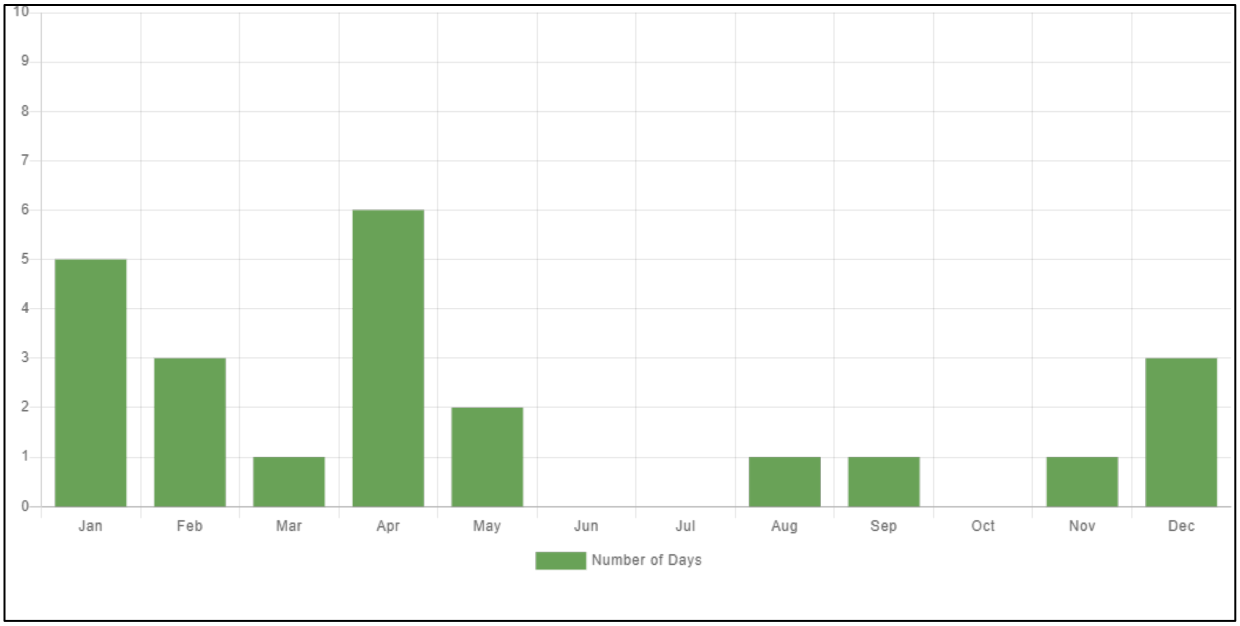


Figure 4.4.4-1. Visibility data for 2016; the clearest days based upon visibility monitoring instrument (IMPROVE #BAND1, NM).

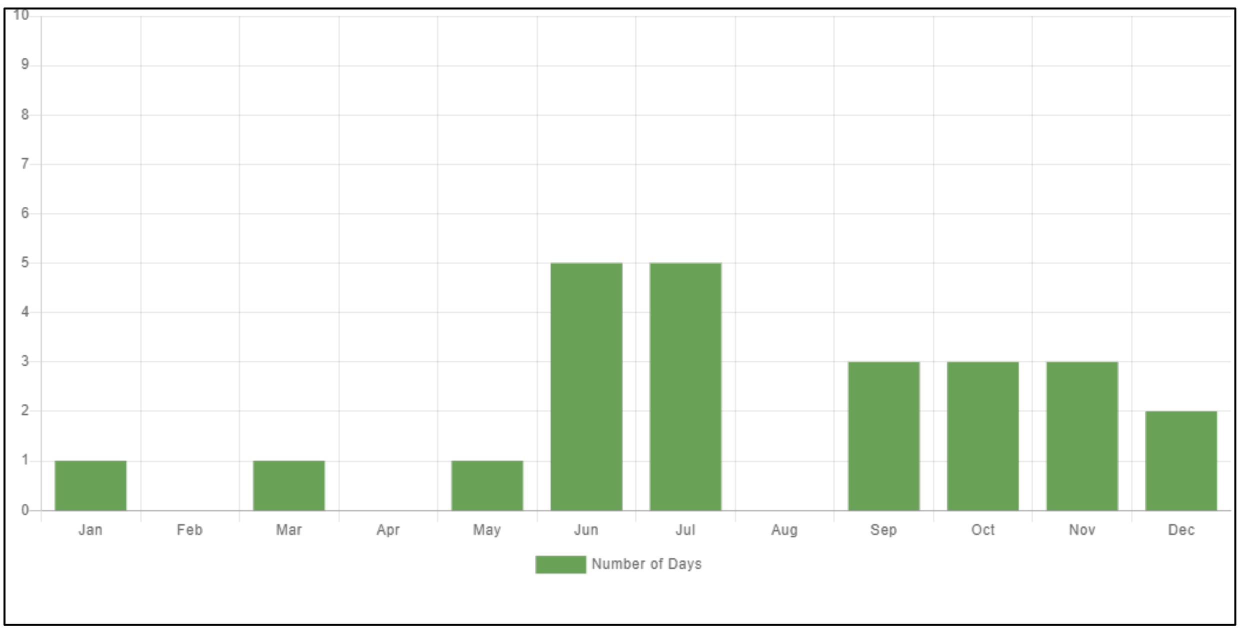


Figure 4.4.4-2. Visibility data for 2016; the haziest days based upon visibility monitoring instrument (IMPROVE #BAND1, NM).

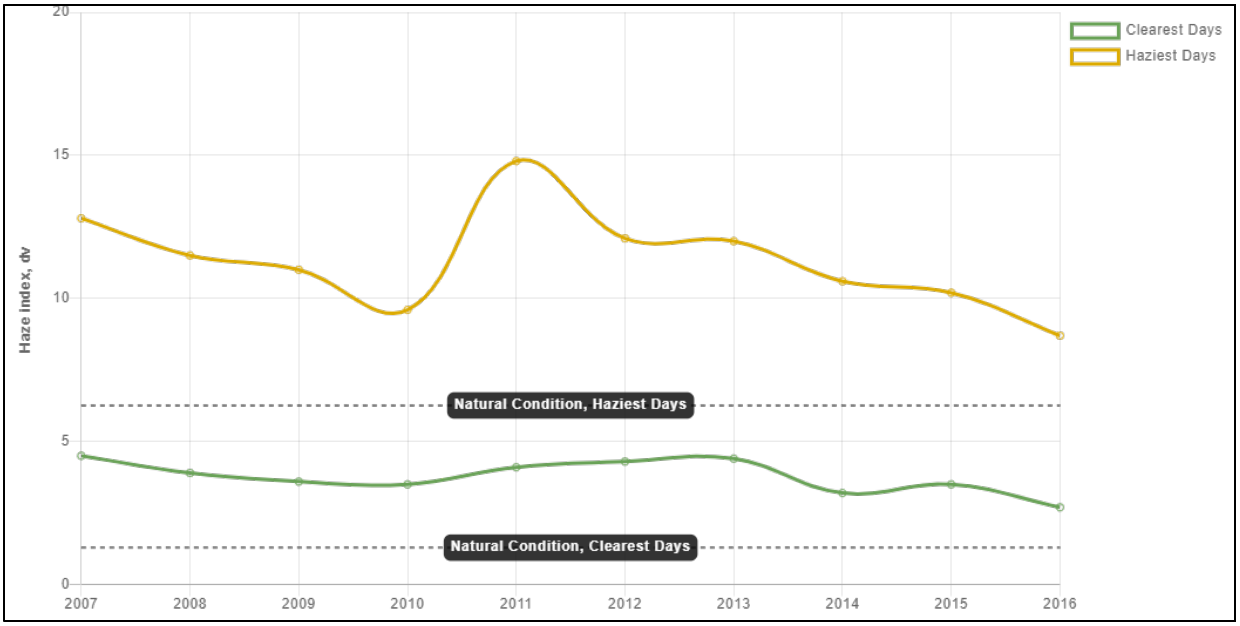


Figure 4.4.4-3. Trends for both haziest and clearest days under natural conditions (IMPROVE #BAND1, NM).

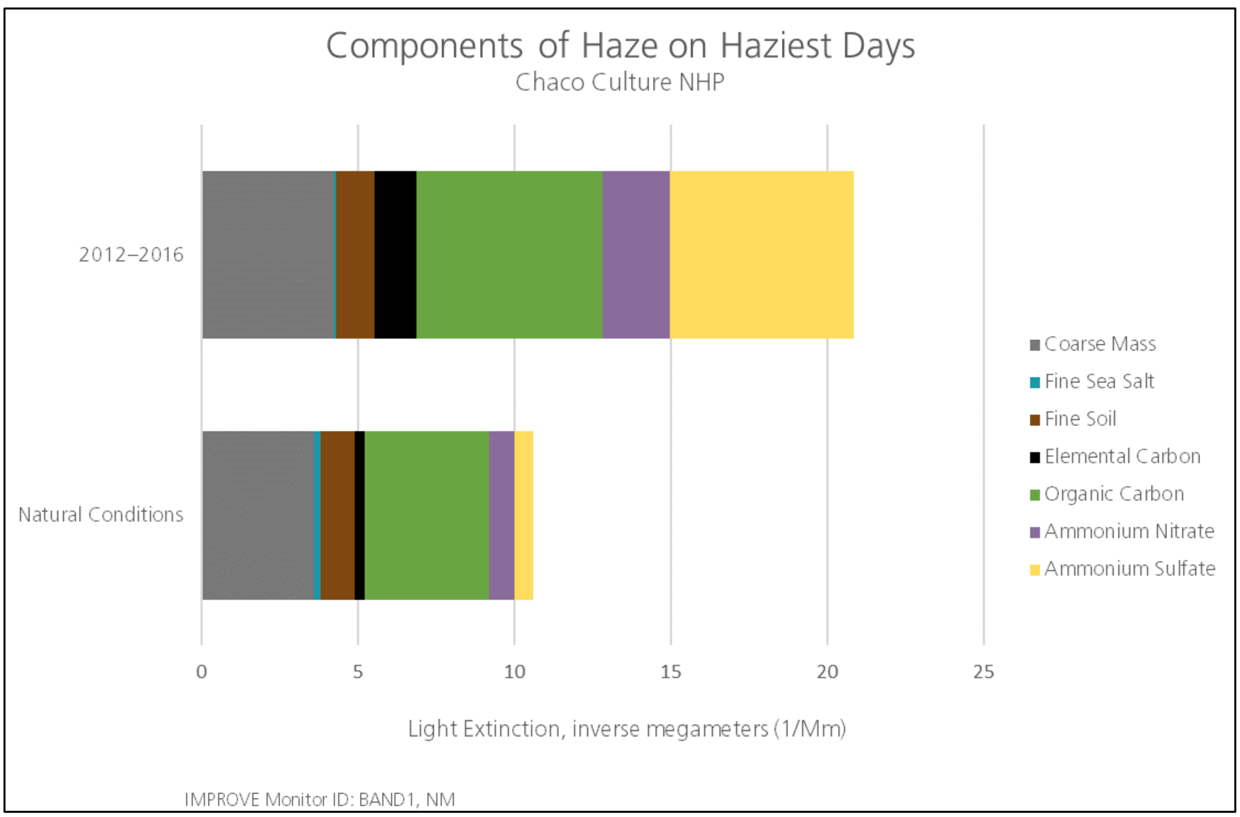


Figure 4.4.4-4. Components of haze on haziest days based upon visibility monitoring instrument (BAND1, NM).

Level of Ozone: Human Health

Human health risk from ground-level ozone warrants moderate concern. Status is based on the 2012–2016 estimated ozone of 66.3 ppb. Trends could not be determined because there were not enough data from the on-site monitoring station. The level of confidence is medium because estimates are based on interpolated data from more distant ozone monitors.

Level of Ozone: Vegetation Health

Vegetation health risk from ground-level ozone warrants significant concern. Status is based on the 2012–2016 estimated W126 metric of 12.6 ppm-hrs. Trends could not be determined because there were not enough data from the on-site monitoring station. The level of confidence is medium because estimates are based on interpolated data from more distant ozone monitors.

Wet Deposition: Nitrogen and Sulfur

Wet nitrogen deposition warrants moderate concern. Status is based on the 2012–2016 estimated wet nitrogen deposition of 0.9 kg/ha/yr; a level that normally indicates good condition. However, the status has been elevated to moderate concern because ecosystems at CHCU may be very highly sensitive to nitrogen-enrichment effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011c; Sullivan et al. 2011d).

Wet sulfur deposition is in good condition. Status is based the 2012–2016 estimated wet sulfur deposition of 0.4 kg/ha/yr. CHCU ecosystems were rated as having moderate sensitivity to acidification effects (Sullivan et al. 2011a; Sullivan et al. 2011b).

A critical load, defined as the level of deposition below which harmful effects to the ecosystem are not expected, is also a useful tool in determining the extent of deposition impacts (i.e., nutrient enrichment) to park resources. It can also serve to communicate these impacts to managers, regulators, and the public.

Pardo et al. (2011) suggested a critical load of 3.0−8.4 kilograms nitrogen per hectare per year (kg N/ha/yr) to protect lichen and herbaceous plants in the North American Deserts, which includes Chaco Culture NHP. Nitrogen deposition levels that are at or above the critical load for park resources warrant “significant concern”.

In CHCU, the estimated 2014–2016 average for total nitrogen deposition (wet plus dry) was at the lower bound, 3.0 kg/ha/yr (NPS-ARD 2019). Thus, total nitrogen deposition levels are at the lower bound of the ecosystem critical loads for lichen and herbaceous plants, and thus these resources may be at risk. Degree of confidence is “medium” because deposition levels are based on interpolated data.

Sullivan (2016) reported that most counties in the vicinity of the Southern Colorado Plateau Network had relatively low levels of sulfur dioxide (SO_2) emissions (< 5 tons per square mile per year [tons/mi^2/yr]), while emissions of oxidized N were generally slightly higher (≥ 5 tons/mi^2/yr or more), and emissions of reduced N were lower (< 2 tons/mi^2/yr). Total S and N deposition at measured locations of SCPN parks from 2010 to 2012 were typically less than 2 kg S/ha/yr and 5 kg N/ha/yr, respectively.

Sullivan (2016) reported Total S, Total N, nitrogen oxides (NO_X) and ammonia (NH_3) for 2001 and 2011. Decreases in Total S, Total N and NO_X, and a slight increase in NH_3 were reported (Table 4.4.4-1). Estimated acid pollutant exposure and ecosystem sensitivity to acidification is considered "low" and "moderate", respectively (Sullivan 2016). Additionally, Sullivan (2016) identified ecosystem sensitivity to nutrient N enrichment as "high", and current estimated nutrient N pollutant exposure is "low".

Importantly, regional SO_2 and NO_X emissions for the three state area (Arizona, New Mexico, and Nevada) reported a four-fold decrease between 2000 and 2014 (Sullivan 2016). SO_2 emissions dropped from ~53,000 tpy (tons per year) in 2000 to ~10,000 tpy in 2014. For the same temporal window, NO_X emissions declined from ~48,000 to ~10,000 typ.

Table 4.4.4-1. Average changes for Total S, Total N, Nitrogen Oxides (NOX), and Ammonia (NH3) between 2001 and 2011 across park grid cells, Chaco Culture National Historical Park, New Mexico. Deposition estimates were determined by the Total Deposition Project, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells (refer to Sullivan 2016). Average per year and differences (i.e., absolute change) provided.

Pollutant	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)
Total S	1.05	0.85	−0.20
Total N	2.66	2.53	−0.13
NO_X	2.15	1.85	−0.29
NH_3	0.52	0.68	0.17

<u>Overall Condition, Trend, and Confidence Level</u>

Park air quality, ecosystems and scenic resources can be impacted by regional and local sources of air pollution such as forest fires (natural or prescribed), dust created from land disturbance and natural sources and pollutant emissions from combustion sources such as vehicles, mining equipment, oil and gas development and coal-fired power plants. In this remote region, emissions from power plants and oil and gas development are likely the most significant anthropogenic influences on air quality at CHCU.

Power Plants

There are numerous power plants in the larger southwestern region that have impacted air quality and scenic resources in nearby parks. However, emissions from many of these facilities have decreased dramatically in the last decade. This includes two of the largest facilities that are located within 100 km of CHCU, the San Juan Generating Station and the Four Corners Power Plant, both located just north of CHCU in San Juan County, NM. As controls were added at these facilities to reduce regional haze impacts at nearby Class I areas, this will also improve air quality conditions at CHCU. The San Juan Generating Station (SJGS) decreased SO_2 and NO_x emissions between 2009 and 2018 through the installation of additional pollution controls and the shutdown of two of the four coal-fired units (Warner and Gannon 2018). These have resulted in a 44% reduction in NOx emissions, a 71%

reduction in SO_2 emissions, a 72% reduction in PM emissions and a 99% reduction in mercury emissions. It is anticipated that SJGS may shut down all of their coal-fired units by 2022, but this is still uncertain.

The Four Corners Power Plant decreased SO_2 and NO_x emissions between 2014 and 2018 through the installation of additional pollution controls and the shutdown of the three older, smaller units. These changes have resulted in a 79% reduction in NO_x emissions and a 76% reduction in SO_2 emissions. In addition, the Navajo Generating Station, located on Navajo tribal land in Coconino County, AZ, was shut down in 2020, and the Navajo Cholla power plant, located in Navajo County, Arizona is anticipated to be decommissioned by 2025. In the near future, the NM Environment Department may evaluate ways to reduce emissions from the Prewitt-Escalante Generating Station located in McKinley County 80 km to the south of CHCU. The state may consider this source to fulfill regional haze planning requirements, as this facility has not implemented any emissions reductions to date. There is a near-term opportunity to work with the NM Environment Department and the Arizona Air Quality Division through the regional haze process to address remaining sources that have not significantly reduced emissions in recent years. (Note: the graphs and maps below do not depict *all* point sources within in the region, but just a subset of the coal-fired power plants.)

Recent trends in NO_x and SO_2 emissions from coal-fired electric generating units within the greater southwestern region are provided in Figs. 4.4.4-5 and 4.4.4-6 (EPA 2018b). A map of these facilities relative to CHCU is provided in Fig. 4.4.4-7.

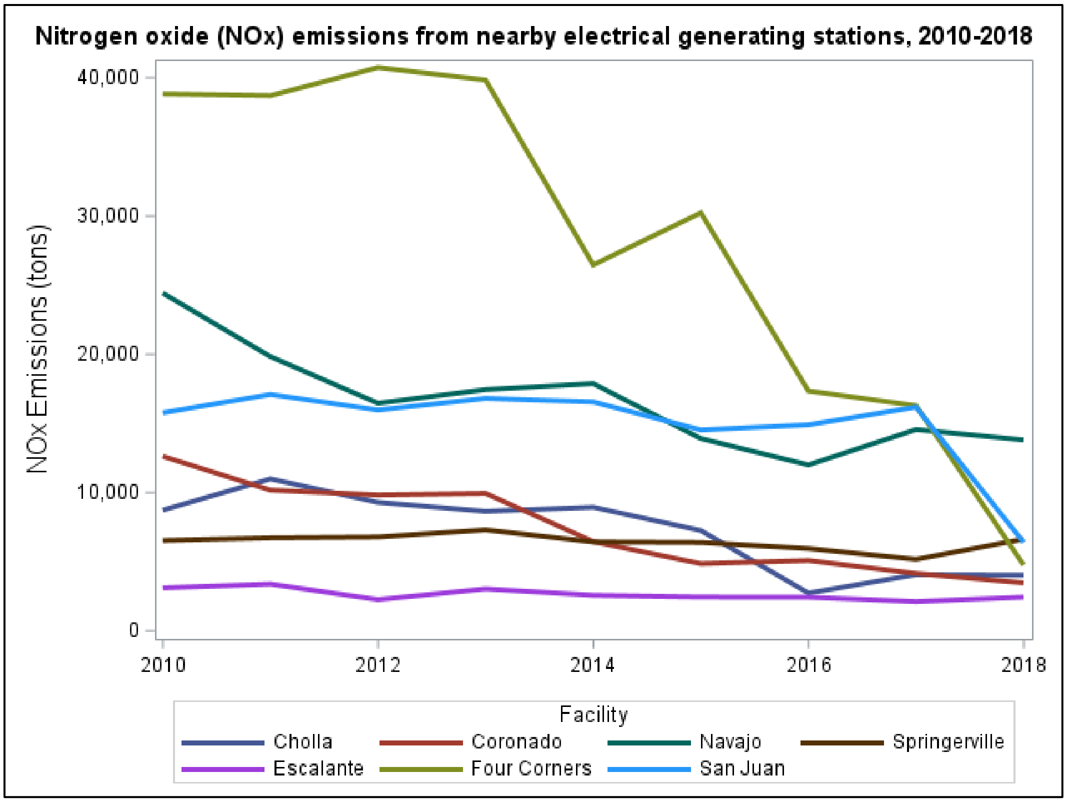


Figure 4.4.4-5. Nitrogen oxide emissions from nearby electrical generating stations (2010–2018), Chaco Culture National Historical Park, New Mexico (EPA 2018b).

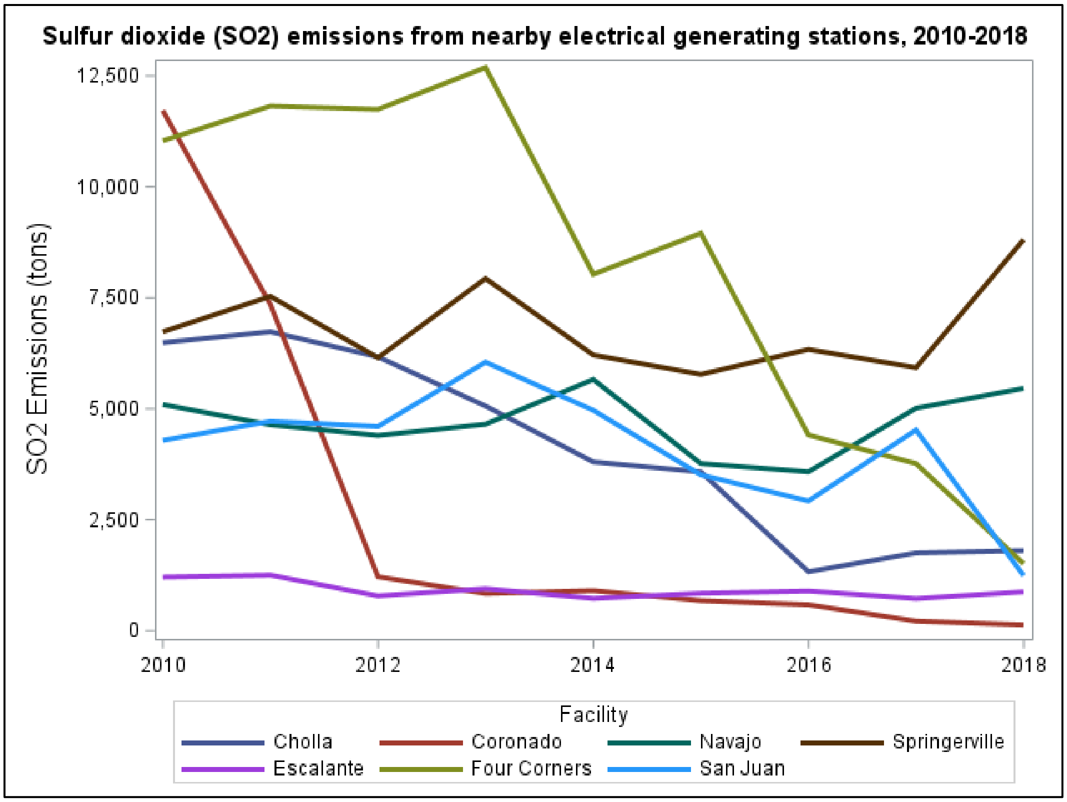


Figure 4.4.4-6. Sulfur dioxide emissions from nearby electrical generating stations (2010–2018), Chaco Culture National Historical Park, New Mexico (EPA 2018b).

