National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Carlsbad Caverns National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/CAVE/NRR—2017/1466

ON THE COVER
Bats flying out of the Natural Entrance of Carlsbad Cavern
Photograph by Peter Jones, NPS

Carlsbad Caverns National Park

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Natural Resource Report NPS/CAVE/NRR—2017/1466

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Carlsbad Caverns National Park (CAVE) managers to develop near-term management priorities, engage in watershed or landscape scale partnership and education efforts, conduct park planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to park management at CAVE. The final project framework contains 10 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each natural resource component in the framework to provide summaries of current condition and trends in selected resources. When possible, existing data for the established measures of each component were analyzed and compared to designated reference conditions. A weighted scoring system was applied to calculate the current condition of each component. Weighted Condition Scores, ranging from zero to one, were divided into three categories of condition: low concern, moderate concern, and significant concern. These scores help to determine the current overall condition of each resource. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by CAVE resource managers or NPS Chihuahuan Desert Network (CHDN) staff.

Existing literature, short- and long-term datasets and input from NPS scientists support condition designations for components in this assessment. However, in some cases, data were unavailable or insufficient for several of the measures of the featured components. In other instances, data establishing reference condition were limited or unavailable for components, making comparisons with current information inappropriate or invalid. In these cases, it was not possible to assign condition for the components. Current condition was not able to be determined for 5 of the 10 components (50%) due to these data gaps.

For those components with sufficient available data, the overall condition varied. There were no components that were considered to be in good condition. Two components, dark night skies and birds, were considered to be of moderate concern. The NPS NSNSD data for the dark night sky component at CAVE is nearly ten years old thus causing the component to have a condition of

moderate concern; it is likely with updated data, the condition would be put in the significant concern category. Three components (Rattlesnake Springs community, air quality, and human impacts on caves) were considered significant concern. Despite all of the measures in the air quality component falling into the moderate concern category, a condition of significant concern was assigned due to the fact that the ecosystem at CAVE may have high sensitivity to nitrogen-enrichment and acidification effects relative to all I&M parks (Sullivan et al. 2011a, b, Sullivan et al. 2011 c, d, NPS 2015). Due to the declines in the discharge rates for the springs in the Rattlesnake Springs community and the loss of historic wetland areas, the Rattlesnake Springs community component was assigned to significant concern. Detailed discussion of these designations is presented in Chapters 4 and 5 of this report.

Several park-wide threats and stressors influence the condition of priority resources in CAVE. Those of primary concern include surrounding oil and gas development, adjacent land uses, drought, climate change, and impacts from visitor use. Understanding these threats, and how they relate to the condition of park resources, can help the NPS prioritize management objectives and better focus their efforts to maintain the health and integrity of the park ecosystem, both above and below ground.

Acknowledgments

We acknowledge Carlsbad Caverns National Park staff, past and present, for the technical expertise provided during scoping, through multiple stages of review, via phone and email; specifically, Kent Schwarzkopf, Luis Florez, Rod Horrocks, Renee West, and Stan Allison. Paul Burger (NPS Hydrologist) and Steve West (Borderlands Environmental Education and Research Consortium) offered logistical insight and critical review of interim documents. Jeremey White NPS Dark Night Skies Division offered information and guidance on the preparation of the dark night skies component. Additional program guidance and reviews were provided by Donna Shorrock (former Intermountain Region NRCA Coordinator) and Jeff Albright, Natural Resource Condition Assessment Coordinator. Thank you to all others who assisted with the development of this document.

Acronyms and Abbreviations

μg/m^2/yr – Microgram per square meter per year

μg/m^3 – Microgram per cubic meter (equivalent to ppb)

ALR – Anthropogenic Light Ratio

AQI – Air Quality Index

ARD – Air Resources Division

BCC – Bird Species of Conservation Concern

BCR – Bird Conservation Region

BLM – Bureau of Land Management

Br – Bromide

CAA – Clean Air Act

CAD – Computer-aided Design

CAVE – Carlsbad Caverns National Park

CCD – Charge-coupled Device

cfs – Cubic feet per second

CFU – Colony-forming Unit

CH_4 – Methane

CHDN – Chihuahuan Desert Network

CL – Condition Level

cms – Cubic meters per second

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

DDT – Dichlorodiphenyltrichloroethane

DO – Dissolved Oxygen

dv – Deciview

EPA – Environmental Protection Agency

Acronyms and Abbreviations (continued)

ESA – Endangered Species Act

FMP – Fire Management Plan

GHG – Greenhouse Gases

GIS – Geographic Information System

gpm – Gallons per minute

GPRA – Government Performance and Results Act

GPS – Global Positioning System

GRTS – Generalized Random-tessellation Stratification

GUMO – Guadalupe Mountains National Park

H_2S – Hydrogen Sulfide

HAPs – Hazardous Air Pollutants

HC – Hydrocarbons

Hg – Mercury

HNO_3 – Nitric Acid

I&M – Inventory & Monitoring

IMBCR – Integrated Monitoring in Bird Conservation Regions

IMPROVE – Interagency Monitoring of Protected Visual Environments Program

IR – Infrared

IRMA – Integrated Resource Management Application

kg/ha/yr – Kilogram per hectare per year

kl – Kiloliters

kW – Kilowatt

LED – Light-emitting Diode

lpm – Liters per minute

LPR – Light Pollution Ratio

Acronyms and Abbreviations (continued)

mag/arcsec^2 – Magnitudes per square arc second

mcd/m^2 – Milli-candela per square meter

MDN – Mercury Deposition Network

MSATs – Mobile-source Air Toxics

MW – Megawatt

N – Nitrogen

N_2O – Nitrous Oxide

NA LCP – North American Landbird Conservation Plan

NAAQS – National Ambient Quality Standard

NADP – National Atmospheric Deposition Program

ng/L – Nanograms per liter

NH_3 – Ammonia

NH_4 – Ammonium

NLCD – National Land Cover Dataset

NMED – New Mexico Environment Department

NO_2 – Nitrite

NO_3 – Nitrate

NO_x – Nitrogen Oxides

NPS – National Park Service

NRCA – Natural Resource Condition Assessment

NSNSD – Natural Sounds and Night Skies Division

NTN – National Trends Network

O_3 – Ozone

P – Phosphorous

PAH – Polycyclic Aromatic Hydrocarbon

Acronyms and Abbreviations (continued)

Pb – Lead

Pcb – Capitan Limestone - Breccia (reef) Member

Pcm – Capitan Limestone - Massive (reef-talus) Member

PIF – Partners in Flight

PM – Particulate Matter

PM_{10} – Coarse Particulate Matter

$PM_{2.5}$ – Fine Particulate Matter

PO_4 – Phosphate

POMS – Portable Ozone Monitoring Station

ppb – Parts per billion

ppm – Parts per million

RAEL – Renewable and Appropriate Energy Laboratory

RF-EMF – Radio-frequency Electromagnetic Fields

RMBO – Rocky Mountain Bird Observatory

S – Sulfur

SL – Significance Level

SMUMN GSS – Saint Mary's University of Minnesota – GeoSpatial Services

SO_2 – Sulfur Dioxide

SO_4 – Sulfate

SOS – Saving Our Shared Birds

SpC – Specific Conductance

SQM – Sky Quality Meter

STORET – Storage and Retrieval Database

TDS – Total Dissolved Solids

TOC – Total Organic Carbon

Acronyms and Abbreviations (continued)

US – United States

USFS – United States Forest Service

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

VOC – Volatile Organic Compound

WCS – Weighted Condition Score

WNS – White-nose Syndrome

ZLM – Zenithal Limiting Magnitude

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 Geographic Information System (GIS) products;[4]
- Summarize key findings by park areas;[5] and
- 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

2.1. Introduction

2.1.1. Enabling Legislation

Established as a unit of the national park system by presidential proclamation in 1923, Carlsbad Caverns National Park (CAVE) preserves Carlsbad Cavern (Photo 1), Lechuguilla Cave, and several other cave and karst structures (Sullivan 1947). In total, as of 2015, 120 caves and 168 karst structures have been documented within the park (Rod Horrocks, CAVE Physical Scientist, written communication, 15 April 2016; Kent Schwarzkopf, CAVE Chief of Resource Stewardship and Science, written communication, 15 April 2016). In creating the park, the presidential proclamation cited the "extraordinary proportions and unusual beauty and variety of natural resources" as the primary reason for establishment (Sullivan 1947, p.21).

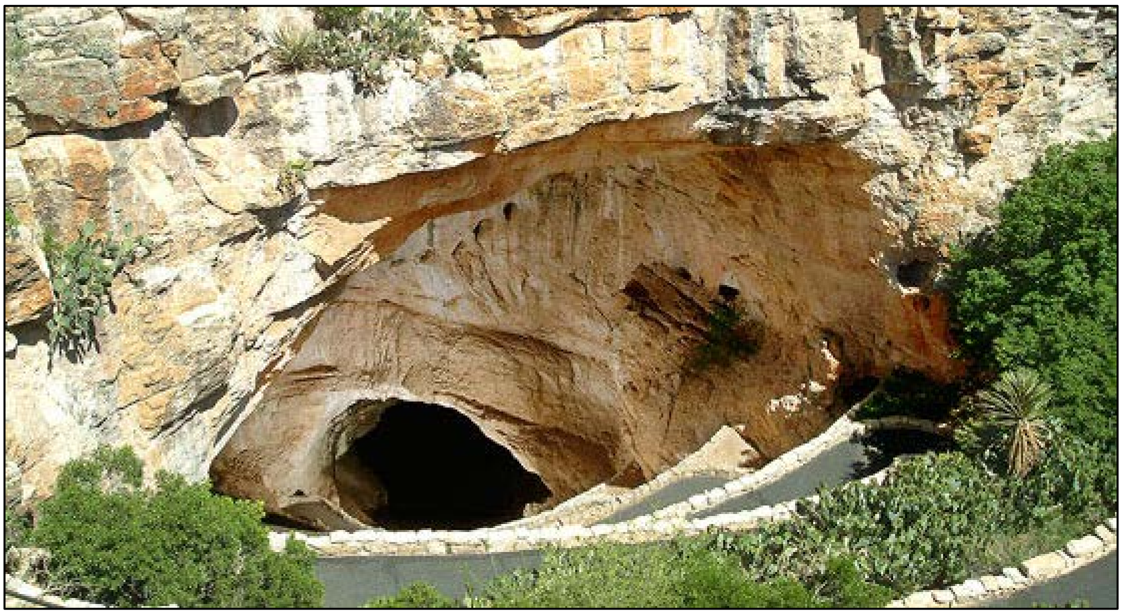


Photo 1. Natural Entrance to Carlsbad Cavern (NPS Photo).

The park boundary was expanded by Congress in 1930, and the name was changed from Carlsbad Cave National Monument to Carlsbad Caverns National Park (Sullivan 1947). The park's boundaries were expanded again in 1933 and once more in 1939 by presidential proclamations, and in 1963 the Rattlesnake Springs Unit was added to the park (NPS 1996). In addition to the cave systems, the park also protects a variety of natural resources, including desert plant communities, bat colonies, and other cave fauna (NPS 2014). Portions of the park were given a "wilderness area" designation in 1978 by Congress, and in 1995, the park was recognized by the United Nations as a World Heritage Site due to the worldwide significance of its resources, especially Lechuguilla Cave (Graham 2007, NPS 2014).

2.1.2. Geographic Setting

CAVE is located in Eddy County in southeastern New Mexico, about 32 km (20 mi) southwest of Carlsbad, New Mexico and 241 km (150 mi) east of El Paso, Texas (Figure 1). It is approximately 8 km (5 mi) north of Guadalupe Mountains National Park (GUMO) (Muldavin et al. 2012).

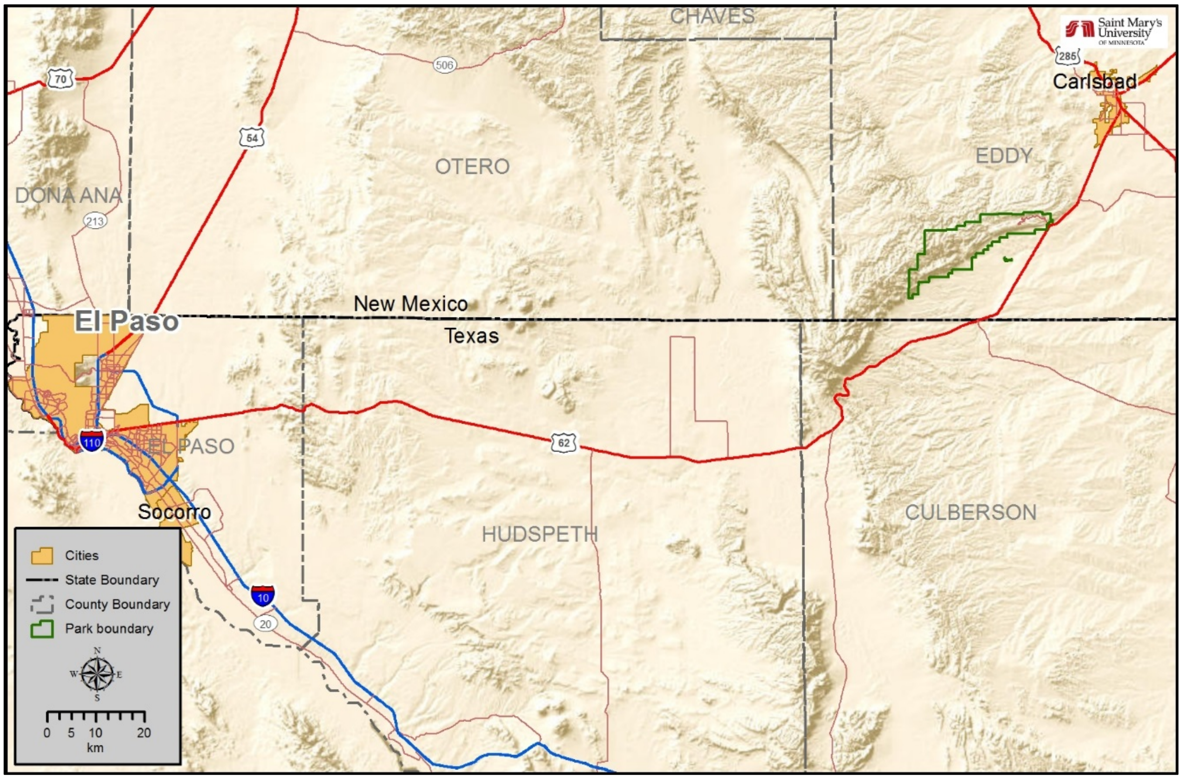


Figure 1. Carlsbad Caverns National Park (CAVE) is located in Eddy County in southeastern New Mexico.

The park is composed of two separate units (Figure 2) encompassing a combined area of 19,926 ha (46,766 ac) (Graham 2007, Muldavin et al. 2012). The main unit extends for approximately 34 km (21 mi) along the Capitan Reef and ranges from 5 to 10 km (3 to 6 mi) wide. This unit contains the namesake cave and most of the park development, which has been built on top of the reef escarpment. This unit also contains 13,406 ha (33,125 ac) of wilderness backcountry that stretches for several miles to the west and south (Graham 2007). This backcountry area includes the escarpment and several deep canyons. The separate Rattlesnake Springs Unit, which contains the park's original water supply, is located approximately 11 km (7 mi) to the southwest and covers about 32 ha (80 ac) (Graham 2007).

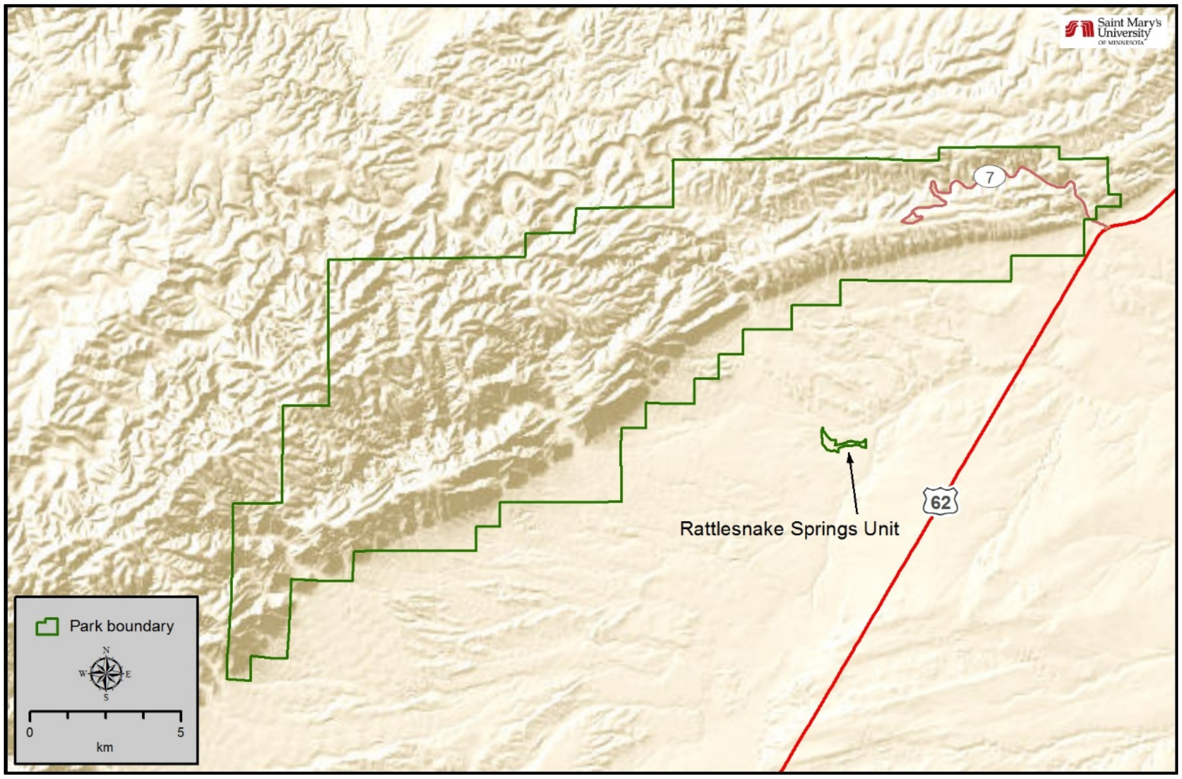


Figure 2. CAVE is comprised of two separate units: the main unit and Rattlesnake Springs Unit.

Approximately 71% of the park (13, 405 ha/33,125 ac) is designated as wilderness area (Graham 2007). The park is bounded by private lands and public lands managed by the Bureau of Land Management (BLM), U.S. Forest Service (USFS), and the New Mexico State Lands Office (Reiser et al. 2012). The adjacent land use is a mix of cattle ranching, oil and gas development, and irrigated agriculture (Muldavin et al. 2012).

The geology of the park is dominated by the limestone and dolomite formations that were part of a Permian reef complex along the edge of an inland sea more than 250 million years ago (Muldavin et al. 2012, NPS 2014). Over time it was uplifted and also tilted upward from east to west to form the Guadalupe Mountains (Muldavin et al. 2012). The Guadalupe escarpment extends from El Capitan, located about 48 km (30 mi) to the southwest in GUMO, northeastward to just past the entrance to CAVE (Muldavin et al. 2012). The escarpment is primarily comprised of the Capitan Limestone, which is broken down into two units: Pcm (massive [reef-talus] member) and Pcb (breccia [reef] member) (Karlstrom 1964) (Figure 3). This escarpment is where the park's signature caverns are found (NPS 1996, Muldavin et al. 2012).

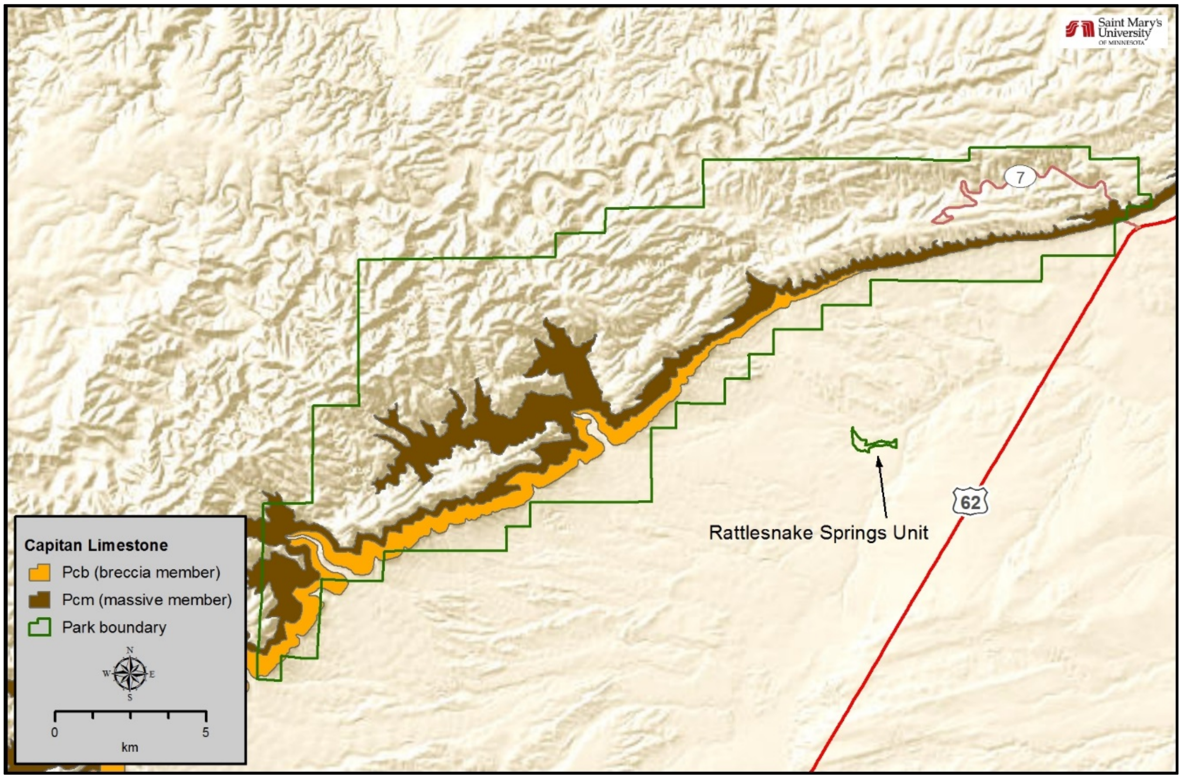


Figure 3. The Guadalupe Mountains escarpment is primarily composed of Capitan Limestone, which is broken down into two units: Pcm (massive member) and Pcb (breccia member) (Karlstrom 1964, Muldavin et al. 2012).

Elevations within CAVE range from a maximum of 1,941 m (6,368 ft) along Guadalupe Ridge in the northwestern corner of the park to about 1,096 m (3,596 ft) in the southeastern part of the park where the escarpment rises out of the desert floor of the Delaware Basin (Muldavin et al. 2012, NPS 2012). The entire Guadalupe Mountains area has several deep canyon drainages that trend east to west, or north to south, where elevations can change by as much as 450 m (1,500 ft) in one kilometer (0.5 mi) through a combination of cliffs and very steep slopes that commonly exceed 50%. This terrain is particularly common in the Rattlesnake, Slaughter and Double Canyon drainages in the central and western parts of the park (Muldavin et al. 2012).

The climate of CAVE is classified as a semi-arid continental climate, characterized by low rainfall (Muldavin et al. 2012). The mean annual temperature for CAVE is approximately 18 °C (64.4 °F) (Table 1). Seasonal temperature ranges can be extreme and daily temperature fluctuations of 17 °C (30 °F) or more can occur (Muldavin et al. 2012). CAVE receives the majority of its precipitation (71%) from monsoonal rains during the late summer months (Davey et al. 2007, Muldavin et al. 2012). The rest of its annual precipitation comes from rain and snow storms out of the west (Muldavin et al. 2012).

Table 1. Monthly climate summary (1981-2010) for CAVE (Station 291480) (WRCC 2015).

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Temperature (°C)													
Max	13.6	15.7	19.6	23.9	28.7	32.7	32.7	31.8	28.5	23.9	28.3	13.9	23.6
Min	1.6	3.3	6.3	10.4	15.2	18.5	19.5	19.1	16.1	11.3	6.1	2.1	10.8
Average Precipitation (cm)													
Total	0.9	1.3	1.2	1.6	3.6	5.5	6.2	6.0	7.6	3.1	1.4	1.4	39.9

2.1.3. Visitation Statistics

Since 1923, CAVE has received over 41 million visitors, averaging approximately 400,000 per year (Figure 4) (NPS 2012). The majority of CAVE visitors (around 90%) come to see Carlsbad Cavern (NPS 1996). There are three different tour options for visitors to choose from: self-guided natural entrance route, self-guided Big Room tour (Photo 2), or the King's Palace tour. Rangers and park volunteers are available for help and to answer questions. Other major attractions at CAVE are the evening bat flights, the 0.8 km (0.5 mi) nature walk to learn about the Chihuahuan Desert, the 14 km (9 mi) Walnut Canyon desert drive, and the Rattlesnake Springs Unit that is well-known for its bird watching (NPS 1996).