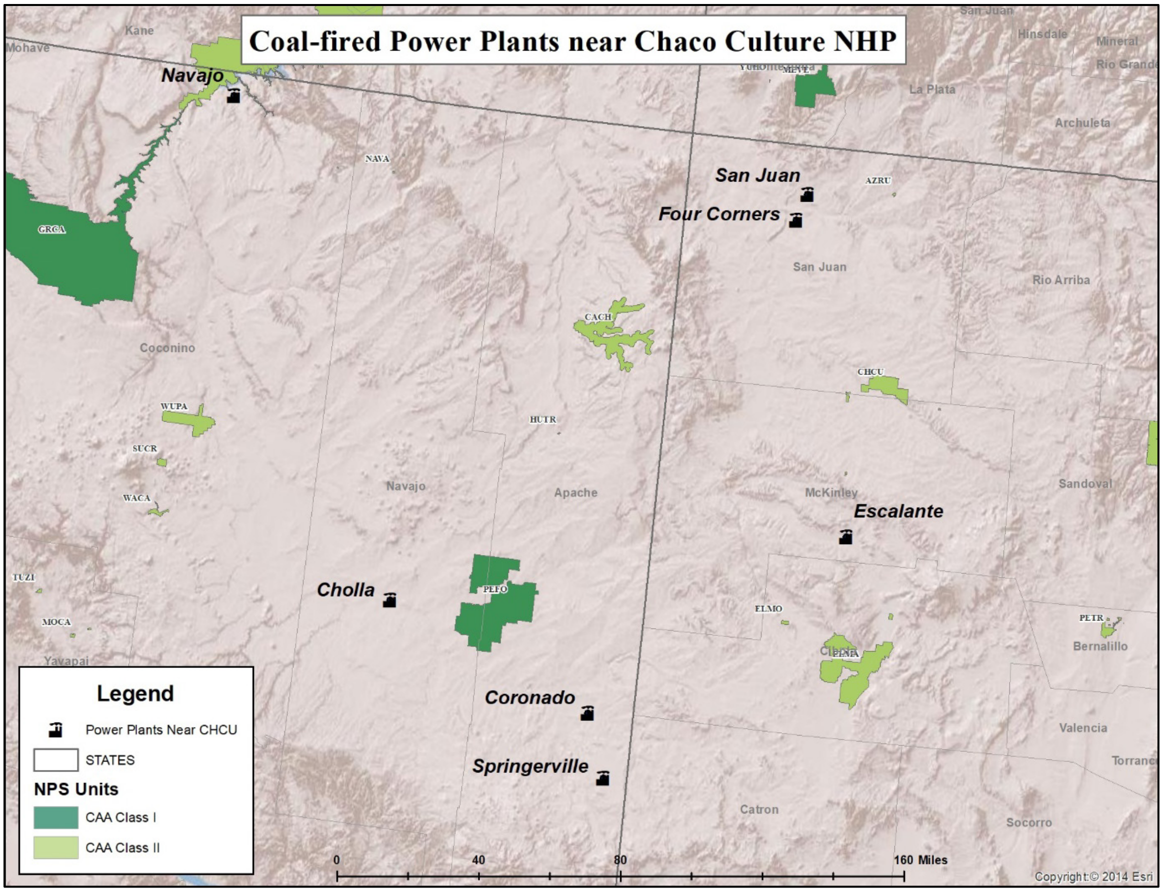


Figure 4.4.4-7. Coal fired power plants near Chaco Culture National Historical Park, New Mexico (Air Resources Division, NPS, Denver, CO).

Oil and Gas Development

Oil and gas operations can emit significant quantities of air pollutants in basins with large-scale development. Pollutants emitted from oil and gas operations include hydrocarbons such as methane (CH4) and a mixture of non-methane hydrocarbons, referred to as volatile organic compounds (VOCs), including alkanes (e.g., C2-C5 alkanes), cycloalkanes, aromatic BTEX compounds (benzene, toluene and xylene), and formaldehyde. Non-hydrocarbon criteria pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), particulate matter (PM) and sulfur dioxide (SO2) are also emitted from oil and gas operations (Pétron et al. 2012). Methane and VOC emissions are primarily emitted from venting and leakage from connections, piping, gathering lines, pipelines, pneumatic devices, tanks and other storage units, heaters, separators, dehydrators, blow down events and well completions. The criteria pollutants NOx, CO, CO2, and SO2 are emitted from combustion sources used in oil and gas operations such as drill rig and fracturing pump engines, compressor engines, flares and combustors, artificial lift and other miscellaneous engines, heaters, separators, and transportation sources such as tanker trucks and drilling traffic.

CHCU is located within the south-central portion of the San Juan Basin (SJB), one of the oldest developed oil and gas basins in the United States (NGI 2016). The first gas well in the SJB was drilled in 1921 and since this time, oil and gas has become a well-established industry within Four Corners region. As of March 2019, there were approximately 29,575 active oil and gas wells within the SJB. The highest concentrations of active wells begin just 10 miles (16 km) north of the park and extend over 70 miles (112.7 km) to the north and east into the southwestern corner of Colorado (Fig. 4.4.4-8).

Historically, the basin has produced primarily natural gas and coal bed methane, and according to EIA, is one of the largest natural gas producing fields in the United States (EIA 2015). Yet, counter to national trends, gas production in the basin has been steadily declining at a rate of 4–5% per year since 2005 (EPA 2018b). However, in 2012, oil and natural gas liquids (NGL) production began increasing as development of the Mancos shale formation became feasible. (Pétron et al. 2012). Technological advancements such as horizontal drilling and hydraulic fracturing are likely driving this shift to oil and NGLs and are anticipated to result in additional development of the Mancos shale formation. The oil and NGL-rich formations are located in the south and central portions of the basin, near CHCU, as can be seen in the distribution of wells by production type (Fig. 4.4.4-8).

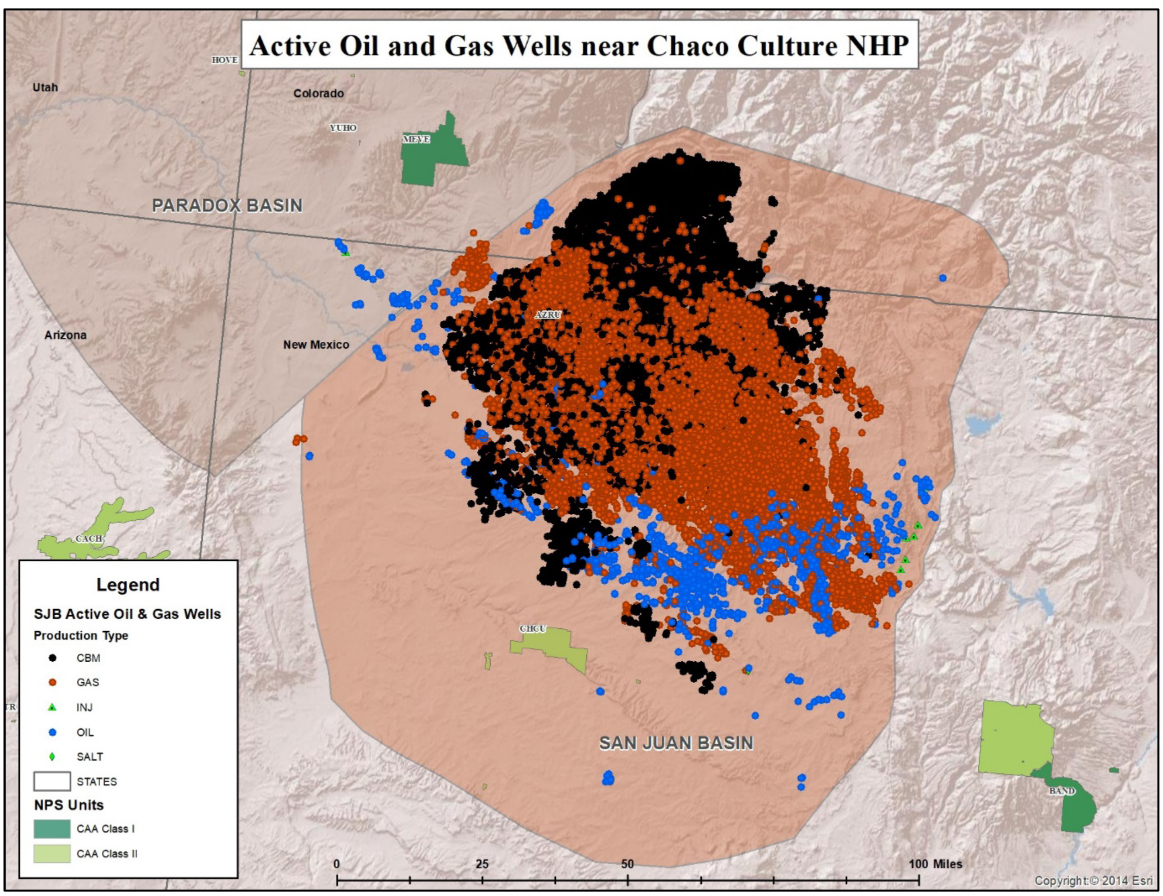


Figure 4.4.4-8. Active oil and gas wells surrounding Chaco Culture National Historical Park (CHCU) within the San Juan Basin, New Mexico (Air Resources Division, NPS, Denver, CO).

The most recent comprehensive oil and gas inventory for the San Juan Basin is available through the Intermountain West Data Warehouse (IWDW 2020) and was developed for the year 2011 (an oil and gas inventory update for year 2014 is underway). Table 4.4.4-2 reports the 2011 emissions for oil and gas point and area sources for the six counties located within the San Juan Basin (IWDW 2020). As demonstrated in the emission inventory, oil and gas sources comprise the majority of the methane, NO_x SO_2, and VOC emissions in the SJB region.

Importantly, the Draft Resource Management Plan Amendment and Environmental Impact Statement for the Mancos-Gallup formations infers that BLM-authorized oil and gas wells under all of the BLM Alternative C sub-alternatives could exceed the indicators of the EPA's National Ambient Air Quality Standards for 8-hour ozone, annual PM2.5, and annual NO_2 (refer to BLM 2020; NPS 2020b).

Table 4.4.4-2. Emissions (tons per year; as of 2011) of methane, NOx, SO2 and VOC for oil and gas, as well as non-oil and gas point (e.g., power plants, etc.) sources for the San Juan Basin, New Mexico (IWDW 2020).

Type	Methane	NOx	SO_2	VOC
Oil and Gas (Area & Point Source)	190,342	46,985	734	47,474
Non-Oil & Gas Point	314	21,214	6,068	555

Recent NPS modeling studies indicate that the emissions from oil and gas development may be significantly contributing to nitrogen deposition and elevated ozone in the four corners regions parks. Cumulatively, current modeled and nitrogen deposition and ozone concentrations are at levels where harmful effects to sensitive vegetation and ecosystems may begin to occur (Thompson et al. 2017; NPS 2018f).

The oil and gas mineral estate near CHCU includes a mix of federal, state, tribal and private mineral ownership, with a significant fraction of federal and tribal ownership. Development of federally-owned minerals provides an opportunity for coordination and consultation between the NPS and the Bureau of Land Management to ensure that park resources, such as air quality, are protected through mitigation and emission reduction measures as mineral development occurs.

The Bureau of Land Management (BLM) in New Mexico is in the process of amending their oil and gas Resource Management Plan for the Mancos/Gallup formations in northwestern New Mexico due to anticipated growth in the development of these geologic formations. The analysis includes an air quality modeling assessment that evaluates the future impacts of increased development, including AQRV impacts at CHCU (Vijayaraghavan et al. 2017). Models of future nitrogen deposition levels predicted that levels would remain at or above levels considered harmful for sensitive ecosystems and oil and gas contributes to these impacts. Opportunities exist for the NPS to work with other federal and state agencies to mitigate these impacts through the planning process.

For assessing the overall condition of air quality at CHCU, three air quality indicators with a total of five measures were used. The indicators/measures for this assessment were intended to capture different aspects of air quality. Based on the indicators and measures, the overall condition of air quality at CHCU warrants moderate concern. NPS-ARD methods were used to derive the overall air quality conditions (Taylor 2017).

All measures, except visibility (haze index), have a "medium" level of confidence. Medium confidence levels resulted from assessments that were based on interpolated data from distant monitors. For visibility, the confidence in the condition and trend is high because assessments were derived based on data from a representative visibility monitor (IMPROVE Monitor ID: BAND1, NM). Although there is now an on-site ozone monitoring station at CHCU, there were not enough annual data to use for conditions and trends in this assessment.

Data Gaps & Needs

Data acquisition and future planning priorities should include:

- Onsite air quality monitoring stations are needed; especially given the increase in oil and gas exploration and extraction operations surrounding the park;
- Support for existing air quality monitoring;
- Continued nitrogen compound monitoring for early detection of elevated levels that may adversely affect CHCU ecosystems;
- Support for monitoring air quality during wildfire events and other times when haze is problematic;
- Management direction and planning efforts emphasizing efforts to protect air quality, scenic views, and resources sensitive to air pollution;
- Identification of sensitive resources, and future air quality needs, and research and monitoring (in consultation with NPS-ARD and the Regional Air Resources Coordinator);
- Monitoring of eight ozone-sensitive native plants (two of which are biological indicator species for ozone) – as determined by CHCU personnel; and,
- Predictions of future trends in air pollution, as well as the future dominant sources of pollution.

Issues

Climate change may exacerbate air pollutant concentrations and effects on resources. For example, increased summertime temperatures may lead to higher ozone levels (EPA 2009). 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).

4.4.5. Sources of Expertise

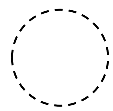
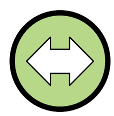
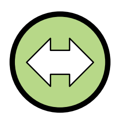
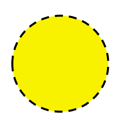
Ksienya Taylor, National Park Service, Air Resources Division

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. For current air quality data and information for this park, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/index.htm.

4.5. Soil Stability and Erosion

A summary of all assessed conditions for soil stability and erosion is provided in Table 4.5-1.

Table 4.5-1. Condition assessment summary for soil stability and erosion, Chaco Culture National Historical Park, New Mexico.

*Indicator	Description	Condition Status/Trend	Summary
Tamarisk removal/loss in Chaco Wash	No current information available on tamarisk extent and the effects rendered once the tamarisk beetle has eradicated the occurrence of this species within Chaco Wash.		No summary available due to a paucity of information available on this indicator. However, loss of tamarisk within Chaco wash may result in increased rates of erosion and instability of some archaeological sites in the absence of a robust reintroduction, revegetation, and erosion control plan.
Erosion/ Erosion Control: Livestock Grazing	Livestock grazing has not occurred within CHCU since 1947 (KellerLynn 2015).		Due to efforts to limit grazing within the park boundary, the ecosystems have persisted over the last 70 years without the impacts of livestock grazing.
Erosion/ Erosion Control: Chaco Wash	Chaco Wash is considered to be at equilibrium or aggrading (KellerLynn 2015).		Although active sheetwash (deposition and erosion) occurs during monsoon-related flash floods, lateral movement of the stream channel and migration within the wash is occurring but is considered stable (KellerLynn 2007, 2015).
Piping	Although piping is a management concern as it can negatively impact archeological sites and cause damage to roads, the effects of piping have not been evaluated in over 40 years (Simons, Li & Associates, Inc. 1982). Upon their evaluation, only Pueblo del Arroyo was at risk of piping.		Presently, only Pueblo del Arroyo remains at risk of the erosional effects of piping.

4.5.1. Background and Importance

CHCU has a millennial-long history of modifications to Chaco Wash for agricultural purposes (KellerLynn 2007). Erosion control measures, which began in the 1900s, and became intensive in the 1930s–1960s, unfortunately involved the use of nonnative alien plant species (including tamarisk and globe-pod hoary cress). These plants likely affected the stream hydrology of Chaco Wash.

Park staff is controlling tamarisk in certain areas where spreading is extensive, channel morphology is changing, and cultural resources are being affected. Additionally, the tamarisk beetle arrived at

CHCU in 2015 (NPS 2015c), which should help reduce the prevalence of tamarisk in the park. The Southern Colorado Plateau Network is developing a protocol to monitor changes in stream channel morphology, although funding is uncertain (KellerLynn 2007).

Piping is a form of erosion occurs when percolating water intrudes into the subsurface forming narrow conduits, tunnels, or "pipes" through soluble sediments (further described in the indicators below). Where this occurs, granular soil material is moved down slope. Soil pipes are prevalent in CHCU and have affected cultural resources. According to Simons et al. (1982), some of the pipes extend hundreds of feet from Chaco Wash. Most of these outlets are in the arroyo walls, perched above the floor of the wash. As the pipes enlarge over time, the overlying material collapses and side ravines that feed into the main arroyo are formed (KellerLynn 2007).

Dust storms occur frequently in the spring, and aeolian dunes used to cover the old entry road (north) into the park (KellerLynn 2007). Additionally, aeolian soils have been mapped on mesa tops in the park, and among the largest sand dunes occur in tributary canyons, such as Weritos Rincon and Pueblo Pintado (KellerLynn 2015).

The most recent soil survey was conducted in 2001 (Zschetzsche and Clark 2001).

Indicators & Measures

Indicator
Tamarisk removal/loss in Chaco Wash
Measures
Tamarisk removal/loss in Chaco Wash

Tamarisk occurs within Chaco Wash. In 1934, to protect archaeological sites within the wash and to prevent the channel from further widening, an extensive erosion control program was undertaken; nearly 100 thousand seedlings of willow, tamarisk, wild plum, and cottonwood were planted in Chaco Arroyo (Hall 2010; KellerLynn 2015). The last formal effort to control the spread of this nonnative alien species was treatments in the Kin Bineola/Kin Klizhin areas in 2006 and Penasco Blanco in 2011 (D. Hawkins, pers. com. 2019). While CHCU does not have an active program, the park is in the early stages preparing for the mechanical and chemical removal of tamarisk and others nonnative invasive plant species (D. Hawkins, pers. com. 2020). Additionally, the tamarisk beetle arrived in 2015 (Fig. 4.5.1-1; NPS 2015c). Although the effects of the tamarisk beetle on tamarisk within CHCU has not been examined, it is likely the beetle is reducing the extent of tamarisk in the park. When this occurs, it is possible the loss of tamarisk within Chaco wash may result in increased rates of erosion and instability of some archaeological sites in the absence of a robust reintroduction, revegetation, and erosion control plan.

Figure 4.5.1-1. Northern tamarisk beetle (Diorhabda carinulata Desbrochers, 1870) was first detected at Chaco Culture National Historical Park in 2015 during a Sierra Club Revegetation Project (NPS 2015c).

Indicator

Erosion/ Erosion Control: Livestock Grazing

Measures

Erosion/ Erosion Control: Livestock Grazing

During the late 1800s through the early 1900s, sheep, goat, and cattle grazing occurred within what is today the park boundary (KellerLynn 2015; White 2017). The NPS fenced the park area to exclude grazing in 1948, which resulted in the return of native grasses, shrubs, and wildlife. Thus, erosion exacerbated by livestock grazing presently is not an issue.

Indicator
Erosion/ Erosion Control: Chaco Wash/ Arroyo

Measures
Erosion/ Erosion Control: Chaco Wash/ Arroyo

Historically, the shifting channel of Chaco Canyon has resulted in largescale erosion. Today, the canyon is cut by Chaco Arroyo, which in turn further incised by an active inner channel. The wash is either in equilibrium or aggrading; lateral movement of the stream channel and migration within the arroyo is occurring but is considered stable (KellerLynn 2007, 2015). However, active sheetwash (deposition and erosion) occurs during monsoon-related flash floods.

Indicator
Piping erosion

Measures
Piping erosion

Piping is a form of erosion where percolating water intrudes into the subsurface forming narrow conduits, tunnels, or "pipes" within the more soluble sediments. Piping is identified as a serious concern for archaeological sites (Simons, Li & Associates, Inc. 1982) and park roads (Zschetzsche and Clark 2001). This phenomenon occurs within Notal and Battlerock soils (KellerLynn 2007, 2015), which are located within Chaco Wash (NRCD 2004). When piping transpires, granular sediment is moved down slope. Soil pipes are prevalent in CHCU and have affected cultural resources (KellerLynn 2007, 2015). According to Simons et al. (1982), some of the pipes extend hundreds of feet from the wash and may have a down slope entrance emptying into an arroyo. Most of these outlets are in the arroyo walls, perched above the floor of the arroyo. As pipes enlarge over time, the overlying material collapses forming side ravines feeding into the main arroyo (KellerLynn 2007).

Nearly 40 years ago, Simons, Li & Associates, Inc. (1982) conducted a soil piping study; they examined the drainage patterns in the Pueblo Bonito area and provided management plans for Chetro Ketl, Pueblo Bonito, Pueblo del Arroyo, and Kin Kletso. As Pueblo del Arroyo is about 5 to 10 m from Chaco Wash, this site has been and remains threatened by the effects of piping (Simons, Li & Associates, Inc. 1982; KellerLynn 2007).

Incidentally, the formation of erosional piping features in CHCU may also serve as important bat habitat (KellerLynn 2007).

4.5.2. Data and Methods

This condition assessment is based primarily upon two documents. In 2007, the park held a scoping meeting to identify significance and geologic resource management issues, as well as determine the status of geologic mapping relevant geological resources (KellerLynn 2007, 2015). The 2007 scoping meeting, as well as two additional meetings held in 2014 resulted in the development and completion of a geological resources inventory report (KellerLynn 2015).

4.5.3. Reference Conditions
Reference conditions for tamarisk in Chaco Wash would involve knowing the extent of this alien plant species prior to the arrival of the tamarisk beetle. Mechanical removal should continue and the effects of both the beetle and mechanical removal should continue to be monitored until tamarisk is eradicated.

For Chaco Wash, reference conditions may be derived from a long-term channel morphology monitoring program. Thirteen transects located throughout the park have been monitored every four to six years since 1999 (KellerLynn 2015). These transects were monitored in 1999, 2005, 2008 and 2012 (KellerLynn 2015). The Southern Colorado Plateau Network has indicated they will repeat these surveys at approximately five-year intervals (KellerLynn 2015).

4.5.4. Condition and Trend
The condition and trend for tamarisk occurrence and infestation in Chaco Wash is largely unknown as there is no information available on the status of this invasive alien species within the park.

Unregulated livestock grazing has not occurred within the park since 1948 (KellerLynn 2015; White 2017). While grazing currently does not occur within the park's administrative boundary. Soil stabilization due to the absence of livestock grazing is considered in "good" condition with the trend "unchanging." Information on current grazing within park boundary was provided by park personnel to develop this report; thus, confidence is "high."

Erosion/ erosion control due to the meandering channel of Chaco Wash appears to be either in equilibrium or aggrading. Any future erosional events that may threaten archaeological sites and infrastructure is not considered to be an issue (KellerLynn 2015). Thus, the condition is considered "good" condition and trend is presently "unchanging." As the geology assessment is less than four years old, confidence is "high."

Although piping is a management concern as it can negatively impact archeological sites and cause damage to roads, the effects of piping have not been evaluated in nearly 40 years (Simons, Li & Associates, Inc. 1982). Upon their evaluation, only Pueblo del Arroyo was at risk of piping (Simons, Li & Associates, Inc. 1982; KellerLynn 2015); thus, this indicator remains at "moderate" concern. As this information is quite dated, the present condition of many archaeological sites is unknown, the trend cannot be evaluated, and confidence in the dataset is low.

<u>Threats, Issues, and Data Gap</u>
Unfortunately, no current data are available concerning the distributional extent of tamarisk in Chaco Wash. Due to a paucity of information available on this indicator, an assessment into the current extent and condition (i.e., whether it's being "controlled" by the beetle) is not possible. Additionally, information is lacking concerning how quickly, and to what extent, native vegetation will respond once tamarisk is removed.

The erosional effects associated with piping remains a treat to the Pueblo del Arroyo. However, as the last piping monitoring study occurred over 40 years ago. Another assessment should be conducted to ascertain whether other sites are at risk, as well as whether the threat posed to Pueblo del Arroyo has intensified and mitigation strategies are warranted.

In terms of available digital information, there is a coarse-scale map representing seven soil types available for CHCU (Zschetzsche and Clark 2001). It is unclear whether a higher resolution map would beneficial for park planning. Additionally, no research has been conducted to model how anthropogenic climate change and sediment loss due to wind storms will adversely affect archaeological resources.

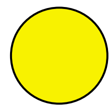
4.5.5. Sources of Expertise

Dana Hawkins, CHCU, National Park Service

4.6. Hydrogeology

A summary of all assessed conditions for hydrogeology is provided in Table 4.6-1.

Table 4.6-1. Condition assessment summary for hydrogeology, Chaco Culture National Historical Park, New Mexico.

Indicator	Description	Condition Status/Trend	Summary
Aquifer (well-house) water quality	3,095 ft deep artesian well (located in the maintenance yard) that taps into the Gallup Sandstone aquifer.		Water quality has been monitored weekly since January 2019; prior to this, it was monitored sporadically since 2009. This water source currently meets EPA potable water standards; however, as pH levels have been elevated over the past two years, the park is exploring water treatment options – thus, well water quality is in moderate condition, as monitoring has only occurred over the past year, trend is unknown; however, confidence is high.

4.6.1. Background and Importance

While there are several intermittent washes and springs in the park (refer to Riparian and Springs section), the primary water source is the intermittent Chaco Wash, which becomes the ephemeral Chaco River in the northwestern extent of the park. Subsequently, attempts were made to access the Chaco Wash alluvium as a potable water supply (Brown 2008). Due to poor water quality and low yields, these efforts were ultimately abandoned (Martin 2005). Today, the park's water supply is a 3,095 ft deep artesian well (located in the maintenance yard) located within the Gallup Sandstone aquifer (Martin 2005). Tapped in 1972, this is the only reliable water source within CHCU.

Given increased oil and gas exploration, mining (coal and uranium) activities, power generation, and associated water and residential development on lands surrounding the park, surface- and ground-water availability and quality is a growing concern (Thomas et al. 2006; Brown 2008). Although coal mining has occurred north (Hejl 1982; Baars 2000), coal extraction is not considered a direct impact on resources; however, surface runoff could affect water quality in the tributaries flowing into Chaco Wash and the Chaco River (Martin 2005). Additionally, coal-fired power plants in the region could affect regional precipitation quality (EPA 2018a; refer to Fig. 4.4.4-7).

The Farmington Field Office of the Bureau of Land Management (BLM) is presently advancing a resource management plan and environmental impact statement to expand upon the number of oil and gas exploration sites surrounding CHCU (BLM 2015). CHCU is concerned that any hydraulic fracturing or wellbore stimulation within the Mancos Shale adjacent to the park boundary may adversely affect the park's sole drinking water source (NPS 2020b).

4.6.2. Data and Methods

Since 2019, well-house (Gallup Sandstone aquifer) water has been monitored for six constituents and temperature (refer to the section below).

Indicators & Measures

Indicator
Aquifer (well-house) water quality
Measure
Aquifer (well-house) water quality

Well-house data has been routinely collected on nearly a weekly basis since 01 January 2019. Prior to January 2019, data had been sporadically collected since 01 August 2009. Presently, CHCU is monitoring levels of total dissolved solids (TDS; mg/L), sulfates (mg/L), iron (mg/L), total hardness (mg/L), pH, alkalinity (mg/L) and temperature (ºF). This water source currently meets EPA potable water standards; however, as pH levels have been elevated over the past two years, the park is exploring water treatment options.

Near the park, the Gallup Sandstone aquifer occurs at a depth of 3,095 ft (943.36 m) deep; as determined by the depth of the artesian well (located in the maintenance yard; Martin 2005). However, Jackson et al. (2015) reported that average fracturing depth in the United States is 8,300 ft. (2,530 m), which is more than twice as deep as the park's well. A primary geologic target for oil and gas development in the region is the Mancos Shale, which surrounds the relatively thin Gallup Sandstone unit. Hydraulic fracturing occurring anywhere that penetrates the Gallup Sandstone aquifer may compromise CHCU's water quality and availability (quantity).

4.6.3. Reference Conditions

As well-house data has been routinely collected on nearly a weekly basis since 01 January 2019, reference conditions associated with this monitoring can be established. Average levels for 2019 were TDS (1,539.2 mg/L), sulfates (88.57 mg/L), iron (13. 74 mg/L), total hardness (8.12 mg/L), pH (8.12), alkalinity (317.45 mg/L), and temperature (84.06 ºF). Well house data is provided from 02 January through 31 December 2019 (Table 4.6.3-1).

Table 4.6.3-1. Well house data is provided from 02 January through 31 December 2019, Chaco Culture National Historical Park, New Mexico (Palmer, P., unpublished data).

2019	TDS (mg/L)	Sulfates (mg/L)	Iron (mg/L)	Total Hardness (mg/L)	pH	Alkalinity (mg/L)	Temp(ºF)
1/2/19	1467	80	0.8	40	8.39	340	73.8
1/28/19	1474	–	0.9	–	8.5	320	–
2/4/19	1453	70	1.3	52	8.4	340	74
2/6/19	1447	80	0.8	30	8.26	360	73
2/11/19	1438	80	1.0	26	8.7	320	76
2/12/19	1464	80	0.8	22	–	300	83
2/13/19	1452	80	1.0	28	8.22	300	82
2/14/19	1474	70	0.6	20	8.81	320	80
2/20/19	1448	80	1.0	10	–	320	72
2/21/19	1494	–	–	–	8.59	320	98
2/22/19	1487	80	0.8	10	–	340	97
2/25/19	1498	–	–	20	–	320	93
2/27/19	1481	80	0.7	20	–	320	89
3/4/19	1468	90	0.8	22	–	300	79
3/6/19	1470	–	–	–	–	–	92
3/11/19	1462	70	1.0	44	8	320	82
3/20/19	1443	60	1.0	10	8.2	300	78
4/2/19	1495	70	0.8	10	8.5	320	83
4/8/19	1466	60	0.7	8	8.7	340	90
4/16/19	1564	70	0.9	–	8.2	340	82
4/22/19	1526	60	0.9	–	7.64	340	85
4/30/19	1578	80	0.8	–	7.47	320	89
5/7/19	1430	80	0.8	–	7.53	360	88
5/16/19	1714	80	0.7	–	8.15	320	94
5/21/19	1554	80	0.8	–	7.87	240	87
5/29/19	1453	–	1.1	35	8.27	–	–
6/17/19	1721	–	0.7	16	7.66	320	98
6/25/19	1780	–	0.9	5	7.73	300	95
7/1/19	1476	>200	1.0	8	7.72	280	–
7/10/19	1686	>200	0.9	22	7.69	360	91
7/24/19	1637	>200	1.0	–	7.9	320	–
7/31/19	1624	>200	0.7	–	7.78	300	92
8/13/19	1598	180	0.8	–	7.77	340	84
8/19/19	1585	160	0.7	–	7.85	300	–
8/29/19	1543	>200	0.6	–	7.77	320	86

Table 4.6.3-1 (continued). Well house data is provided from 02 January through 31 December 2019, Chaco Culture National Historical Park, New Mexico (Palmer, P., unpublished data).

2019	TDS (mg/L)	Sulfates (mg/L)	Iron (mg/L)	Total Hardness (mg/L)	pH	Alkalinity (mg/L)	Temp(°F)
9/29/19	1543	>220	0.6	0	7.77	320	86
9/11/19	1520	200	0.7	0	7.68	340	90
9/27/19	1646	80	0.4	0	7.86	320	88
9/30/19	1580	80	0.4	0	7.94	340	84
10/6/19	1489	>200	0.8	0	8.0	260	77
10/16/19	1573	90	0.6	0	7.84	320	84
11/6/19	1515	80	0.7	0	8.5	300	74.7
11/12/19	1514	90	0.8	0	8.44	300	77.0
11/20/19	1760	60	1.1	0	8.6	300	70
11/27/19	1551	80	1.0	0	8.52	300	78
12/4/19	1542	80	0.7	6	8.25	320	85
12/11/19	1546	80	0.8	8	8.27	300	80
12/17/19	1729	140	1.1	4	8.6	320	75
12/31/19	1562	120	0.9	5	8.4	320	84

4.6.4. Condition and Trend

Emerging Issues, Data Gaps & Needs

With increased oil and gas exploration on adjacent BLM, reservation, and leased lands targeted within the Mancos Shale formation (BLM 2015), both water quality and water quantity may be adversely affected by these activities. Because the Gallup Sandstone aquifer is located between thick confining sequences of the Mancos Shale formation, any directional drilling, hydraulic fracturing, or wellbore stimulation within this formation adjacent to the park boundary could potentially adversely impact CHCU's sole drinking water source (NPS 2020b). Typical fracking fluids consist of 90% water, 9.5% sand, and 0.5% chemical additives (USGS 2018). Thus, the process is extremely water resource intensive and routinely involves four to 25 million gallons of water, which is extracted, treated with additives, and then reinjected at each drilling site (Clark et al. 2013). Given the importance of this water source for the park, efforts should be made to avoid potential contamination of the aquifer and excessive withdrawals from the aquifer.

Importantly, contamination in the form of total suspended solids (TSS; Olmstead et al. 2013) and methane levels (Osborn et al. 2011) could occur due to fracking. These levels are correlated with being higher when testing occurs closer to a fracturing site (e.g., Olmstead et al. 2013). Thus, a monitoring program, which involves at least TSS and methane sampling is needed for early detection of any changes to water quality of the Gallup Sandstone aquifer.

Currently (2020), the U.S. Geological Survey is conducting a three-year investigation to assess the potential risk of groundwater contamination at CHCU from oil and gas extraction (USGS 2018). Ultimately, their finding will identify flow direction in the Greater Chaco Region, present results of water quality analyses both inside and outside CHCU, as well as other findings related to this investigation.

4.6.5. Sources of Expertise

Steven A. Monroe, Southern Colorado Plateau Inventory and Monitoring Network Program, National Park Service, Flagstaff, Arizona

Phillip Palmer, National Park Service, Chaco Culture National Historical Park, New Mexico

Don Weeks, Natural Resources Division, National Park Service, Lakewood, Colorado

4.7. Riparian Zones and Springs

A summary of all assessed conditions for riparian zones and springs is provided in Table 4.7-1.

Table 4.7-1. Condition assessment summary for riparian zones and springs, Chaco Culture National Historical Park, New Mexico.

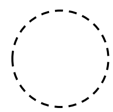
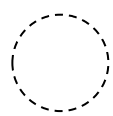
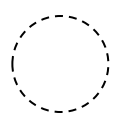
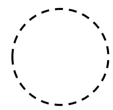
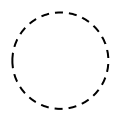
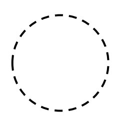
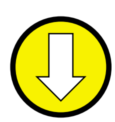
Indicator	Description	Condition Status/Trend	Summary
Native riparian composition and structure	Four primary riparian vegetation types occur within Chaco, Gallo and Fajada Washes, types and percent cover provided – cottonwood (*Populus* spp.; 4.8%), willow (*Salix exigua;* 1%), mixed woody shrub (56%) and *Tamarix* spp. (6%); these four vegetation types were used to develop a riparian vegetation land cover map of Chaco Wash and tributaries (Hanna and Floyd-Hanna 2003).		While the riparian vegetation map produced by Hanna and Floyd-Hanna (2003) is the best data available on riparian vegetation for CHCU, these data are 16 years old; the map produced by Salas et al. (2011) expanded upon this earlier effort. Currently, recruitment of cottonwood is low, the status of the tamarisk beetle has not been assessed, and the impacts of global climate change is unknown; thus, given these factors and the age of the dataset (~10 years old), confidence in the data is medium, while condition, status, and trend are largely indeterminable.
Tamarisk occurrence & distribution	As of 2003, tamarisk occurred within 6% of Chaco Wash (12 ha or 29.7 acres; Hanna and Floyd-Hanna 2003).		Information from Hanna and Floyd-Hanna (2003) is 16 years old. While it is likely the tamarisk beetle will ultimately reduce tamarisk cover, this has not been assessed or quantified. Thus, information is insufficient to determine condition, status or establish a trend.
Sensitive spring ecosystems	Wijiji spring is considered a “medium priority” for monitoring (Perkins et al. 2018) as it represents the only hanging garden/ Helocrene vegetation in CHCU. Aquatic invertebrate communities discussed below.		No information was available on the Wijiji spring vascular plant community. Information is insufficient to determine condition, status or establish a trend.

Table 4.7-1 (continued). Condition assessment summary for riparian zones and springs, Chaco Culture National Historical Park, New Mexico.

Indicator	Description	Condition Status/Trend	Summary
Aquatic invertebrate community	Twenty-one invertebrate morphospecies were documented from seven different sites containing standing water (Freehling and Johnson 2000). Additionally, Drake (1949) identified four aquatic snail species in CHCU.		Only six of 25 morphospecies were identified to species level. Thoroughly assessing the aquatic invertebrate community and identifying collected organisms to low taxonomic levels (i.e., species level) will enable NPS personnel to more fully assess the importance of riparian areas and potentially identify endemic species; presently, information is insufficient to determine condition, status or establish a trend.
Surface water quality	Although water quality analysis revealed that exceedances of New Mexico or EPA standards were documented for ammonia, nitrogen, total phosphorus, aluminum, barium, beryllium, copper, lead, manganese, and mercury (Brown 2008), this dataset is 43 to 26 years old and there's no current dataset for comparison. Thus, these findings do not represent current water quality conditions.		Water quality data was collected by the USGS from January 1976 to October 1983. Thus, samples were collected between 43 and 26 years ago. Sampling ended in 1983, and water quality has not been studied since (Brown 2008). Thus, these data cannot be used to determine condition, status, or establish a trend.
Stream Flow (Chaco River)	Daily streamflow data was collected for nearly 30 years (1976 to 2003); mean monthly discharge ranged from 13.1 ft^3/s in February and 0.34 ft^3/s in December between 1979 and 1990 (Brown 2008); flow rates documented from 1976 through 2003 indicated a peak flow of 4,970 ft^3/s for 23 August 2003 (Brown 2008).		Data are over 16 years old. Importantly, it is not possible to examine changes in flow rates due to anthropogenic climate change. Given the dataset's age and this variable, it is not possible to determine condition, status, or establish a trend.
Alluvial groundwater levels	A 17 year dataset of from well monitoring sites was analyzed to determine groundwater levels within Chaco Wash. Continued decline of alluvial groundwater levels and concomitant cottonwoods mortality are likely to continue.		Groundwater levels are 8 to ~11 meters below the floodplain, which is at least partially responsible for cottonwood decline (Soles and Monroe 2021). Condition is considered moderate, and as a decline in levels were identified for all years monitored, trend is in decline. Given that a 17 year dataset was used to assess this indicator, confidence is high.

4.7.1. Background and Importance

There are three washes that occur within the park including Chaco, Fajada, and Gallo Wash. Extending 20 km in length, Chaco Wash is largest drainage and represents the most important riparian area within CHCU; this wash actually becomes the Chaco River in the northwestern extent of the park (Brown 2008). A critically important habitat for numerous mammal, bird, and reptile species, Chaco Wash contains flowing water several months of the year (Hanna and Floyd-Hanna 2003). Four vegetation types occur within Chaco Wash consisting of cottonwood (*Populus fremontii*), willow (*Salix exigua*), mixed woody shrub, and tamarisk (*Tamarix* spp.; Hanna and Floyd-Hanna 2003; Salas et al. 2011). These vegetation types were further parsed into three primary vegetation associations: *Salix exigua* Temporarily Flooded Shrubland; *Populus fremontii*/ *Salix exigua* Forest; and, *Tamarix* spp. Semi-natural Temporarily Flooded Shrubland Alliance (Salas et al. 2011).

Importantly, Hanna and Floyd-Hanna (2003) reported two problems with cottonwood. Trees appear to have little recruitment into the population, and adult trees had experienced canopy die-back. In Chaco Wash, cottonwood stands consist of *Populus fremontii* and hybrids with *P. angustifolia* (Hanna and Floyd-Hanna 2003). As riparian vegetation dynamics in northwestern New Mexico is not well studied, Hanna and Floyd-Hanna (2003) intimated the following regarding Chaco River cottonwood stand health. First, hybridization between the two cottonwood species has resulted in a "hybrid swarm" within Chaco River. Such stands have similar fitness to parental populations, and similar seed viability, but may have up to twice as many asexual ramets (Hanna and Floyd-Hanna 2003). Schweitzer et al. (2002) suggested that introgression from *P. angustifolia* enhances asexual reproductive traits, while the genetic influx of *P. fremontii* genes promotes traits that enhance seed viability. Additionally, hybridization of these two species may become more susceptible to herbivory, particularly by the poplar bud gall mite *Aceria parapopuli* (Hanna and Floyd-Hanna 2003). Conversely, McIntyre and Whitham (2003) found hybrids supported low mite extinction rates and increased population growth rates; factors that may affect the relative vigor of hybrid and parent trees.

Regarding canopy die-back, most of the stands had a mean vigor of 25 to 50% live crown cover. In the far western part of the River, mean vigor was slightly higher, ranging from 50 to 75% live crown cover. Hanna and Floyd-Hanna (2003) suggested the low live crown cover may not be due to cottonwood hybridization. Also, frost damage, insect infestation, and other extrinsic factors may be further exacerbating low live crown cover and thus tree vigor.

Historically, nearly 100 thousand seedlings of willow, tamarisk, wild plum, and cottonwood were planted in Chaco Arroyo. This was done in the early 1930s to protect archaeological sites within the wash and to prevent the channel from further widening, an extensive erosion control program was undertaken; (Hall 2010; KellerLynn 2015). Therefore, it should be noted that this program may have created a false baseline (D. Hawkins, pers. comm. 2020). As such, the assessment of cottonwood recruitment should be interpreted with this in mind.

On a landscape level, the Southern Colorado Plateau Network (SCPN) has identified seven vital signs pertaining to riparian and spring ecosystems: (1) riparian vegetation composition, and structure,

(2) spring ecosystems, (3) aquatic invertebrate community, (4) stream water quality, (5) spring water quality, (6) stream flow and depth to groundwater, and (7) fluvial geomorphology (Thomas et al. 2006). Riparian vegetation composition and structure (both native and nonnative), spring ecosystems, the aquatic invertebrate community, and water quality are treated in this section. Fluvial geomorphology will be discussed in the hydrogeology section.

4.7.2. Data and Methods

Riparian vegetation

A supervised classification was used to develop the vegetation landcover map for riparian extent within Chaco Wash and adjacent tributaries (Hanna and Floyd-Hanna 2003). Four band IKONOS imagery, used in the classification, was acquired on 11 August 2001 (Hanna and Floyd-Hanna 2003). In January 2003, 60 field releves were sampled to define vegetation categories within the arroyo; these data were used as the training data. In May of 2003, 120 additional field releve plots were established and assigned to one of the 4 vegetation classes; these plots were used for accuracy assessment. Cross-tabulation analysis was conducted to test the accuracy of the supervised classification. Refer to Hanna and Floyd-Hanna (2003) for a complete discussion on the methods employed.

Salas et al. (2011) conducted a vegetation classification analysis and developed a CHCU-wide vegetation map. Methods used to produce the vegetation map are described in detail at the U.S. National Vegetation Classification website (USNVC 2019) and summarized in Salas et al. (2011).

Sensitive spring ecosystems

Perkins et al. (2018) proposed a spring monitoring plan for the southern Colorado Plateau. They divided springs in this region into, "high", "medium", and "low" priority for management. Only one spring at CHCU, Wijiji spring, was identified as "medium priority" for monitoring and potential future management.

Aquatic invertebrate communities

Information related to invertebrates was based upon two baseline studies (Drake 1949; Freehling and Johnson 2000). Aquatic invertebrates were sampled at seven locations applying three standard aquatic sampling techniques (aquatic D-net sampling for benthic organisms, aquatic light traps and dip nets) during 22–27 August and 18–21 September 1999 and 16–19 September 2000 (Freehling and Johnson 2000). Opportunistic hand collecting of aquatic snails was conducted in the Chaco River in October 1946, and April, June, July, August, and October of 1947 (Drake 1949).

Water quality

Water quality data was collected by the USGS from January 1976 to October 1983. To evaluate water quality, 797 surface-water samples were collected across three stream groups: (1) Chaco Wash and Chaco River; (2) the three Chaco River tributary washes – Escavada, Fajada, and Gallo Washes; and, (3) Kimmenioli Wash. For additional information regarding the breakdown of number of samples per stream group, and coordinate data of sample sites, refer to Brown (2008). Data were analyzed using standards developed by the State of New Mexico and the U.S. Environmental

Protection Agency including aquatic life, warm water fishery, and livestock watering standards (Brown 2008).

Stream flow

Data appears to have been collected using USGS flow station 09367680, located within Chaco Wash between 1979 and 2003 (Brown 2008).

Alluvial groundwater levels

In 1999, the NPS, Water Resources Division (WRD) installed monitoring wells on three of the 13 transects and a streamflow gaging station (Soles and Monroe 2021). These sites were monitored by WRD from 1999 through 2006. From 2007–2017, Soles and Monroe (2021) continued these monitoring efforts. This 17 year dataset was analyzed to estimate annual and seasonal changes in alluvial groundwater levels within Chaco Wash.