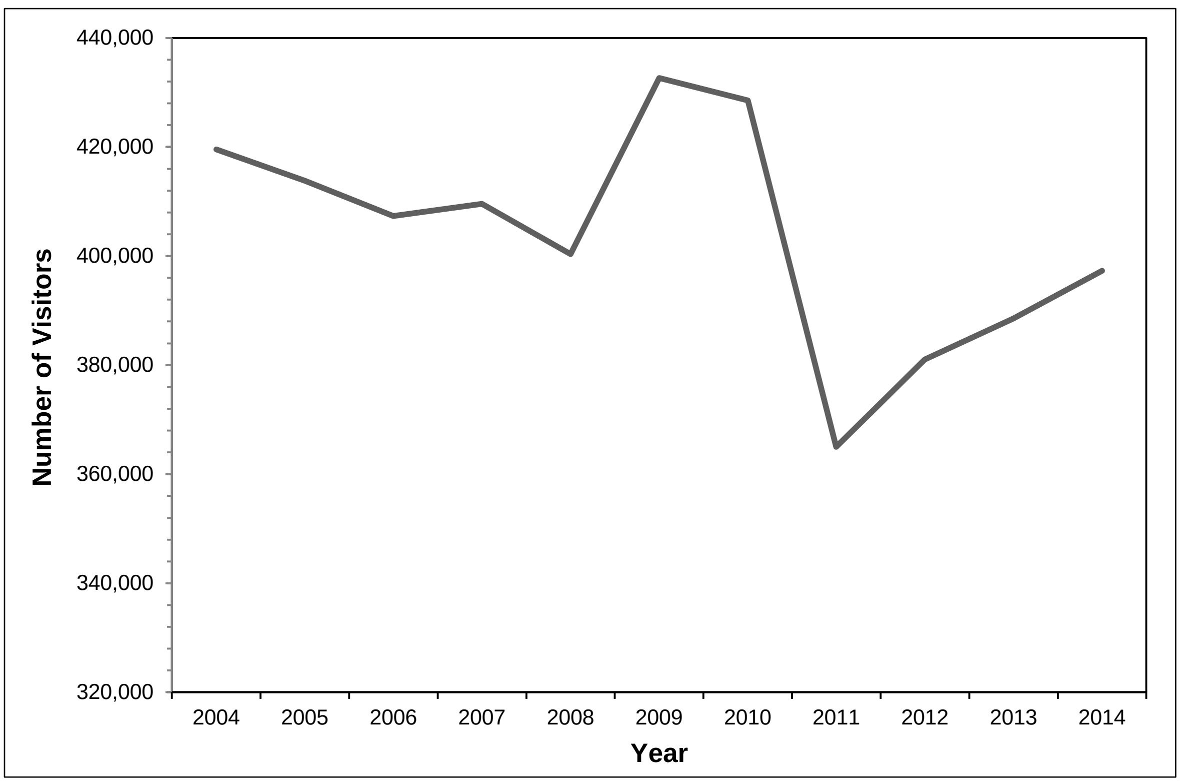


Figure 4. Annual number of visitors to CAVE, 2004 through 2014 (NPS 2016).

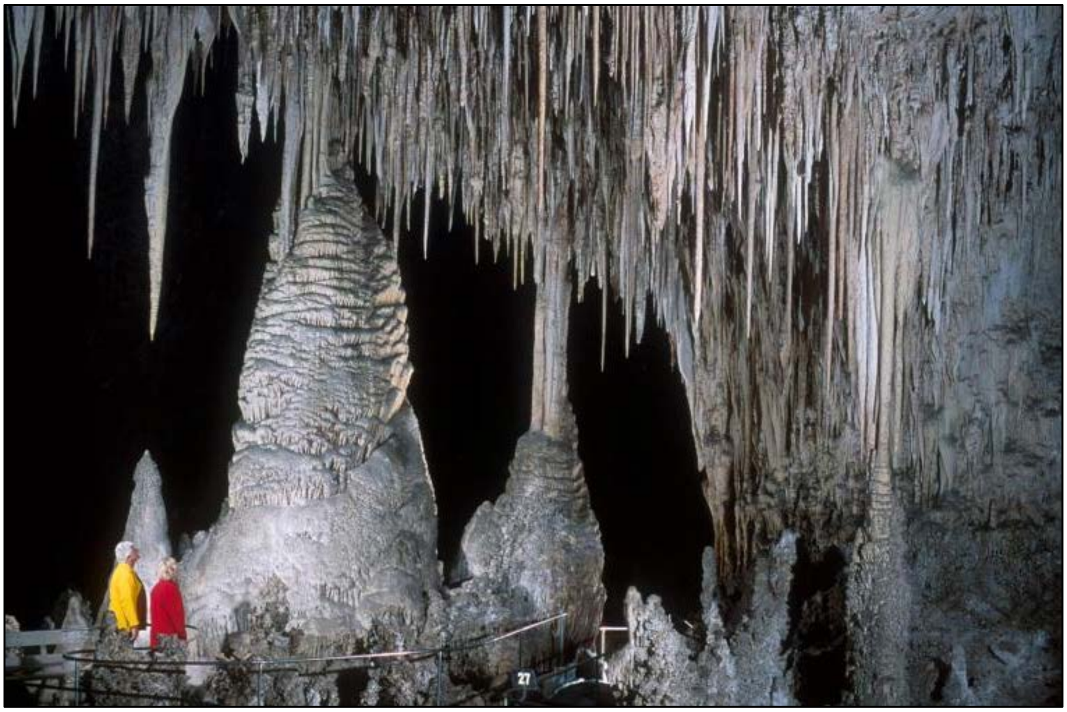


Photo 2. Temple of the Sun, along the Big Room Trail (Photo by Peter Jones, NPS).

2.2. Natural Resources

2.2.1. Ecological Units and Watersheds

Figure 5 shows that CAVE falls within two Level III ecoregions with the majority of the park within the Arizona/New Mexico Mountains Level III Ecoregion (EPA 2010). This ecoregion is characterized as:

> *Forests of spruce, fir, and Douglas-fir, common in the Southern Rockies and the Wasatch and Uinta Mountains, are only found in limited areas at the highest elevations in this region. Chaparral is common at lower elevations in some areas, pinyon-juniper and oak woodlands occur at lower and middle elevations, and the higher elevations are mostly covered with open to dense ponderosa pine forests. These mountains are the northern extent of some Mexican plant and animal species. Surrounded by deserts or grasslands, these mountains in Arizona and New Mexico can be considered biogeographical islands* (EPA 2013, p.6).

The Environmental Protection Agency (EPA) divides Level III Ecoregions into smaller Level IV Ecoregions. In CAVE, the Arizona/New Mexico Mountains includes two Level IV Ecoregions: the Chihuahuan Desert Slopes and the Madrean Lower Montane Woodlands (Figure 6) (EPA 2010). The majority of the park is located within the Chihuahuan Desert Slopes Level IV Ecoregion (EPA 2010).

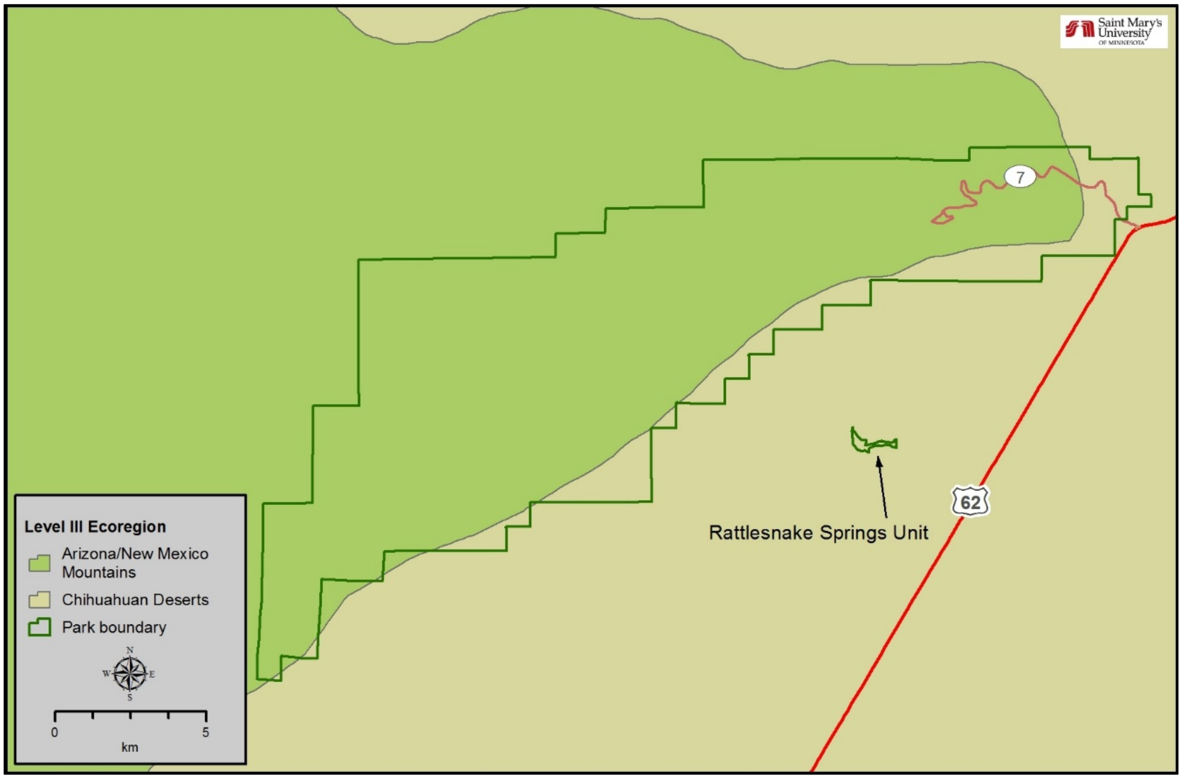


Figure 5. Level III Ecoregions for CAVE (EPA 2010).

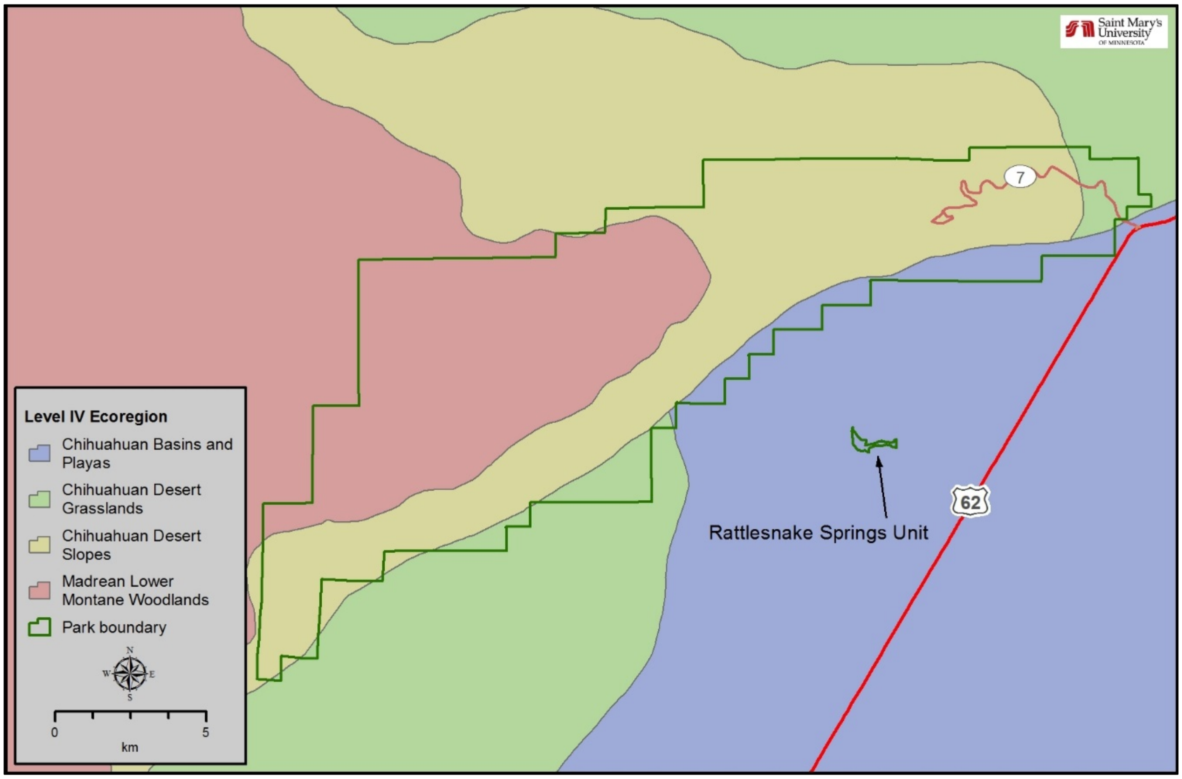


Figure 6. Level IV Ecoregions for CAVE (EPA 2010).

Portions of the park along its southern boundary and the Rattlesnake Springs Unit belong to Chihuahuan Deserts Level III Ecoregion (refer to Figure 5). This area is divided fairly equally between the Chihuahuan Basins and Playas and the Chihuahuan Desert Grasslands Level IV Ecoregions (EPA 2010). All of the Rattlesnake Springs Unit lies within the Chihuahuan Basins and Playas ecoregion (Figure 6).

The entirety of CAVE falls within the Upper Pecos-Black subbasin watershed (Reid 2005). This subbasin can be found in the Pecos River Basin, which encompasses approximately 64,750 km^2 (25,000 mi^2) (NMOSE/ICE 2016).

2.2.2. Resource Descriptions

The most prominent geological feature in the park is the limestone cave systems (NPS 1996). Three distinct cave dissolution periods have occurred in the Guadalupe Mountains within CAVE (NPS 2003). The caves have formed over the last 20 million years, as faulting and other forces pushed up the Guadalupe Mountains, allowing sulfuric acid to dissolve the surrounding limestone (NPS 2014). Extensive cave systems developed, resulting in the passages and rooms of Carlsbad Cavern, Lechuguilla Cave, and others (NPS 2003). As of 2015, there were 120 caves and 168 karst structures within the park; however, this number is subject to change as cave exploration continues (Horrocks, written communication, 15 April 2016, Schwarzkopf, written communication, 15 April 2016). This exploration not only locates new caves, but also increases the knowledge of the documented caves. For example, in 1986, the known length of Lechuguilla Cave was only a few meters. By 1994 its documented length had grown to 125 km (78 mi) (NPS 2003), and as of 2012 approximately 217 km (135 mi) had been discovered (NPS 2012). Geological processes are still ongoing in the caves and are most readily apparent in the locations where speleothems continue to form (Photo 3) (NPS 2003). An example of this ongoing formation can be found in Lechuguilla Cave where helictites are found forming underwater. These unique speleothems are not known to be in any other cave in the world and are among the rare and unique speleothems that have been found in Lechuguilla Cave (NPS 2003).

Located at the northern end of the Chihuahuan Desert ecosystem, CAVE supports a highly diverse and unique vegetation community, including many species that are at the geographic limits of their range (Reiser et al. 2012, NPS 2014). The park is one of the few places where the rich biodiversity of Chihuahuan Desert is preserved and protected (NPS 2014). CAVE contains a total of 85 plant associations and 941 vascular plants, ranging from evergreen trees to desert shrubs and grasses (Muldavin et al. 2012, NPS 2015).

Photo 3. Helictite speleothems found in Lechuguilla Cave (Photo by Shawn Thomas, NPS).

A variety of wildlife species are found scattered across the various ecosystems of CAVE. Many of them, such as black bear (*Ursus americanus*) and spotted skunk (*Spilogale putorius*), are rarely seen (Roemer 1999). The NPS Certified Species List (NPS 2015) identifies 68 mammalian species as present or "probably present" within CAVE. Seventeen bat species (Order Chiroptera) have been documented using a variety of habitats at the park. Three non-native species are present in the park, the eastern fox squirrel (*Sciurus niger*) (Photo 4), Rocky Mountain elk (*Cervus canadensis nelsoni*) and the Barbary sheep (*Ammotragus lervia*) (NPS 2015).

Photo 4. The eastern fox squirrel (*Sciurus niger*) is listed as a non-native species present in CAVE (NPS 2015).

The bird community of CAVE is diverse, with 367 species occurring within the park's boundaries (NPS 2015). CAVE is home to (or may provide habitat for) three federally listed species: black-capped vireo (*Vireo atricapilla*; endangered), lesser prairie-chicken (*Tympanuchus pallidicinctus*; threatened) (Photo 5) (NPS 2015), and the southwestern willow flycatcher (*Empidonax traillii extimus*, endangered) (NPS 2001). Additionally, there are six state-threatened or endangered bird species that may occur in CAVE: Baird's sparrow (*Ammodramus bairdii*; threatened), Costa's hummingbird (*Calypte costae*; threatened), gray vireo (*Vireo vicinior*; threatened), Lucifer hummingbird (*Calothorax lucifer*; threatened), Neotropic cormorant (*Phalacrocorax brasilianus*; threatened), and thick-billed kingbird (*Tyrannus crassirostris*; endangered) (NPS 2015).

Photo 5. Two federally listed species are found in CAVE: on the left is a black-capped vireo (*Vireo atricapilla*) (NPS photo) and on the right is a lesser prairie-chicken (*Tympanuchus pallidicinctus*) (Audubon photo).

There are 77 herptile species that have either been documented or are suspected to occur at CAVE (NPS 2015). The gray-banded kingsnake (*Lampropeltis alterna*), blotched water snake (*Nerodia erythrogaster transversa*), mottled rock rattlesnake (*Crotalus lepidus lepidus*), and Rio Grande cooter (*Pseudemys gorzugi*) are state-listed species of concern present at the park (Valentine-Darby 2010). The park's aquatic habitats also support two native fish species: the roundnose minnow (*Dionda episcopa*) and the state-threatened greenthroat darter (*Etheostoma lepidum*).

2.2.3. Resource Issues Overview

Development and Anthropogenic Impacts

The surrounding development from the oil and gas industry, as well as agricultural development, is affecting the park's viewshed, soundscape, air quality, and biologic, cultural, and cave resources (NPS 2014). Oil wells can be found as close as 3.2 km (2 mi) from the CAVE boundary, with drilling activities occurring primarily to the southeast of the park (Figure 7). Every well within New Mexico is at a different status of use; status includes active, new, plugged, or cancelled. Plugged wells indicate depletion or lacking in production of oil or gas (State of New Mexico OCD 2016b). Cancelled wells indicate that the permit to lease was cancelled and drilling did not occur (New Mexico Commission of Public Records 2016). New wells are newly designed and approved wells; dates of approval range from 2003 to 2015 (State of New Mexico OCD 2016a). This close proximity between the park and these oil and gas wells increases the potential for water and air contamination.

For example, fumes from the diesel fuel engines increase air pollution and, in combination with the flaring of gas wells, could have a potential effect on star gazing at night (NPS 2014).

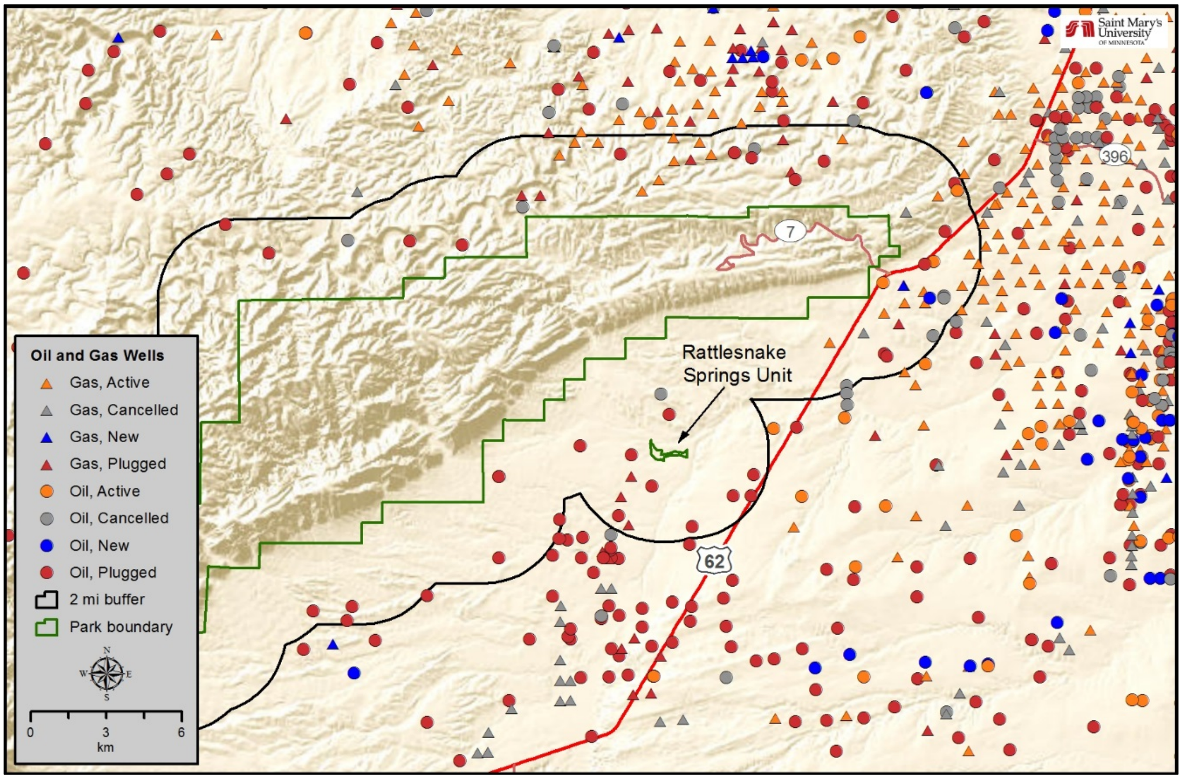


Figure 7. Oil and gas wells found near CAVE. The black line represents a 3.2-km (2-mi) buffer around the park (State of New Mexico OCD 2016a).

Development within the park also poses a potential threat to the surrounding ecosystem through increased runoff from parking lots, sewage spills, and underground leaks from storage containers. Developed areas within the park includes 19 primary buildings such as visitor centers and bathrooms, a road system, and parking lots for over 900 vehicles (Burger et al. 2002) (Figure 8, Figure 9).

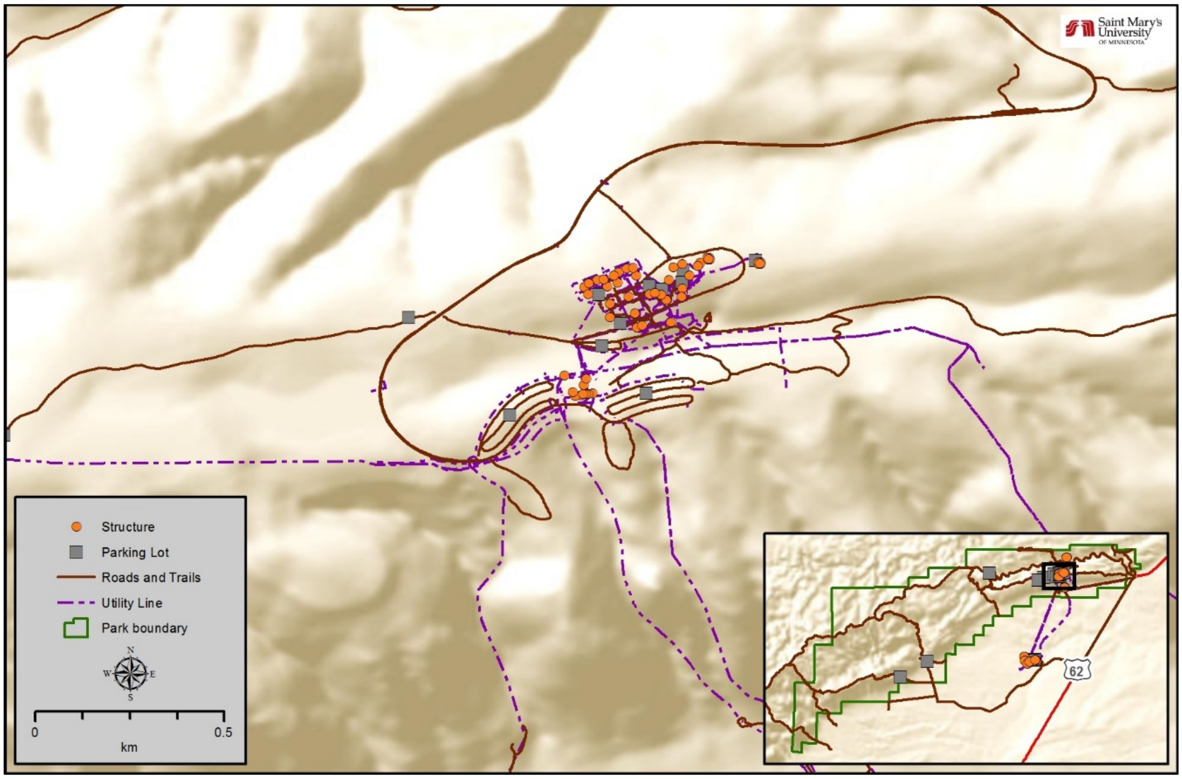


Figure 8. Park development at the main unit in CAVE includes parking lots and bathrooms.