Indicators & Measures

Indicator
Native riparian composition and structure
Measure
Native riparian composition and structure

Riparian vegetation consists of three primary vegetation associations with the area in acres (ac) and hectares (ha): *Salix exigua* Temporarily Flooded Shrubland (4 ac; 2 ha); *Populus fremontii*/ *Salix exigua* Forest (1,430 ac; 579 ha); and, *Tamarix* spp. Semi-natural Temporarily Flooded Shrubland Alliance (92 ac; 37 ha; Salas et al. 2011). Classic riparian vegetation (i.e., Rocky Mountain Lower Montane Riparian Woodland and Shrubland and Northwestern Great Plains Floodplain) occurs along within Chaco River consisting of the alien species tamarisk (*Tamarix* spp.), as well as cottonwood (*Populus fremontii*), willow (*Salix exigua*), and shrubland species (Hanna and Floyd-Hanna 2003; Salas et al. 2011). In a separate analysis, which examined the extent of woody vegetation communities within the Chaco, Gallo, and Fajada Washes, Hanna and Floyd-Hanna (2003) found that *Populus fremontii* stands occupied 10.5 ha (25.8 acres) or 4.8% of the total area of Chaco Wash. *Salix exigua* stands encompassed 2.8 ha (6.9 acres) or 1% of the total area. Mixed woody shrubs (predominantly *Ericameria nauseosa*, *Artemisa* spp. and *Atriplex* spp.) within the riparian zone accounted for 121 ha (or 56% of the total area). As these studies combined plant species differently, comparison are difficult to render. Thus, information is insufficient to determine condition, status or establish a trend.

Tamarix spp. extent is discussed in the next section.

Indicator
Tamarisk distribution

Measure
Tamarisk distribution

Refer to Biology Section. The nonnative alien species, tamarisk (*Tamarix* spp.), occurred within 12 ha (29.7 acres) or 6% of Chaco River (Hanna and Floyd-Hanna 2003). The Northern tamarisk beetle (*Diorhabda carinulata* Desbrochers, 1870) was detected at Chaco Culture National Historical Park in 2015 during a Sierra Club Revegetation Project (NPS 2015c); however, the effects of its arrival have not been quantified. Salas et al. (2011) identified the “Tamarix spp. Semi-natural Temporarily Flooded Shrubland Alliance” as encompassing 37 ha (92 acres). While the difference between Hanna and Floyd-Hanna (2003) and Salas et al. (2011) represents a three-fold increase in the extent of tamarisk, there is no information to suggest whether tamarisk extent has contracted over the past 8 years due to the arrival of the tamarisk beetle, nor do we know whether these differences represent differences in the analytical techniques applied. Ergo, information is not sufficient to determine condition, status or establish a trend.

Indicator
Aquatic invertebrate communities

Measure
Aquatic invertebrate communities

Only Wijijii spring has been sampled for aquatic invertebrates, and it was sampled once. As the three primary washes contain intermittent water, aquatic invertebrates are likely to be intermittent as well. Sampling perennial water sources (i.e., Wijijii spring) will be the most viable means of assessing aquatic invertebrate communities. In total, 25 aquatic invertebrate morphospecies were documented; of these, six were identified to species level (Drake 1949; Freehling and Johnson 2000). However, few animals were identified to species. Additional work, involving species level taxonomic identifications will be required to more fully evaluate the importance of this water source and the invertebrate communities it supports.

Information is not sufficient to determine condition, status or establish a trend.

Indicator
Sensitive spring ecosystems

Measure
Sensitive spring ecosystems

Wijiji spring is considered a “medium priority” for monitoring (Perkins et al. 2018) as it represents the only hanging garden/ Helocrene vegetation in CHCU. Hanging gardens are a common spring type on the Colorado Plateau but are considered rare elsewhere in the U.S. (Perkins et al. 2008). The presence of perennial, low-flowing seeps, and the absence of flooding provides a stable, localized, mesic environment, which gives rise to isolated oases of rare vegetation communities. In some aeolian sandstones, groundwater seeping creates protective alcoves that reduce solar radiation, temperature, and evaporation potential when compared to surrounding areas (May et al. 1995). Subsequently, these areas typically support rare and endemic vascular plant species and are thus considered areas of conservation concern (Fowler 1995; Spence 2008).

Unfortunately, no additional information was available on hanging garden vascular plant species or whether endemic plant species occurred within this vegetation type at CHCU. Subsequently, we do not have adequate information to assess whether the condition is unchanging, and information is insufficient to determine a status or establish a trend.

Indicator
Water Quality

Measure
Water Quality

Water quality analyses were based upon samples collected between 43 to 26 years ago. The USGS collected 797 surface-water samples between January 1976 and October 1983 across three stream groups: (1) Chaco Wash and Chaco River; (2) the three Chaco River tributary washes – Escavada, Fajada, and Gallo Washes; and, (3) Kimmenioli Wash. Analysis revealed that CHCU exceeded New Mexico or EPA standards for ammonia, nitrogen, total phosphorus, aluminum, barium, beryllium, copper, lead, manganese, and mercury (Brown 2008). Radiological constituents, gross alpha radio activity, exceeded the standard for livestock watering (Brown 2008). These values may have resulted from naturally occurring radionuclides in surrounding geology and/or atmospheric deposition (Brown 2008). For more information and explanations regarding exceedances, refer to Brown (2008).

Management policies have changed, and analytical techniques have improved over the past 26 years. Thus, these results cannot be used for any meaningful interpretations of current water quality. This outmoded dataset cannot be used to determine condition, status or establish a trend.

Indicator
Stream Flow (Chaco River)

Measure
Stream Flow (Chaco River)

Daily streamflow data was collected for nearly 30 years (1976 to 2003) at USGS Station 09367680 in Chaco Wash. Between 1979 and 1990, mean monthly discharge ranged from 13.1 ft^3/s in February to 0.34 ft^3/s in December (Brown 2008). Additionally, flow rates were documented from 1976 through 2003 with a peak flow of 4,970 ft^3/s for 23 August 2003 (Brown 2008). As would be expected for the arid southwestern U.S., there were numerous periods when no flow was documented while the station was operational (Brown 2008).

Data is between 40 and 16 years old. Importantly, it is not possible to examine changes in flow rates due to anthropogenic climate change or other recent stochastic events. Subsequently, it is not possible to determine condition, status or establish a trend.

Indicator
Alluvial groundwater levels
Measure
Alluvial groundwater levels

From 2007 through 2017, groundwater declined on average of 0.05 m/year for the nine monitored sites (Soles and Monroe 2021). Overall, water levels in the wells have dropped a total of 0.8 – 1.0 m since 2000. During all but one year within the 10 year monitoring period, groundwater levels fell farther during the summer months than they rose over the fall and winter (Soles and Monroe 2021). Incidentally, the rate of decline over the summer months varies, and is dependent, in part, on surface flow conditions. If surface flow is of sufficient duration and/or magnitude may temporarily mitigate or potentially reverse the rate of groundwater level decline. Soles and Monroe (2021) suggested that some floodplain vegetation species can rapidly utilize accessible groundwater during the growing season.

However, current groundwater depths are considered extreme for survival of cottonwood trees. Soles and Monroe (2021) intimated that there was no evidence to suggest a reversal of the 17-year declining groundwater levels. Furthermore, they suggested the increasing depths of groundwater were at least partly responsible for cottonwood mortality in Chaco Wash. They further asserted that continued decline of alluvial groundwater levels and mortality of remaining cottonwoods are likely to continue.

4.7.3. Reference Conditions

Reference conditions were only possible for alluvial groundwater levels, and this was inferred. Groundwater levels have been consistently declining over the 17 year monitoring period. No other reference conditions were estimated for the other riparian indicators or measures.

4.7.4. Condition and Trend

<u>Threats, Issues and Data Gaps</u>

Native riparian composition and structure

The greatest threats to riparian areas are: (1) cottonwood trees are not producing seeds and thus progeny for new recruitment in riparian corridors are lacking (Thomas et al. 2009), and (2) increased temperatures and drought conditions due to climate change (Butterfield and Munson 2016; Bunting et al. 2017). Additionally, the recent arrival of the tamarisk beetle (*Diorhabda* spp.) in 2015 has not been assessed, nor has recruitment of new cottonwood trees been recently examined. Research is needed to address these lacunas in CHCU riparian habitats. Importantly, a reintroduction, revegetation, and erosion control plan should be developed.

Tamarisk distribution

Refer to biology section. No current information available on tamarisk extent or whether the tamarisk beetle is present within this area. This should be addressed.

Sensitive spring ecosystems

Wijiji spring is considered a “medium priority” for monitoring (Perkins et al. 2018) as it is the only site presently known to support hanging Garden/ Helocrene vegetation (Perkins et al. 2018). A complete inventory of flora and fauna is required to best manage this spring.

Aquatic invertebrate communities

Information related to invertebrates was based upon two baseline studies (Drake 1949; Freehling and Johnson 2000). However, four aquatic gastropod species were identified (Drake 1949), and two other aquatic invertebrates were identified to species level (Freehling and Johnson 2000). No information was available given current distribution of the four snail species identified from Chaco River; as this study was conducted 70 years ago, additional surveys should be conducted to determine whether these species are still present. Additional studies on aquatic invertebrates should be conducted to determine community composition both within all CHCU water bodies including Chaco Wash/ River and Wijiji spring.

Water quality

Water quality analyses were conducted 26 years ago and based on sampled collected between 43 to 26 years ago. Contemporary water quality monitoring and analysis are needed to collect the data necessary to establish baseline conditions and develop management strategies in accordance with these findings.

Stream flow

Data was collected 16 to 40 years ago. It is not possible to document or examine flow rate changes due to anthropogenic climate change or other stochastic events. To understand current stream flow behavior, a stream flow monitoring program should be re-established in Chaco River.

4.7.5. Sources of Expertise

Stacey Stumpf, Southern Colorado Plateau Network National Park Service Inventory & Monitoring Division, National Park Service and Dana Hawkins, Chaco Culture National Historical Park, National Park Service.

4.8. Vegetation and Wildlife

4.8.1. Background and Importance

As Chaco Canyon has been a protected area in central western New Mexico since 1907 and oil and gas exploration activities surround this protected area, the park will likely emerge as an important oasis for native ecosystems and the animals they support. Historically, sheep, goat and cattle grazing occurred within the park boundary (White 2017). In 1948, a livestock exclusion fence was built around the park (KellerLynn 2015; White 2017). Due to this and other efforts to limit grazing within the park boundary, the ecosystems have persisted over the last 70 years without the impacts of livestock grazing.

Biological inventories of various taxonomic groups have occurred since at least 1972 (Jones 1972). The park supports at least 28 mammal (Bogan et al. 2007) and 56 bird species (Cully 1981). Several plant inventories and mapping projects have been conducted (e.g., Potter and Kelley 1980; Cully 1985; Floyd-Hanna et al. 1993; Floyd-Hanna and Hanna 2004) with the inventory and mapping project by Salas et al. (2011) being the most thorough. However, thorough surveys investigating the diversity and abundance of plant species, as well as thorough inventories to catalog the species of terrestrial and aquatic invertebrate species (i.e., to potentially identify new species) has not been conducted.

<u>Vegetation: Invasive Alien Plants</u>

A summary of all assessed conditions for vegetation is provided in Table 4.8.1-1.

Table 4.8.1-1. Condition assessment summary for vegetation, Chaco Culture National Historical Park, New Mexico.

Indicator	Description	Condition/ Status/Trend	Summary
Tamarisk occurrence in Chaco River/ Wash	Tamarisk is an alien species; however, the distribution is likely to change significantly due to the presence of the tamarisk beetle; although alien, this tree species provides habitat for birds and serves as a nursery tree for numerous plant species; as of 2003 (Floyd-Hanna and Hanna 2004), this species occurred within 6% of Chaco Wash (12 ha or 29.7 acres); no current information available on tamarisk extent or whether the tamarisk beetle is present within Chaco Wash.		Information from Floyd-Hanna and Hanna (2004) is 16 years old. While it is likely the tamarisk beetle will ultimately reduce coverage of tamarisk, this has not been quantified. Thus, information is insufficient to determine condition, status or establish a trend.

Table 4.8.1-1 (continued). Condition assessment summary for vegetation, Chaco Culture National Historical Park, New Mexico.

Indicator	Description	Condition/ Status/Trend	Summary
Distributions of other Invasive Alien Plant Species	Of the 17 invasive alien species known to occur within the region, *Salsola kali* (Russian thistle), *Halogeton glomeratus* (Halogeton), *Kochia scoparia* (burningbush), and *Bromus tectorum* (cheatgrass) were considered species of concern (Floyd-Hanna and Hanna 2004).		Information from Floyd-Hanna and Hanna (2004) is 16 years old. Thus, information is insufficient to determine condition, status or establish a trend.

Indicators & Measures

Indicator
Tamarisk occurrence in Chaco Wash

Measures
Tamarisk occurrence in Chaco Wash

The most well-documented nonnative alien plant species is tamarisk. It was introduced in 1934 to protect archaeological sites within the wash and to prevent the channel from further widening, which has altered stream-channel morphology (KellerLynn 2015). Floyd-Hanna and Hanna (2004) mapped the extent of tamarisk in Chaco Wash, and identified it as occurring within 12 ha (29.7 acres) or 6% of Chaco Wash (Hanna and Floyd-Hanna 2003). Incidentally, no significant expansion of tamarisk was documented between 1974 and 2003 (Salas et al. 2011).

The last effort to control tamarisk was in 2011 (D. Hawkins, pers. com. 2019). Although the park does not have an active program for mechanical removal of tamarisk, the tamarisk beetle arrived in 2015 (NPS 2015c).

Indicator
Nonnative Alien Plant Species

Measures
Nonnative Alien Plant Species

Little information is known concerning the distributions of nonnative alien plant species at CHCU. Hanna and Floyd-Hanna (2003) and Floyd-Hanna and Hanna (2004) identified 18 nonnative alien species known to occur in the area (Table 4.8.1-2). Of these, only four were considered species of concern and included *Bromus tectorum* (cheat grass), *Halogeton glomeratus* (Halogeton), *Kochia scoparia* (burningbush), and *Salsola kali* (Russian thistle; Floyd-Hanna and Hanna 2004). *B. tectorum* occurs throughout the lower elevations of Chaco Canyon and is most common along roadsides. Bogan et al. (2007) further supported, albeit anecdotally, that cheatgrass has invaded several thousand hectares within the park; however, no additional information was provided. *H. glomeratus* was considered abundant in limited areas (in particular, on Razito-Shiprock soils), while *K. scoparia* has been confirmed within Chaco Wash. *S. kali* was considered the most pervasive and invasive and occurs through most of the lowland areas adjacent to Chaco Wash; incidentally, this area is also the most heavily impacted by tourism use. Tamarix is discussed in treated as a separate indicator (see above).

Table 4.8.1-2. Eighteen nonnative alien plant species identified either by literature review as potentially occurring or direct observation (with an *) as occurring within Chaco Culture National Historical Park, New Mexico (Hanna and Floyd-Hanna 2003; Floyd-Hanna and Hanna 2004).

Scientific Name	Authority	Common Name
Acroptilon repens	L.	Russian knapweed
**Bromus tectorum*	L.	cheat grass
Lepidium draba	L.	hoary cress
Carduus nutans	L.	nodding plumeless thistle
**Tamarix* spp.?	–	tamarix
Centaurea diffusa	Lam.	diffuse knapweed
Centaurea stoebe ssp. *micranthos*	(Gugler) Hayek	spotted knapweed
Centaurea solstitialis	L.	yellow star thistle
Cirsium arvense	(L.) Scop.	Canada thistle
Convolvulus arvensis	L.	field bindweed
Cynoglossum officinale	L.	houndstongue
**Halogeton glomeratus*	(M. Bieb.) C.A. Mey.	barilla
**Kochia scoparia*	(L.) Schrad.	common kochia
Lactuca serriola	L.	prickly lettuce
Linaria vulgaris	Mill.	yellow toadflax
Marrubium vulgare	L.	white horehound
Ranunculus testiculatus	Crantz	little bur
**Salsola kali*	L.	tumbleweed

Based upon the analysis of pilot data, Floyd-Hanna and Hanna (2004) suggested soil type and texture were important variables in determining the susceptibility of lowland areas to alien plant species invasions. They further indicated that two soil types, Notal Silty Clay Loam and the Battlerock-notal complexes, were the most susceptible. Additionally, the presence of moderate to well-developed microbial crusts was correlated with lower invasive densities (Floyd-Hanna and Hanna 2004).

Salas et al. (2011) developed a CHCU vegetation map, which employed existing vegetation alliances and associations. Within each description, they provide information on plant species occurrences including invasive alien plant species. Tamarisk occurred within four alliances including *Atriplex* *canescens* Shrubland Alliance, *Ericameria nauseosa* Shrubland Alliance, *Salix* (*exigua,* interior) Temporarily Flooded Shrubland Alliance, and *Tamarix* spp. Semi-natural Temporarily Flooded Shrubland Alliance (Salas et al. 2011). Cheatgrass was identified as occurring within four vegetation alliances: *Atriplex canescens* Shrubland Alliance, *Atriplex confertifolia* Shrubland Alliance, *Ephedra torreyana* Sparsely Vegetated Alliance, and *Forestiera pubescens* Temporarily Flooded Shrubland Alliance (Salas et al. 2011). *Halogeton glomeratus* occurred in one vegetation alliances, *Sarcobatus vermiculatus* Shrubland Alliance. *Salsola kali* occurs within the following vegetation alliances: *Pleuraphis jamesii* Herbaceous Alliance, *Atriplex canescens* Shrubland Alliance, *Atriplex confertifolia* Shrubland Alliance, *Ericameria nauseosa* Shrubland Alliance, and Weedy forbs (Non-NVC; Salas et al. 2011), while B. scoparia was detected in the *Bouteloua gracilis* Herbaceous Alliance, *Pleuraphis jamesii* Herbaceous Alliance, *Sarcobatus vermiculatus* Shrubland Alliance, and *Ericameria nauseosa* Shrubland Alliance (Salas et al. 2011).

While this information is considered quite useful in characterizing previous conditions of CHCU, the Floyd-Hanna and Hanna (2004) is over 15 years old. No recent information on alien plant species was available.

<u>Wildlife</u>
A summary of all assessed conditions for wildlife is provided in Table 4.8.1-3.

Table 4.8.1-3. Condition assessment summary for wildlife, Chaco Culture National Historical Park, New Mexico.

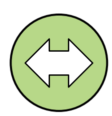
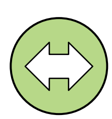
Indicator	Description	Condition Status/Trend	Summary
Elk occurrence	Elk detected during both 2007 and 2017 surveys (Bender et al. 2007; White 2017).		The CHCU Foundation Document (NPS 2015a) identified an elk management plan as a top natural resource priority; however, elk management has not been sufficiently addressed. Standardized monitoring more frequently than decadally is recommended. Currently, the CHCU elk was assessed during two surveys (2007 and 2017), condition is considered "good", trend is probably "unchanging" and confidence in data is "medium."
Elk population size	Elk population was relatively unchanged between 2007 (53 individuals; Bender et al. 2007) and 2017 (49 individuals; White 2017).		Currently, the elk population is relatively unchanged when the two surveys (2007 and 2017) were compared; condition is considered "good", trend is probably "unchanging" and confidence in data is "medium."

Table 4.8.1-3 (continued). Condition assessment summary for wildlife, Chaco Culture National Historical Park, New Mexico.

Indicator	Description	Condition Status/Trend	Summary
Mule deer occurrence and population size	No information is available on the occurrence of mule deer on CHCU.		No information is available regarding mule deer occurrence at CHCU; thus, condition, trend and confidence are unknown.
Bat species richness	Fifteen bat species have been documented (Valdez et al. 2002; Bogan et al. 2007).		Two studies using similar techniques to identify species in CHCU. This baseline work is likely complete. Condition is considered “good”, trend is probably “unchanging” and confidence in data is “high.”
Bat summer roosts	Not known		Only anecdotal information is available regarding bat summer use (i.e., maternity and bachelor roosts); thus, condition, trend and confidence are unknown.
Bat hibernacula	Not known		Only anecdotal information is available regarding bat winter use; thus, condition, trend and confidence are unknown.
Amphibian diversity	Three species known (Persons and Nowak 2006).		One inventory, which included both field surveys and an examination of existing collections; confidence is “medium” to “high” confidence regarding the completeness of this survey; thus, the condition is “good”. As these populations are not presently being monitored, establishing a trend is not possible.
Reptile diversity	Fourteen species known (Persons and Nowak 2006).		One inventory, which included both field surveys and an examination of existing collections; confidence is “medium” to “high” confidence regarding the completeness of this survey; thus, the condition is “good”; as these populations are not presently being monitored, establishing a trend is not possible.

Table 4.8.1-3 (continued). Condition assessment summary for wildlife, Chaco Culture National Historical Park, New Mexico.

Indicator	Description	Condition Status/Trend	Summary
Amphibian habitat extent	All available amphibian habitat has been identified (Persons and Nowak 2006).		Drought and other disturbance events to impact intermittently standing water and the Wijijii spring has not been assessed; climate change will exacerbate drought conditions; as the contraction and expansion of available amphibian habitat has not been monitored, condition and trend evaluations are "unknown"; however, confidence is "high" regarding where suitable habitat can and has occurred.
Invertebrate species diversity	Thirty-five invertebrate species are known to Chaco Canyon (Drake 1949; Freehling and Johnson 2000). Of these, 31 are aquatic invertebrate morphospecies (Drake 1949; Freehling and Johnson 2000) and four are terrestrial snails (Drake 1949); no additional invertebrate surveys have occurred within the park.		Importantly, thoroughly assessing the invertebrates of this spring will enable NPS personnel to more fully assess the importance of this spring resources and identify species endemic to the spring. Insufficient information to determine condition, status or establish a trend.

Indicators & Measures

Indicator
Ungulates

Measures
Ungulates

Although historic evidence of elk (*Cervus elaphus*) bones were known from CHCU archaeological sites (Truett 1996), the first contemporary elk herd did not arrive until 2000 (White 2017). Bender et al. (2007) first reported on the population dynamics, health, habitat use, distribution, and foraging impacts of this herd. Their work included aerial surveys using a Bell 206B Jet Ranger helicopter, where elk were detected, captured, and examined. Bender et al. (2007) identified a population increase of more than 53 individuals with a mean annual rate of 15% since initial colonization. Annual growth rates ranged from 4 to 22% throughout the study (Bender et al. 2007). Furthermore, they found the population's calf productivity and survival resembled those of the most productive and fastest growing elk herds (Eberhardt et al. 1996, Bender et al. 2007, Bender and Piasecke 2010). In 2017, White (2017) applied a different method for censusing the herd. Her team flew a Cessna 185 fixed wing aircraft, covered the entire area using ~200 m wide transects at an altitude around ~152.5

m AGL. As groups of elk encountered, they were herded, counted, and examined. A total of 49 individuals were detecting within seven groups ranging in size from one and 14 individuals (White 2017).

To characterize browse impacts of elk, both Bender et al. (2007) and White (2017) also examined the differences in willow and four-wing saltbush use. According to White (2017) willow (*Salix* spp.) was a key browse species within Chaco Wash, while four-wing saltbush (*Atriplex canescens*) use consumed at a higher rate in the side canyons/arroyos of Chaco Wash. According to White (2017), this indicates a reversal of the predominant use areas in the last ten years, with the "control" areas of eastern Chaco Wash and the side canyons north of South and West Mesas showing significantly higher foraging impacts than the "use" areas. The absolute percent use was much higher than the highest rates observed in the initial 2004–2007 study. Elk population was 53 individuals in 2007 (Bender et al. 2007) and 49 individuals in 2017 (White 2017).

Although the park's Resource Management Plan indicates an elk management plan was a top natural resource priority (NPS 2015a). Unfortunately, this plan has not been fully developed.

Although mule deer are known to reside in the park, none were observed during the 2017 survey (White 2017). No additional information exists for mule deer in CHCU.

Indicator

Bat Diversity & Roost Habitat

Measures

Bat Diversity & Roost Habitat

Information on bat presence in CHCU is based upon one study conducted between 1999 and 2000 by mist netting and ultrasonic bat detection at water sources (Valdez et al. 2002), and mist netting in 2003 (Bogan et al. 2007). From this effort, a total of 15 species were identified (Table 4.8.1-4).

No information is available concerning where CHCU bat species roost during winter or summer.

Table 4.8.1-4. Fifteen bat species of Chaco Culture National Historical Park from (1) Valdez et al. (2002) and (2) Bogan et al. (2007).

Species	1	2
Pallid bat (*Antrozous pallidus*)	X	X
Townsend's big-eared bat (*Corynorhinus townsendii*)	X	–
Silver-haired bat (*Lasionycteris noctivagans*)	X	–
Hoary bat (*Lasiurus cinereus*)	X	–
Spotted bat (*Euderma maculatum*)	X	X
Big brown bat (*Eptesicus fuscus*)	X	–
California myotis (*Myotis californicus*)	X	–
Western small-footed myotis (*Myotis ciliolabrum*)	X	–

Table 4.8.1-4 (continued). Fifteen bat species of Chaco Culture National Historical Park from (1) Valdez et al. (2002) and (2) Bogan et al. (2007).

Species	1	2
Long-eared myotis (*Myotis evotis*)	X	–
Fringed myotis (*Myotis thysanodes*)	X	–
Long-legged myotis (*Myotis volans*)	X	–
Yuma myotis (*Myotis yumanensis*)	X	–
Canyon bat (*Parastrellus hesperus*)	X	–
Big free-tailed bat (*Nyctinomops macrotis*)	–	X
Mexican free-tailed bat (*Tadarida brasiliensis*)	X	–

Indicator
Reptiles and Amphibian Diversity

Measures
Reptiles and Amphibian Diversity

A total of 17 reptile and amphibian species consisting of eight lizard, six snake, and two frog and one amphibian species occur at CHCU (Table 4.8.1-5). Of these, only the glossy snake (*Arizona elegans*) was considered "rare", and none of these species were identified as federally "endangered" or "threatened" (Persons and Nowak 2006; ECOS 2020). However, road mortality, especially of snakes, could potentially impact populations in the developed areas of the park.

Indicator
Amphibian habitat extent

Measures
Amphibian habitat extent

Areas supporting suitable habitat for amphibians is known within the park (Persons and Nowak 2006). However, there is no monitoring program to monitor changes to amphibian habitat. Drought and other disturbance events are likely to negatively impact both intermittently standing water and the Wijijii spring. Furthermore, climate change is anticipated to exacerbate drought conditions. These events will likely stress amphibian populations.

Table 4.8.1-5. Seventeen reptile and amphibian species of Chaco Culture National Historical Park from Persons and Nowak (2006). For ID, species' presence was confirmed by specimens either collected by Persons and Nowak (2006) (1) or during a previous study (SP).

Species	ID	NPSpecies Abundance
Tiger salamander (*Ambystoma tigrinum*)	SP	Common
Plains spadefoot (*Spea bombifrons*)	SP	Uncommon
Mexican spadefoot (*Spea multiplicata*)	SP	Common
Eastern collared lizard (*Crotaphytus collaris*)	SP	Common
Lesser earless lizard (*Holbrookia maculata*)	SP	Common
Greater short-horned lizard (*Phrynosoma hernandesi*)	SP	Common
Sagebrush lizard (*Sceloporus graciosus*)	SP	Abundant
Eastern fence lizard (*Sceloporus undulatus*)	SP	Abundant
Ornate tree lizard (*Urosaurus ornatus*)	SP	Uncommon
Side-blotched lizard (*Uta stansburiana*)	SP	Abundant
Plateau striped whiptail (*Cnemidophorus velox*)	1	Abundant
Glossy snake (*Arizona elegans*)	SP	Rare
Night snake (*Hypsiglena torquata*)	1	Common
Striped whipsnake (*Masticophis taeniatus*)	SP	Uncommon
Gopher snake (*Pituophis catenifer*)	SP	Common
Western terrestrial garter snake (*Thamnophis elegans*)	SX	Uncommon
Western rattlesnake (*Crotalus viridis*)	SP	Common

Indicator

Invertebrate species richness

Measures

Invertebrate species richness

The most comprehensive study of Chaco Canyon invertebrates was an aquatic invertebrate inventory conducted at seven water sources during late summer/early fall of 1999 and early fall of 2000. Seven different sites were sampled where a total of 21 morphospecies were identified consisting of one mayfly (Order Ephemeroptera), three dragonfly (Order Odonata), four hemipteran, five coleopteran (beetle), and eight dipteran (fly) species (Table 4.8.1-6; Freehling and Johnson 2000). Of these, species level identifications were possible for only two species. The authors suggested as of 2000, there were few studies on aquatic invertebrates in the San Juan Basin. Of these, Drake (1949) identified four freshwater snail species from the eastern reach of "Chaco River" near Pueblo Bonito.

Furthermore, Freehling and Johnson (2000) further suggested it was impossible to assess the importance of the seven aquatic habitats and the species they support without additional inventories. Additionally, one of their study sites, the Wijiji spring, was identified as a "medium priority" for monitoring (Perkins et al. 2018). Further study of this spring may reveal species new to science, which may elevate the importance of this water resource.

Regarding terrestrial invertebrate surveys, Drake (1949) also identified 10 terrestrial gastropods from the Chaco Wash area. No additional terrestrial invertebrate surveys have been conducted in the park.

Overall, there is a paucity of data concerning the invertebrate fauna of Chaco Canyon. The aquatic invertebrate survey was a baseline study, and only four species of terrestrial invertebrates have been cataloged thus far. Additional work should be conducted to both begin to characterize the terrestrial invertebrate fauna and appropriately access the importance of the aquatic habitats and the species they support.

Table 4.8.1-6. Thirty-five known invertebrate morphospecies of Chaco Culture National Historical Park, New Mexico from (1) Drake (1949) and (2) Freehling & Johnson (2000).

Taxonomy	**1**	**2**
Mollusca	–	–
Gastropoda	–	–
Planorbidae	–	–
Helisoma tenue cf. *sinuosum* (Bonnet)	X	–
Pristilomatidae	–	–
Hawaiia minuscula (Amos Binney, 1840)	X	–
[1]*Hawaiia minuscula alachuana* Dall	–	–
Basommatophora	–	–
Lymnaeidae	–	–
Fossaria parva (I. Lea, 1841)	X	–
Planorbidae	–	–
Gyraulus circumstriatus (Tryon, 1866)	X	–
Lymnaeinae	–	–
[2]*Stagnicola bulimoides cockerelli* (Pilsbry and Ferriss)	X	–
Stylommatophora	–	–
Pupillidae	–	–
Pupilla cf. *blandi*	X	–
Pupilla hebes (Ancey, 1881)	X	–
Pupoides hordaceus (Gabb, 1866)	X	–
Pupoides albilabris (C. B. Adams, 1841)	X	–
Vertigo ovata Say, 1822	X	–

[1] *Hawaiia minuscula* (Amos Binney, 1840) is taxonomically valid, but the subspecies was not; thus, the subspecies was not included in the total tally of gastropods.

[2] Species taxonomy could not be confirmed.

[3] Species was listed as Gastrocopta pellucida hordeacella (Pilsbry) by Drake (1949); this subspecies is not taxonomically valid.

Table 4.8.1-6 (continued). Thirty-five known invertebrate morphospecies of Chaco Culture National Historical Park, New Mexico from (1) Drake (1949) and (2) Freehling & Johnson (2000).

Taxonomy	**1**	**2**
Succineidae	–	–
Succinea grosvenori I. Lea, 1864	X	–
Valloniidae	–	–
Vallonia cyclophorella Sterki, 1892	X	–
Vallonia gracilicosta Reinhardt, 1883	X	–
Vertiginidae	–	–
[3]*Gastrocopta pellucida* (Pfeiffer, 1841)	X	–
Ephemeroptera	–	–
Baetidae	–	–
Callibaetis montanus Eaton	–	X
Arthropoda	–	–
Odonata	–	–
Libellulidae	–	–
Sympetrum corruptum (Hagen)	–	X
Coenagrionidae	–	–
Enallagma sp.	–	X
Lestidae	–	–
Lestes sp.	–	X
Hemiptera	–	–
Corixidae	–	–
Corisella sp.	–	X
Gerridae	–	–
Gerris sp.	–	X
Notonectidae	–	–
Notonecta sp. A	–	X
Notonecta sp. B	–	X
Coleoptera	–	–
Dytiscidae	–	–
Hydaticus sp.	–	X
Laccophilus sp.	–	X
Rhantus sp.	–	X
Hydrophilidae	–	–

[1] *Hawaiia minuscula* (Amos Binney, 1840) is taxonomically valid, but the subspecies was not; thus, the subspecies was not included in the total tally of gastropods.

[2] Species taxonomy could not be confirmed.

[3] Species was listed as Gastrocopta pellucida hordeacella (Pilsbry) by Drake (1949); this subspecies is not taxonomically valid.

Table 4.8.1-6 (continued). Thirty-five known invertebrate morphospecies of Chaco Culture National Historical Park, New Mexico from (1) Drake (1949) and (2) Freehling & Johnson (2000).

Taxonomy	1	2
Berosus sp.	–	X
Helophoridae	–	–
Helophorus sp.	–	X
Diptera	–	–
Ceratopogonidae sp.	–	X
Chironomidae sp.	–	X
Culicidae sp.	–	X
Dolichopodidae sp.	–	X
Muscidae sp.	–	X
Sciaridae sp.	–	X
Sciomyzidae sp.	–	X
Tipulidae sp.	–	X

[1] *Hawaiia minuscula* (Amos Binney, 1840) is taxonomically valid, but the subspecies was not; thus, the subspecies was not included in the total tally of gastropods.

[2] Species taxonomy could not be confirmed.

[3] Species was listed as Gastrocopta pellucida hordeacella (Pilsbry) by Drake (1949); this subspecies is not taxonomically valid.

4.8.2. Data and Methods

Tamarisk

No current information is available on tamarisk.

Nonnative Alien Plant Species

Floyd-Hanna and Hanna (2004) applied a stratified random sampling approach for identifying sample plots. They generated one thousand sample plots using the following criteria: 1) soil type, 2) time since last grazed, and 3) canyon bottom (as it receives the highest visitation). They then selected a subset for data collection. Field data collection involved recording percent cover and abundance of each species, the total number of individuals (which provided a density estimate), as well as several independent variables to characterize the habitat where the nonnative alien plant species occurred. For a complete description of the methods, refer to Floyd-Hanna and Hanna (2004).

Ungulates

White (2017) applied three techniques for studying elk: (1) aerial surveys were conducted via a Cessna 185 fixed wing aircraft on March 25, 2017; (2) four to six infrared motion-sensed camera traps were set between October 12, 2016 and June 28, 2017 at various locations in CHCU backcountry (however, no map or coordinate data were provided); and (3) browse impact surveys were conducted within Chaco Wash and select side arroyos using the same methods as Bender (2007).

Bats

Bats were sampled in 1999 and 2004 (Valdez et al. 2002; Bogan et al. 2007); however, precise dates were not provided for all fieldwork. Bats were mist-netted and acoustic surveys were conducted at 10 locations (9 locations near water and at one mine entrance) between 24 April and 28 July 2000.

Invertebrates

Aquatic invertebrates were sampled at seven locations applying three standard aquatic arthropod sampling techniques (aquatic D-net sampling for benthic organisms, aquatic light traps and dip nets) during 22–27 August and 18–21 September 1999 and 16–19 September 2000 (Freehling and Johnson 2000). Opportunistic hand collecting of both aquatic and terrestrial snails occurred in October 1946, and April, June, July, August, and October of 1947 (Drake 1949).

4.8.3. Reference Conditions

For tamarisk, this species occurred within 12 ha (29.7 acres) or 6% of Chaco Wash (Floyd-Hanna and Hanna 2004) as of 2003. Salas et al. (2011) intimates no significant expansion was observed between 1974 and 2003. Concerning other nonnative alien plant species, Floyd-Hanna and Hanna (2004) identified four concern species more than 15 years ago; given that their distributions have not be reassessed since this initial assessment, it is probable that their distributions have changed. Therefore, a reference condition for the distribution of tamarisk and other nonnative alien plant species is not possible.

Given the paucity of invertebrate data available for CHCU, a reference condition for this indicator is not possible either.

Species lists for bats, reptiles, and amphibians may be used as reference conditions to establish current diversity of these taxonomic groups. Moreover, the count data from the elk surveys from 2007 and 2017 may be useful in monitoring changes in population size over time. Given the paucity of information available on CHCU invertebrate communities, establishing a reference condition for invertebrates is not possible.

4.8.4. Condition and Trend

Aside from diversity of bats, reptiles, and amphibians, it was not possible to establish conditions and trends for other biological indicators.

Threats, Issues, and Data Gap

No summary available on the extent of tamarisk in Chaco Wash; however, the tamarisk beetle was confirmed in 2015. Thus, it is possible the extent of tamarisk may contract as the beetle population increases. However, an assessment into the current extent and condition of tamarisk, as well as the extent to which it is being "controlled" by the beetle is needed.

No formal invasive alien plant species surveys have been recently conducted. The expansion of alien plant species threatens park ecosystems and processes, and their threat could be magnified by climate change effects (e.g., tamarisk, the four nonnative alien plant species of concern, as well as potential newly arriving nonnative alien plant species).

Ungulates

The park's Resource Management Plan indicates an elk management plan was a top natural resource priority (NPS 2015a). However, development of this plan has not been sufficiently addressed. Additionally, while mule deer are known to reside in the park, none were observed during the 2017 survey (White 2017). Data collected every 10 years will not be sufficient to draw robust inference concerning population numbers of elk, to establish a baseline for mule deer population demographics, or to address stochastic events and interannual variability. More frequent surveys will be required to most accurate estimate population trends, as well as develop a science-based management plan for elk and mule deer. While helicopter surveys with multiple observers has been widely applied to estimate population size (e.g., Bristow et al. 2019) and was applied to estimate CHCU elk populations in the past, the use of unmanned aerial vehicles (UAVs) with continuous imagery capture (photo, video, and IR; refer to Prosekov et al. 2020) should be explored as both a more sustainable and cost-effective alternative. The use of UAVs for ungulate population surveys could potentially enable to the park to collect data on elk and mule deer populations on an annual to biennial basis.

For elk, White (2017) suggests their survey was inconclusive concerning several key aspects of elk biology and habitat use. Further study and ultimate development of a management plan (which involves annual to biennial monitoring) and employing the same censusing techniques (within the context of a management plan), will be required to most accurately estimate herd size.

Other data gaps to consider include the following: determine the extent that elk and deer using the washes/ Chaco River drainage; document the dynamics of ungulate herd movements; identify and quantify future actions (e.g., increased oil and gas exploration activities adjacent to park lands) that may negatively affect/ hinder natural movements; quantify the role(s) of ungulate populations in the ecosystem; and, assess the populations of medium to large predators (e.g., mountain lion and coyote) in the park.

Bats

In general, little is known concerning the distributions of most mammals on the Colorado Plateau (Bogan et al. 2007). Beyond a species list for bats, nothing is known regarding their roost habitat at CHCU or how they select habitat within the park. Thus, data gaps include the need for a roost inventory to identify critical habitat, as well as a telemetry study to start to characterize how bats select habitat within CHCU. As white-nose syndrome (an epizootic disease responsible for the mortality of millions of bats in eastern North America; WNSRT 2020) moves westward, knowledge of where roost sites are located will be of critical importance for future management and monitoring.

An assessment of archaeological sites, earth cracks, and talus slopes and soil piping features should be conducted to determine use by bats. A telemetry study may also be useful to ascertain where bats are roosting.

Herpetofauna

A likely threat to reptile and amphibian populations includes the expansion of natural gas and oil drilling on adjacent Navajo lands and outlying areas (Persons and Nowak 2006), but the long-term and long-range effects on herpetofauna have not been well-documented. Changes in the hydrology of Chaco Wash due to drought or land use practices outside CHCU may reduce the availability of amphibian breeding sites.

Invertebrates

No terrestrial invertebrate surveys have been conducted; thus, the potential is high for new species discoveries. Furthermore, as the existing aquatic invertebrate survey was baseline in nature, additional work should be conducted to appropriately access the importance of the aquatic habitats and the species they support.

4.8.5. Sources of Expertise

Megan Swan botanist with the Southern Colorado Plateau I&M Network, NPS, provided insightful comments that improved the vegetation sections; Kristen Philbrook, NPS, Lakewood, Colorado is the IMR regional wildlife biologist and reviewed the ungulate section. Esther Nelson, wildlife biologist for USDA Forest Service, provided review for the reptiles and amphibians section.

Chapter 5. Discussion

The 11 natural resources (with 34 indicators) were grouped into three broad categories: landscape-scale, supporting environment (i.e., physical resources), and biological integrity. This NRCA includes an assessment of condition and trend for key resources determined by assessing multiple indicators for each focal resource (Chapter 4). A summary is provided below for all resource categories. Slightly less than half of the indicators were identified as in "good" condition (11 indicators) with 14 indicators as unknown/ data deficient. An additional nine indicators were identified as "moderate" to "significant" concern. These were air quality (all four indicators), the acoustic environment (two of three indicators), soils (one of four indicators), alluvial groundwater levels (one indicator), and hydrogeology (one indicator; Table 5-1).

The most significantly impacted resources include acoustic environment, air quality, and hydrogeology. Interestingly, these indicators are within natural resources for which the most recent and thorough datasets exist. For acoustic environment, reduction in listening area was of significant concern with a deteriorating trend. As oil and gas exploration continues to expand towards the park boundary, noise associated with this activity is likely to intensify. Thus, the acoustic environment should continue to be monitored as these activities increase. While important for understanding noise pollution at a landscape scale, the results of the geospatial sound model were included; this condition was of moderate concern. A trend could not be established given the nature of the modeling effort.

Haze index was of moderate concern, yet trend was identified as improving. Additionally, ozone for vegetation health was of significant concern, while ozone levels for human health and wet nitrogen deposition were of moderate concern; however, no trend could be determined due to data deficiencies (only four years of data).

Erosion associated with piping at Pueblo del Arroyo was identified as being of moderate concern – as this archaeological site remains at risk. Monitoring should continue at this site to both gauge the erosional impacts, as well as to identify and implement mitigation strategies.

Finally, aquifer water quality is considered to be of moderate concern. This is because pH levels have been elevated over the past two years. Due to this concern, park personnel are evaluating water treatment options. Moreover, contamination in the form of total suspended solids (TSS; Olmstead et al. 2013) and methane levels (Osborn et al. 2011) could occur in this water source due to fracking activities in the Mancos Shale formation (which is where the Gallup Sandstone aquifer occurs). Although oil and gas exploration activities are occurring miles away, these activities could still contaminate the park's only reliable potable water source.

Although the 11 natural resource elements have been thoroughly evaluated in the preceding pages, these elements are collapsed into four broad categories for gap analysis. The aim is to succinctly highlight where additional research and/or data collection is recommended to best manage resources for CHCU. For each of the four groups, data gaps are summarized, project ideas proposed, and resource(s) addressed by each proposal or project idea are identified.

Table 5-1. Summary of resources and overall condition summary, Chaco Culture National Historical Park, New Mexico.

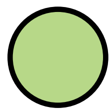
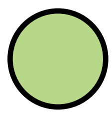
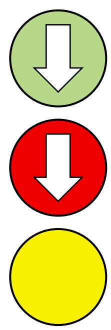
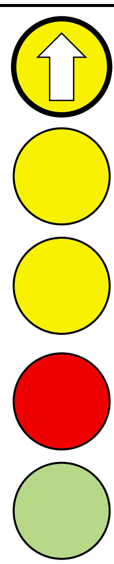
Resource	Overall Condition	Overall Condition Discussion
Viewshed		Viewsheds are an important part of the visitor experience at national monuments and parks, and features on the visible landscape influence a visitor's appreciation and understanding of a particular region. Overall, however, the monument's current viewshed is good and confidence is relatively high. Trend could not be determined due to a lack of sufficient data.
Night Sky		Retaining dark night sky conditions is important for protecting the wilderness character of CHCU. In 2013, the park was designated an International Dark Sky Park. Data used to evaluate the current condition is limited. Overall current condition is good, and confidence is high given that some of the data was recently collected. No reference conditions were available because the data was sporadically collected over an 18 year period; thus, trend could not be determined.
Acoustic Environment		In general, our ability to appreciate the solitude of the natural environment is becoming increasingly rare. In national parks and monuments, anthropogenic sounds not only negatively impact the visitor experience, but also wildlife behavior and survival. Overall, the quality of this resource is deteriorating. Mean time audible for anthropogenic sound is in "good" condition, but the trend is identified as declining. Percent reduction in listening area when sound was recorded was of "significant concern" and declining. The geospatial sound model was identified as "moderate concern."
Air quality		Air quality impacts are related to both the air we breathe and the overall impact on ecosystems. As with most national park lands, CHCU air quality is influenced by activities located outside its boundary. Haze, ozone levels for human health, and wet deposition of nitrogen are of "moderate" concern. Ozone levels for vegetation are of "significant" concern, and deposition of sulfur are in "good condition." Given the duration of most of the dataset (~4 years; 2012–2016), confidence is "medium". However, confidence is high for the haze index as it was determined using data collected from 2007–2016. Trend was identified as improving for visibility (for haze); no other trends could be estimated.

Table 5-1 (continued). Summary of resources and overall condition summary, Chaco Culture National Historical Park, New Mexico.