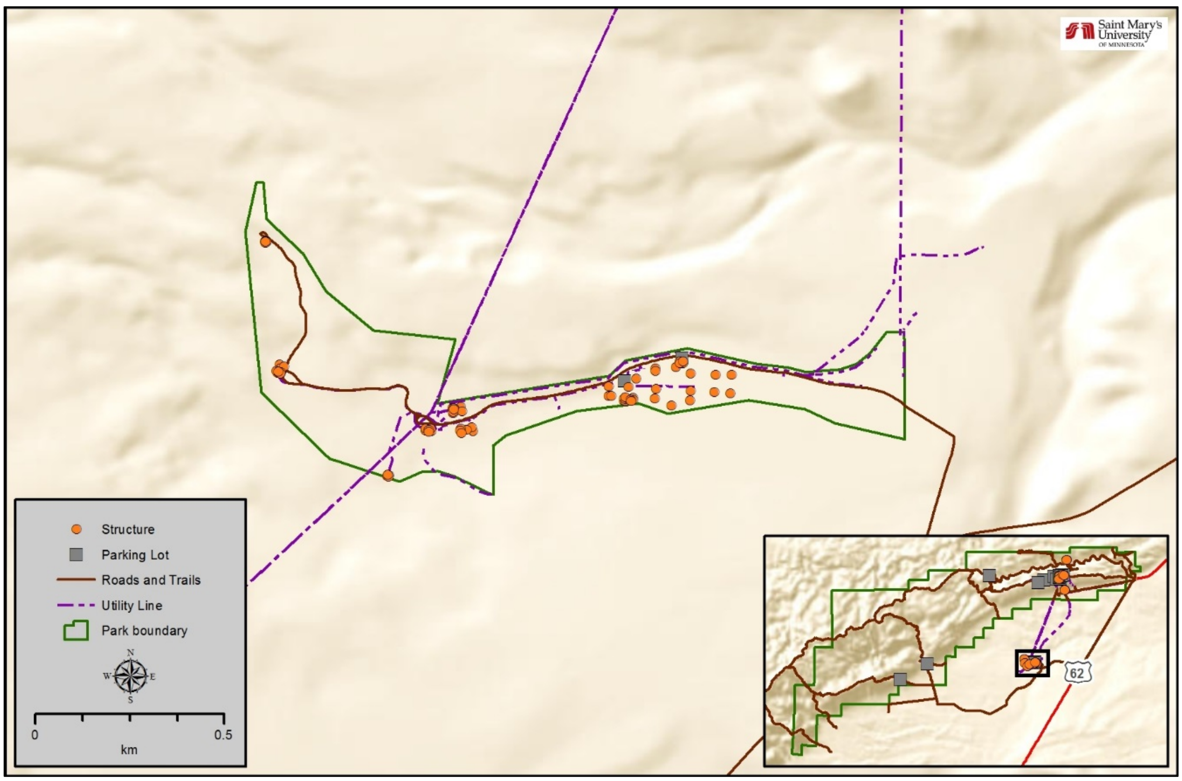


Figure 9. Park development at the Rattlesnake Springs Unit in CAVE includes structures such as bathrooms and picnic tables.

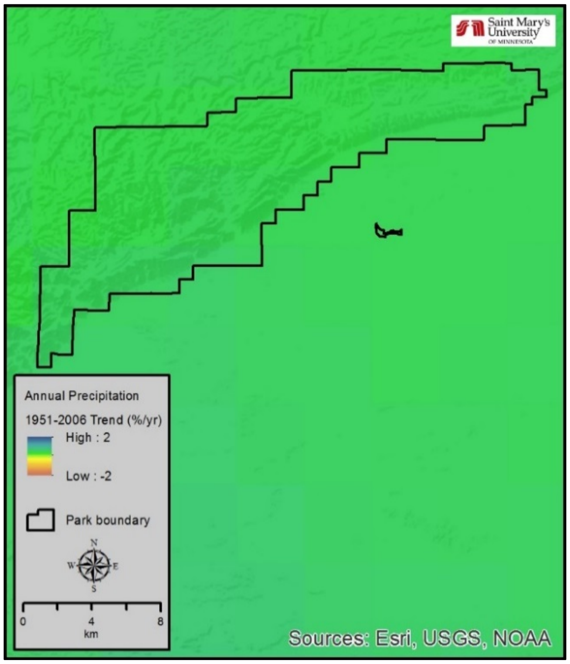
In order for people to understand caves, they need to be able to enter them and learn from them; thus, the need for the park infrastructure (e.g., parking lots, bathrooms, etc.) (Burger and Pate 2001). However, there is a balance between letting people explore and keeping the cave ecosystem intact and healthy. The human visitation of caves can have an impact on microbial communities through the introduction of nutrients from waste, lint and hair, remnants from shoes, and dropped food crumbs (Johnston et al. 2012). Along with the potential for excess nutrients, other anthropogenic effects on the cave ecosystem include vandalism and staining and polishing from unauthorized touching of cave formations. In the past, as many as 2,000 speleothems per year have been stolen or vandalized (NPS 2014).

Climate Change

Global climate change is expected to impact the entire U.S. during this century, although the expected changes vary across the country. According to the CHDM I&M, climate change could impact CAVE’s ecological systems through disrupting soil-water relationships, plant-soil processes, and nutrient cycling (Davey et al. 2007). Predictions of potential future vulnerabilities from climate change in CAVE were summarized by Gonzalez (2014), p. 1:

- Under high emissions, fire frequencies could increase up to 25% by 2100 (Moritz et al. 2012).
- Past warming has reduced snowfall and rainfall across northern New Mexico, which may continue to reduce summer streamflow and water supplies further south (Garfin et al. 2014).
- *Agave* and *Yucca* species could have reduced germination under hotter temperatures in the southern Chihuahuan Desert (Pérez-Sánchez et al. 2011).
- Continued increases in precipitation may contribute to continued shrub encroachment in the Chihuahuan Desert, but decreased precipitation would tend to reduce shrub and grass productivity (Munson et al. 2013).

Since 1951, the regional climate around CAVE has shown little change; mean annual precipitation amounts slightly increased with winter having the largest increase in precipitation levels out of all seasons (Figure 10; [PRISM Group 2007]), while annual mean temperatures slightly decreased, with little variation between seasons (<1% decrease) (Figure 11; [PRISM Group 2007]). On the other hand, throughout the next century predicted climate characteristics around CAVE could provide different scenery. Predictions articulate mean annual precipitation around CAVE to decrease (~7% by 2050, ~8% by 2100) (Figure 12), with the spring season showing the largest decrease (~13% by 2050, ~28% by 2100) (Figure 13; [Maurer et al. 2007]). Annual mean temperature is expected to increase 2.2-2.8 °C (4-5 °F) by 2050 and 4.4-5 °C (8-9 °F) by 2100 (Figure 14; [Maurer et al. 2007]); spring shows the largest increase (2.8-3.3 °C [5-6 °F]) by 2050, while fall shows a larger increase (4.4-5 °C [8-9 °F]) by 2100 (Figure 15). These predictions are based off the A2 (high) emissions scenario (Maurer et al. 2007). Predicted warmer temperatures could accelerate the evapotranspiration process, and with lower predicted precipitation amounts, this could result in less available moisture in the already arid environment that CAVE sits in. The potential for greater aridity means overall drier conditions, particularly in the winter months (Figure 16, [Maurer et al. 2007]). These altered climate changes could also influence plant distributions, insect and disease outbreaks, and disturbance regimes (e.g., fire, flooding, and erosion) (Davey et al. 2007).



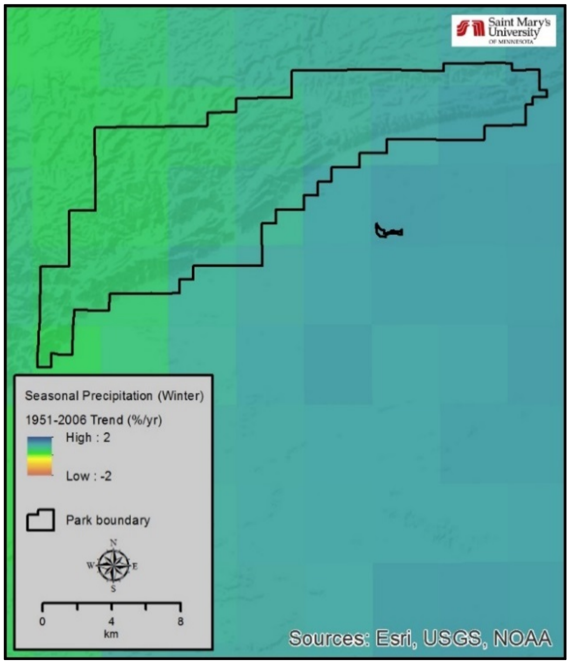


Figure 10. Change in mean annual precipitation (left) and mean winter precipitation (right) in the CAVE region between 1951 and 2006 (PRISM Group 2007).

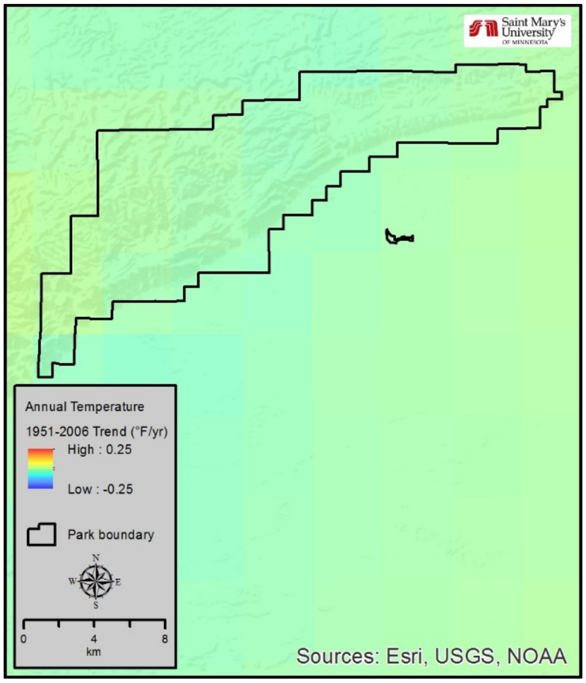


Figure 11. Change in mean annual temperature in the CAVE region between 1951 and 2006 (PRISM Group 2007).

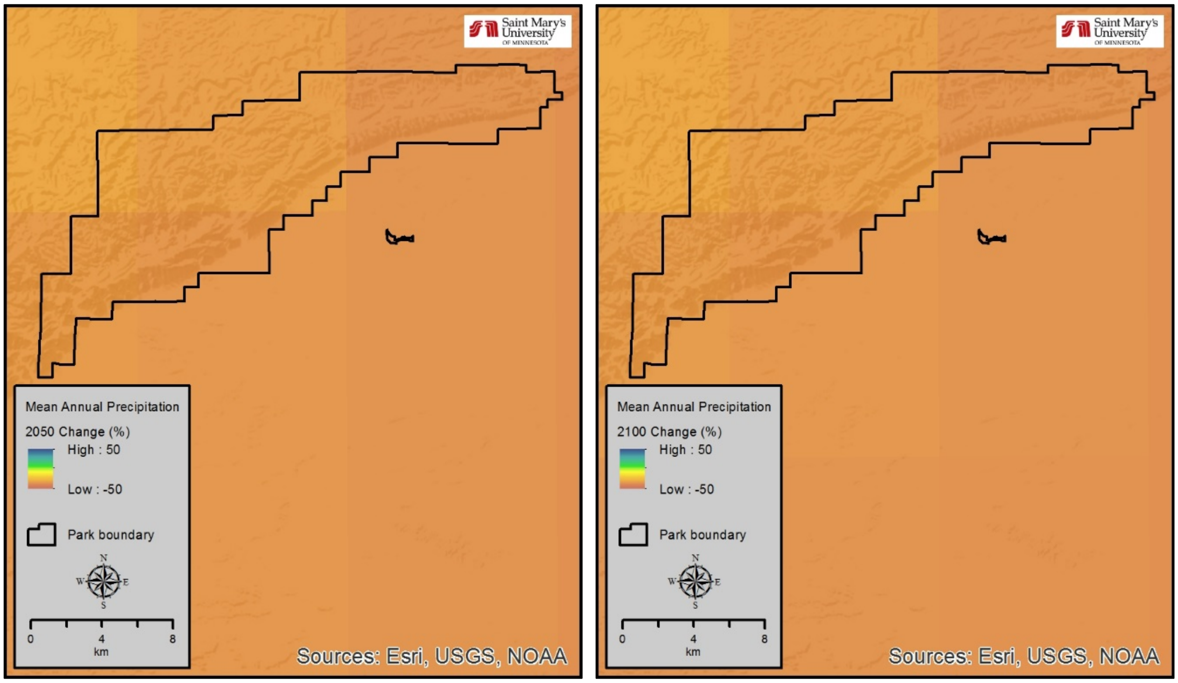


Figure 12. Projected change in mean annual precipitation by 2050 (left; decrease ~7%) and mean annual precipitation by 2100 (right; decrease ~8%) in the CAVE region (Maurer et al. 2007). Projections based on an ensemble average (E-50) circulation model and the A2 (high) emissions scenario.

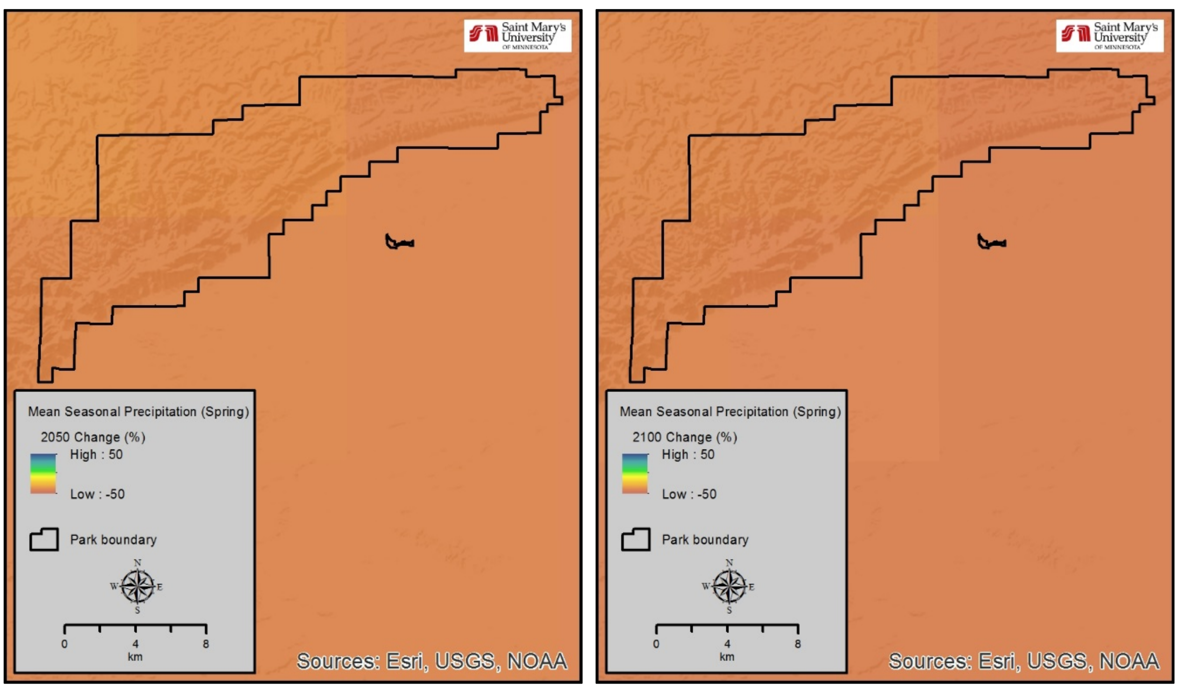


Figure 13. Projected change in mean spring precipitation by 2050 (left; decrease ~13%) and mean spring precipitation by 2100 (right; decrease ~28%) in the CAVE region (Maurer et al. 2007). Projections based on an ensemble average (E-50) circulation model and the A2 (high) emissions scenario.

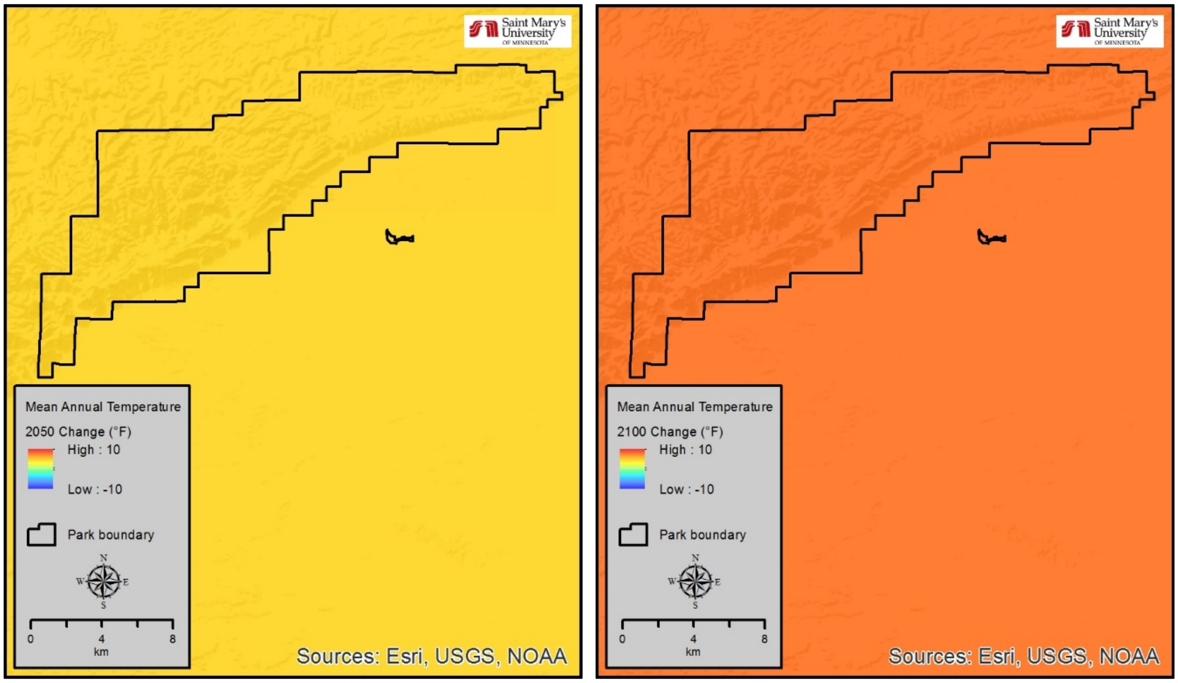


Figure 14. Projected change in mean annual temperature by 2050 (left; increase at 2.2-2.8 °C [4-5 °F]) and mean annual temperature by 2100 (right; increase at 4.4-5 °C [8-9 °F]) in the CAVE region (Maurer et al. 2007). Projections based on an estimate average (E-50) circulation model and the A2 (high) emissions scenario.

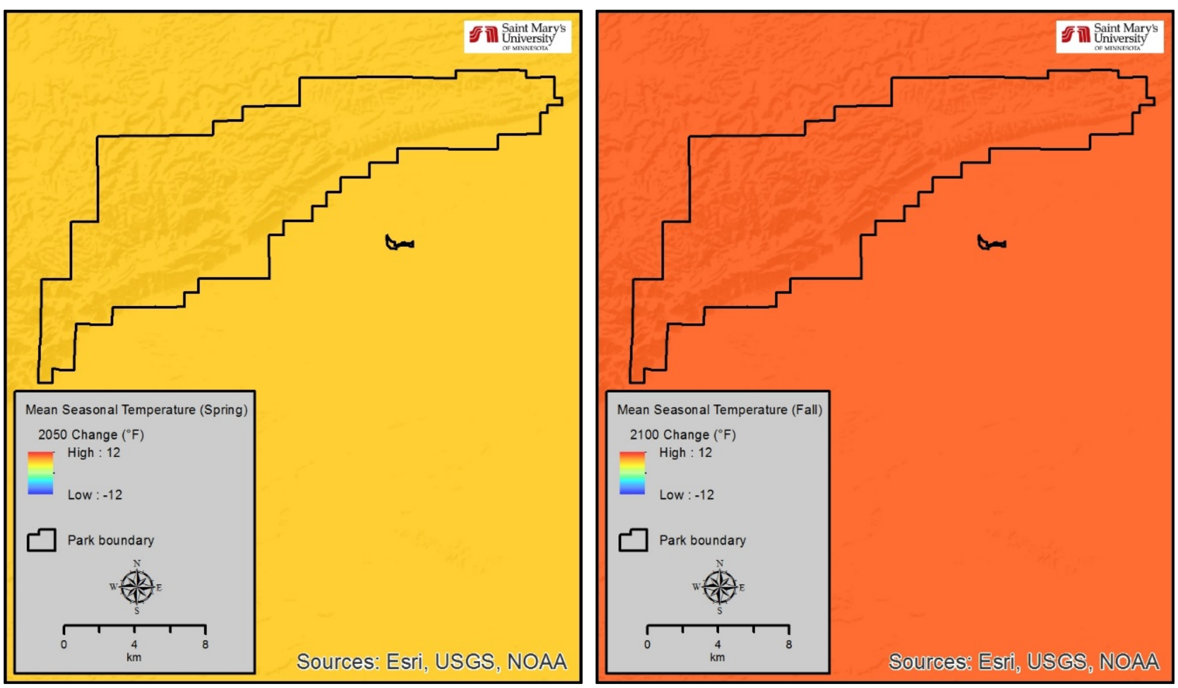


Figure 15. Projected change in mean spring temperature by 2050 (left; increase at 2.8-3.3 °C [5-6 °F]) and mean fall temperature by 2100 (right; increase at 4.4-5 °C [8-9 °F]) in the CAVE region (Maurer et al. 2007). Projections based on an estimate average (E-50) circulation model and the A2 (high) emissions scenario.

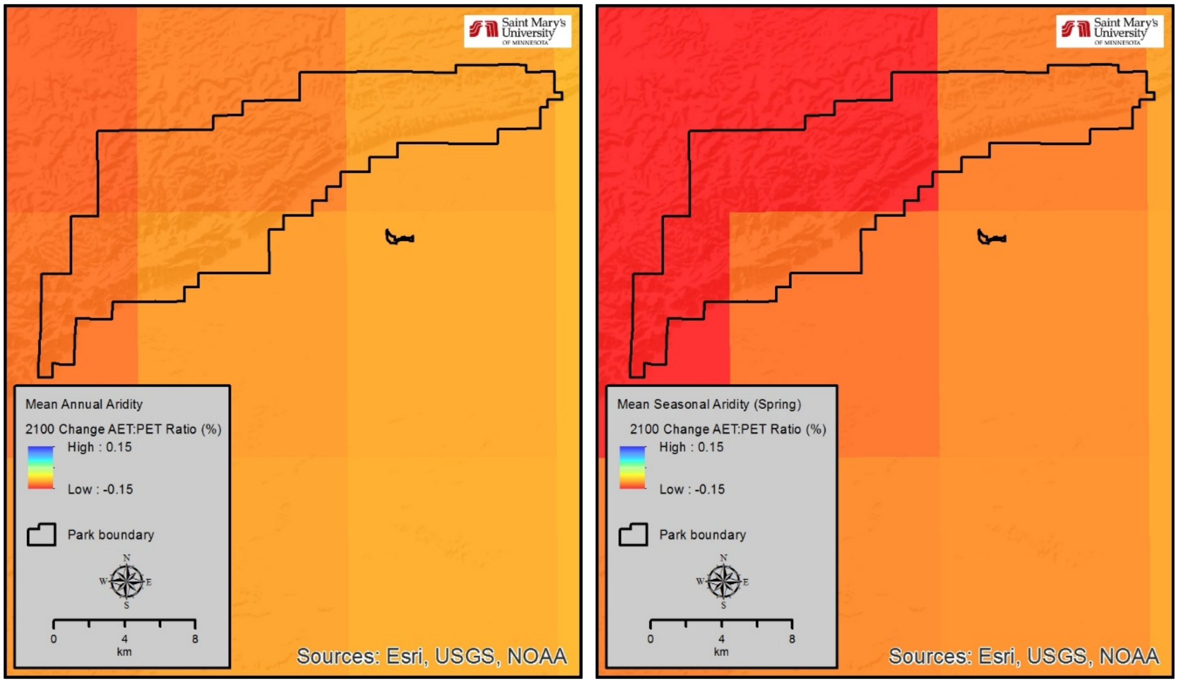


Figure 16. Projected change in mean annual aridity (left; ~11% increase) and mean spring aridity (right; ~14% increase) by 2100, as predicted by the change in AET: PET ratio (Maurer et al. 2007). Projections based on an estimate average (E-50) circulation model and the A2 (high) emissions scenario.

Non-Native Plant Species

There are 59 non-native plant species found within the park (NPS 2015). Exotic plant surveys have identified several non-native species that pose a significant or widespread problem within the park (Reiser et al. 2012). These include tree of heaven (*Ailanthus altissima*), Johnsongrass (*Sorghum halepense*) and Lehmann lovegrass (*Eragrostis lehmanniana*). Russian olive (*Elaeagnus angustifolia*) and Johnsongrass have become major components of the vegetation at Rattlesnake Springs. Other non-native plants that have potential to spread in disturbed areas include Malta starthistle (*Centaurea melitensis*) and white horehound (*Marrubium vulgare*) (Reiser et al. 2012). A complete list can be found in Table 2.

Table 2. Non-native plant species documented in CAVE (NPS 2015).

Scientific Name	Common Name	Scientific Name	Common Name
Ailanthus altissima	tree of heaven	*Onopordum acanthium*	scotch thistle
Asparagus officinalis	garden asparagus	*Opuntia ficus-indica*	Indian fig
Avena fatua	wild oats	*Oxalis corniculata*	creeping oxalis
Bromus catharticus	rescuegrass	*Panicum coloratum*	Klein grass
Bromus japonicus	Japanese brome	*Peganum harmala*	African rue
Bromus rubens	foxtail brome	*Plantago lanceolata*	English plantain

Table 2 (continued). Non-native plant species documented in CAVE (NPS 2015).

Scientific Name	Common Name	Scientific Name	Common Name
Centaurea melitensis	Malta starthistle	*Plantago major*	broadleaf plantain
Centaurea solstitialis	yellow starthistle	*Poa annua*	annual bluegrass
Convolvulus arvensis	European bindweed	*Polypogon monspeliensis*	annual rabbitsfoot grass
Cynodon dactylon	Bermuda grass	*Populus nigra*	Lombardy poplar
Descurainia sophia	flixweed	*Portulaca oleracea*	common purslane
Digitaria sanguinalis	hairy crabgrass	*Prunus armeniaca*	apricot
Echinochloa crus-galli	barnyardgrass	*Prunus domestica*	European plum
Elaeagnus angustifolia	Russian olive	*Rorippa tenerrima*	watercress
Eleusine indica	goosegrass	*Salix X sepulcralis*	weeping willow
Eragrostis barrelieri	Mediterranean lovegrass	*Salsola kali*	Russian thistle
Eragrostis cilianensis	stinkgrass	*Sisymbrium altissimum*	tall tumblemustard
Eragrostis lehmanniana	Lehmann lovegrass	*Sisymbrium irio*	London rocket
Erodium cicutarium	cutleaf filaree	*Sonchus asper*	perennial sowthistle
Euphorbia davidii	David's spurge	*Sonchus oleraceus*	annual sowthistle
Hordeum marinum ssp. gussoneanum	Mediterranean barley	*Sorghum halepense*	Johnsongrass
Kochia scoparia	common kochia	*Taraxacum officinale*	common dandelion
Lactuca serriola	prickly lettuce	*Thlaspi arvense*	fanweed
Lamium amplexicaule	common henbit	*Tragopogon dubius*	goat's beard
Malus pumila	paradise apple	*Tragopogon porrifolius*	purple salsify
Marrubium vulgare	white horehound	*Tribulus terrestris*	goathead
Medicago lupulina	black medic clover	*Ulmus pumila*	Siberian elm
Melilotus officinalis	yellow sweetclover	*Verbascum thapsus*	wooly mullein
Mentha spicata	bush mint	*Verbena hastata*	blue verbena

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

Under the natural resource management section in the park’s general management plan (NPS 1996, p. 11), it states:

> *The most significant resource in the park is its caves. In accordance with NPS policies and regulations, underground portions of the natural environment will be protected and preserved to ensure ecosystem integrity while providing for visitor*

enjoyment. Biological, geological, and other natural processes will be allowed to continue with a minimum of human disturbance or change. However, because cave resources and processes are not free from human influences, actions will be taken to prevent adverse impacts and to meet resource management activities.

The park compiled a list of the methods managers will use to comply with the previously mentioned NPS policies and regulations (NPS 1996, p.13):

- Modify cave tour methods and sizes,
- Change or add barriers and signs,
- Relocate trails in limited areas,
- Increase NPS ranger presence,
- Provide lint containment structures along trails,
- Have visitors wear special garments,
- Experiment with trail surface materials and washing techniques,
- Install off-trail alarm devices and audiovisual monitoring devices, and
- Develop new modes of visitor education.

2.3.2. Status of Supporting Science

The CHDN identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2010, the CHDN completed and released a Vital Signs Monitoring Plan. Table 3 shows the CHDN Vital Signs selected for monitoring in CAVE (NPS 2010).

Table 3. CHDN Vital Signs selected for monitoring in CAVE (NPS 2010).

Category	CHDN Vital Sign	Category 1[a]	Category 2[b]	Category 3[c]	No Monitoring Planned
Air and Climate	Ozone	X			
	Wet and Dry Deposition				X
	Visibility and Particulate Matter				X
	Basic Meteorology	X			
Geology and Soils	Dune Formation and Stability				X
	Dune Morphology				X
	River Channel Characteristics				X

a. Category 1 represents Vital Signs for which the network will develop protocols and implement monitoring.

b. Category 2 represents Vital Signs that are monitored by SHIL, another NPS program, or by another federal or state agency using other funding.

c. Category 3 represents high-priority Vital Signs for which monitoring will likely be done in the future.

Table 3 (continued). CHDN Vital Signs selected for monitoring in CAVE (NPS 2010).

Category	CHDN Vital Sign	Category 1[a]	Category 2[b]	Category 3[c]	No Monitoring Planned
	Soil Hydrologic Function		X		
	Biological Soil Crusts		X		
	Soil Erosion (Wind and Water)		X		
	Bare Ground			X	
Water	Groundwater Quantity		X		
	Surface Water Dynamics	X			
	Persistence of Springs		X		
	Surface Water Quality		X		
	Aquatic Invertebrates		X		
Biological Integrity	Invasive/Non-native Plants		X		
	Plant Community Composition		X		
	Bird Communities		X		
	Heteromyid Rodent Communities				X
Landscapes (Ecosystem Pattern and Processes)	Land Cover			X	
	Land-use Changes			X	

a. Category 1 represents Vital Signs for which the network will develop protocols and implement monitoring.

b. Category 2 represents Vital Signs that are monitored by SHIL, another NPS program, or by another federal or state agency using other funding.

c. Category 3 represents high-priority Vital Signs for which monitoring will likely be done in the future.

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Chapter 3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and SMUMN GSS. Project stakeholders include the CAVE resource management team and CHDN I&M Program staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1. Preliminary Scoping

A preliminary scoping meeting was held on 10-12 February 2015. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to CAVE managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by CAVE resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid CAVE resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: CAVE resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs program, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.
- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.
- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.
- Utilize “gray literature” and reports from third party research to the extent practicable.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a “framework” is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

“Components” in this process are defined as natural resources (e.g., birds, plant communities), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more “measures” that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain “stressors,” which are also considered during assessment. A “stressor” is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the NRCA scoping process, key resource components were identified by NPS staff and are represented as “components” in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in CAVE. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A “reference condition” is a benchmark to which current values of a given component’s measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as “pre-fire suppression." In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). Key resources for the park were adapted from the CHDN Vital Signs Monitoring Plan (NPS 2010). This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized in April 2015 following acceptance from NPS resource staff. It contains a total of 10 components (Figure 17) and was used to drive analysis in this NRCA. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

CAVE NRCA Final Framework

Natural Resource Condition Assessment

	Component	*Measures*	*Stessors*	*Reference Condition*
Biotic Composition				
Ecological Communities				
	Rattlesnake Springs Community	Groundwater levels, Discharge, Southwest willow flycatcher nesting habitat, Extent of wetland vegetative communities, Cottonwood plantation stand quality	Drought, irrigation, visitor use, climate change, livestock trespass, oil and gas development, BLM application of herbicides to adjacent Federal lands via aerial application	No loss of wetland vegetation over time. Optimal Southwestern willow flycatcher nesting habitat. Maintain senior water rights.
	Seeps and springs (excluding Rattlesnake Springs)	Plant community composition, Species richness, Discharge, Water quality, Areal extent	Barbary sheep, non-native plant species, drought, climate change, fire,	Historic wetland community conditions
Mammals				
	Bats	Species richness, Species abundance, Number of caves utilized, Number of maternity roosts/species	Wind power development, pesticide application, White-nose syndrome, adjacent landuse/land development changes, noise and light, cell phone towers, park infrastructure	Undefined
Birds				
	Birds	Species richness, Abundance of species of conservation concern	Brood parasitism, fire, predation, fox squirrels, fluctuation of stream flow (at Rattlesnake Springs), cell phone towers, collisions with man-made structures	Historic nesting and population surveys
Reptiles				
	Herpetofauna	Species abundance, Species richness, Trends in species of conservation concern	vehicle-related mortality, oil and gas developments (drop in water table/bad frack out, chemical introduction into water, increase in traffic), climate change, irrigation and water draws at Rattlesnake Spg, fire, feral hogs (not yet documented in park but are in the area),	Undefined

Figure 17. Carlsbad Caverns National Park natural resource condition assessment framework.

CAVE NRCA Final Framework

Natural Resource Condition Assessment

	Component	Measures	Stessors	Reference Condition
Environmental Quality				
	Air quality	Ozone, Atmospheric deposition of sulfur/nitrogen, Visibility, Particulate matter	Oil and gas development, El Paso/Juarez air pollution, wildfire, vehicle emissions	NPS ARD Reference Conditions
	Dark night skies	NPS NSD suite of measures	Oil and gas development and flares, growth of Carlsbad, gas plant in Orla, TX, park lighting, highway traffic, construction	Absence of anthopogenic light
Physical Characteristics				
Geologic and Hydrologic				
	Infrastructure impacts on caves	Pool water quality, Cave air quality, Cave climatic conditions, Nutrient loading, Groundwater quality	Cave lighting, elevator shaft, use of underground lunchroom concessions, trails in caves, rotting wood structure in caves, number of of visitors, park Infrastructure	Absence of Infrastructure, zero impacts on the cave
	Human impacts on caves	Number of broken formations, Annual lint accummulation, Number of visitors annually, Photo monitoring of lower use areas, Introduced microbes and pathogens	Human waste, visitor touching of formations, accidental and intentional breakage of formation, anthropogenic seismic events, disturbance of previously undisturbed sediments, soil contamination by White-nose syndrome or other pathogens, research efforts/visitation of sensitive cave areas	Absence of Infrastructure, zero impacts on the cave
	Groundwater	Depth to groundwater, Water quality, Recharge area, Human water use/withdrawl downgradient	Climate change, historic overgrazing, groundwater pumping for human and agricultural/industrial use, oil and gas development	Historic groundwater levels

Figure 17 (continued). Carlsbad Caverns National Park natural resource condition assessment framework.

3.2.2. Reporting Area

Unless specifically noted, the current condition summaries describe the condition of the resource within the boundaries of CAVE.

3.2.3. General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

<u>Data Mining</u>

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time CAVE staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were also provided by NPS staff. Additional data and literature were acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

<u>Data Development and Analysis</u>

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component, as well as recommendations from NPS reviewers and sources of expertise including NPS staff from CAVE and the CHDN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

<u>Scoring Methods and Assigning Condition</u>

Significance Level

A set of measures are useful in describing the condition of a particular component, but all measures may not be equally important. A “Significance Level” represents a numeric categorization (integer scale from 1-3) of the importance of each measure in assessing the component’s condition; each Significance Level is defined in Table 4. This categorization allows measures that are more important for determining condition of a component (higher Significance Level) to be more heavily weighted in calculating an overall condition. Significance Levels were determined for each component measure in this assessment through discussions with park staff and/or outside resource experts.

Table 4. Scale for a measure's Significance Level in determining a components overall condition.

Significance Level (SL)	Description
1	Measure is of low importance in defining the condition of this component.
2	Measure is of moderate importance in defining the condition of this component.
3	Measure is of high importance in defining the condition of this component.

Condition Level

After each component assessment is completed (including any possible data analysis), SMUMN GSS analysts assign a Condition Level for each measure on a 0-3 integer scale (Table 5). This is based on all the available literature and data reviewed for the component, as well as communications with park and outside experts.

Table 5. Scale for Condition Level of individual measures.

Condition Level (CL)	Description
0	Of **NO** concern. No net loss, degradation, negative change, or alteration.
1	Of **LOW** concern. Signs of limited and isolated degradation of the component.
2	Of **MODERATE** concern. Pronounced signs of widespread and uncontrolled degradation.
3	Of **HIGH** concern. Nearing catastrophic, complete, and irreparable degradation of the component.

Weighted Condition Score

After the Significance Levels (SL) and Condition Levels (CL) are assigned, a Weighted Condition Score (WCS) is calculated via the following equation:

$$WCS = \frac{\sum_{i=1}^{\#\ of\ measures} SL_i * CL_i}{3 * \sum_{i=1}^{\#\ of\ measures} SL_i}$$

The resulting WCS value is placed into one of three possible categories: good condition (WCS = 0.0 to 0.33); condition of moderate concern (WCS = 0.34 to 0.66); and condition of significant concern (WCS = 0.67 to 1.0). Figure 18 displays all of the potential graphics used to represent a component's condition in this assessment. The colored circles represent the categorized WCS; red circles signify a significant concern, yellow circles a moderate concern and green circles that a resource is in good condition. White circles are used to represent situations in which SMUMN GSS analysts and park staff felt there were currently insufficient data to make a statement about the condition of a component. For example, condition is not assessed when no recent data or information are available, as the purpose of an NRCA is to provide a "snapshot-in-time" of current resource conditions. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5-10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent times. A horizontal arrow indicates an unchanging condition or trend, and an arrow pointing down indicates deterioration in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. In situations where the trend of the component's condition is currently unknown, no arrow is given.

Table 6. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

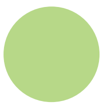
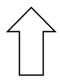
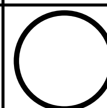
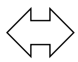
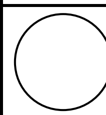
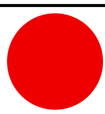
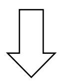
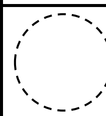
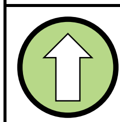
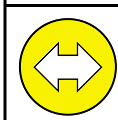
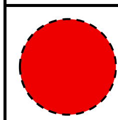
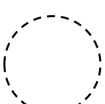
Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Table 7. Example indicator symbols and descriptions of how to interpret them.

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.

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and CAVE and CHDN staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature is limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or e-mail conversation with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by CAVE resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and outside resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description

This section describes the relevance of the resource component to the park and the context within which it occurs in the park setting. For example, a component may represent a unique feature of the park, it may be a key process or resource in park ecology or it may be a resource that is of high management priority. Also emphasized are interrelationships that occur among the featured component and other resource components included in the NRCA.

Measures

Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values

This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods

This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend

This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component is presented and interpreted in this section.

Threats and Stressor Factors

This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps

This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff seeking to prioritize monitoring or data gathering efforts.

Overall Condition

This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise

This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

Literature Cited

This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note, citations used in appendices and plates referenced in each section (component) of Chapter 4 are listed in that component's "Literature Cited" section.

3.2.4. Literature Cited

Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. http://glei.nrri.umn.edu/default/glossary.htm (accessed 31 January 2013).

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

National Park Service (NPS). 2010. Chihuahuan Desert Network vital signs monitoring plan. Natural Resource Report NPS/CHDN/NRR—2010/188. National Park Service, Fort Collins, Colorado.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):12671276.

Chapter 4. Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 10 key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressor factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

The order of components follows the project framework (Figure 17):

- 4.1. Rattlesnake Springs Community
- 4.2. Seeps and Springs
- 4.3. Bats
- 4.4. Birds
- 4.5. Herpetofauna
- 4.6. Air Quality
- 4.7. Dark Night Skies
- 4.8. Infrastructure Impacts on Caves
- 4.9. Human Impacts on Caves
- 4.10. Groundwater

4.1. Rattlesnake Springs Community

4.1.1. Description

Rattlesnake Springs is a separate unit of the park that lies approximately 11 km (7 mi) southwest of the main park entrance (Graham 2007). The 32.4 ha (80 ac) property and the associated water rights were purchased by the NPS in 1934 to provide a water supply for the park (Bowen 2006). CAVE's water supply was originally pumped from a pool that collects the discharge from Rattlesnake Springs, but is now supplied by a well that was drilled in 1963, just 100 m (328 ft) from the spring itself (Bjorklund and Motts 1959, Huff et al. 2006). This well draws water from the same alluvial aquifer as the springs. In addition to water supply, Rattlesnake Springs provides critical wetland habitat for a variety of plants and wildlife, including several species of conservation concern, in a largely arid environment (Bowen 2006, NPS 2001, 2010). Flow from the springs supports an approximately 1,000 m (3,280 ft) long stream with associated marshes and riparian woodlands (Photo 6) (NPS 2001).

Photo 6. A wetland downstream of Rattlesnake Springs (Photo by Kevin Benck, SMUMN GSS).

Over 350 species of birds, 40 species of amphibians and reptiles, and 30 mammal species occur at Rattlesnake Springs (Martin 2011). These include the Rio Grande leopard frog (*Lithobates berlandieri*), the state-threatened greenthroat darter (Photo 7), and the federally endangered southwestern willow flycatcher (NPS 2001). The New Mexico Surface Water Quality Bureau stated that the spring water is of excellent quality (Hopkins 2003).

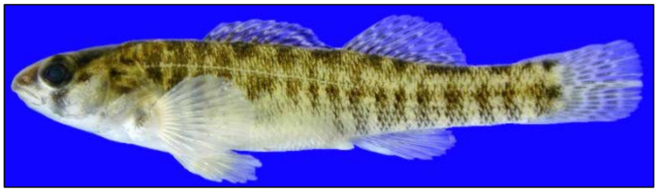


Photo 7. The green-throated darter (Photo by Chad Thomas, Texas State University – San Marcos).

The spring at Rattlesnake Springs is artesian (i.e., water is discharged due to natural pressure), discharging from "a karstic, well-indurated, limestone conglomerate" in an alluvial fan (Bowen 2006, p. 7). The discharge occurs at a point where the alluvial sediments narrow between outcrops of the Castile Formation, forcing groundwater to the surface (Bowen 2006). The groundwater in the alluvium is recharged by precipitation in the upper Black River valley, particularly from flood waters running through the canyons along Guadalupe Ridge (Figure 18) (Bjorklund and Motts 1959, Cox 1963). Largely due to this steady water supply, Cox (1963, p. 10) noted that "Vegetation is thick near the springs and aquatic plants grow in the pool." The forested areas supported by the springs include stands of Rio Grande cottonwood (*Populus deltoides* ssp. *wislizenii*), an increasingly rare vegetation community that is considered globally threatened due to hydrological alterations (Muldavin et al. 2012).

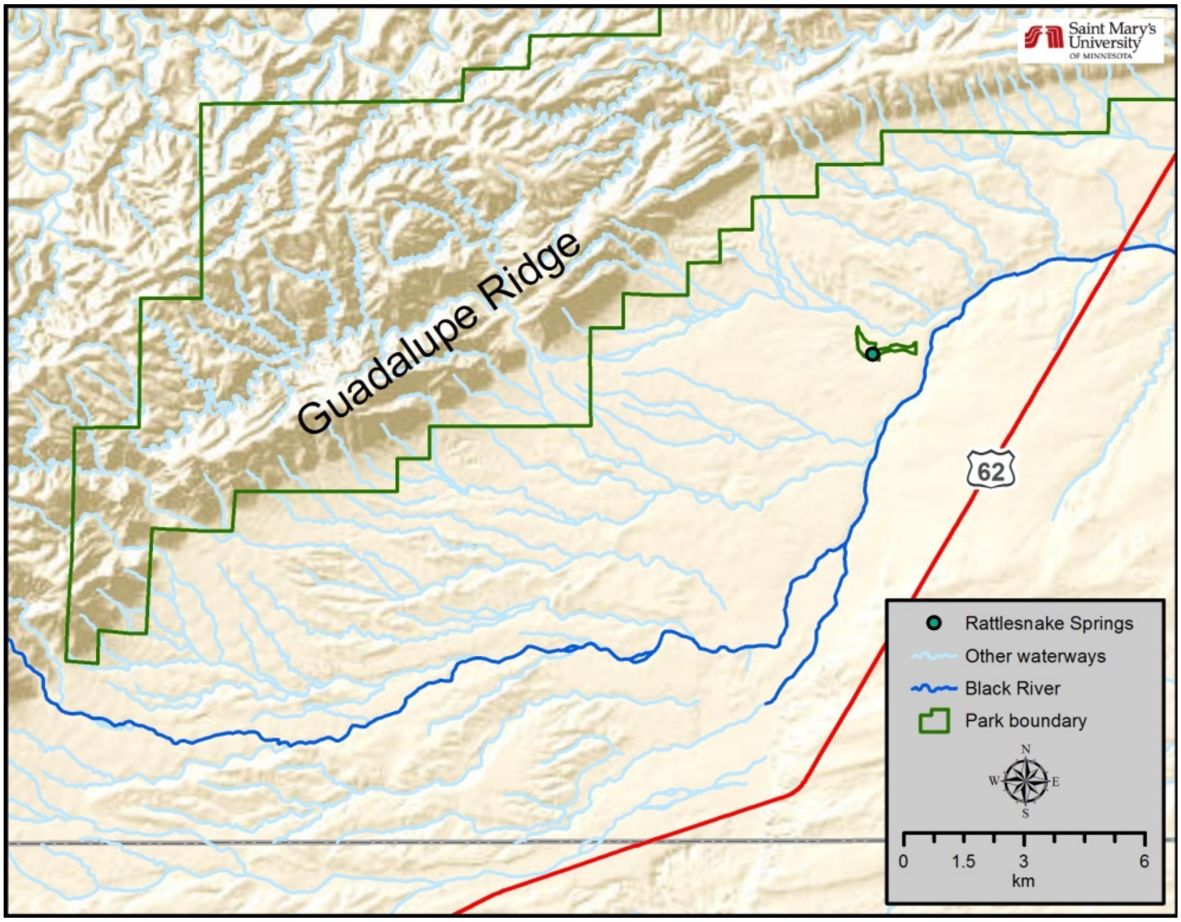


Figure 18. The locations of the Black River and Guadalupe Ridge canyons relative to Rattlesnake Springs.

The area around Rattlesnake Springs was settled in the late 1800s by Henry Harrison, who farmed the property, raised livestock, and established orchards (NPS 1964). He acquired water rights of 105 acre-feet per year along with the property, which are now owned by the NPS (Bowen 2006). As of 2006, the park was drawing approximately 946.4 liters per minute (lpm) (250 gallons-per-minute [gpm]) from the well at Rattlesnake Springs, which did not appear to affect the spring flow (Bowen 2006). Today, the natural spring flow is still collected in an artificial pool about 2.3 m (7.5 ft) deep (Photo 8) (Cox 1963, Martin 2011). Water can be released from the pool through outlet gates into four ditches to irrigate surrounding lands or to feed wetlands. Some water is diverted to Washington Ranch, a neighboring private property, for irrigation and fish ponds (Martin 2011).

Photo 8. The pond that collects spring discharge at Rattlesnake Springs (Photo by Kevin Benck, SMUMN GSS). The structure to the right of the small sign is a headgate for one of the diversion ditches.

4.1.2. Measures

- Groundwater levels
- Discharge
- Extent of wetland vegetative communities
- Southwestern willow flycatcher nesting habitat
- Cottonwood plantation stand quality

4.1.3. Reference Conditions/Values

For this assessment, the project team identified the reference conditions as no loss of wetland vegetation over time and the presence of optimal southwestern willow flycatcher nesting habitat. However, the conditions necessary for "optimal" habitat have not been quantitatively defined. Some information regarding southwestern willow flycatcher preferences are included in this NRCA and may serve as a starting point for identifying potential nesting habitat at CAVE. The park also seeks to maintain its senior water rights (priority date of 1880).

4.1.4. Data and Methods

Hale (1955) conducted an investigation to determine groundwater conditions in the upper Black River Valley, the relationship between area groundwater and surface water, and the impacts of pumping at area wells on surface waters, including Rattlesnake Springs. Field work was completed from April to June of 1952. Data gathered included spring flow measurements and well water levels. Hale (1955) noted that the trend in water levels at Well 25.24.26.121 (south of the springs) were correlated with trends in Rattlesnakes Springs flow and the height of the spring pool. Bjorklund and Motts (1959) described the geology and water resources of the Carlsbad area, also including Rattlesnake Springs. Field investigations were completed between 1953 and 1958. The report presents discharge data for the springs from 1953-1958 (Bjorklund and Motts 1959).

Cox (1963) measured Rattlesnake Springs discharge and nearby well levels to determine if pumping from irrigation wells was impacting the spring. This investigation was triggered by NPS concern over declining spring flow during the 1950s. Flow data were collected using recorders installed on

Parshall flumes on diversion ditches 1 and 2, located at the northeast corner of the Rattlesnake Springs pool (Cox 1963). Water levels were measured bimonthly at 12 area wells and collected from a data recorder on well 25.24.26.121 (Cox 1963).