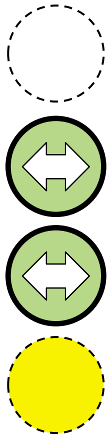
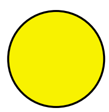
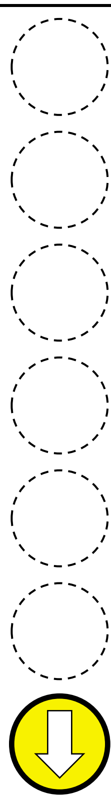
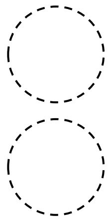
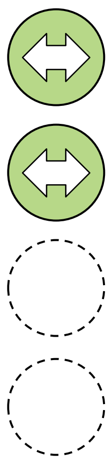
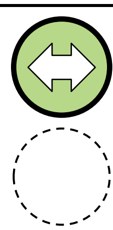
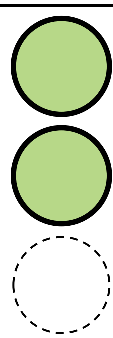
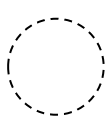
Resource	Overall Condition	Overall Condition Discussion
Soil stability and erosion		Conditions for soil stability and erosion ranged from unknown to “moderate concern”. Tamarisk is an indicator evaluated for various resources. For soils, the loss of tamarisk cover may result in increased erosion within Chaco Wash and should be monitored in the future. Erosion due to livestock grazing and within Chaco Wash is presently in “good condition”. Sheep, goat, and cattle grazing has not occurred within the park in over 70 years (KellerLynn 2015; White 2017), while erosion in Chaco Wash is considered to be at equilibrium or aggrading (KellerLynn 2015). Finally, Pueblo del Arroyo remains at risk of the erosional effects of piping and is thus at the level of “moderate concern.”
Hydrogeology		The park’s water supply comes from a 3,095 ft deep artesian well, which accesses the Gallup Sandstone aquifer. Water quality has been monitored weekly since January 2019; prior to this, it was monitored sporadically since 2009. Although water quality currently meets EPA potable water standards, pH levels have been elevated over the past two years. Currently, the park is exploring water treatment options – thus, well water quality is in “moderate condition.”
Riparian		For all six indicators associated with riparian zones and springs, data was lacking. Thus, their conditions are “unknown”. Native riparian plant communities have not been examined in over nine years, the present status of tamarisk in Chaco River/Wash is unknown and the vascular plant community within Wijiji spring has not been inventoried. Furthermore, the aquatic invertebrate communities in both Chaco River/Wash and Wijiji spring have not been sufficiently examined. Finally, water quality samples of surface waters were collected between 43 and 26 years ago. Alluvial groundwater levels are declining (from 2007–2017) and anticipated to continue; thus, condition is of moderate concern with a declining trend (Soles and Monroe 2021).

Table 5-1 (continued). Summary of resources and overall condition summary, Chaco Culture National Historical Park, New Mexico.

Resource	Overall Condition	Overall Condition Discussion
Vegetation: Invasive alien plant species		The present extent of tamarisk and other nonnative alien plant species is unknown in the park. Both were inventoried over 15 years ago (refer to Hanna and Floyd-Hanna 2003; Floyd-Hanna and Hanna 2004). Thus, it is likely conditions have changed.
Ungulates		The CHCU Foundation Document (NPS 2015a) indicated an elk management plan was a top natural resource priority; however, elk management has not been sufficiently addressed over that time period. CHCU elk populations were assessed during two surveys (2007 and 2017); thus, the condition is considered “good”, trend is probably “unchanging”, and confidence in data is “medium.” A standardized monitoring program occurring more frequently than decadally is recommended. No information is available regarding mule deer occurrence at CHCU; thus, condition, trend and confidence are unknown for this ungulate species.
Bat diversity and roost habitat		Fifteen bat species have been identified within CHCU via two studies and is considered to be representative of bat species known to occur within the park. However, the occurrence and extent of bat summer roosts (i.e., maternity and bachelor roosts) and hibernacula within the park boundary is unknown.
Herpetofauna diversity and amphibian habitat extent		Three amphibians are known from CHCU. Reptile species richness is 14 species. While these richness values were based upon one field inventory supplemented with an examination of existing museum collections, they are a likely representative of CHCU herpetofauna. As no population at present is monitored, establishing a trend is not possible. Amphibian habitat extent is known. Drought and other stochastic events may adversely affect standing water and edge habitats, and climate change is expected to exacerbate drought conditions. Thus, amphibian habitat should be assessed and potentially monitored.
Invertebrate species diversity		Thirty-five invertebrate species are known to Chaco Canyon (Drake 1949; Freehling and Johnson 2000). Of these, 31 are aquatic invertebrate morphospecies (Drake 1949; Freehling and Johnson 2000) and four are terrestrial snails (Drake 1949); no additional invertebrate surveys have occurred within the park.

5.1. Landscape Resources

While it is possible to manage natural resources that occur within the jurisdictional boundaries of national parks and monuments, the NPS is significantly challenged in their ability to safeguard landscape-scale resources, including viewsheds, night sky, soundscapes, and air quality. The conditions of these resources are largely to entirely influenced by anthropogenic activities occurring outside NPS boundaries. Because of this, partnerships for preservation will be critical for maintaining or improving landscape-scale conditions. Thus, such partnerships should be explored and established.

Primary landscape-scale threats to the CHCU's landscape-scale resources are: (1) degradation of the viewscape by potential future oil and gas exploration activities, as well as increased wildfire frequence outside the park boundary; (2) diminished dark sky quality due to light pollution from growing population centers such as Farmington; (3) increasing noise pollution resulting due to increased vehicular traffic within the park and oil and gas exploration operations outside the park; and, (4) smog and ozone levels produced from distant metropolitan areas including Albuquerque and Phoenix.

Gaps to be addressed for landscape-scale resources include additional sampling for both the acoustic environment and monitoring of dark sky conditions within the park boundary.

1. Park viewshed could be impeded in the future by oil and gas exploration activities occurring adjacent to park lands. Additionally, the presence of energy exploration activities visible from Highway 57 and New Mexico County Road 7950 would further reduce the visitor experience. To the extent possible, efforts should be made to retain the remote unmarred aesthetic of the landscape.

2. As sky glow from surrounding municipalities is expected to intensify in the future, data from a monitoring program would be an effective tool for working with local governments to help reduce these effects.

3. For the acoustic environment, data was collected for 10 days from late spring to early summer of 2014 at four locations. Increasing sampling intensity (i.e., longer duration sampling) would provide the more robust dataset as a baseline in preparation for heightened oil and gas exploration activities outside the park boundary, as well as to make a stronger case for proposing noise mitigation strategies.

5.2. Supporting Environment

For hydrogeology, the park's water supply comes from a well tapped into the Gallup Sandstone aquifer. Increased oil and gas exploration on adjacent BLM, reservation, and leased lands targeted within the Mancos Shale formation (BLM 2015) may adversely affect both water quality and water quantity of this water source. Because this aquifer is located within the Mancos Shale formation, any directional drilling, hydraulic fracturing, or wellbore stimulation within this formation adjacent to the park boundary could potentially adversely impact CHCU's only water source (NPS 2020b). Importantly, contamination in the form of total suspended solids (TSS; Olmstead et al. 2013) and methane (Osborn et al. 2011) could occur due to fracking. Therefore, continued monitoring of the park's water supply will be vitally important for early detection of any changes to water quality.

The present status of tamarisk in Chaco Wash is not known. Although the tamarisk beetle was confirmed within the park in 2015, no monitoring program exists. As tamarisk once occurred within 12 ha (29.7 acres) or 6% of Chaco Wash (Floyd-Hanna and Hanna 2004), monitoring the effects of tamarisk beetle on tamarisk should be implemented. Also, if tamarisk is eradicated by the beetle and a native vegetation restoration program is not implemented, this could result in increased erosion within the Chaco Wash corridor. Increased erosion could adversely impact some archaeological sites within the corridor.

5.3. Biological Integrity: Vegetation

Gaps for vegetation resources should include the following.

1. A tamarisk beetle/ tamarisk monitoring program, and if deemed necessary, a native riparian vegetation restoration program to both mitigate the effect of erosion and potentially restore ecological stability to Chaco River/Wash.

Currently, CHCU lacks a nonnative alien plant species removal and monitoring program. This will be required to both manage for established alien plant species, as well as for early detection of newly colonizing species.

5.4. Biological Integrity: Wildlife

Park managers consider the most important wildlife resources to be ungulates, bats, and amphibians and reptiles. Development of an elk management plan is considered a top natural resource priority (NPS 2015a). Unfortunately, little progress has been made to bring this priority to fruition. Additionally, significant bat roosts within the park should be identified and amphibian habitat should be monitored.

Thus, **data gaps for wildlife** include the following.

1. To date, the Chaco Canyon elk population has been surveyed twice (2007 and 2017), and there are no data for mule deer populations within the park. Additional and more frequent surveys will be required to both accurately estimate elk population trends, and to develop a science-based management plan for elk and mule deer. The use of unmanned aerial vehicles (UAVs) with continuous imagery capture (photo, video, and IR; refer to Prosekov et al. 2020) should be explored as both a more sustainable and cost-effective alternative. The use of UAVs for ungulate population surveys could potentially enable to the park to collect data on elk and mule deer populations on an annual to biennial basis.

2. Aside from two mist-netting studies to characterize bat diversity (Valdez et al. 2002; Bogan et al. 2007), little is known regarding bat natural history within the park. Importantly, there is little data on locations of summer bats roosts nor for hibernacula roosts within the park. With the westward advance of white-nose syndrome (WNS; refer to WNSRT 2020), understanding bat distributions within the park may be vital to managing for cave and crevice-roosting bat species should WNS arrive in New Mexico.

3. One herpetofauna survey has been conducted in CHCU (Persons and Nowak 2006). This work resulted in identifying both park reptile and amphibian diversity, as well as known amphibian habitat. However, the park presently lacks a monitoring program to assess the conditions of amphibian habitat. If the CHCU continues to rank amphibian populations as an important natural resource, a monitoring program of known habitats should be considered.

4. Finally, little is known concerning CHCU's invertebrate diversity. Thirty-one of the 35 known invertebrate species were identified from aquatic surveys (Drake 1949; Freehling and Johnson 2000), and very little data exist for terrestrial arthropods. Additionally, 70 years have passed since terrestrial snails were identified within the park (Drake 1949). An inventory project should be conducted to reexamine aquatic invertebrates, representatively sample terrestrial arthropods, as well as search for the four known terrestrial snail species to determine whether they are still extant within the park. For ground-dwelling arthropods, a pitfall trapping sampling protocol should be undertaken, and a similar to the approach applied at other southwestern U.S. National Parks is recommended (refer to Higgins et al. 2014; Ralston et al. 2017). This protocol could be augmented by adding a Malaise trapping component (to detect flying insects) at each arthropod sampling location.

5.5. Anthropogenic Climate Change

Natural resources and ecosystem processes are highly dynamic. Importantly, understanding the effects of anthropogenic climate change and decoupling these effects from other human activities can be challenging. However, increased temperature and drought due to anthropogenic climate change will result in changes to resource conditions in the American Southwest (e.g., Seager et al. 2007; Cayan et al. 2010). A recent report produced by SCPN and USGS examined modeling soil water availability in the near and long-term future at CHCU under several climate change scenarios (Andrews et al. 2020). Identifying sound practices to mitigate for these impacts, within an adaptive management framework, will be required to best manage CHCU's natural resources into the future. In general, anthropogenic climate change will result in increased temperatures, a decrease in the average number of days below freezing, and increased drought conditions.

Importantly, the following impacts due to climate change may result in increased summer temperature, storm frequency, and/or severity and droughts:

- Increased erosion rates and exposure of archaeological resources;
- Archeological sites that are not stabilized may be further negatively impacted;
- More summer days with temperatures exceeding 95° F (35° C) may change park visitation patterns;
- Increased temperatures during the summer will have significant impacts on water resources (e.g., Chaco River and Wijiji spring), species composition, and habitat that support a range of biological resources;

- Impacts associated with nonnative alien plant species occurrence and distribution will be magnified; and,
- Negative impacts on wilderness and scenic values.

While many of the effects of anthropogenic climate change are already occurring, we do not know how intensely resources will respond, nor do we know how the effects of anthropogenic climate change will interact with other human activities (e.g., pollution, landscape conversion, habitat fragmentation, etc.). Moreover, the impacts to species and wilderness at CHCU was discussed here in a rather general sense. However, the Intergovernmental Panel on Climate Change states that "many species will be unable to track suitable climates under mid- and high-range rates of climate change during the 21st century ([with] medium confidence; IPCC 2014). Lower rates of change will pose fewer problems. Some species will adapt to new climates. Those that cannot adapt sufficiently fast will decrease in abundance or go extinct in part or all of their ranges." Figure 5.5-1 provides a comparison of maximum speeds that species can disperse across landscapes (based on observations and models; vertical axis on left) to the speeds with which temperatures are expected to move across landscapes (climate velocities for temperature; vertical axis on right). It should be noted that these responses will be affected by and interplay with other human activities. Although these dispersal speeds verses temperature changes are based upon coarse taxonomic groups, this information may be generalized to understand how organisms may respond to increased average temperatures at CHCU.

Unfortunately, most parks, including Chaco Canyon, lack the information necessary to model how climate change will impact their natural resources. Thus, the information provided in this summary of natural resources to be impacted should not be considered exhaustive. However, it does encapsulate those resources likely to be most significantly impacted. Through effective monitoring, it is expected that park managers will be able to make effective decisions within an adaptive management paradigm. Importantly, park personnel working with park visitors should aspire to stay current with the evidence-based information on climate change and aim to effectively and credibly communicate this information to the general public. This will be critically important as anthropogenic climate change will increasingly affect all aspects of resources, operations, and visitor experiences within U.S. National Parks and Monuments (Monahan and Fisichelli 2014).

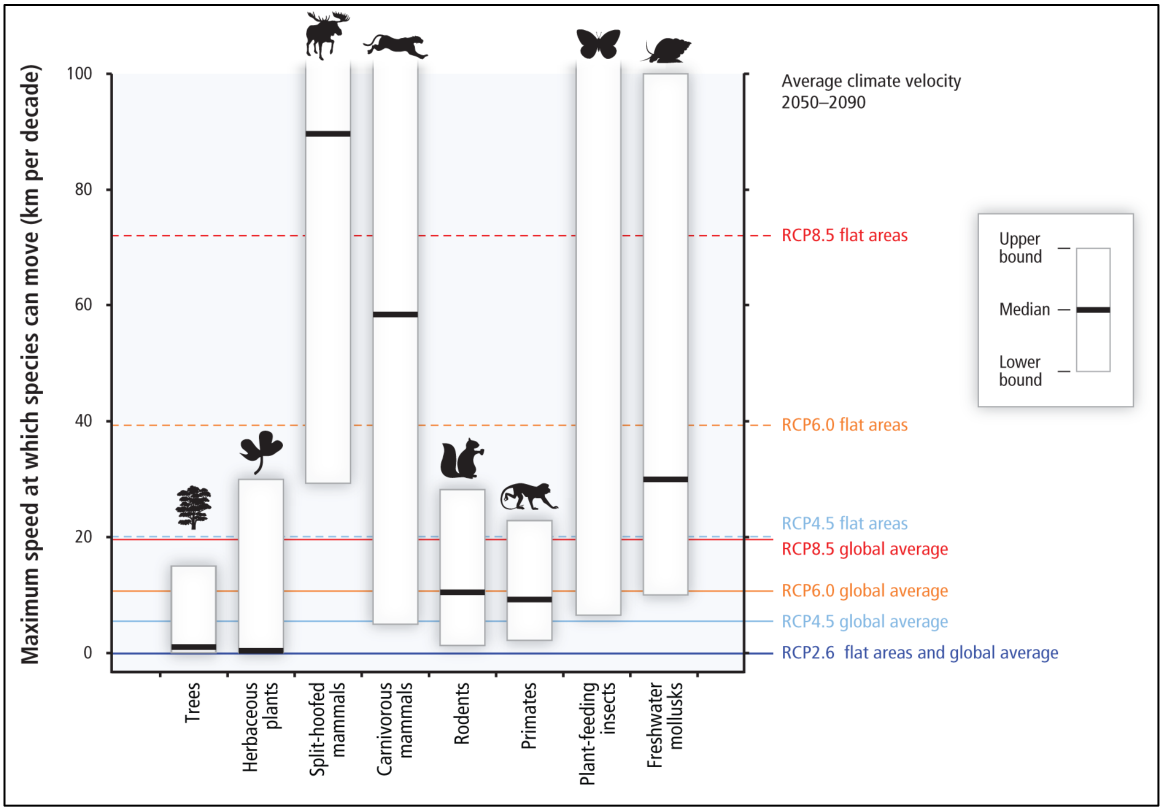


Figure 5.5-1. White boxes with black bars indicate ranges and medians for maximum movement speeds of selected species. These speeds are based on observational data and models (vertical axis on left) and depict how these organisms may disperse to suitable habitat, compared to speeds with which temperatures are projected to move across landscapes (climate velocities for temperature; vertical axis on right). Representative Concentration Pathways (i.e., RCP 2.6, 4.5, 6.0, and 8.5) for 2050–2090 are horizontal lines showing climate velocity for the global-land-area average and for large flat regions. Species with maximum speeds below each line are expected to respond to climatic warming without human intervention. From IPCC (2014).

Literature Cited

Abatzoglou, J. T. and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western U.S. forests. *Proceedings of the National Academy of Sciences* 113: 11770–11775.

Air Quality Standards for Ozone; Final Rule, October 26, 2015.

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. 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, USA. Pp. 78–100.

Ambrose, S. and S. Burson. 2004. Soundscape studies in national parks. *George Wright Forum* 21: 29–38.

Andrews, C.M., D'Amato, A.W., Fraver, S., Palik, B., Battaglia, M.A. and Bradford, J.B., 2020. Low stand density moderates growth declines during hot droughts in semi-arid forests. Journal of Applied Ecology, 57(6), 1089–1102.

Baars, D.L. 2000. The Colorado Plateau: A geologic history. University of New Mexico Press, Albuquerque, NM. Pp. 254.

Barber, J.R., C.L. Burdett, S.E. Reed, K.A. Warner, C. Formichella, K.R. Crooks, D.M. Theobald and K.M. Fristrup. 2011. Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences. *Landscape Ecology* 26: 1281–1295.

Barber, J.R., K.M. Fristrup, C.L. Brown, A.R. Hardy, L.M. Angeloni and K.R. Crooks. 2010. Conserving the wild life therein: protecting park fauna from anthropogenic noise. *Park Science* 26: 26–31.

Barber, J.R., K.R. Crooks and K.M. Fristrup. 2009. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology and Evolution* 25: 180–189.

Bayne, E.M., L. Habib, and S. Boutin. 2008. Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conservation Biology* 22:1186–1193.

Bee, M.A., and E.M. Swanson. 2007. Auditory masking of anuran advertisement calls by road traffic noise. *Animal Behavior* 74: 1765–1776.

Bender, L.C. and J.R. Piasecke 2010. Population demographics and dynamics of colonizing elk in a desert grassland-scrubland. *Journal of Fish and Wildlife Management* 2: 152–160.

Bender, L.C., J.R. Piasecke, and T. Kaminski 2007. Growth, health, and impacts of a pioneering elk herd on and adjacent to Chaco Culture National Historical Park, New Mexico. USGS New Mexico Cooperative Fish and Wildlife Research Unit; Departments of Fisheries and Wildlife & Animal and Range Sciences, New Mexico State University, Las Cruces, New Mexico.

Binkley, D., C. Giardina, I. Døckersmith, D. Morse, M. Scruggs, and K. Tonnessen. 1997. Status of air quality and related values in Class I National Parks and Monuments of the Colorado Plateau. U.S. Department of the Interior, National Park Service, Air Resources Division, Denver, Colorado.

Blickley, J.L., D. Blackwood, and G.L. Patricelli. 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage grouse at leks. *Conservation Biology* 26: 461–471.

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/IMR/SCPN/NRTR-2007/054. National Park Service, Natural Resource Program Center, Fort Collins, CO. Pp. 118.

Bortle, J.E. 2001. The Bortle Dark-Sky Scale. Sky & Telescope, Feb. edition. URL: http://www.skyandtelescope.com/astronomy-resources/light-pollution-and-astronomy-the-bortle-dark-sky-scale/ Accessed: 21 March 2017.

Bristow, K.D., M.J. Clement, M.L. Crabb, L.E. Harding, and E.S. Rubin. 2019. Comparison of aerial survey methods for elk in Arizona. *Wildlife Society Bulletin* 43: 77–92.

Brooks, M.L. 2003. Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert. *Journal of Applied Ecology* 40: 344–353.

Brown, A.L. 1990. Measuring the effect of aircraft noise on sea birds. *Environment International* 16: 587–592.

Brown, C.L., A.R. Hardy, J.R. Barber, K.M. Fristrup, K.R. Crooks and L.M. Angeloni. 2012. The effect of human activities and their associated noise on ungulate behavior. *PlosOne* 7: e40505.

Brown, J.B. 2008. Review of available water-quality data for the Southern Colorado Plateau Network and characterization of water quality in five selected park units in Arizona, Colorado, New Mexico, and Utah, 1925 to 2004: U.S. Geological Survey Scientific Investigations Report 2008–5130. Pp. 118.

Brown, J.B., 2008. Review of available water-quality data for the Southern Colorado Plateau Network and characterization of water quality in five selected park units in Arizona, Colorado, New Mexico, and Utah, 1925 to 2004: U.S. Geological Survey Scientific Investigations Report 2008–5130. Pp. 118.

Bullough, J.D., M.S. Rea, and M.G. Figueiro. 2006. Of mice and women: light as a circadian stimulus in breast cancer research. *Cancer Causes and Control* 17: 375–383.

Bunting, E.L., S.M. Munson and M.L. Villarreal. 2017. Climate legacy and lag effects on dryland plant communities in the southwestern US. Ecological Indicators 74: 216–229.

Bureau of Land Management [BLM]. 2015. Mancos-Gallup Resource Management Plan Amendment and Environmental Impact Statement, Assessment of the Management Situation (March 2015). Farmington Field Office, Bureau of Land Management Farmington, NM. Pp. 268.

BLM. 2020. Farmington Mancos-Gallup Draft Resource Management Plan Amendment and Environmental Impact Statement. Farmington Field Office, Bureau of Land Management Farmington, NM. Pp. 352.

Butterfield, B.J. and S.M. Munson. 2016. Temperature is better than precipitation as a predictor of plant community assembly across a dryland region. Journal of Vegetation Science 27: 938–947.

Buxton, R.T., R. Galvan, M.F. McKenna, C.L. White and V. Seher. 2017. Visitor noise at a nesting colony alters the behavior of a coastal seabird. *Marine Ecology Progress Series* 570: 233–246.

Cayan, D.R., T. Das, D.W. Pierce, T.P. Barnett, M. Tyree, and A. Gershunov. 2010. Future dryness in the southwest U.S. and the hydrology of the early 21st century drought. Proceedings of the National Academy of Science 107: 21271–21276.

Chan, A.Y., P. Giraldo-Perez, S. Smith, and D.T. Blumstein. 2010. Anthropogenic noise affects risk assessment and attention: the distracted prey hypothesis. *Biology Letters* 6: 458–461.

Cho, J.R., E.Y. Joo, D.L. Koo, and S.B. Hong. 2013. Let there be no light: the effect of bedside light on sleep quality and background electroencephalographic rhythms. *Sleep Medicine* 14: 1422–1425.

Clark, C.E., Horner, R.M., and Harto, C.B. 2013. Life cycle water consumption for shale natural gas and conventional natural gas. *Environmental Science and Technology* 47: 11829–11836.

Cooperative Institute for Research in Environmental Sciences [CIRES]. 2018. The new world atlas of artificial sky brightness. URL: https://cires.colorado.edu/Artificial-light. Accessed: 19 March 2018.

Cully, A.C. 1985. Checklist of Plants, Chaco Canyon National Monument (Appendix A). *In* Environment and Subsistence of Chaco Canyon, New Mexico (F. J. Mathien, Ed.). Publications in Archeology 18E, Chaco Canyon Studies. National Park Service, Albuquerque, NM. Pp. 11.