Bowen (2006) used geologic information and hydrologic data to construct and test a conceptual flow model for the Rattlesnake Springs system. Continuous spring flow data were available from 1984 through 1997, although pre-1989 data had to be adjusted due to a re-calibration of the flume system in 1989. Prior to that year, records had overestimated the actual discharge by 50% (Bowen 2006). Bowen (2006) also discussed yield and water quality data from four wells drilled in the vicinity spring in 1963.

Porter et al. (2009) provides basic information regarding the hydrology of Rattlesnake Springs and the surrounding region, as well as some depth to groundwater readings from nearby wells and a graph of Rattlesnake Springs discharge. The three wells with depth to groundwater data are all outside CAVE boundaries and range from 1.2 km (0.75 mi) to 7.2 km (4.5 mi) from Rattlesnake Springs itself (Figure 19) (Porter et al. 2009).

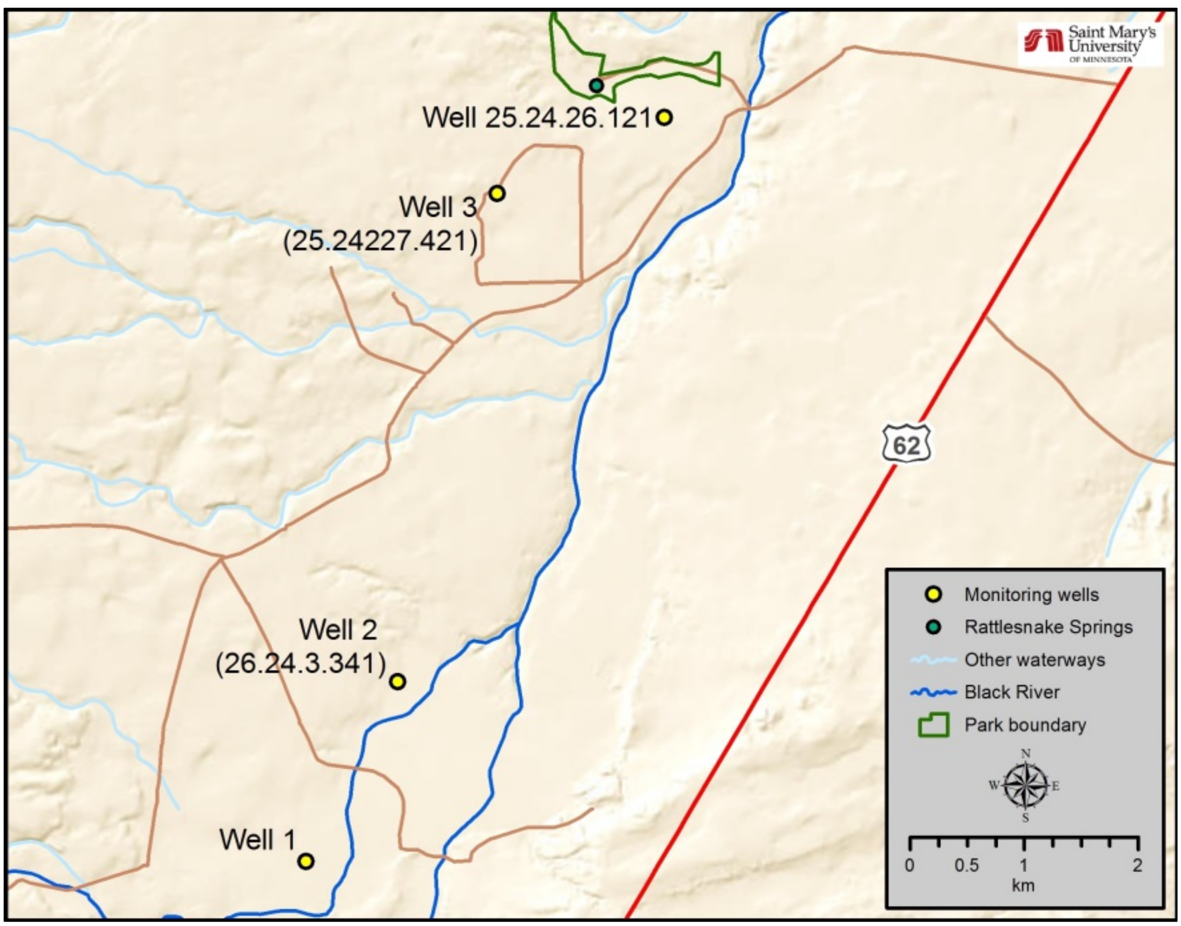


Figure 19. Locations of wells with available depth to groundwater data.

Muldavin et al. (2012) created a park-wide vegetation map and classification system for CAVE based on high-resolution satellite imagery and ground sampling. Four hundred vegetation plots were surveyed across the park over three field seasons beginning in 1999. This map provided information regarding the extent of wetland communities around Rattlesnake Springs. Roemer (2002) mapped cottonwood locations within the Rattlesnake Springs Unit and classified each tree by size (mature, young, sapling).

The CHDN recently established a springs monitoring program for selected network parks, including CAVE. The monitoring objectives are (NPS 2014):

- Surface Water Dynamics: Determine status, variability, and long-term trend in spring discharge at selected springs.
- Surface Water Quality: Determine status and long-term trend in core water quality parameters at selected springs.
- Aquatic Invertebrates: Determine long-term trend in community composition of macroinvertebrates at selected springs.
- Persistence of Springs: Determine status and long-term trends in the persistence of selected springs.
- Riparian Vegetation: Determine the status and trend in common spring vegetation richness (including non-native taxa), and at selected springs, the extent of area of common spring plant species and abundance of common spring species (NPS 2014).

Data collected will include flow rate (i.e., discharge), water quality parameters (e.g., temperature, pH, dissolved oxygen, conductivity), riparian plant taxa richness, and percent vegetative cover for common perennial plants (NPS 2014). At the time this NRCA was in preparation, initial data from the CHDN monitoring program was still in review and analyses and was not ready for inclusion in this report.

4.1.5. Current Condition and Trend

<u>Groundwater Levels</u>

As mentioned previously, the discharge at Rattlesnake Springs is primarily groundwater from a small alluvial aquifer in the region (Bowen 2006). Therefore, local groundwater levels have a direct impact on spring flow. Hale (1955) and Cox (1963) noted that the trend in water levels at Well 25.24.26.121 (about 168 m [550 ft] south of the springs, see Figure 19) were correlated with trends in Rattlesnake Springs' flow. According to Cox, if the water level in this well drops to 3.1 m (10.2 ft) below land surface, Rattlesnake Springs will stop flowing and the pool will dry up.

Hale (1955) and Cox (1963) reported groundwater levels at this well from 1952-1954 and from 1952-1961, respectively. At the time, the casing on Well 25.24.26.121 extended 1 m (3 ft) above the ground surface (Hale 1955), so that measurements above ground level were actually possible. Hale (1955) recorded daily high and low water levels in the well from February 1953 through June 1954. During this time, water level measurements never dropped more than 0.6 m (2 ft) below the surface and stayed above ground level during the winter months (Figure 20).

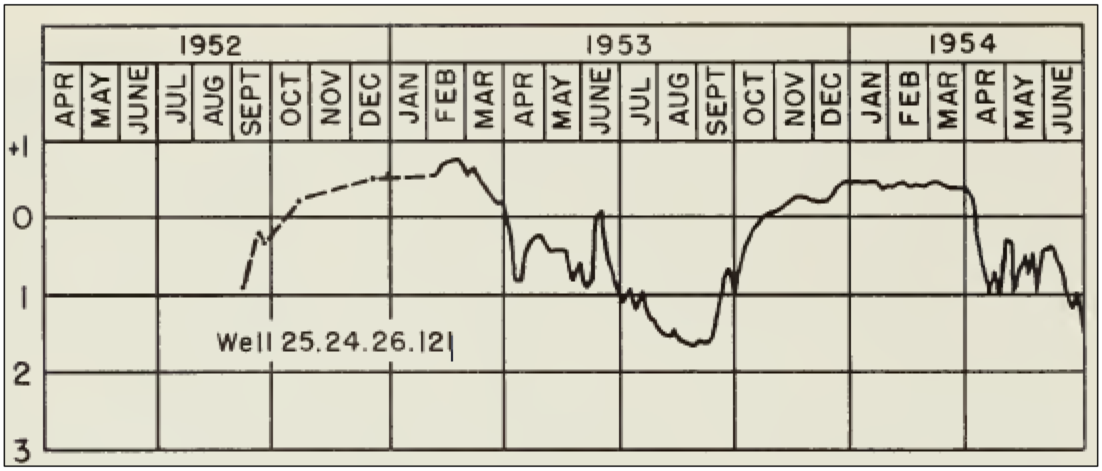


Figure 20. Water levels (ft) in Well 25.24.26.121 near Rattlesnake Springs, 1952-1954 (reproduced from Hale 1955). Zero represents ground level; because the well casing extends approximately 1 m (3 ft) above the ground, measurements above zero are possible.

Water levels at Well 25.24.26.121 remained within 0.6 m (2 ft) of the surface through 1956, but first dropped below this level in the summer of 1957 (Cox 1963). Annual low water levels were near 1 m (3 ft) below the surface from 1959-1961, and high water levels did not rise to the ground level during the winters of 1957-58 and 1960-61 (Figure 21). The lowest recorded water level was 1.1 m (3.5 ft) below the surface on 10 September, 1960 (Cox 1963).

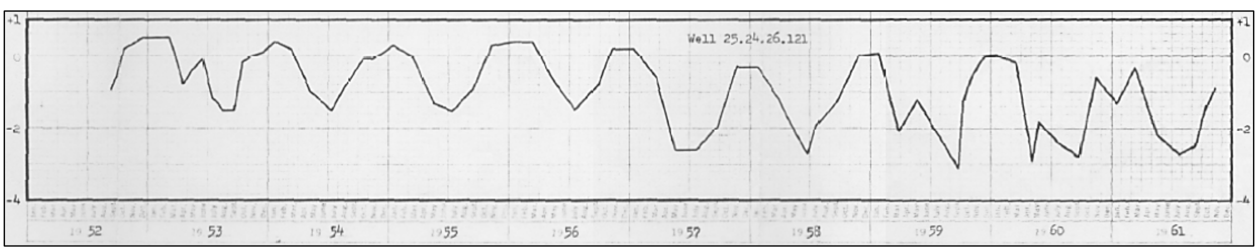


Figure 21. Water levels (ft) in Well 25.24.26.121 near Rattlesnake Springs, 1952-1961 (reproduced from Cox 1963).

More recent information could be found regarding water levels in Well 25.24.26.121. However, Porter (2009) included graphs of depth to groundwater for three other wells in the vicinity of Rattlesnake Springs from 1952-2006. While these wells are not directly indicative of conditions at Rattlesnake Springs, the results suggest a regional downward trend in groundwater depth since the 1990s (Figure 22; Porter 2009).

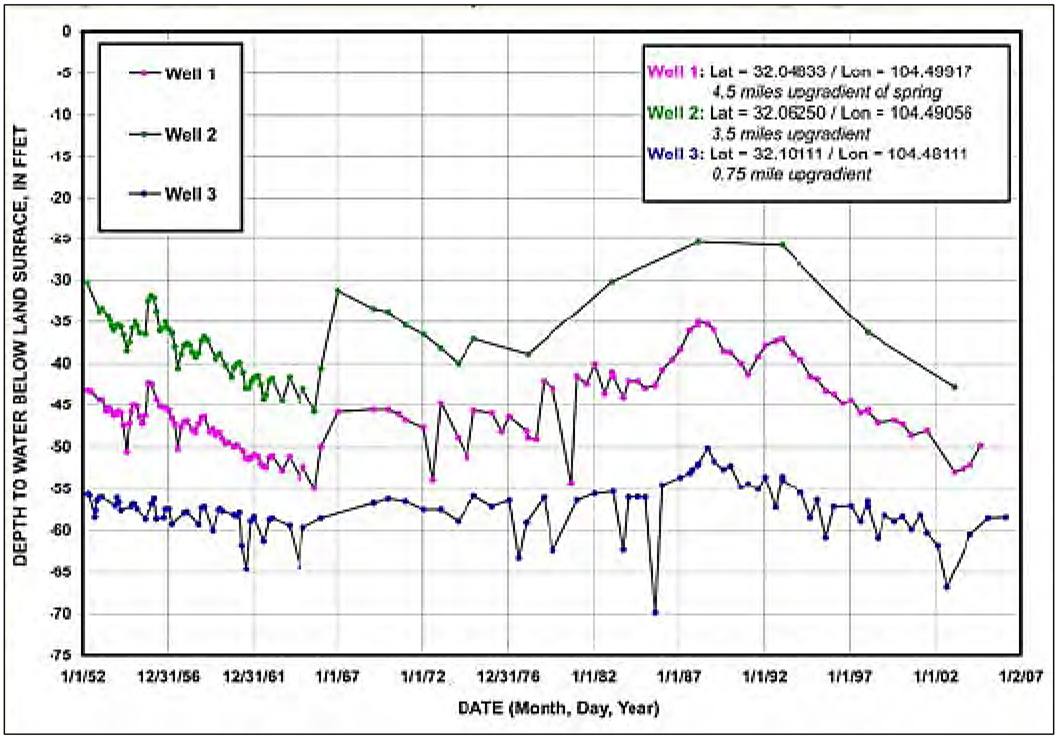


Figure 22. Depth to groundwater in three wells near Rattlesnake Springs, 1952-2006 (reproduced from Porter 2009).

<u>Discharge</u>

Discharge at Rattlesnake Springs varies widely throughout the year; flow is lowest during the summer when groundwater is being pumped for irrigation and highest in late winter when pumping slows down or ceases and precipitation is able to recharge the aquifer (Bjorklund and Motts 1959, Cox 1963, Bowen 2006). Rattlesnake Springs discharge or flow has been measured regularly over time. However, these measurements have not been at consistent time intervals or with identical methods; data are also not stored in a uniform format or in a single, accessible database. The earliest reported discharge measurement is from Sullivan (1908, as reported by Bjorklund and Motts 1959), who stated that spring flow averaged 0.12 cubic meters per second (cms) (4.25 cubic feet per second [cfs]). The next available discharge data are monthly measurements from April 1952 through February 1958 reported by Bjorklund and Motts (1959). During that time period, flow ranged from 0.03 to 0.12 cms (1.2 to 4.2 cfs), averaging around 0.07 cms (2.5 cfs) (Figure 23). The highest flows recorded each year appeared to decline over time.

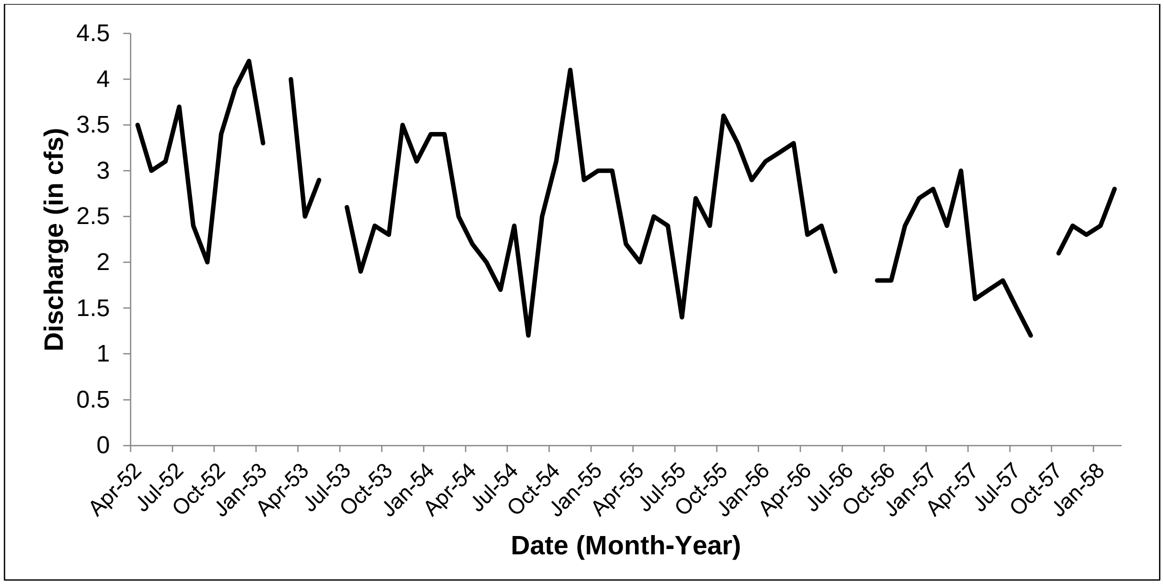


Figure 23. Rattlesnake Springs discharge (in cfs), April 1952-February 1958 (Bjorklund and Motts 1959).

Cox (1963) reported discharge at Rattlesnake Springs from 1952-1961. During this time, discharge ranged from >0.01 to 0.13 cms (0.17 to 4.7 cfs), with higher flows occurring earlier in the period and lower flows in later years (Cox 1963). From February 1961 to February 1962, flow did not exceed 0.08 cms (2.8 cfs) and remained below 0.01 cms (0.5 cfs) for much of July and August (Figure 24).

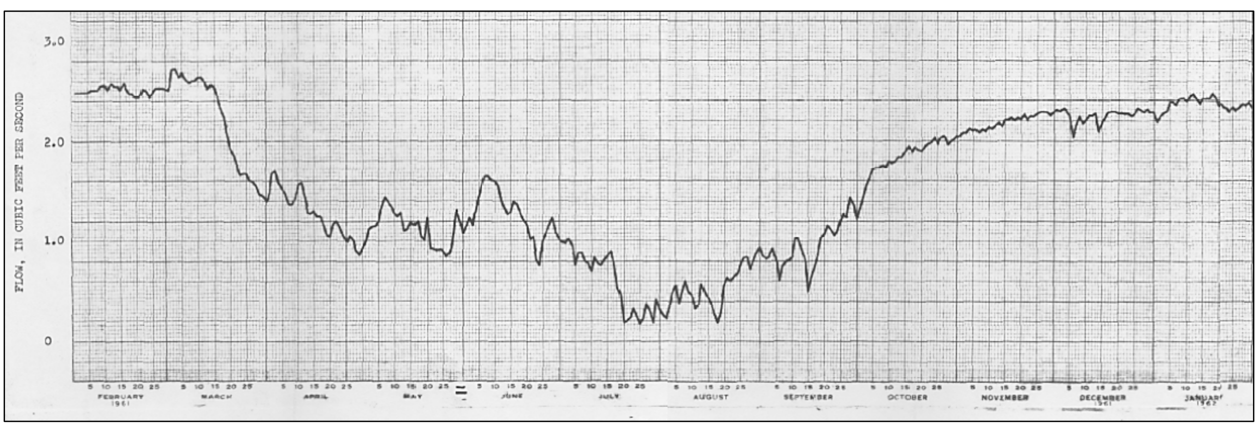


Figure 24. Rattlesnake Springs discharge (in cfs), February 1961-February 1962 (reproduced from Cox 1963). Note the decline in summer, during the agricultural irrigation season.

The next reported discharge measurements for Rattlesnake Springs are found in Bowen (2006), covering the period from 1984 to 1997. However, data from 1984-1989 were adjusted due to a re-calibration of the flume system in 1989 and represent estimates (Bowen 2006). Between 1989 and 1997 alone, discharge ranged from a low of 0.06 cms (2.2 cfs) in August 1994 to a high of 0.12 cms (4.3 cfs) in April 1990 with an overall average of 0.09 cms (3.2 cfs) (Figure 25).

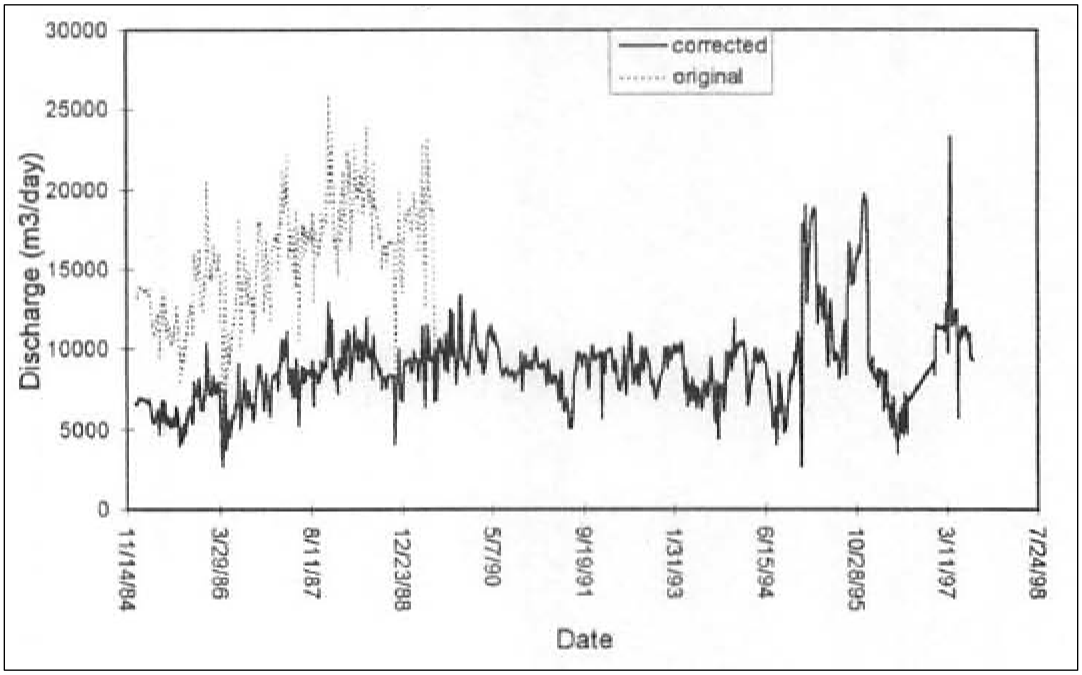


Figure 25. Rattlesnake Springs discharge in m^3/day, November 1984 through 1997 (reproduced from Bowen 2006). Note that the upper, dashed line from 1984-1989 represents original measurements and the solid line represents corrected estimates, based on flume recalibration.

Porter (2009) included a hydrograph of Rattlesnake Springs discharge from 2001 to 2007. During this time, spring flow appears to have ranged from just above 0 cms (0 cfs) to around 0.13 cms (4.5 cfs), with a declining trend over time (Figure 26). Porter (2009) suggests that, based on well data, spring discharge has likely been decreasing since around 1990. The decline appears to coincide with a precipitation deficit that extended from about 1989 through at least 2004 (Porter 2009). In June 2006, the NPS stated that Rattlesnake Springs flow measurements had dropped significantly in the past month, indicating the lowest discharge values ever recorded (NPS 2006).

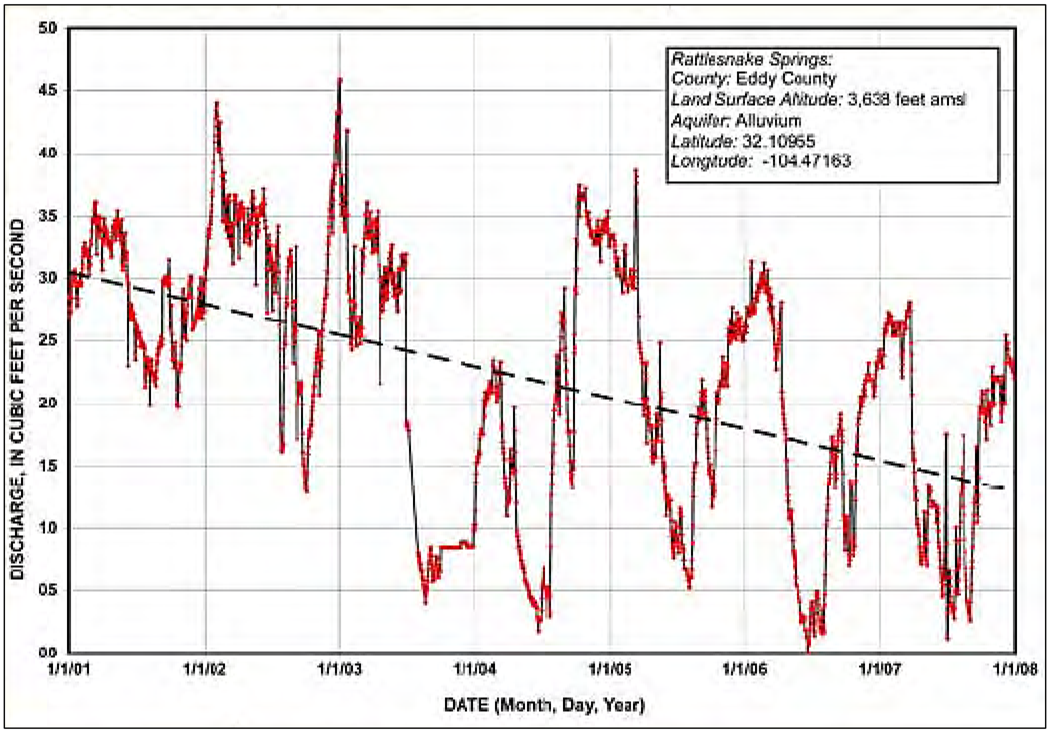


Figure 26. Rattlesnake Springs discharge (in cfs), 2001-2007 (reproduced from Porter 2009).