Cully, J.F., Jr. 1981. Baseline biology of birds and mammals at Chaco Canyon National Monument, New Mexico. Unpublished report on file with Chaco Canyon National Historical Park, National Park Service, New Mexico. Pp. 29.

Davey, C.A., K.T. Redmond, and D.B. Simeral. 2006. Weather and Climate Inventory, National Park Service, Southern Colorado Plateau Network. Natural Resource Technical Report NPS/SCPN/NRTR—2006/007. National Park Service, Fort Collins, Colorado. Pp. 118.

de la Torre, M., M.G.H. MacLean, D. Myers. 2003. Chaco Culture National Historical Park: A case study. The Getty Conservation Institute, Los Angeles, CA. Pp. 66.

Dooling R.J. and A.N. Popper. 2007. The effects of highway noise on birds. Unpublished report to California Department of Transportation, contract 43A0139. California Department of Transportation, Division of Environmental Analysis, Sacramento, CA. Pp. 74.

Drake, R.J. 1949. Mollusca of the eastern basin of the Chaco River, New Mexico. *The Nautilus* 62: 5–8.

Dumyahn, S.L. and B.C. Pijanowski. 2011a. Soundscape conservation. Landscape Ecology 26:1327–1344.

Dumyahn, S.L. and B.C. Pijanowski. 2011b. Beyond noise mitigation: managing soundscapes as common-pool resources. *Landscape Ecology* 26: 1311–1326.

Duriscoe, D. 2015. NPS night skies program data night report explanation. Natural Sounds and Night Skies Division, National Park Service, Fort Collins, CO., Pp. 6.

Eberhardt, L.E., L.L. Eberhardt, B.L. Tiller, and L.L. Cadwell. 1996. Growth of an isolated elk population. *Journal of Wildlife Management* 60: 369–373.

Engler, T.W., S. Kelley & M. Cather. 2014. Reasonable foreseeable development (RFD) for northern New Mexico, Final Report. Unpublished report on file with Farmington Field Office, Bureau of Land Management, Farmington, NM. Pp. 33.

Environmental Conservation Online System [ECOS]. U.S. Fish and Wildlife Service. https://ecos.fws.gov. Accessed: 18 March 2020.

Environmental Protection Agency [EPA]. 2003. Guidance for estimating natural visibility conditions under the regional Haze Rule, EPA-454/B-03-005 (September 2003). http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_envcurhr_gd.pdf. Accessed: 11 June 2018.

EPA. 2009. Assessment of the impacts of global change on regional U.S. air quality: a synthesis of climate change impacts on ground-level ozone. An Interim Report of the U.S. EPA Global Change Research Program. EPA/600/R-07/094F. National Center for Environmental Assessment, Washington, DC. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=203459 Accessed: 12 June 2018. Pp. 131.

EPA. 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. http://www.epa.gov/ttn/naaqs/standards/ozone/data/20140829pa.pdf Accessed: 12 June 2018.

EPA. 2018a. 2014 National emissions inventory data. February 16, 2018 version. https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data. Accessed: 17 May 2018.

EPA. 2018b. Regional haze in Arizona. https://www3.epa.gov/region9/air/az/haze/index.html#20170316. Accessed: 17 May 2018.

Falchi, F., P. Cinzano, C.D. Elvidge, D.M. Keith, and A. Haim. 2011. Limiting the impact of light pollution on human health, environment and stellar visibility. *Journal of Environmental Management* 92: 2714–2722.

Falchi, F., P. Cinzano, D. Duriscoe, C.C. Kyba, C.D. Elvidge, K. Baugh, B.A. Portnov, N.A. Rybnikova, and R. Furgoni, 2016. The new world atlas of artificial night sky brightness. *Science advances* 2: e1600377.

Floyd-Hanna, L, and D. Hanna. 2004. Chaco Canyon National Historical Park Exotic Flora Species Inventory. Unpublished report on file with Chaco Canyon National Historical Park, NM.

Floyd-Hanna, L., D. Hanna, F. Hays, and K. Heil. 1993. Vegetation Inventory of Chaco Culture National Historic Park. Unpublished report on file with Chaco Canyon National Historical Park, NM.

Fowler, J.F. 1995. Biogeography of hanging gardens on the Colorado Plateau. Unpublished Ph.D. dissertation. University of Wyoming, Laramie.

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. http://doi.org/10.1098/rstb.2013.0165

Francis, C.D., C.P. Ortega, and A. Cruz. 2009. Noise pollution changes avian communities and species interactions. *Current Biology* 19: 1415–1419.

Francis, C.D., C.P. Ortega and A. Cruz. 2011a. Noise pollution changes avian communities and species interactions. *Current Biology* 19: 1415–1419.

Francis, C.D., J. Paritsis, C.P. Ortega and A. Cruz. 2011b. Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. *Landscape Ecology* 26: 1269–1280.

Francis, C.D. and J.R. Barber. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. *Frontiers in Ecology and the Environment* 11: 305–313.

Freehling, M. and K. Johnson. 2000. Inventory of aquatic invertebrates, Chaco Canyon National Historical Park. New Mexico Natural Heritage Program, Albuquerque, NM. Pp. 24.

Garcia-Saenz, A., A.S. de Miguel, A. Espinosa, A. Valentin, N. Aragonés, J. Llorca, P. Amiano, V.M. Sánchez, M. Guevara, R. Capelo, and A. Tardón. 2018. Evaluating the association between artificial light-at-night exposure and breast and prostate cancer risk in Spain (MCC-Spain study). *Environmental Health Perspectives (Online)* 126: 047011.

Gaston, K.J., J. Bennie, T.W. Davies, and J. Hopkins. 2013. The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological Reviews* 88: 912–927.

Goldstein, M.I., A.J. Poe, E. Cooper, D. Youkey, B.A. Brown, and T.L. McDonald. 2005. Mountain goat response to helicopter overflights in Alaska. *Wildlife Society Bulletin* 33: 68–699.

Goudie, R.I. 2006. Multivariate behavioural response of harlequin ducks to aircraft disturbance in Labrador. *Environmental Conservation* 33: 28–35.

Habib, L., E.M. Bayne, and S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. *Journal of Applied Ecology* 44: 176–184.

Haim, A., A. Yukler, O. Harel, H. Schwimmer, and F. Fares. 2010. Effects of chronobiology on prostate cancer cells growth in vivo. *Journal of Sleep Science* 3: 32–35.

Hall, S.A. 2010. New interpretations of alluvial and paleovegetation records from Chaco Canyon, New Mexico. *In* J.E. Fassett, K. E. Zeigler, and V. Lueth, editors. Four Corners Area. Fall Field Conference Guidebook 61. New Mexico Geological Society, Socorro, New Mexico. Pp. 231–246. https://nmgs.nmt.edu/publications/guidebooks/downloads/61/61_p0231_p0245.pdf Accessed: 20 July 2019.

Hanna, D.D. and L. Floyd-Hanna. 2003. Assessing riparian vegetation condition, Chaco Canyon National Historical Park. Final Report CHCU-N-007.004, National Park Service, Chaco Canyon National Historical Park, NM. Pp. 34.

Hejl, Jr., H.R. 1982. Hydrologic investigations and data-collection network in strippable coal areas in northwestern New Mexico: U.S. Geological Survey Open-File Report 82–358. Pp. 32.

Higgins, J.W., Cobb, N.S., Sommer, S., Delph, R.J. and Brantley, S.L., 2014. Ground-dwelling arthropod responses to succession in a pinyon-juniper woodland. Ecosphere, 5(1), 1–29.

Hölker, F., C. Wolter, E.K. Perkin, and K. Tockner. 2010a. Light pollution as a biodiversity threat. *Trends in Ecology and Evolution* 25: 681–682.

Hölker, F., T. Moss, B. Griefahn, W. Kloas, C.C. Voigt, D. Henckel, A. Hänel, P.M. Kappeler, S. Völker, A. Schwope, and S. Franke. 2010b. The dark side of light: a transdisciplinary research agenda for light pollution policy. *Ecology and Society* 15, 13. Pp. 11.

Hygge, S., G.W. Evans, and M. Bullinger. 2002. A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. *Psychological Science* 13: 469–474.

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

Intergovernmental Panel on Climate Change [IPCC]. 2014. Climate change 2014: impacts, adaptation, and vulnerability. Accessed 30 May 2019. URL: http://www.ipcc.ch/report/ar5/wg2/.

Intermountain West Data Warehouse [IWDW]. 2020. http://views.cira.colostate.edu/iwdw/.

Jackson, R.B., Lowry, E.R., Pickle, A., Kang, M., DiGiulio, D. and Zhao, K., 2015. The depths of hydraulic fracturing and accompanying water use across the United States. *Environmental Science & Technology* 49: 8969–8976.

Jarup, L., W. Babisch, D. Houthuijs, G. Pershagen, K. Katsouyanni, E. Cadum, M.L. Dudley, P. Savigny, I. Seiffert, W. Swart, and O. Breugelmans, 2008. Hypertension and exposure to noise near airports: the HYENA study. *Environmental Health Perspectives*, 116: 329–333.

Jones, K. L. 1972. The ecology of Chaco Canyon: Preliminary survey. University of New Mexico; Contract No. 14-10-7:931-47. Pp. 80.

KellerLynn, K. 2007. Geologic Resource Evaluation Scoping Summary, Chaco Canyon National Historical Park, New Mexico. National Park Service, Fort Collins, Colorado. Pp. 18.

KellerLynn, K. 2015. Chaco Culture National Historical Park: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2015/1045. National Park Service, Fort Collins, Colorado. Pp. 100.

Kernodle, J. M. 1996. Hydrogeology and steady-state simulation of ground-water flow in the San Juan Basin, New Mexico, Colorado, Arizona, and Utah. Water Resources Investigations Report 95-4187. U.S. Geological Survey, Albuquerque, New Mexico. Pp. 126.

Kinney, P.L. 2008. Climate change, air quality, and human health. *American Journal of Preventative Medicine* 35: 459–467.

Kohut, R.J. 2007. Ozone risk assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail. NPS/NRPC/ARD/NRTR—2007/001. National Park Service, Fort Collins, CO. https://irma.nps.gov/DataStore/Reference/Profile/643892. Accessed: 17 May 2018.

Kohut, B., C. Flanagan, E. Porter, J. Cheatham. 2012. Foliar ozone injury on cutleaf coneflower at Rocky Mountain National Park, Colorado. *Western North American Naturalist* 72(1): 32–42.

Lekson, S.H. 2006. Chaco matters: an introduction. *In* The archaeology of Chaco Canyon: an eleventh-century Pueblo regional center (S.H. Lekson, ed.), School of American Research Press, Santa Fe, NM. Pp. 3–44.

Lekson, S. H. 2015. Chaco Matters: An Introduction. In The Archaeology of Chaco Canyon: An Eleventh-Century Pueblo Regional Center (Brooks, J.E., ed.). School of American Research Press, Santa Fe, NM. Pp. 3–44.

Lignell, B. 2018. Reporting Information for Commercial Air Tour Operations over National Park Units – 2017 Annual Report. Natural Sounds and Night Skies Division, Ft. Collin, CO. https://www.nps.gov/subjects/sound/upload/NRSS_NRR_2017_Air_Tour_Report_Final508.pdf Accessed: 14 March 2019.

Lynch, E., D. Joyce and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. *Landscape Ecology* 26: 1297–1309.

Mace B.L., P.A. Bell and R.J. Loomis. 2004. Visibility and natural quiet in national parks and wilderness areas: Psychological considerations. Environment and Behavior 36: 5–31.

Martin, L. 2005. A general description of the hydrogeology, water supply wells, groundwater monitoring, and potential threats to groundwater resources of Chaco Culture National Historical Park, New Mexico. Technical Report NPS/NRWRD/NRTR-2005/325. Water Resources Division, National Park Service, Fort Collins, CO. Pp. 35.

May, C.L., J.F. Fowler and N.L. Stanton. 1995. Geomorphology of the hanging gardens of the Colorado Plateau. *In* Proceedings of the 2nd Biennial Conference on Research in Colorado Plateau National Parks (C. Van Riper, ed.). National Park Service Transactions and Proceedings Series NPS/NRNAU/ NRTP-95/11.

McIntyre, J.P.J. and T.G. Whitham. 2003. Plant genotype affects long term herbivore population dynamics and extinction: conservation implications. *Ecology* 84: 311–3323.

McKenna, M.F., B. Lignell, A. Rapoza, C. Lee, V. Ward and J. Rocchio. 2016. A Framework to Assess the Effects of Commercial Air Tour Noise on Wilderness. *Journal of Forestry* 114: 365–372.

Mennitt, D., K. Fristrup, K. Sherrill, and L. Nelson. 2013. Mapping sound pressure levels on continental scales using a geospatial sound model. Proceedings from Internoise Conference, Innsbruck, Austria, September 15–18, 2013. Pp. 11.

Meyer, M.E., K.A. Taylor, R.G. Sullivan, J. Von Haden, and D. Ford. 2016. Enjoy the View—visual resources inventory report: Chaco Culture National Historical Park. Natural Resource Report. NPS/CHCU/NRR—2016/1353. National Park Service. Fort Collins, CO. Pp. 50.

Miller, N.P. 2008. U.S. National Parks and management of park soundscapes: A review. *Applied Acoustics* 69: 77–92.

Monahan, W.B. and N.A. Fisichelli. 2014. Climate exposure of U.S. national parks in a new era of change. Plos One 9: e101302.

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.

Morley, E.L., G. Jones, and A.N. Radford. 2014. The importance of invertebrates when considering the impacts of anthropogenic noise. *Proceedings of the Royal Society B: Biological Sciences* 281: 20132683.

Morrell, S., R. Taylor, and D. Lyle. 1997. A review of health effects of aircraft noise. *Australian and New Zealand Journal of Public Health* 21: 221–236.

Natural Gas Intelligence [NGI]. 2016. NGI's North American shale & resource plays, 2016 factbook. pp. 123. https://www.desmogblog.com/sites/beta.desmogblog.com/files/2016-Shale-Factbook_0.pdf. Accessed 4 April 2019.

Nelson, M.D. 2015. Chaco Culture National Historical Park: Acoustic monitoring report. Natural Resource Report NPS/NRSS/NSNS/NRR—2015/907. Natural Sounds & Night Skies Division, National Park Service, Fort Collins, CO. Pp. 41.

Newman, P., B.D. Taff, D. Weinzimmer, J. Newton and C. Leslie. 2014. Soundscape social science survey for air tour management and soundscape planning at Bandelier National Monument. Natural Resource Technical Report NPS/BAND/NRTR— 2014/845. National Park Service, Fort Collins, CO. Pp. 166.

New Mexico Department of Workforce Solutions [NMDWS]. 2017. State of the Workforce Report. New Mexico Department of Workforce Solutions, Economic Research & Analysis Bureau, Albuquerque, NM. Pp. 47. https://www.dws.state.nm.us/Portals/0/DM/LMI/NM_2017_SOTW_Report.pdf Accessed: 28 January 2019.

Nilsson, J. and P. Grennfelt. 1988. Critical Load for Sulphur and Nitrogen. Report from a workshop at Skoloster, Sweden, NORD Report, Copenhagen. Pp. 418.

National Park Service [NPS]. 1988. Resource Management Plan, Chaco Culture National Historical Park. National Park Service.

NPS. 2006. Management Policies. U.S Department of Interior, National Park Service, Washington D.C. https://www.nps.gov/policy/MP_2006.pdf Accessed: 14 February 2019.

NPS. 2010a. Standard NRCA report outline – annotated version 3.1, Pp. 4.

NPS. 2011a. 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.

NPS. 2012a. A call to action: preparing for a second century of stewardship and engagement. Washington, D.C. Pp. 28.

NPS. 2013a. Reporting Information for Commercial Air Tour Operations over National Park Units – 2013 Annual Report. Natural Sounds and Night Skies Division, Ft. Collin, CO. https://www.nps.gov/subjects/sound/upload/2013-Annual-Report_508.pdf. Accessed: 14 March 2019.

NPS. 2014a. Interim NRCA Guidance (Feb. 2014), Acoustic Environment. NPS, Natural Sounds and Night Skies Division, Ft. Collin, CO. Pp. 12.

NPS. 2014b. Reporting Information for Commercial Air Tour Operations over National Park Units – 2014 Annual Report. Natural Sounds and Night Skies Division, Ft. Collin, CO. https://www.nps.gov/subjects/sound/upload/2014-Annual-Report_508.pdf Accessed: 14 March 2019.

NPS. 2015a. Foundation Document, Chaco Culture National Historical Park, National Park Service, Pp. 40.

NPS. 2015b. Reporting Information for Commercial Air Tour Operations over National Park Units – 2015 Annual Report. Natural Sounds and Night Skies Division, Ft. Collin, CO. https://www.nps.gov/subjects/sound/upload/2015-Air-Tour-Report_508.pdf Accessed: 14 March 2019.

NPS. 2015c. Sierra Club Revegetation Project, 6/23/15–6/24/15. Unpublished report on file with the National Park Service, Chaco Canyon National Historical Park, New Mexico. Pp. 2.

NPS. 2016a. Best practices. Natural Sounds and Night Skies Division, Natural Resource Stewardship and Science, Fort Collins, CO. https://www.nps.gov/subjects/nightskies/practices.htm Accessed: 29 June 2018.

NPS. 2016b. Reporting Information for Commercial Air Tour Operations over National Park Units – 2016 Annual Report. Natural Sounds and Night Skies Division, Ft. Collin, CO. https://www.nps.gov/subjects/sound/upload/2016_Annual_Report_Public_20171102.pdf Accessed: 14 March 2019.

NPS. 2018a. Guidance for Evaluating Visual Resources in Natural Resource Conditions Assessments. Air Resources Division, National Park Service, Fort Collins, Colorado. Pp. 9.

NPS. 2018b. Night skies data report: photometric assessment of night sky quality – Chaco Canyon Natural Historical Park. Natural Resource Report NPS/NRSS/NSNSD/NRR—2018/XXX. National Park Service, Fort Collins, Colorado. Pp. 48.

NPS. 2018c. Measuring lightscapes. National Park Service, Washington, D.C. https://www.nps.gov/subjects/nightskies/measuring.htm Accessed: 12 June 2018.

NPS. 2018d. Reporting Information for Commercial Air Tour Operations over Units of the National Park System 2017 Annual Report Natural Resource Report NPS/NRSS/NSNSD/NRR—2018/1694, Natural Sounds and Night Skies Division, Ft. Collins, CO. Pp. 44. https://www.nps.gov/subjects/sound/upload/NRSS_NRR_2017_Air_Tour_Report_Final508.pdf Accessed: 29 March 2019.

NPS. 2018e. Effects of air pollution. National Park Service, Washington, D.C. https://www.nps.gov/subjects/air/effects.htm Accessed: 12 June 2018.

NPS. 2018f. Ozone effects on plants. National Park Service, Washington, D.C. https://www.nps.gov/subjects/air/nature-ozone.htm. Accessed: 17 May 2018.

NPS. 2018g. Nitrogen critical loads and estimated exceedances in NPS areas (2013–2015). Natural Resource Stewardship and Science Directorate, Air Resources Division, Denver, CO. https://irma.nps.gov/DataStore/Reference/Profile/2252031. Accessed: 24 May 2018.

NPS. 2019a. Park conditions and trends. National Park Service, Washington, D.C. https://www.nps.gov/subjects/air/park-conditions-trends.htm. Accessed: 11 February 2019.

NPS. 2019b. NPSpecies – The National Park Service biodiversity database. IRMA Portal version. National Park Service, Washington, D.C. https://irma.nps.gov/npspecies. Accessed 14 February 2019.

NPS. 2019c. O radiant dark! O starry night! Natural Sounds and Night Skies Division, Ft. Collins, CO. https://www.nps.gov/subjects/nightskies/index.htm. Accessed: 29 January 2019.

NPS. 2020a. Recreational visits by month Chaco Culture National Historical Park. Visitor Use Statistics, Social Science Program, National Park Service. https://irma.nps.gov/STATS/SSRSReports/Park%20Specific%20Reports/Recreation%20Visitors%20By%20Month%20(1979%20-%20Last%20Calendar%20Year)?Park=CHCU. Accessed: 13 August 2020.

NPS. 2020b. Memorandum 21 May 2020, National Park Service Comments on Farmington Mancos-Gallup Draft Resource Management Plan Amendment and Environmental Impact Statement, NPS, Chaco Culture National Historical Park, Pp. 9.

National Park Service, Air Resources Division [NPS-ARD]. 2008. Southern Plains Network Vital Signs Monitoring Plan. Natural Resource Report NPS/SOPN/NRR-2008/028. National Park Service, Fort Collins, CO. Pp. 58.

NPS-ARD. 2018. Guidance for evaluating air quality in Natural Resource Conditions Assessments (March 2018). Natural Resource Stewardship and Science Directorate, Air Resources Division, Denver, CO. https://www.nps.gov/subjects/air/upload/Guidance-For-Evaluating-AQ-In-NRCA_03-08-2018-2.pdf Accessed: 11 June 2018.

NPS-ARD. 2019. Nitrogen critical loads and estimated exceedances in NPS Areas (2014–2016). Natural Resource Stewardship and Science Directorate, Air Resources Division, Denver, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2258993 Accessed: 22 March 2019.

Natural Resource Conservation Service [NRCS]. 2004. Soil survey of Chaco Canyon National Historical Park, New Mexico. Natural Resource Conservation Service, U.S. Department of Agriculture, Washington D.C. Pp. 161.

Olmstead, S.M., Muehlenbachs, L.A., Shih, J.S., Chu, Z. and Krupnick, A.J., 2013. Shale gas development impacts on surface water quality in Pennsylvania. *Proceedings of the National Academy of Sciences* 110: 4962–4967.

Osborn, S.G., Vengosh, A., Warner, N.R., and Jackson, R.B. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences* 108: 8172–8176.

Pardo, L.D., M.J. Robin-Abbott, and C.T. Driscoll. 2011. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. Gen. Tech. Rep. NRS-80. U.S. Department of Agriculture Forest Service, Northern Research Station, Newtown Square, PA. http://www.nrs.fs.fed.us/pubs/38109. Accessed: 06 March 2019.

Pauley S.M. 2004. Lighting for the human circadian clock: recent research indicates lighting has become a public health issue. *Medical Hypotheses* 63: 588–596.

Perkins, D. W., R. Wissinger, M. Moran, Steve Monroe, H. Thomas, L. McCoy, and E. Soles. 2018. Springs Monitoring Protocol Implementation Plan for park units in the Southern Colorado Plateau Network. Natural Resource Report NPS/SCPN/NRR—2018/1771. National Park Service, Fort Collins, CO. Pp. 34.

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. Pp 186.

Pétron, G., Frost, G., Miller, B.R., Hirsch, A.I., Montzka, S.A., Karion, A., Trainer, M., Sweeney, C., Andrews, A.E., Miller, L. and Kofler, J., 2012. Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study. Journal of Geophysical Research: Atmospheres, 117(D4).

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, CO. https://irma.nps.gov/DataStore/DownloadFile/428539. Accessed: 11 June 2018. Pp. 44.

Potter, L.D. and N.E. Kelley. 1980. Aerial photointerpretation of vegetation of Chaco Canyon National Monument. Unpublished report on file with Chaco Canyon National Historical Park, National Park Service, NM. Pp. 17.

Prosekov, A., A. Kuznetsov, A. Rada, and S. Ivanova. 2020. Methods for Monitoring Large Terrestrial Animals in the Wild. *Forests* 11, 808.

Ralston, B.E., Cobb, N.S., Brantley, S.L., Higgins, J. and Yackulic, C.B., 2017. Taxonomic and compositional differences of ground-dwelling arthropods in riparian habitats in Glen Canyon, Arizona, USA. Western North American Naturalist, 77(3), 369–384.

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.

Reijnen, R. and R.U.U.D. Foppen. 2006. Impact of road traffic on breeding bird populations. *In* The ecology of transportation: managing mobility for the environment (Davenport, J. and J.L. Davenport, Eds.). Springer Publishing Co., Dordrecht, Netherlands. Pp. 255–274.

Royal Commission on Environmental Pollution [RCEP]. 2009. Artificial light in the environment. The Stationery Office Limited, London. Pp. 43. URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228832/9780108508547.pdf.pdf. Accessed: 13 March 2018.

Salas, D., L. Floyd-Hanna, and D. Hanna. 2011. Vegetation classification and mapping project report: Chaco Culture National Historical Park. Natural Resource Technical Report NPS/SCPN/NRTR—2011/452. National Park Service, Fort Collins, Co. Pp. 146.

Schaub, A., J. Ostwald, and B. M. Siemers. 2008. Foraging bats avoid noise. *Journal of Experimental Biology* 211: 3174–3180.

Schweitzer, J.A., G.D. Martinsen, and T.G. Whitham. 2002. Cottonwood hybrids gain fitness traits of both parents: mechanisms for their long term persistence? *American Journal of Botany* 89: 981–990.

Schwinning, S., B.I. Starr, N.J. Wojcik, M.E. Miller, J.E. Ehleringer, 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.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316: 1181–1184.

Shannon, G., M.F. McKenna, L.M. Angeloni, K.R. Crooks, K.M. Fristrup, E. Brown, K.A. Warner, M.D. Nelson, C. White, J. Briggs, S. McFarland. 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews* 91: 982–1005.

Sheppard, P.R., A.C. Comrie, G.D. Packin, K. Angersbach, and M. K. Hughes. 2002. The climate of the US Southwest. *Climate Research* 21: 219–238.

Shier, D.M., A.J. Lea, and M.A. Owen. 2012. Beyond masking: Endangered Stephen's kangaroo rats respond to traffic noise with foot drumming. *Biological Conservation* 150: 53–58.

Siemers, B.M. and A. Schaub. 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of the Royal Society B: Biological Sciences* 278: 1646–1652.

Simons, Li & Associates, Inc. 1982. Soil piping in the vicinity of Pueblo Bonito, Chaco Culture National Historical Park, New Mexico. Unpublished final report on file with the National Park Service, Southwest Region. Project NM-NPS-03. Simons, Li & Associates, Inc., Fort Collins, Colorado.

Slabbekoorn, H. and W. Halfwerk. 2008. Behavioural ecology: noise annoys at community level. *Current Biology* 19: R693–R695.

Smith, M. 2009. Time to turn off the lights. *Nature* 457, 27.

Soles, E.S. and S.A. Monroe. 2021. Alluvial groundwater decline at Chaco Culture National Historical Park, with summary results from pilot riparian vegetation methods (2007–2017 water years), Southern Colorado Plateau Network, National Park Service, Flagstaff, Arizona.

Souther, S., M.W. Tingley, V.D. Popescu, D.T.S. Hayman, M.E. Ryan, T.A. Graves, B. Hartl, and K. Terrell. 2014. Biotic impacts of energy development from shale: research priorities and knowledge gaps. *Frontiers in Ecology and the Environment* 12: 330–338.

Spence, J. 2008. Spring-supported vegetation along the Colorado River on the Colorado Plateau: Floristic, vegetation structure and environment. *In* Aridland Springs in North America: Ecology and Conservation (L.E. Stevens and V.J. Meretsky, eds.). University of Arizona Press, Tucson. Pp. 185–210.

Sullivan, T.J. 2016. Air quality related values (AQRVs) for Southern Colorado Plateau Network (SCPN) parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/SCPN/NRR—2016/1157. National Park Service, Fort Collins, CO. https://irma.nps.gov/DataStore/DownloadFile/548637. Accessed: 11 June 2018. Pp. 78.

Sullivan, T. J., McDonnell, T. C., McPherson, G. T., Mackey, S. D., Moore, D. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition. Natural Resource Report NPS/NRPC/ARD/NRR—2011/313. National Park Service, Denver, CO. https://irma.nps.gov/DataStore/DownloadFile/427566. Accessed: 11 June 2018. Pp. 132.

Sullivan, T. J., McPherson, G. T., McDonnell, T. C., Mackey, S. D., Moore, D. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition. Natural Resource Report NPS/NRPC/ARD/NRR—2011/330.

National Park Service, Denver, CO. https://irma.nps.gov/DataStore/DownloadFile/425475. Accessed: 11 June 2018. Pp. 28.

Sullivan, T. J., McPherson, G. T., McDonnell, T. C., Mackey, S. D., Moore, D. 2011c. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition. Natural Resource Report NPS/NRPC/ARD/NRR—2011/349. National Park Service, Denver, CO. https://irma.nps.gov/DataStore/DownloadFile/428429. Accessed 11 June 2018. Pp. 132.

Sullivan, T. J., McDonnell, T. C., McPherson, G. T., Mackey, S. D., Moore, D. 2011d. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition. Natural Resource Report NPS/NRPC/ARD/NRR—2011/372. National Park Service, Denver, CO. https://irma.nps.gov/DataStore/DownloadFile/428452. Accessed: 11 June 2018. Pp. 34.

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, CO. https://www.nps.gov/subjects/air/upload/NRR-NPS_AQAnalysisMethods_08-24-2017-3.pdf. Accessed: 11 June 2018. Pp. 72.

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

The Nature Conservancy [TNC]. 2002. An assessment of the Colorado Plateau ecoregion. The Nature Conservancy, Moab, UT. Pp. 131.

Thomas, L.P., M.N. Hendrie, C.L. Lauver, S.A. Monroe, N.J. Tancreto, S.L. Garman, and M.E. Miller. 2006. Vital signs monitoring plan for the Southern Colorado Plateau Network: Natural Resources Report NPS/SCPN/NRR-2006/002, National Park Service, Fort Collins, Colorado. Available at http://science.nature.nps.gov/im/units/scpn/publications.cfm.

Thomas, K.A., M.L. McTeague, A. Cully, K. Schulz, and J.M.S. Hutchinson. 2009. Vegetation classification and distribution mapping report: Petrified Forest National Park. National Resource Technical Report NPS/SCPN/NRTR— 2009/273. National Park Service, Fort Collins, Colorado. Pp. 295.

Thompson, T.M., Shepherd, D., Stacy, A., Barna, M.G. and Schichtel, B.A., 2017. Modeling to evaluate contribution of oil and gas emissions to air pollution. Journal of the Air & Waste Management Association, 67(4), 445–461.

Truett, J. 1996. Bison and elk in the American Southwest: In search of the pristine. *Environmental Management* 20: 195–206.

Turina, F., E. Lynch, and K. Fristrup. 2013. Recommended indicators and thresholds of acoustic resources quality: NPS State of the Park reports interim guidance (December 2013). National Park Service, Natural Sounds and Night Skies Division, Fort Collins, CO. Pp. 10.

U.S. Census Bureau [USCB]. 2010. 2010 Census Urban and Rural Classification. Accessed: July 18 2018. http://www2.census.gov/geo/tiger/TIGER2010/UA/2010.

USCB. 2020. Annual estimates of the resident population: July 1, 2019. https://data.census.gov/ Accessed: 09 July 2020.

U.S. Department of Transportation [US DOT]. 2018. Travel monitoring: travel volume trends. Accessed: 19 July 2018. http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm.

U.S. Energy Information Administration [EIA]. 2015. Top 100 U.S. oil and gas fields, March 2015. U.S. Energy Information Administration. Washington, D.C. https://www.eia.gov/naturalgas/crudeoilreserves/top100/pdf/top100.pdf. Accessed: 4 April 2019.

U.S. Federal Register [USFR]. 1963. Clean Air Act, Public Law 95-124; Final Rule, December 17, 1963 & as amended November 15, 1990 (Public Law No: 101-549).

USFR. 2015. Vol. 80 No. 206, 40 CFR Part 50, 51, 52, et al. National Ambient.

U.S. Geological Survey [USGS]. 1987. Hydrologic unit map. USGS Water Supply Paper # 2294, USGS, Denver, CO. Pp. 20. https://pubs.usgs.gov/wsp/wsp2294/pdf/wsp_2294_a.pdf Accessed: 20 June 2020.

USGS. 2018. Investigation of the vulnerability of water resources at Chaco Culture National Historical Park related to threats from oil and natural gas drilling. Project proposal. Ben Linhoff, New Mexico Water Science Center, Albuquerque, NM (blinhoff@usgs.gov), Pp. 5.

U.S. National Vegetation Classification [USNVC]. 2019. The U.S. National Vegetation Classification, your guide to inventorying natural and cultural plant communities. http://usnvc.org. Accessed: 11 December 2019.

Valdez, E. R., S. Haymond, M. A. Bogan, and L. Ellison. 2002a. Bat population study and monitoring program at Chaco Culture National Historical Park, New Mexico, 1999 and 2000. Final Report to National Park Service.

Vijayaraghavan, K., Z. Liu, J. Grant, T. Shah, J. Jung, L. Huang, W. C.-Hsieh, R. Morris. 2017. Colorado Air Resource Management Modeling Study (CARMMS): 2025 CAMx modeling results for the high, low and medium oil and gas development scenario. Prepared for the Bureau of Land Management, Colorado State Office, Lakewood, CO. Ramboll Environ US Corporation, Novato, CA. pp. 128. https://www.blm.gov/sites/blm.gov/files/documents/files/program_natural%20resources_soil%20air%20water_airco_quicklins_CARMMS2.0_with%20Appendices.pdf. Accessed: 4 April 2019.

Warner, O. and M. Gannon. 2018. San Juan Generating Station update. PNM meeting, October 24, 2018. https://www.env.nm.gov/wp-content/uploads/sites/2/2016/11/6_102418-FINAL-SJGS_PNM_4CAQG_Meeting.pdf.

Western Regional Climate Center [WRCC]. 2020. Chaco Culture National Historical Park, NM (291647). https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?nm1647 Accessed: 03 July 2020.

White, L. 2017. Current status of elk (*Cervus elaphus*) and their impacts at Chaco Culture National Historical Park. Unpublished report on file with Chaco Canyon National Historical Park, New Mexico. Pp. 13.

White Nose Syndrome Response Team [WNSRT]. 2020. White nose syndrome. https://www.whitenosesyndrome.org Accessed: 10 July 2020.

Wood, L. 2015. Acoustic environment and soundscape resource summary, Petrified Forest National Park. National Park Service, Natural Sounds and Night Skies Division, Fort Collins, CO. Pp. 4.

Zschetzsche, S. and G.H. Clark. 2001. Soil survey of Chaco Canyon National Historical Park, New Mexico. United States Department of Agriculture, Natural Resources Conservation Service, in cooperation with the United States Department of the Interior, National Park Service, Pp. 162.

Appendix A. (Bortle Dark-sky Scale)

Table A-1. Bortle Dark-sky scale for gauging light pollution (Bortle 2001). Classes range from 1 (best conditions) through 9 (worst conditions). Title was assigned by Bortle to describe either viewing conditions or proximity to different types of human population centers. NELM (naked-eye limiting magnitude), while considered a poor criterion, still aids in parameterizing Bortle's nine classes. Sky brightness or magnitude is provided in measurements of one arc second ($mag/arcsec^2$). Description provides a summary of sky conditions and objects viewable (or not) in the night sky.

Class	Title	NELM	Brightness	Description
1	Excellent dark-sky site	7.6–8.0	21.7–22.0	• Zodiacal light visible and colorful • Gegenschein, zodiacal band and sky glow visible • Scorpius and Sagittarius regions of the Milky Way cast obvious shadows • Many constellations, particularly fainter ones, barely recognizable due to the large number of stars • Many Messier and globular clusters naked-eye objects • Galaxy M33 is a naked-eye object • Limiting magnitude with 12.5" reflector is 17.5 (with effort)
2	Typical truly dark site	7.1–7.5	21.5–21.7	• Zodiacal light distinctly yellowish and bright enough to cast shadows at dusk and dawn • Sky glow may be weakly visible near horizon • Clouds only visible as dark holes against the sky • Surroundings barely visible silhouetted against the sky • Summer Milky Way highly structured • Many Messier objects and globular clusters are naked-eye objects • Galaxy M33 easily seen with naked eye • Limiting magnitude with 12.5" reflector is 16.5
3	Rural sky	6.6–7.0	21.3–21.5	• Zodiacal light striking in spring and autumn, color is still visible • Some light pollution evident at horizon • Clouds illuminated near horizon, dark overhead • Nearby surroundings vaguely visible • Summer Milky Way appears complex • Galaxies M15, M4, M5, and M22 are naked-eye objects • M33 easily visible with averted vision • Limiting magnitude with 12.5" reflector is 16

Class	Title	NELM	Brightness	Description
4	Rural/ suburban transition	6.1–6.5	20.4–21.3	• Zodiacal light still visible, but does not extend halfway to the zenith at dusk or dawn • Light pollution domes visible in several directions • Clouds illuminated in the directions of the light sources, dark overhead • Surroundings clearly visible, even at a distance • Milky Way well above the horizon is still impressive, but lacks detail • M33 is a difficult averted vision object, only visible when high in the sky • Limiting magnitude with 12.5" reflector is 15.5
5	Suburban sky	5.6–6.0	19.1–20.4	• Only hints of zodiacal light seen on the best nights in autumn and spring • Light pollution visible in most, if not all, directions • Clouds noticeably brighter than the sky • Milky Way very weak or invisible near the horizon, and looks washed out overhead • At half-moon (first/last quarter) in a dark location the sky appears like this, but with the difference that the sky appears dark blue • Limiting magnitude with 12.5" reflector is 15
6	Bright suburban sky	5.1–5.5	18.0–19.1	• Zodiacal light invisible • Light pollution makes the sky within 35° of the horizon glows grayish white • Clouds anywhere in the sky appear fairly bright • Even high clouds (cirrus) appear brighter than the sky background • Surroundings are easily visible • Milky Way only visible near the zenith • M33 not visible, M31 modestly apparent • Limiting magnitude with 12.5" reflector is 14.5
7	Suburban/ urban transition	4.6–5.0	18.0–19.1	• Light pollution makes entire sky light gray • Strong light sources evident in all directions • Clouds brightly lit • Milky Way invisible • Galaxies M31 and M44 may be glimpsed, but with no detail • Through a telescope, the brightest Messier objects are pale ghosts of their true selves • At full moon in a dark location the sky appears like this, but with the difference that the sky appears blue • Limiting magnitude with 12.5" reflector is 14

Class	Title	NELM	Brightness	Description
8	City sky	4.1–4.5	<18.0	• Sky light gray or orange – one can easily read • Stars forming familiar constellation patterns may be weak or invisible • M31 and M44 are barely glimpsed by an experienced observer on good nights • Even with telescope, only bright Messier objects can be detected • Limiting magnitude with 12.5" reflector is 13
9	Inner-city sky	4.0	<18.0	• Sky brilliantly lit • Many stars forming constellations are invisible and many fainter constellations are invisible • Aside from the Pleiades, no Messier object is visible to the naked eye • The only objects to observe are the Moon, the planets, and a few of the brightest star clusters

Appendix B. (Geospatial Sound Model (LA_{50})

Maps (B-1 and B-2) depicting median natural and existing sound levels of the geospatial sound model (LA_{50} Zero Impact), Chaco Canyon National Historical Site, New Mexico (from Mennitt et al. 2013).

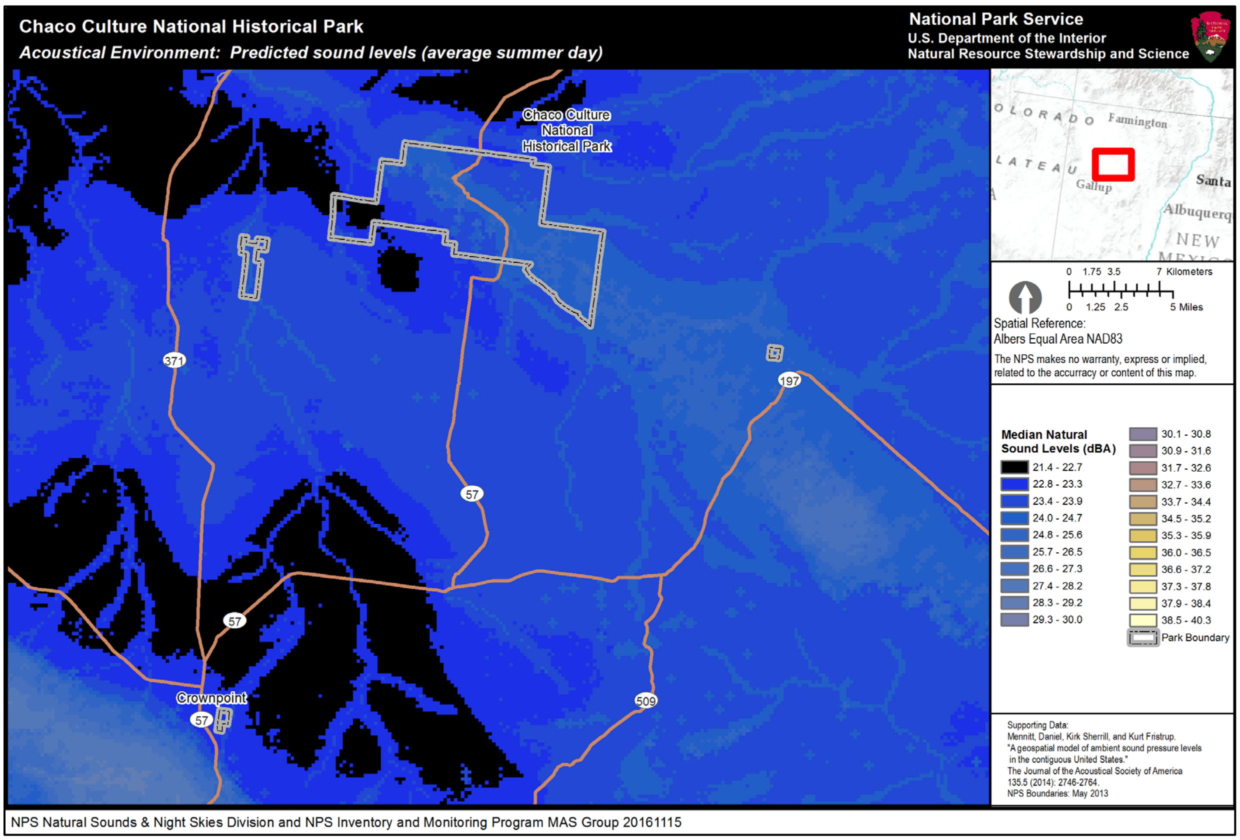


Figure B-1. Median natural sound pressure levels generated using version 3.2 of the geospatial model, Chaco Culture National Historical Park, New Mexico (Mennitt et al. 2013). Color scale indicates the decibel level predicted in the park based on natural sound sources only. Sound level is measured in A-weighted decibels (dB). Black and dark blue colors indicate low decibel levels gradating from lighter blue to yellow indicate higher decibel levels.

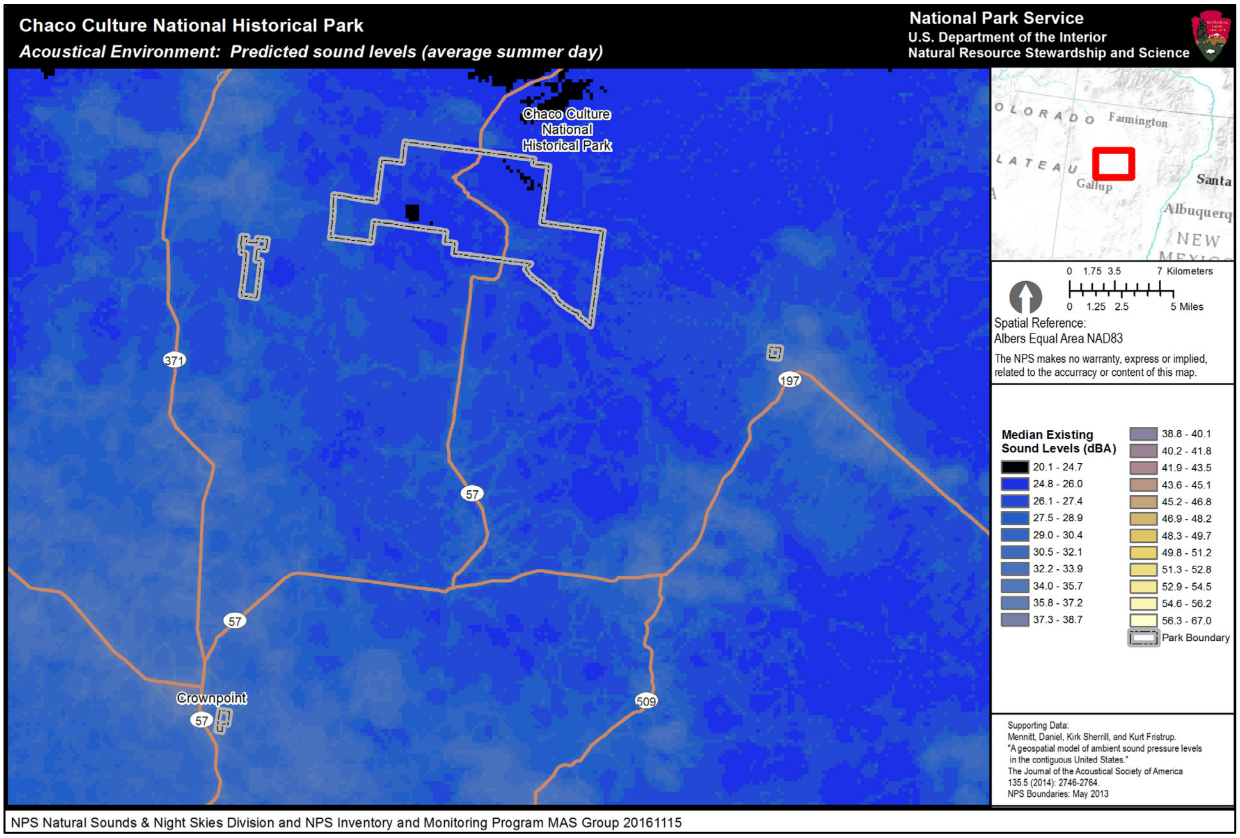


Figure B-2. Median existing sound pressure levels generated using version 3.2 of the geospatial model, Chaco Culture National Historical Park, New Mexico (Mennitt et al. 2013). Color scale indicates the decibel level predicted in the park based only on both human-caused and natural sound sources. Sound level is measured in A-weighted decibels, or dB. Black and dark blue colors indicate low decibel levels gradating to lighter blue to yellow indicating higher decibel levels.

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