Extent of Wetland Vegetative Communities

According to Muldavin et al. (2012), two wetland vegetation community types occur around and downstream from Rattlesnake Springs: forested wetland and herbaceous wetland. Forested wetlands comprise a larger area with 3.9 ha (9.6 ac), while herbaceous wetlands cover 0.9 ha (2.2. ac), for a total wetland extent of 4.8 ha (11.8 ac) (Table 8; Muldavin et al. 2012). The locations of these wetlands are shown in Figure 27.

Table 8. Wetland vegetation community extent around and downstream of Rattlesnake Springs (Muldavin et al. 2012).

Vegetation Community	Area (ha)	Area (ac)
Forested wetland	3.9	9.6
Herbaceous wetland	0.9	2.2
Total	**4.8**	**11.8**

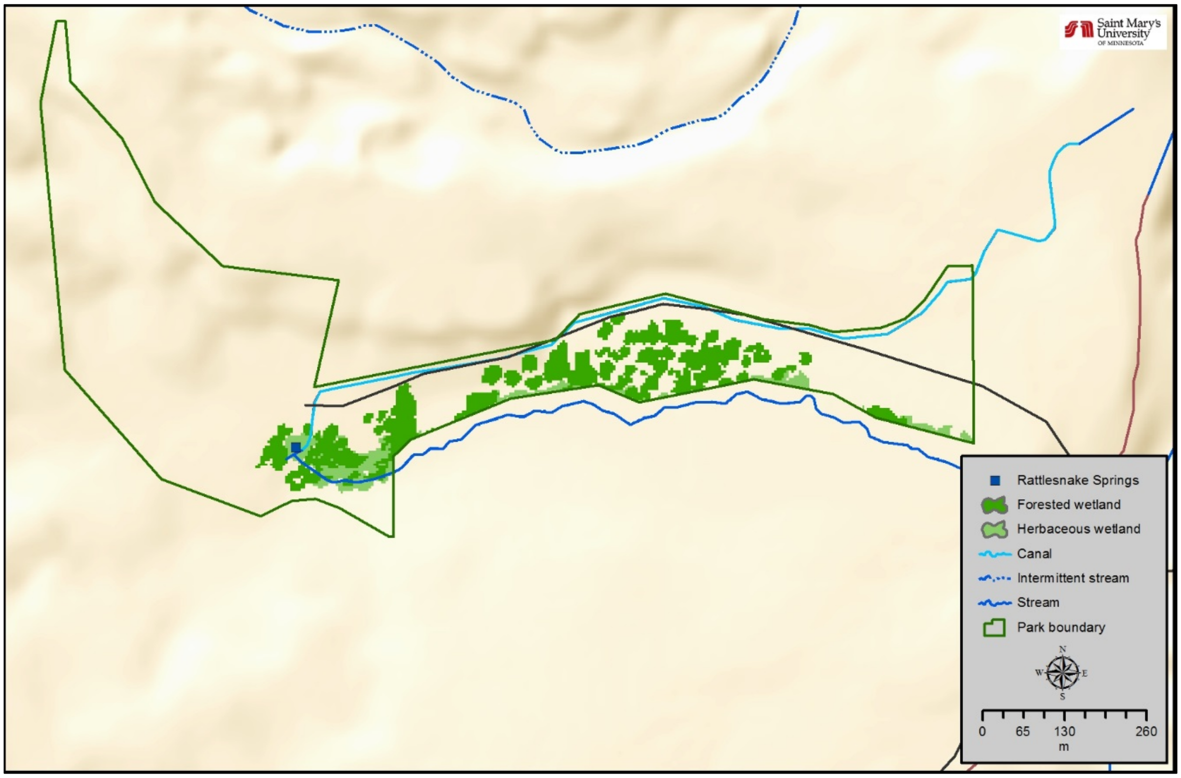


Figure 27. Location and extent of forested and herbaceous wetlands around and downstream of Rattlesnake Springs (Muldavin et al. 2012). The area just south of the boundary containing the stream is owned by The Nature Conservancy and also supports wetland/riparian vegetation (Schwarzkopf, written communication, April 2016).

Southwestern Willow Flycatcher Nesting Habitat

Cottonwood-willow riparian habitats, like those found at Rattlesnake Springs, are essential habitat for the southwestern willow flycatcher (Photo 9) (Finch and Stoleson 2000). All known breeding sites across the species' range are characterized by dense riparian vegetation adjacent to surface water or saturated soils (USFWS 2002, Brodhead 2005). Dense vegetation is particularly important in the low to mid-story, about 1-3.7 m (3-12 ft) off the ground (Sogge et al. 2010). This small flycatcher is an aerial forager that catches flying invertebrates in the air or from vegetation. Therefore, while dense vegetation is required for nesting, flycatchers prefer habitats that also have openings or edges that provide foraging opportunities (Brodhead 2005). The species appears to avoid narrow corridors when nesting, with most successful nests found in habitat patches at least 9 m (30 ft) wide (Sogge et al. 2010). Total habitat patch size is also important to these flycatchers; the median breeding habitat patch size is 1.8 ha (4.4 ac) (USFWS 2002).

Photo 9. A southwestern willow flycatcher feeding nestlings (Photo by J. Cartron, USFWS).

The southwestern willow flycatcher has been known to utilize Rattlesnake Springs during migration for many years (NPS 2001) but was just recently documented nesting there (Schwarzkopf, written communication, April 2016). Flycatcher numbers have declined in recent decades due to human degradation and destruction of riparian habitats, leading the subspecies to be classified as federally endangered by the U.S. Fish and Wildlife Service (USFWS) in 1995 (USFWS 2002, Brodhead 2005).

Threats and Stressor Factors

Threats to the Rattlesnake Springs community include irrigation, drought, climate change, visitor use, oil and gas activity, invasive exotic species, livestock trespass, historical drainage modifications (e.g., the USFS "duck ponds"), fertilizer use on neighboring lands, and aerial herbicide applications by the BLM. Irrigation using surface waters diverted from Rattlesnake Springs occurred as early as the 1860s (Bjorklund and Motts 1959). The use of groundwater pumped from wells for irrigation began in the upper Black River valley in the mid-1940s; as of the mid-2000s, agricultural irrigation was occurring on approximately 214 ha (530 ac) in the vicinity of Rattlesnake Springs (Bowen 2006). Cox (1963) determined that pumping from two wells just southwest of Rattlesnake Springs (25.24 .27.124 and 25.24.27.421) directly impacts the flow at the spring and water levels in the collecting pool. Pumping at one additional well slightly further away to the southwest (25.24.34 .112) was found to impact spring flow only slightly (Cox 1963). However, the flow model developed by Bowen (2006) suggests that current groundwater withdrawals for irrigation are not having a significant effect on spring output. While the pumping does impact discharge at Rattlesnake Springs, the associated decline in total flow volume appears to be small (Bowen 2006). This could change if demand for groundwater and pumping rates increased.

Oil and gas drilling activities in the area are also potential threats to the Rattlesnake Springs community. The Permian Basin of southeast New Mexico, which includes Eddy County where CAVE is located, is the state's major oil producing region (NM EMNRD 2014). Many oil and gas activities require groundwater. The increasingly-used hydraulic fracturing method (i.e., fracking), which involves injecting fluid into wells, can require more water than conventional drilling methods.

In 2010, fresh water withdrawals for oil and gas operations totaled nearly 2.8 million liters (739 million gal) state-wide (NM EMNRD 2014). Although this accounts for only 1% of New Mexico’s total water use, it may have a local impact on groundwater levels in high-activity areas. Oil and gas activities also include a risk of spills or leaks that could contaminate ground or surface waters. Potential contaminants from these operations range from carcinogens such as aromatic hydrocarbons and polycyclic aromatic hydrocarbons to sulfides, which produce an unpleasant odor and can corrode metal pipelines (Bowen 2006). In recent decades, concern was raised over an El Paso Natural Gas injection and gas storage facility just 3.2 km (2 mi) from Rattlesnake Springs (Bowen 2006, Graham 2007). Bowen’s (2006) flow model suggested that area geological constraints and water table characteristics should prevent any contamination at this facility from reaching Rattlesnake Springs. However, hydrocarbons have been detected in Rattlesnake Springs' water samples taken during high flow events, indicating that some contamination may occur under certain conditions (Paul Burger, NPS Hydrologist, written communication, April 2016).

Additional potential sources of contamination or damage are livestock trespass, aerial herbicide applications, fertilizer use on neighboring lands (e.g., excess nutrients), and visitor use. Livestock graze on lands adjacent to the Rattlesnake Springs unit and occasionally get on to park property. If this occurs, animals could trample sensitive vegetation and contaminate any waters or wetlands they enter. Visitors may also trample vegetation and could contaminate spring waters, if not careful (NPS 2010). Lastly, there is a risk that herbicides applied by other agencies to control aggressive brush species (e.g., creosote bush [*Larrea tridentata*] and tarbush [*Flourensia cernua*]) may runoff into the park. The Carlsbad and Las Cruces Districts of the BLM have used aircraft to drop herbicide pellets on lands in southern New Mexico (BLM 2009, 2014, Luis Florez, CAVE Biologist, email communication, 15 April 2016). These pellets are designed to dissolve with precipitation, releasing the herbicide into the soil. The use of pellets essentially eliminates the risk of airborne chemical drift, and the BLM policy of applying pellets in the fall/early winter when precipitation is gentle should reduce the risk of inadvertent spread through surface runoff (BLM 2009). However, it is possible that pellets could be displaced by runoff if intense rainfall occurs shortly after application. To reduce this risk, the BLM policy is to incorporate a 100-m buffer around all non-target plants or special habitats (BLM 2009).

Invasive exotic plant species are a major threat to natural ecosystems world-wide, as they can displace native plant species, fragment native habitat, and alter ecosystem functions (Wilcove et al. 1998, Reiser et al. 2012). Invasive species are opportunistic and, in the arid southwest, they may colonize open sites necessary for cottonwood regeneration and seedling survival (Howe and Knopf 1991). The exotic species Russian olive and Johnsongrass are known to occur at Rattlesnake Springs and may negatively impact the unit’s cottonwood-willow and herbaceous wetlands (NPS 2001). However, the NPS is not currently allowed to remove Russian olive, as it provides habitat for the endangered southwestern willow flycatcher (Schwarzkopf, written communication, April 2016). The exotic aquatic plant watercress (*Nasturtium officinale*) is also known to occur in the natural channel downstream from the spring (NPS 2007). Invasive aquatic animals in the pond, such as the green sunfish (*Lepomis cyanellus*) and largemouth bass (*Micropterus salmoides*), may threaten the native Rattlesnake Springs community as well (Burger, written communication, April 2016).

Potential effects of climate change in the desert southwest include increased temperatures, changes in the amount and timing of precipitation, and more climate extremes (e.g., heat waves, droughts) (NAST 2001, Davey et al. 2007). According to Bowen (2006), the greatest impact on Rattlesnake Springs' flow is climatic variation. Below-average precipitation is known to reduce the flow of Rattlesnake Springs, as was documented during the 1950s drought (Cox 1963, Bowen 2006). An extended drought could even cause spring flow to cease completely (Bowen 2006). A reduction in flow and water levels at Rattlesnake Springs will impact all the plants and wildlife that rely on the area as habitat and as a water source, including the endangered southwestern willow flycatcher. Drought would not only affect spring discharge directly, but could increase pumping of groundwater for irrigation, which would further impact spring flow.

Data Needs/Gaps

Current information regarding the measures selected for this component is somewhat limited. While discharge data for Rattlesnake Springs have been recorded in recent decades using various methods and at different intervals, these data have not been organized or compiled and were not available for this NRCA (Stan Allison, CAVE Cave Technician, written communication, 7 August 2015). The extent of wetland vegetation at Rattlesnake Springs has been mapped fairly recently (Muldavin et al. 2012), but no historical information on wetland extent could be found to determine if changes have occurred. Southwestern willow flycatchers have recently been documented nesting at Rattlesnake Springs, but the unit has not been evaluated to determine the amount and quality of flycatcher nesting habitat. Monitoring of cottonwood size class distribution and regeneration would help in assessing cottonwood stand quality. Muldavin et al. (2012) suggested that, given the development and hydrological modifications that have occurred at Rattlesnake Springs, an in-depth ecological analysis would be necessary to identify the best management options for this significant wetland area. Further study of the water table levels, groundwater flow paths, and the relationship between groundwater and surface waters around Rattlesnake Springs would contribute to a better understanding of the spring's discharge (NPS 2010).

Overall Condition

Groundwater Levels

The project team assigned this measure a *Significance Level* of 3. Groundwater level data are available for wells near Rattlesnake Springs during the 1950s and early 1960s (Hale 1955, Cox 1963), but no more recent data are available from these specific wells for comparison. Porter (2009) reported groundwater levels from three wells in the vicinity of Rattlesnake Springs, but not as close to the spring as wells measured in the 1950s. These more recent data suggest a regional downward trend in groundwater depth since the 1990s (Figure 25; Porter 2009). As a result, this measure was assigned a *Condition Level* of 2, indicating moderate concern.

Discharge

The discharge measure was also assigned a *Significance Level* of 3. As with groundwater levels, Rattlesnake Springs discharge data are available for the 1950s and early 1960s (Bjorklund and Motts 1959, Cox 1963). Porter (2009) presented discharge data for Rattlesnake Springs from 2001- 2007 (Figure 26). While spring discharge varies seasonally, these most recent available data suggest that

Rattlesnake Springs discharge has dropped to the lowest values ever recorded (NPS 2006). More current data are needed to determine if discharge is still low or if it has rebounded. Therefore, at this time, discharge is of high concern (*Condition Level* = 3).

Extent of Wetland Vegetative Communities

The project team also assigned this measure a *Significance Level* of 3. According to Muldavin et al. (2012), wetland communities cover just 4.8 ha (11.8 ac) of CAVE's Rattlesnake Springs unit (Figure 27). Muldavin et al. (2012, p. 48) stated that these wetland areas "have been significantly reduced from their historical extent" due to hydrological modifications to meet the water needs of the park and adjacent landowners. Although many of the hydrological modifications are no longer needed, they have already impacted or are still affecting the wetland riparian system. Because the remaining wetlands are relatively small and represent only a fraction of their historical extent, this measure was given a *Condition Level* of 3 (high concern).

Southwestern Willow Flycatcher Nesting Habitat

This measure was assigned a *Significance Level* of 3. Southwestern willow flycatchers nest in dense riparian vegetation adjacent to surface water or saturated soils (USFWS 2002, Brodhead 2005). The species was just recently documented nesting at Rattlesnake Springs (Schwarzkopf, written communication, April 2016). To date, the vegetation community at Rattlesnake Springs has not been evaluated to determine the amount and quality of flycatcher habitat. As a result, a *Condition Level* cannot be assigned for this measure.

Cottonwood Plantation Stand Quality

This measure was assigned a *Significance Level* of 1. Measures with a *Significance Level* of 1 are not discussed in depth in the current condition section of this assessment, but available information is summarized here in the overall condition section. Cottonwood stands are rare and unique habitats in the Southwest that support a diversity of wildlife and are particularly important as stopover sites for migratory birds (Howe and Knopf 1991, Skagen et al. 1998). Unfortunately, riparian systems throughout the western U.S. have experienced substantial changes in flow regimes over the past century, largely due to human alterations for water diversion and storage (Howe and Knopf 1991). Cottonwoods and other native riparian plant species rely upon regular flooding to create freshly-scoured sites suitable for seed germination and seedling survival. Human alterations of flow regimes have reduced flood frequency and magnitude and shifted the timing and duration of high water levels (Howe and Knopf 1991). This lack of flooding limits cottonwood regeneration and recruitment, threatening the long-term survival of cottonwood stands (Howe and Knopf 1991). Riparian cottonwoods are also threatened by the invasion of exotic plants such as Russian olive; woody invasive species tend to colonize the open sites required for cottonwood regeneration and can shade out any seedlings that manage to germinate (Howe and Knopf 1991).

Cottonwood stand quality could be evaluated by measuring the size class distribution of trees (as size classes are roughly comparative to age classes), searching for evidence of cottonwood regeneration (e.g., seedlings or young trees), and recording the percent cover of exotic woody species. Little information is available for these parameters at Rattlesnake Springs. A 2002 effort to map cottonwood locations within the Rattlesnake Springs unit also classified trees as mature (>10.2 cm [4 in] in diameter), young (5.1-10.2 cm [2-4 in] diameter), sapling (<5.1 cm [2 in] diameter), or stump (Roemer 2002). Of the 285 cottonwoods mapped, 238 were classified as mature. Only 25 were in the young class and 16 were saplings (Roemer 2002). The remaining six were stumps. The locations of these cottonwoods by size class are shown in Figure 28. Since this is the only data available regarding the cottonwood stands at Rattlesnake Springs, a *Condition Level* cannot be assigned for this measure.

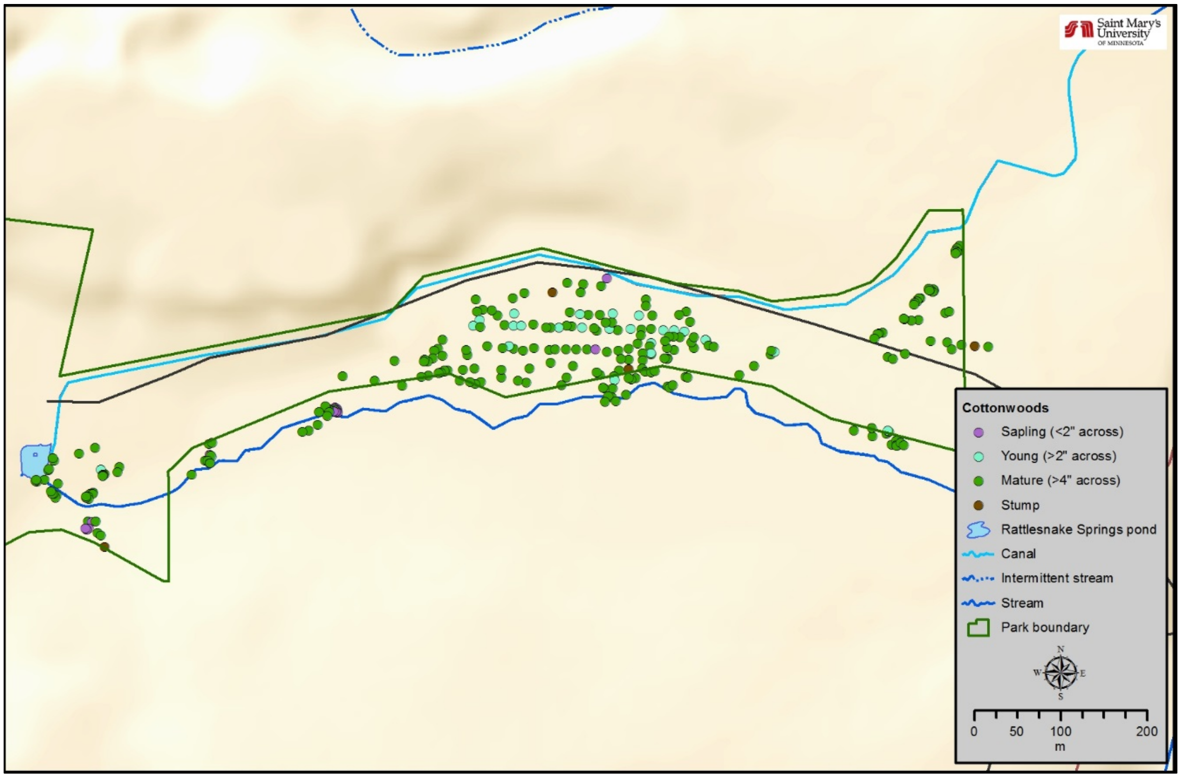


Figure 28. Location of cottonwood trees of various sizes within the Rattlesnake Springs unit of CAVE (Roemer 2002).

Weighted Condition Score

The *Weighted Condition Score* for the Rattlesnake Springs community is 0.89, which indicates high concern. Given that no data were available for groundwater levels or discharge after 2007, no trend is given and a medium confidence border has been assigned.

Rattlesnake Springs Community			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.89**
Groundwater Levels	3	2	
Discharge	3	3	
Wetland Vegetative Community Extent	3	3	
Southwest Willow Flycatcher Nesting Habitat	3	N/A	
Cottonwood Plantation Stand Quality	1	N/A	

4.1.6. Sources of Expertise

- Cheryl McIntyre, CHDN Physical Scientist.
- Paul Burger, NPS Hydrologist.
- Kent Schwarzkopf, CAVE Chief of Resource Stewardship and Science.
- Colleen Filippone, NPS Regional Hydrologist.
- Luis Florez, CAVE Biologist.
- Stan Allison, CAVE Cave Technician.

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4.2. Seeps and Springs

4.2.1. Description

Seeps and springs provide critical water resources for plants, wildlife, and humans within the arid environment of CAVE (Photo 10) (NPS 2010a, b). They provide habitat that allows for the existence of native species that otherwise would not survive in the region, increasing the park's biodiversity (NPS 2010a). These water sources are rare and sparsely distributed across the landscape, but play an important role in the functioning of desert ecosystems. As a result, the CHDN has selected the persistence of springs as a Vital Sign for network parks, including CAVE (NPS 2010a).

Photo 10. A seep in CAVE's West Slaughter Canyon (Photo by Shawn Thomas, NPS).

Within CAVE, seeps and springs vary in size, persistence, and landscape position (NPS 2010b). Groundwater, primarily from aquifers recharged by precipitation events, is the source of most springs in the park (NPS 2010a). Many seeps and springs form at the contact between the Yates and Tansill geological formations (i.e., rock units) (Graham 2007). The Tansill Formation is less permeable than the overlying Yates Formation and stops precipitation inputs from infiltrating down to lower layers (Burger, written communication, April 2016). Groundwater collects above these clay layers and flows horizontally until it discharges along canyon walls as a spring or seep, such as at Big Hill Seep along the park's Walnut Canyon Drive (Graham 2007).

Several of the park's springs were modified to support ranching activities and guano mining in the early 1900s. The remains of metal and earthen storage tanks and check dams can still be found at some locations (Graham 2007). As of 2005, 52 seeps and springs had been inventoried within CAVE, approximately 27 of which are considered permanent (e.g., flowing year-round) (Reid and Reiser 2005). The locations of nearly 50 of these springs are shown in Figure 29.

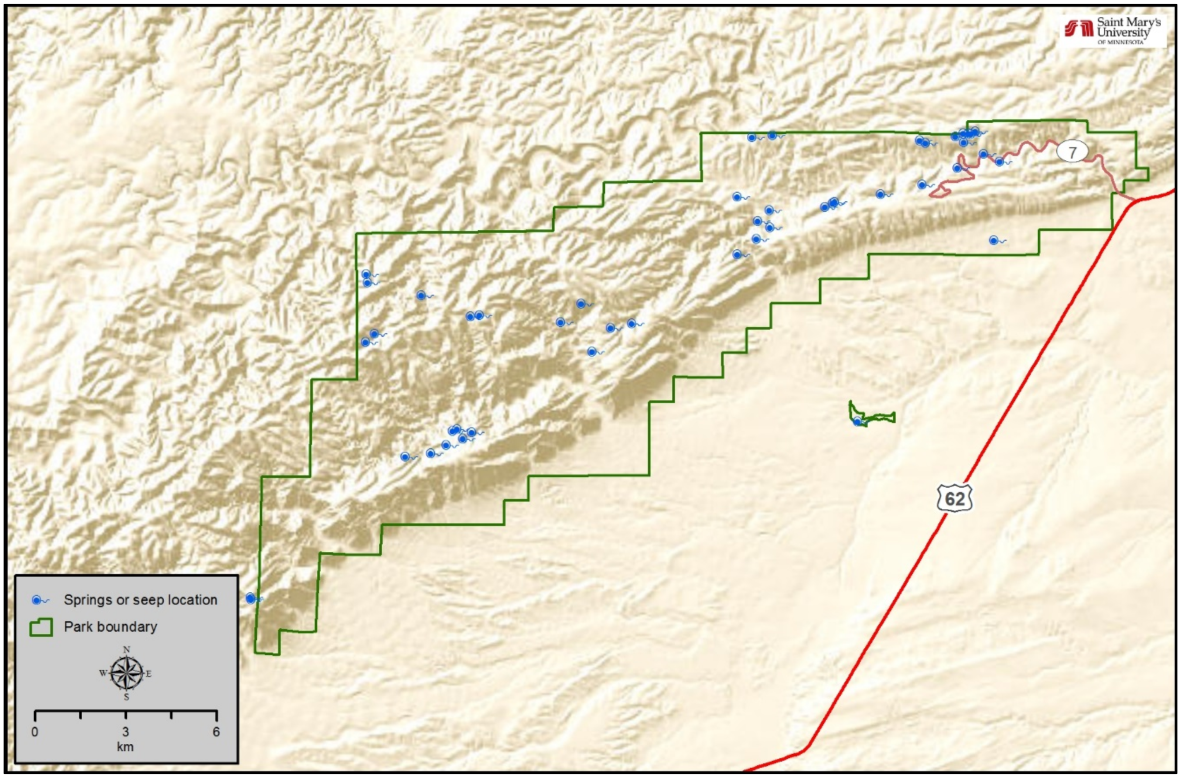

Figure 29. Locations of mapped seeps and springs within CAVE (NPS 2014a).

4.2.2. Measures

- Areal extent
- Species richness
- Plant community composition
- Discharge
- Changes in water quality

4.2.3. Reference Conditions/Values

Reference conditions for CAVE's springs and seeps were not determined by park natural resource managers. For the purpose of the water quality portion of this assessment, available data from CAVE will be compared to the EPA's standards for the protection of aquatic life (EPA 2015a).

4.2.4. Data and Methods

Since the previous chapter in this report focused exclusively on the Rattlesnake Springs community, this section will cover only the seeps and springs in the larger, main unit of CAVE. Data on the park's seeps and springs has been collected intermittently since its early years. NPS memos from the 1950s refer to letters from the 1930s reporting on flow rates at Oak Spring (Dunn 1959). In 1953, Good (1953) surveyed previously mapped permanent springs in the park to determine if they could provide an emergency drinking water supply during backcountry patrols or local fires. Field visits were completed during the winter and spring of 1953. Park staff also visited various springs, seeps, and other spring-fed surface water features (e.g., pot holes) intermittently throughout the 1960s and early 1970s. The NPS has scanned copies of data sheets and some notes from these visits, including discharge estimates/observations (NPS 1972).

Laws and Emmons (2000) conducted field searches for backcountry springs in CAVE during the spring of 2000. Forty different locations were visited; the majority was previously reported springs, some of which were found to be dry, but two were newly discovered by the field crew (Laws and Emmons 2000). Data collected included flow rate (when measurable), water temperature, wetted extent, and pool depth, along with plant and wildlife species observations. Because this report was not located until near the end of the NRCA process, SMUMN GSS analysts were only able to incorporate flow rates and vegetation observations. Additional analysis would be needed to assess extent and pool depth measurements.

Muldavin et al. (2012) created a vegetation map and classification system for CAVE based on high-resolution satellite imagery and ground sampling. Over three field seasons starting in 1999, 400 vegetation plots were surveyed across the park.

Water quality data for the park's springs, including some discharge measurements, were obtained through the EPA's Storage and Retrieval (STORET) data warehouse (http://www.epa.gov/storet/dw_home.html). This database contains water quality measurements collected by various federal and state agencies and included at least some data for over 30 seeps and springs at CAVE (EPA 2015b).

The CHDN recently established a springs monitoring program for selected network parks, including CAVE. Data collected include flow rate (i.e., discharge), water quality parameters (e.g., temperature, pH, dissolved oxygen, conductivity), riparian plant taxa richness, and percent vegetative cover for common perennial plants (NPS 2014b). At the time this NRCA was in preparation, initial data from this monitoring program was only available for the water quality, discharge, and extent measures.

4.2.5. Current Condition and Trend

Areal Extent

Measuring the extent of seep and spring communities is difficult, due to the ephemeral nature of some of these features. In addition, many spring communities are likely too small to be mapped by vegetation surveys based on aerial imagery. Muldavin et al. (2012) identified only one vegetation map unit in the main CAVE unit (i.e., excluding Rattlesnake Springs) as specifically associated with seeps and springs: the Oak-Madrone band cove woodlands. This community type covered 20.6 ha

(51.0 ac) within CAVE, or approximately 0.1% of the park’s total area (Muldavin et al. 2012). The known locations of these woodlands are shown in Figure 30. Several arroyo riparian shrubland communities in the park may occur around seeps and springs, but these could also be supported by precipitation-fed ephemeral washes. Since there is no way to determine from the vegetation mapping data which of these riparian shrublands are supported by seeps and springs, information on their extent is not included here.

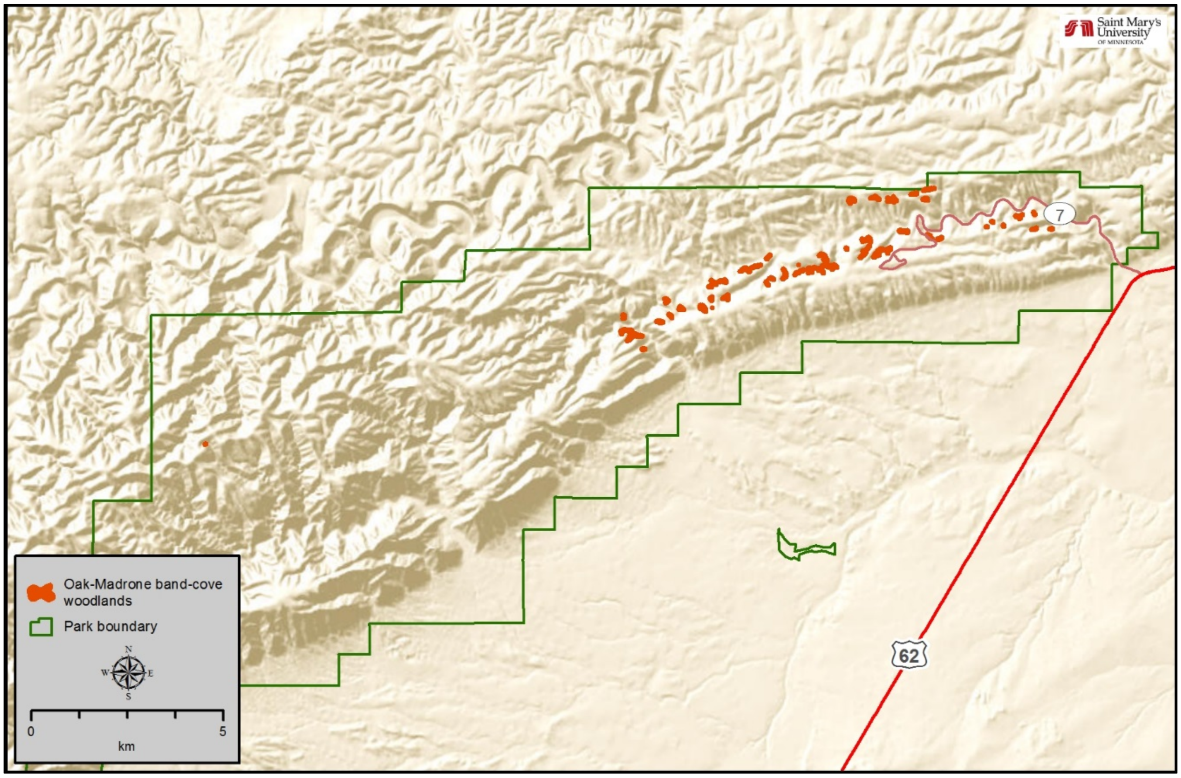

Figure 30. Locations of Oak-Madrone band cove woodlands, as mapped by Muldavin et al. (2012).

The CHDN has monitored the wetted extent of selected CAVE seeps and springs (NPS 2016). Measurements taken at these sites were wetted width, depth, and the length of any brooks fed by the springs (NPS 2016). The measured brook lengths ranged from 0.2 m to over 140 m (0.7-459 ft), while depths ranged from 0 to 1.5 m (4.9 ft). All available wetted extent data are included in Appendix A.

Species Richness

The seeps and springs in the main unit at CAVE have not been surveyed specifically for plant species richness. Given that these areas contain more moisture than what is available in the majority of the park’s desert ecosystems (NPS 2010a), it is possible that species richness may be higher here than in other vegetation communities.

<u>Plant Community Composition</u>

The plant composition of CAVE's seep and spring communities also has not been specifically surveyed. Muldavin et al. (2012) briefly described the composition of CAVE's Oak-Madrone band cove woodlands, which are known to be associated with seeps and springs. This community is typically dominated by gray oak (*Quercus grisea*) and Texas madrone (*Arbutus xalapensis*), with additional tree species such as bigtooth maple (*Acer grandidentatum*), Mohr's shin oak (*Quercus mohriana*) and netleaf hackberry (*Celtis reticulata*) (Muldavin et al. 2012). The shrub layers in these stands are diverse and can include Texas mulberry (*Morus microphylla*), mescal bean (*Sophora secundiflora*), evergreen sumac (*Rhus virens* var. *choriophylla*), and southwestern chokecherry (*Prunus serotina* var. *rufula*). Herbaceous ground cover (grasses and forbs) is usually low (Muldavin et al. 2012).

Laws and Emmons (2000) noted plant species that were observed in the vicinity of seeps and springs during field visits in 2000. The species observed are listed in Table 9. Many more plant species likely occur around CAVE's seeps and springs but have not yet been officially documented.

Table 9. Plant species observed in the vicinity of CAVE seeps and springs by Laws and Emmons (2000).

Scientific Name	Common Name
Trees	
Quercus muehlenbergii	Chinkapin oak
Quercus sp.	oak species
Arbutus xalapensis	Texas madrone
Juniperus pinchotii	Pinchot juniper
Juniperus monosperma	one-seed juniper
Juniperus deppeana	alligator juniper
Chilopsis linearis	desert willow
Celtis reticulata	netleaf hackberry
Acer grandidentatum	bigtooth maple
Pinus ponderosa	Ponderosa pine
Prunus serotina	black cherry
Populus deltoides ssp. wislizeni	Rio Grande cottonwood
Juglans microcarpa	little walnut
Shrubs/vines	
Lonicera albiflora	western white honeysuckle

Table 9 (continued). Plant species observed in the vicinity of CAVE seeps and springs by Laws and Emmons (2000).

Scientific Name	Common Name
Shrubs/vines (continued)	
Berberis trifoliolata	algerita
Choisya dumosa var. arizonica	Arizona orange
Vitis arizonica	canyon grape
Herbaceous	
Cladium jamaicense	Jamaica swamp sawgrass
Andropogon sp.	bluestem species
Phlox nana	Santa Fe phlox
Castilleja integra	wholeleaf Indian paintbrush
Adiantum capillus-veneris	common maidenhair fern
Parthenium incanum	mariola
Penstemon sp.	beardtongue species

Discharge

Discharge has been estimated intermittently at various seeps and springs throughout CAVE. It is difficult to compare estimates between years, as measurements are often from different months, and flow fluctuates naturally over the course of the year. Springs with the greatest numbers of measurements are Oak Spring (in the eastern part of the park) and Longview (in the southwest) (Figure 31). Estimates for Oak Spring extend from 1931, when it was the sole water supply source for the park (which lasted until 1935) through 1990 (Appendix B). Discharge ranged from a low of 0.1 lpm (0.03 gpm) in October 1969 to 19.4 lpm (5.1 gpm) in July 1931 (EPA 2015b). The most recent available measurements (1985-1990) all fell between 2-5 lpm (0.5-1.3 gpm). Longview Spring estimates extend from 1953 through 2000 (Laws and Emmons 2000, EPA 2015b). During this period, discharge ranged from 0.1 lpm (0.03 gpm) in November 1962 to 8.8 lpm (2.3 gpm) in January 1975 (Appendix C). From 1986 to 1991, measurements fluctuated between a low of 0.4 lpm (0.1 gpm) in April 1987 and a high of 3.8 lpm (1.0 gpm) in July 1991 (EPA 2015b).

Of the remaining seeps and springs in the park, only Dog Pen Seep and Stone Ranch Spring have data that cover a similar time period (1953-2010) (Figure 31; Appendix D). Dog Pen Seep historically had low discharge values, mostly between 0.1 and 0.6 lpm (0.03-0.2 gpm) (EPA 2015b), but was measured at 2.0 lpm (0.5 gpm) in November 2010 (NPS 2016). Stone Ranch Spring discharge was consistently <1.0 lpm (< 0.3 gpm) from 1953-1985, with higher values in June 1985 (4.4 lpm [1.16 gpm]) and January 1988 (4.7 lpm [1.25 gpm]). In October 2010, discharge was measured at 1.6 lpm (0.4 gpm) (NPS 2016). Discharge measurements from most other CAVE seeps and springs are <2.0 lpm (<0.5 gpm), with occasional spikes, possibly related to precipitation events, although these rarely exceed 5.0 lpm (1.3 gpm) (EPA 2015b, NPS 2016). Additional discharge measurements for park seeps and springs are included in Appendix D.

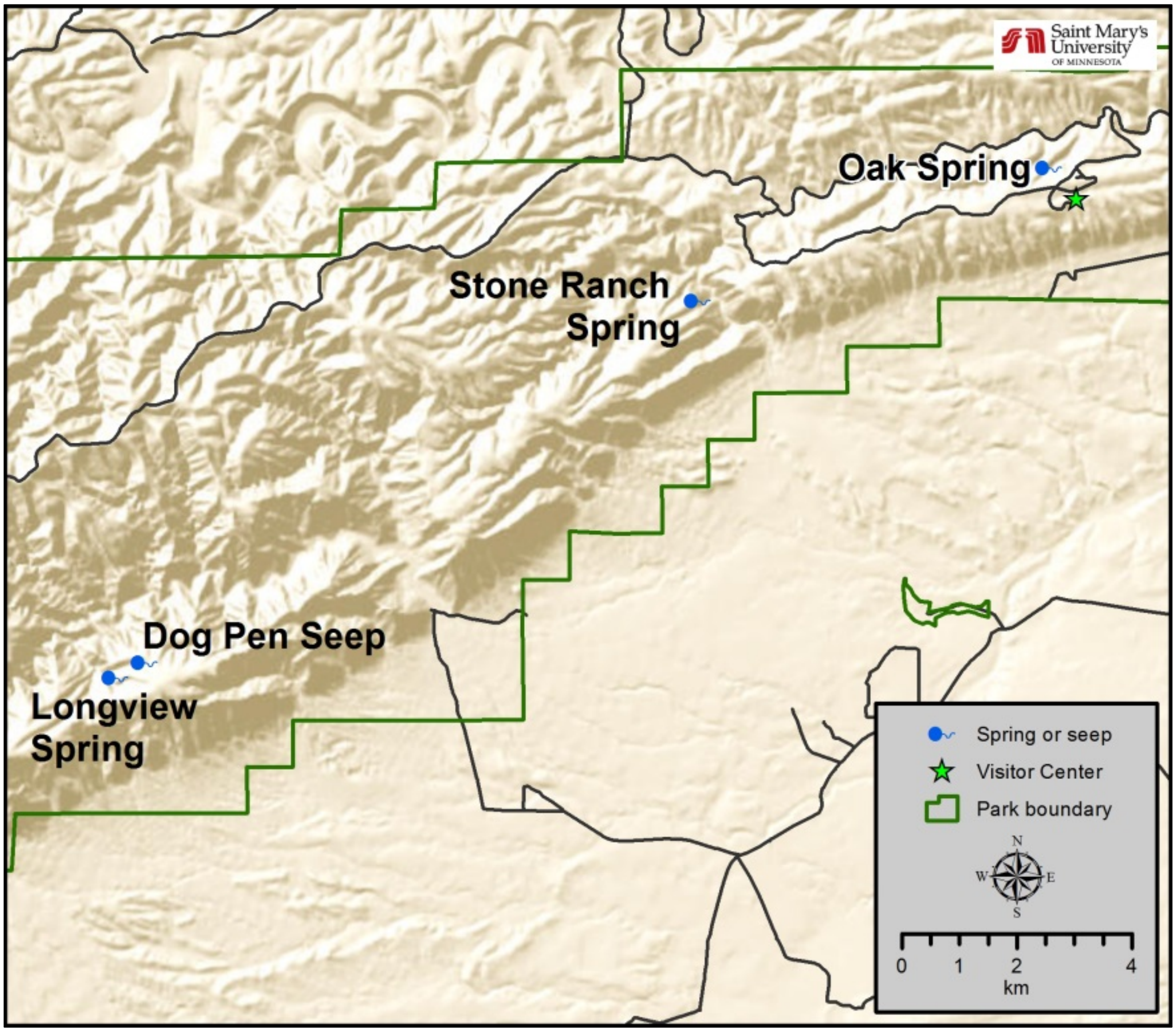

Figure 31. Locations of CAVE seeps and springs with the longest period of discharge data.

<u>Changes in Water Quality</u>

Water quality impacts both the aquatic organisms living in a water body and terrestrial organisms relying on it as a water supply (NPS 2010a). Fluctuations in groundwater quality, and therefore spring water quality, are often related to variations in precipitation amounts (Bjorklund and Motts 1959). Recharge from precipitation increases groundwater supply, and additional water helps to dilute or lower the levels of various elements or ions in the water. Water quality parameters of interest to the NPS include water temperature, specific conductance, pH, and dissolved oxygen (DO) (Reid and Reiser 2005). Data regarding these parameters at CAVE's seeps and springs are somewhat limited. STORET data contained historic pH readings for 21 park seeps and springs; 18 of these springs had only one measurement (EPA 2015b). According to notes in the STORET database, most of these readings were taken using a pH strip and are not highly precise (i.e., all values are whole numbers with no decimal places). More recently, the CHDN collected more precise pH measurements at several CAVE seeps and springs (NPS 2016). All seeps and springs had pH values between 7 and 9, indicating the water is neutral or slightly alkaline (Table 10). The EPA standard for the protection of aquatic life is a pH range of 6.5-9.0 (EPA 2015a).

Table 10. pH readings for CAVE seeps and springs (EPA 2015b, NPS 2016).

Seep/Spring	Date	pH	Seep/Spring	Date	pH
Oak Spring	6/26/1985	7	Big Hill Seep	10/31/1976	8
	7/25/1995	7		6/26/1985	8
	10/23/2010	7.87		10/21/2010	8.61
Oak Spring 2	10/23/2010	7.31	Grammer Seep	6/26/1985	7
Upper Lechuguilla Seep	6/29/1985	8		10/22/2010	7.35
	11/8/2010	7.61	East Upper Grammer Seep	6/26/1985	8
Stone Ranch Spring	6/29/1985	7		10/22/2010	8.54
	10/24/2010	8.34		4/26/2014	8.29*
Lowe Ranch Spring	6/26/1985	7	Upper Middle Grammer Seep	6/26/1985	7
	11/19/2010	7.54		10/23/2010	7.84
Upper Lowe Ranch Spring	6/26/1985	8	Crown Rock Seep	7/5/1985	7
	4/4/1986	8		11/5/2010	7.54
	11/19/2010	7.34	Putnam Tank Spring	7/25/1985	7
Slaughter Pot Hole	7/2/1985	8		3/31/2012	8.06*
	11/20/2010	8.29	Longview Spring	7/5/1985	8
	4/27/2014	8.93		11/5/2010	7.91
	10/9/2014	8.05*	Iron Pipe Spring	7/5/1985	7
	2/26/2015	8.23*		11/5/2010	8.04
	3/29/2012	7.54		10/25/2010	8.37
Dog Pen Seep	7/5/1985	8	Able Seep	7/25/1985	7
	11/6/2010	8.06		3/30/2012	7.15
East Lechuguilla Seep	6/28/1985	7	Sewer Lagoon Tank Spring	7/2/1985	8
West Lechuguilla Seep	6/28/1985	8	Arc Pool	10/21/2010	8.17
	11/8/2010	7.77*	Forgetful Seep	10/26/2010	8.08

*Multiple measurements taken during the same visit, and values were averaged.

Table 10 (continued). pH readings for CAVE seeps and springs (EPA 2015b, NPS 2016).

Seep/Spring	Date	pH	Seep/Spring	Date	pH
Angels Bath Spring	10/23/2010	7.93	No Name Seep 3	10/21/2010	8.88
Cut Log Seep	11/5/2010	8.52	No Name Seep 6	10/25/2010	8.64
Maple Spring	11/20/2010	7.48	No Name Seep 7	10/24/2010	8.40
No Name Seep 4	10/21/2010	8.16	No Name Seep 10	11/6/2010	8.28
	4/26/2014	8.14*	Rock Wren	11/20/2010	7.59
	10/9/2014	7.67	Spider Cave Seep	10/23/2010	8.27
	2/26/2015	8.42	Previously Unknown Seep	10/10/2014	7.91

*Multiple measurements taken during the same visit, and values were averaged.

Other historic water quality data are only available for Oak Spring and Big Hill Seep (~1.5 km [~1 mi] northeast of Oak Spring). Samples were taken in October 1976 at Big Hill Seep and in July 1995 at Oak Spring; the parameters sampled at each site are not identical (Table 11).

Table 11. Water quality sampling results for Oak Spring (25 July 1995) and Big Hill Seep (31 October 1976) (EPA 2015b). ND= non-detect. EPA standards are for the protection of aquatic life, unless otherwise noted (EPA 1986, 2015a).

Measures of Water Quality	Oak Spring	Big Hill Seep	EPA standard (chronic)
Temperature (°C)		9	
Dissolved Solids (mg/L)	270		<15,000 (fish)[c]
Alkalinity (mg/L)	340		>20
Specific conductance (µS/cm)		400	
Arsenic, inorganic (µg/L)	ND		150
Barium (µg/L)	103	80	1,000[b]
Cadmium (µg/L)[a]	ND		0.25
Chromium (µg/L)[a]	ND	5	74
Copper (µg/L)[a]	ND	16	18 (1-hour average)
Nitrate (mg/L)	7		10[b]
Uranium (µg/L)		0.88	
Aluminum (µg/L)	21	338	87

a. Criteria for these metals depend on hardness; values given here correspond to a hardness of 100 mg/L (EPA 1986, 2015a).

b. Human health standard (EPA 1986); no standard available for aquatic life.

c. Not a legally-binding standard, but the level at which health effects are believed to occur (EPA 1986).

Table 11 (continued). Water quality sampling results for Oak Spring (25 July 1995) and Big Hill Seep (31 October 1976) (EPA 2015b). ND= non-detect. EPA standards are for the protection of aquatic life, unless otherwise noted (EPA 1986, 2015a).

Measures of Water Quality	Oak Spring	Big Hill Seep	EPA standard (chronic)
Chloride (mg/L)	30		230
Iron (µg/L)	ND	256	1,000
Manganese (µg/L)	ND		50-100[b]
Silver (µg/L)[a]	ND	7	4.1
Sulfur (mg/L)	ND		
Zinc (µg/L)	5	60	120
Phosphate/Phosphorus (µg/L)	ND	5	
Total organic carbon (mg/L)	11		

a. Criteria for these metals depend on hardness; values given here correspond to a hardness of 100 mg/L (EPA 1986, 2015a).

b. Human health standard (EPA 1986); no standard available for aquatic life.

c. Not a legally-binding standard, but the level at which health effects are believed to occur (EPA 1986).

The CHDN sampled CAVE seeps and springs for water temperature, DO, total dissolved solids (TDS), and specific conductance (SpC) between 2010 and 2015 (NPS 2016). Additional water quality data (e.g., alkalinity, chloride, and sulfate) was collected at four springs: Slaughter Pothole, Upper East Grammer Seep, No Name Seep 4, and Previously Unknown Seep (NPS 2016). Water temperatures ranged from 5-28 °C (41-82 °F) and varied by season (Table 10). DO levels ranged from 1.1-15.6 mg/L, with most values falling between 6.0 and 9.0 mg/L (NPS 2016). SpC was generally between 300 and 800 µS/cm, while TDS ranged from 177-637 mg/L (Table 12). Additional data for the subset of four springs mentioned above are shown in Table 13.

Table 12. Water quality data for CAVE seeps and springs collected by the CHDN (NPS 2016).

Seeps/Springs	Date	Temp (°C)	DO (mg/L)	TDS (mg/L)	SpC (µS/cm)
Able Seep	3/30/2012	17	1.12	409.5	628
Angels Bath Spring	10/23/2010	16.5	6.07	552.5	848
Arc Pool	10/21/2010	19.4	7.76	275.6	424.8
Big Hill Seep	10/21/2010	18.4	6.97	267.8	411.9
Crown Rock	11/5/2010	15.7	3.8	384.15	590.5
Cut Log Seep	11/5/2010	5.5	8.97	498.55	787.3
Dog Pen Seep	11/6/2010	12.1	8.01	250.9	386.5

*Multiple measurements taken during the same visit, and values were averaged.

Table 12 (continued). Water quality data for CAVE seeps and springs collected by the CHDN (NPS 2016).

Seeps/Springs	Date	Temp (°C)	DO (mg/L)	TDS (mg/L)	SpC (µS/cm)
Forgetful Seep	10/26/2010	15.3	6.4	520	654
Grammer Seep	10/22/2010	16.8	2.11		812
Iron Pipe Spring	11/5/2010	19.3	6.09	468	723
Kids Spring	10/25/2010	16.1	6.67		745
Kirkland Spring	3/29/2012	27.2	2.5	565.5	867
Longview Spring	11/5/2010	16.6	7.21	422.5	647
Lowe Ranch Spring	11/19/2010	13.9	4.61	408.85	629.3
Maple Spring	11/20/2010	15.1	2.2	416	636
No Name Seep 3	10/21/2010	23.4			770
No Name Seep 4	10/21/2010	21.6	7.42		746
No Name Seep 4	4/26/2014	22.1*	8.78*	435.5*	673*
No Name Seep 4	10/9/2014	21.5	4.65	501.5	908
No Name Seep 4	2/26/2015	5.4	15.62	436.8	671.9
No Name Seep 6	10/25/2010	13.5	8.34	481	681
No Name Seep 7	10/24/2010	19.2	7.61	487.5	754
No Name Seep 10	11/6/2010	6.1	8.36	451.1	694.1
Oak Spring	10/23/2010	18.4	8.35		566
Oak Spring 2	10/23/2010	18.4	4.97		550.9
Previously Unknown Seep	10/10/2014	16.4	6.65	637	979
Putman Tank	3/31/2012	17.9*	2.60*	505.22*	777.7*
Rock Wren	11/20/2010	10.6	5.25	393.25	605.1
Slaughter Pot Hole	4/27/2014	15.3	7.37	177.45	272.8
Slaughter Pot Hole	10/9/2014	19.5*	7.37*	238.03*	366.4*
Slaughter Pot Hole	2/26/2015	7.1*	8.66*	181.45*	279.1*
Spider Cave Seep	10/23/2010	12.4	7.4		785
Stone Ranch Spring	10/24/2010	28	7.01		588
Upper East Grammer Seep	10/22/2010	15.7	7.27	373.75	575.5

*Multiple measurements taken during the same visit, and values were averaged.

Table 12 (continued). Water quality data for CAVE seeps and springs collected by the CHDN (NPS 2016).

Seeps/Springs	Date	Temp (°C)	DO (mg/L)	TDS (mg/L)	SpC (µS/cm)
Upper East Grammer Seep	4/26/2014	15.8*	7.50*	369.2*	568.5*
Upper Lechuguilla	11/8/2010	15.9	6.07	513.5	792
Upper Lowe Ranch Spring	11/19/2010	15.5	1.86	377	576.2
Upper Middle Grammer Spring	10/23/2010	21.1	5.54	396.5	569
West Lechuguilla Seep	11/8/2010	16.9*	5.01*	185.9*	286.2

*Multiple measurements taken during the same visit, and values were averaged.

Table 13. Additional water quality data (in mg/L) for a subset of CAVE seeps and springs, also collected by the CHDN (NPS 2016). ND = undetectable.

Category and Date	Alkalinity			Chloride	Magnesium	Sulfate	Calcium
Seeps/Springs	$CaCO_3$	HCO_3	CO_3	(Cl)	(Mg)	(SO_4)	(Ca)
No Name Seep 4							
4/26/2014	285*	353*	170*	5.6*	575*	57.5*	42*
10/9/2014	340	410	200	4.8	220	ND	82
2/26/2015	370	460	220	2.6	275	30	62
Previously Unknown Seep							
10/10/2014	330	400	200	23	400	18	48
Slaughter Pothole							
4/27/2014	115	145	70	1.6	160	ND	44
Slaughter Pothole							
10/9/2014	175	215	105	4.6	120	9	34
2/26/2015	140	170	85	0.6	110	1	36
Upper East Grammer Seep							
4/26/2014	75	100	50	4	420	ND	60

*Multiple measurements taken during the same visit, and values were averaged.

Threats and Stressor Factors

Threats to CAVE's seeps and springs include exotic plant species, Barbary sheep, drought, climate change, and fire. Barbary sheep, a non-native species, was first introduced in New Mexico in the 1940s by private ranching operations (Novack et al. 2009). The species is native to arid environments in Africa and is highly tolerant of drought conditions. Barbary sheep were first observed in CAVE in 1959 and are now established in several of the park's canyons and ridges, including Slaughter Canyon, Double Canyon, Midnight Escarpment, and Walnut Canyon (Novack et al. 2009; Schwarzkopf, written communication, April 2016). Based on 2004-2005 surveys, Novack et al. (2009) estimated that 40-50 Barbary sheep inhabited the park at that time. Barbary sheep may have a greater negative impact on vegetation around seeps and springs (e.g., trampling), as they are larger than native ungulates such as mule deer and bighorn sheep (Novack et al. 2009). NPS staff has noted trampling around some of CAVE's seeps and springs, which disturbed vegetation and exposed the areas to increased erosion (Burger, written communication, April 2016). Exotic, invasive plant species may also impact seep and spring communities by competing with or replacing native species and altering ecosystem functions (e.g., water and nutrient cycling) (Westbrooks 1998).

Potential effects of climate change in the desert Southwest include increased temperatures, changes in the amount and timing of precipitation, and more climate extremes (e.g., heat waves, droughts) (NAST 2001, Davey et al. 2007). The groundwater aquifers that supply CAVE's seeps and springs are recharged by precipitation. If precipitation decreases or droughts become more frequent in the area, spring discharge can be expected to decline. This decline in flow and, therefore, water availability could have a significant impact on the park's plant and wildlife communities (NPS 2010a). The increased temperatures associated with climate change could contribute to higher evaporation rates and faster transpiration by plants, meaning surface waters associated with springs could be lost to the atmosphere faster. The CHDN monitoring program noted evidence of significant impact on vegetation and soils from drying at No Name Seep 2 in October 2010 and at Wild Cow Seep in April 2012 (NPS 2016). Moderate disturbance to vegetation or soils from drying was noted at two additional seeps/springs in October 2010 and at three additional springs in the spring of 2012 (NPS 2016).

Riparian habitats such as those typically surrounding seeps and springs are not adapted to fire, and when fires do occur the effects are usually profound (Busch 1995, Finch and Stoleson 2000). In a study on the lower Colorado River floodplain, for example, Busch (1995) found that Fremont cottonwood (*Populus fremontii*) frequency was significantly lower in burned plots than in unburned plots. Fires can also facilitate non-native plant invasions (e.g., *Tamarix* spp.) of seep and spring habitats, which can in turn increase fire frequency within the ecosystem (Busch 1995). Fires are not uncommon at CAVE, occurring on about half of the park's main unit between 2009 and 2011 (Schwarzkopf, written communication, April 2016). The CHDN spring monitoring program noted evidence of moderate disturbance from fire at Slaughter Pothole in November 2010 and at No Name Seep 4 in April 2014 (NPS 2016).

Data Needs/Gaps

Data on the vegetation communities supported by the park's seeps and springs is limited. These areas have not been specifically surveyed for plant species richness or community composition. Also, the full areal extent of seeps and springs is unknown, partly due to their ephemeral nature and relatively small size. Additional records from 2000 regarding wetted extent and pool depths at CAVE seeps and springs (Laws and Emmons 2000) were recently rediscovered and could be analyzed to provide a baseline for comparison in future surveys. Consistent measurements of discharge and water quality parameters over time are needed as well to better assess these metrics and to identify any seasonal trends. Further study of the park's water table levels, groundwater flow paths, and the relationship between groundwater and surface waters would contribute to a better understanding of seeps and springs (NPS 2010a). This could allow park managers to more accurately predict the impacts of natural and human-induced hydrological shifts, including climate change.

Overall Condition

Areal Extent

This measure was assigned a *Significance Level* of 2. Assessing the extent of seep and spring communities is difficult, as some of these areas are ephemeral and many are likely too small to be mapped by surveys based on aerial imagery. Only one vegetation community within the main CAVE unit is known to be associated with seeps and springs: Oak-Madrone band cove woodland (Muldavin et al. 2012). This woodland type covers just 0.1% of the park's total area (Muldavin et al. 2012). Several arroyo riparian shrubland communities also likely occur around seeps and springs, but this has not been confirmed by surveys. CHDN monitoring has measured the wetted extent of CAVE seeps and springs, but most park locations have only been visited/sampled once (NPS 2016). Since there is no clear picture of the full extent of seep and spring communities within CAVE, a *Condition Level* has not been assigned for this measure.

Species Richness

This measure was assigned a *Significance Level* of 3. CAVE's seep and spring communities have not been surveyed specifically for plant species richness. Therefore, a *Condition Level* cannot be assigned at this time.

Plant Community Composition

The project team assigned this measure a *Significance Level* of 3.The plant community composition of CAVE's seep and spring communities also has not been specifically surveyed. Muldavin et al. (2012) briefly described the composition of one vegetation community associated with seeps and springs, but it is likely that these areas support a number of additional species. Due to the lack of data, a *Condition Level* has not been assigned.

Discharge

The discharge measure was assigned a *Significance Level* of 3. Discharge has been measured intermittently at CAVE seeps and springs. Some sites have estimates from the 1930s, but discharge measurements have not been collected consistently, in timing or methodology. Therefore, no conclusions can be drawn regarding current condition or trends over time (*Condition Level* = N/A). The new CHDN springs monitoring program will contribute greatly to a better understanding of this measure over time.

Changes in Water Quality

The project team also assigned this measure a *Significance Level* of 3. Water quality data for CAVE's seeps and springs are also limited and, in many cases, only exist for one point in time. As a result, changes in water quality over time cannot be evaluated and a *Condition Level* cannot be assigned. As with discharge, the new CHDN springs monitoring program is expected to contribute to a better understanding of seep and spring water quality over time.

Weighted Condition Score

A *Weighted Condition Score* could not be calculated for CAVE's seeps and springs due to a lack of consistent data for the selected measures. The current condition and trend of this resource is unknown.

Seeps and Springs			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Areal Extent	2	N/A	
Species Richness	3	N/A	
Plant Community Composition	3	N/A	
Discharge	3	N/A	
Changes in Water Quality	3	N/A	

4.2.6. Sources of Expertise

- Cheryl McIntyre, CHDN Physical Scientist.
- Paul Burger, NPS Hydrologist.
- Kent Schwarzkopf, CAVE Chief of Resource Stewardship and Science.

4.2.7. Literature Cited

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4.3. Bats

4.3.1. Description

Bats have an occupancy history at CAVE dating back at least 45,000 years according to guano analysis (Horrocks, written communication, 22 April 2016). In the decades prior to becoming a national park, CAVE's bats played a pivotal role in the area's popularity. Anecdotal history recorded in Graham (2007, p. 3) reads:

> *Stories have it that in the late 1800s James Larkin White, a local cowboy in southeastern New Mexico, investigated a column of "smoke" and found millions of bats emerging from a huge hole in the ground. This became known as "Bat Cave." Bat Cave was later named Carlsbad Cave before becoming Carlsbad Cavern. Seeking a profit, miners staked claims and removed over 100,000 tons of bat guano, an extremely rich fertilizer, from Carlsbad and other Guadalupe Mountains caves from 1901 – 1921.*

While many species of bats live within CAVE's boundaries, it is the large colony of Brazilian free-tailed bats (*Tadarida brasiliensis*) that garners the most attention from visitors and staff alike. The colony, recently estimated at more than 300,000-400,000 animals, draws interested observers for their evening and morning spectacle of flight (Photo 11) (Hristov et al. 2010). The bats fly in a counterclockwise motion, swirling upward and out of the cave's entrance for up to two hours each evening. This phenomenon of hundreds of thousands of bats swirling up out of the cave was described by Hristov et al. (2010, p. 184) as a "spectacular tornado-like vortex."

Photo 11. Brazilian free-tailed bats exiting Carlsbad Cavern to search for food (Photo by Nick Hristov, NPS).

A total of 17 bat species are found within CAVE (NPS 2015). There are fourteen species of cave-roosting bats found in the State of New Mexico, and nine have been documented within CAVE bat communities (NPS 2015, USGS 2015). Bats roost in caves for shelter and carrying out their various life functions; bats are often referred to as trogloxenes, meaning they are reliant on cave habitat to roost and complete parts of their life cycle (Baker et al. 2015). Certain species, such as the big brown bat (*Eptesicus fuscus*), are known to roost in tree cavities (Taylor 2006). Roost types include maternity (nursery), bachelor, night, and hibernation (hibernacula) and are distinguishable from each other by clustering pattern (USGS 2015). Maternity roosts, where females birth and rear their offspring, are characterized by congregations of tightly clustered groups and the presence of pups, which are typically pink and hairless (USGS 2015). The maternity roost in Carlsbad Caverns is purported to have a roosting population of around one million Brazilian free-tailed bats (USGS 2015). Bachelor roosts consist of male bats roosting in diffuse patterns along the ceiling and walls (USGS 2015). These typically form following the breeding season (USGS 2015). Night roosts serve as both a dining area and resting spot, used throughout the night as bats come in and out between hunting trips (USGS 2015). Finally, the hibernacula roosts are where bats spend the winter for hibernation (USGS 2015).

The bat species present at CAVE are insectivorous. When gathered in large colonies, like the Brazilian free-tailed bat colony in Carlsbad Cavern, they are capable of consuming large quantities of insects in one night (Taylor 2006, Graham 2007, USGS 2015). One of the few night-time predators of insects, and the only flying mammal in the world, bats can consume up to 600 mosquitoes per hour (Graham 2007). Brazilian free-tailed bats have also been observed feeding on agricultural pests such as boll weevils (*Anthonomus grandis*), cucumber beetles (*Diabrotica* spp. and *Acalymma* spp.), and corn earworm moths (*Helicoverpa zea*) (Graham 2007, USGS 2015). The bats at CAVE feed primarily on various moth species (Graham 2007).

Bats have the potential to be used as bioindicators (O'Shea et al. 2003). This is due to a number of reasons. Bats are important to biodiversity, they possess ecological and economic value as ecosystem components, and they are vulnerable to rapid population declines (O'Shea et al. 2003). Bats play integral roles in terrestrial and subterranean (i.e., trogloxene) ecosystems, functioning as pollinators of local flora, insectivores, and transferring surface nutrients to the interior of caves (Baker et al. 2015). Species with specialized roosting requirements and limited suitable roosts are important to monitor, as they are particularly vulnerable to habitat loss and local extirpation. Fluctuations in bat populations can be related to climate change, changes in water quality, agricultural intensification, loss and fragmentation of forests, fatalities at wind turbines, disease, pesticide use, and overhunting (Jones et al. 2009).

4.3.2. Measures

- Species richness
- Species abundance
- Number of caves utilized
- Number of maternity roosts per species

4.3.3. Reference Conditions/Values

A specific reference condition has not been defined for the bat populations at CAVE. Ideally, this reference condition would be based on the known, historical condition of each measure identified for analysis. While data on historical conditions is available for estimated population size, differences in the methodologies do not allow for a direct comparison between findings. The remaining measures are largely understudied and represent data gaps.

4.3.4. Data and Methods

Burgess et al. (1997) is a compendium of articles specific to CAVE, covering multiple decades of research. Several of these articles discuss the bat species present historically and their environment within the park's caves. While much of the current literature focuses on the Brazilian free-tailed bat, the location and habits of the fringed myotis (*Myotis thysanodes*) are discussed in this document as well. Also discussed are the methodologies of historical attempts to count bats along with the more current methods of infrared photography and sound recordings.

Graham (2007) reported on the geologic resources of CAVE and provided a historical perspective on bat counts from the early 1900s. Background information on bat biology was included, as well as the possible role of DDT (dichloro-diphenyl-trichloroethane) in the apparent decline of the park's Brazilian free-tailed bat population (Graham 2007).

Betke et al. (2008) conducted census surveys at eight caves in North America between 2000 and 2006 to estimate Brazilian free-tailed bat colonies. The Carlsbad Cavern survey was conducted on 11 August 2005. Betke et al. (2008) estimated the number of bats per colony through image analysis of thermal imaging videos recorded during evening exoduses at cave openings.

Geluso (2008) netted bats at the large natural opening to Carlsbad Cavern from November 2004 to March 2005. The intent was to study the winter activity of Brazilian free-tailed bats that opted out of normal migration. Netting was conducted one night each month during this period. A 9-m (29.5-ft) mist net was suspended from aluminum poles just inside the large natural cave opening for all netting nights, with the exception of one night when netting was conducted at a smaller natural opening located 400 m (1,312 ft) to the east. Geluso (2008) recorded time of capture and presence of insect parts in each bat's mouth. Several bats captured during the netting were held in containers for a period of time to determine if they had been feeding by checking for scat. Bats held in this manner were reexamined to record sex, age (estimated by amount of tooth wear), body mass, number of fecal pellets, and time of release.

Hristov et al. (2010) reported on the seasonal variation in colony size of the Brazilian free-tailed bats at CAVE. New thermal infrared (IR) imaging technology combined with computer modelling produced estimates of the population with a new degree of accuracy and sophistication. Data was collected from March through October of 2005 (Hristov et al. 2010). Several times throughout each month, the nightly emergences of the bats were photographed with the thermal IR photography. These images were analyzed in an effort to count individual bats, and also to determine the amount of space each bat occupies in flight. The actual counts were recorded and the maximum possible emergence rate was calculated based on the space occupied by individual bats in flight (Hristov et al. 2010). This research also includes a summary of past attempts to count the number of bats in the Brazilian free-tail bat colony and the methods used in order to estimate the population size. Previous estimates of the Brazilian free-tailed bat population at CAVE reviewed in this report include those by Allison (1937), Altenbach (1979), Constantine (1967), and Route (1998).

4.3.5. Current Condition and Trend

Species Richness

According to the NPS certified species list, 17 bat species have been confirmed as present in the park (NPS 2015). Nine of these species are cave-roosting bats and the other eight species have alternate roosting behaviors (NPS 2015, USGS 2015). Two additional species, the Mexican long-nosed bat (*Leptonycteris nivalis*) and the spotted bat (*Euderma maculatum*), are unconfirmed, but may be present considering their distribution range (NPS 2015). While currently not present within the park, the long-eared myotis (*Myotis evotis*) has been historically found in the park (NPS 2015). Table 14 shows the bat species known or expected to occur in the park. Burgess et al. (1997) lists seven bat species identified from skeletal remains that were found inside Lechuguilla Cave between 1991 and 1996.

Table 14. Species of bats known or possibly occurring in CAVE. UC = unconfirmed, NP = not in park/historic, S = skeletal evidence

Scientific Name	Common Name	NPS 2015	Burgess et al. 1997	Cave Dwellers (USGS 2015)
Antrozous pallidus	pallid bat	X		X
Corynorhinus townsendii	Townsend's big-eared bat	X	S	X
Eptesicus fuscus	big brown bat	X	S	X
Euderma maculatum	spotted bat	UC		X
Lasionycteris noctivagans	silver-haired bat	X		
Lasiurus borealis	eastern red bat	X		
Lasiurus cinereus	hoary bat	X	S	
Leptonycteris nivalis	Mexican long-nosed bat	UC		
Myotis californicus	California myotis	X		
Myotis ciliolabrum	western small-footed myotis	X	S	X
Myotis evotis	long-eared myotis	NP		
Myotis thysanodes	fringed myotis	X		X
Myotis velifer	cave myotis	X	S	X
Myotis volans	long-legged myotis	X	S	
Myotis yumanensis	Yuma myotis	X	S	X
Nyctinomops femorosaccus	pocketed free-tailed bat	X		
Nyctinomops macrotis	big free-tailed bat	X		

Table 14 (continued). Species of bats known or possibly occurring in CAVE. UC = unconfirmed, NP = not in park/historic, S = skeletal evidence

Scientific Name	Common Name	NPS 2015	Burgess et al. 1997	Cave Dwellers (USGS 2015)
Parastrellus hesperus	western pipistrelle	X		X
Perimyotis subflavus subflavus	eastern pipistrelle	X		
Tadarida brasiliensis	Brazilian free-tailed bat	X		X

Species Abundance

Total population abundance of all bat species present in CAVE is largely a data gap, with most population estimate research focusing on the Brazilian free-tailed bat colony. Estimating colony size and counting bats during their nightly exodus is very challenging. According to Baker et al. (2015), when consistently conducted internal surveys are the most efficient and accurate population assessment. Bats are easiest to count while in hibernation torpor, since they are less likely to become aroused by the presence of researchers. However, if hibernation is disturbed, it can be very costly for the bats in terms of expending stored energy accumulated during the summer (Baker et al. 2015). Recommendations for winter surveys are to follow cautionary guidance, such as scheduling one survey annually by trained researchers and to maintain minimal disturbances to the bats (Baker et al. 2015).

The majority of the bat population estimates were determined by counting bats as they exited the caves in the evening to feed. These efforts were largely focused on determining the size of the Brazilian free-tailed bat colony. The size of the Brazilian free-tailed bat colony in CAVE has been estimated using various methods such as emergence counts, roost density, and mark and recapture. Hristov et al. (2010) compiled and researched past population estimates for accuracy (Table 13). Hristov et al. (2010) thoroughly examined the earliest estimates (Allison 1937, 1928 and 1936 estimates) of the Brazilian bat colony size and compared these results with research on recently recorded emergence rates (i.e., bats/min). Betke et al. (2008) is included in Table 15, but it should be noted that although this was considered an accurate estimate, it is based on only one evening exodus so it isn't likely comparable to the estimate obtained by Hristov et al. (2010).

Table 15. Historic Brazilian free-tailed bat colony size estimates in Carlsbad Cave (recreated from Hristov et al. 2010).

Source	Year	Estimated Colony Size	Methodology
Allison (1937)	1928	3,000,000	emergence count
Allison (1937)	1936	8,741,760	emergence count
Constantine (1967)	1957	239,000	roost density and mark-recapture

Table 15 (continued). Historic Brazilian free-tailed bat colony size estimates in Carlsbad Cave (recreated from Hristov et al. 2010).

Source	Year	Estimated Colony Size	Methodology
Altenbach et al. (1979)	1979	218,153	emergence count
Route et al. (1998)	1996	79,000	roost density
Route et al. (1998)	1997	353,000	roost density
Hristov et al. (2010)	2005	438,551	thermal infrared imaging and computer vision analysis
Betke et al. (2008)	2005	341,026	emergence video analysis

The historic estimates reported by Allison (1937) of 3 million bats in 1928 and 8.7 million in 1936 has been called into question by more recent research efforts (Betke et al. 2008, Hristov et al. 2010). Until recently, the Brazilian free-tailed bat population in the park was believed to have declined significantly, as past estimates (now believed to be inflated counts) indicating a massive colony decline. Using technology (e.g., thermal imaging and computer modeling) to allow for more accurate counting methodologies has revealed highly inconsistent nightly and seasonal emergences from Carlsbad Cavern (Hristov et al. 2010). Highly variable population estimates within a span of a few evenings to a few weeks are thought to be pulse-driven in unison with precipitation events which trigger insect emergences (Hristov et al. 2010). Furthermore, the dimensions of the cave opening and thermal infrared imaging have been used to calculate the maximum emergence rate possible (bats/minute). The results of this analysis clearly dispute the early estimates of over eight million bats emerging in a single night (Hristov et al. 2010). Hristov et al. (2010) calculated that the observed emergence rate (18,210 bats/minute) was near the maximum emergence rate possible for the Carlsbad Cave opening. Based on data derived from this observation, Hristov et al. (2010) concluded that the likely size of the 1936 emergence was less than 1 million bats.

Geluso (2008) netted bats at two openings to Carlsbad Cavern in order to report on winter (November to March) behavior. The majority of bats captured on these two occasions were Brazilian free-tailed bats (369) (Geluso 2008). A single fringed myotis was also captured (Geluso 2008). The number of Brazilian free-tailed bats captured clearly indicates that some bats opt out of migration to Mexico and remain in the park year-round; however, this may not be indicative of overall abundance (Geluso 2008).

Studies conducted by Burgess et al. (1997) indicate that Carlsbad Cavern is an important refuge and reproduction location for Brazilian free-tailed bats. A 1996 count estimating bat densities during spring pre-birth and again in the fall when pups had begun to take flight, found an 82% increase in population size (Burgess et al. 1997). In spring, the estimated count was 193,000 bats and the fall estimate was 352,000 bats (Burgess et al. 1997). These estimates were based on calculations using infrared photography inside the cave where bats were roosting (Burgess et al. 1997).

The most recent estimates of the Brazilian free-tailed bat colony in Carlsbad Cavern were conducted several times monthly from March to October 2005 (Hristov et al. 2010). Consecutive night emergences exhibited large fluctuations (Hristov et al. 2010). The peak population estimate was 1,045,913 individuals and the lowest estimated population was 10,621 individuals (Hristov et al. 2010). Although these estimates of the Brazilian free-tailed bat colony size are much lower compared to historic estimates made by others (Table 15), there are doubts that the apparent decline is actually that severe and the difference is more likely due to inaccuracy in estimations (Hristov et al. 2010).

Number of Caves Utilized

As of 2015, 120 caves have been documented within the park as well as 168 karst structures (Schwarzkopf and Horrocks, written communication, April 2016). The most famous of these, Carlsbad Cavern, contains the largest underground chamber (the Big Room) in the United States. Within the Carlsbad Cavern, in a passage known as the Bat Cave, is where a large, migratory colony of Brazilian free-tailed bats gathers to roost and rear pups each summer (March to November) (Burgess et al. 1997, Hristov et al. 2010). Within Carlsbad Cavern, there is also a small colony of fringed myotis that have a maternity roost nearly 305 m (1,000 ft) below the surface (Burgess et al. 1997). Slaughter Canyon Cave contains very old guano piles, although it appears that it is no longer occupied by bats (Polyak et al. 2006). Northup (2013) collected samples of bat guano from caves in the park known to host bats, including Carlsbad Cavern, Goat Cave, Lake Cave, and Ogle Cave. Overall, the park has many caves and the total number utilized by bats is a data gap at this time. Currently, there is documentation on a total of four caves that are used by bats in the park; there are likely other caves used by bats that have not yet been documented (Northup 2013).

Number of Maternity Roosts per Species

The review of the available literature documented the location of only one maternity roost in Carlsbad Cavern. This was a fringed myotis maternity roost, situated 305 m (1,000 ft) below the surface in a passage known as the Left-Hand Tunnel (Burgess et al. 1997). This location is not only the lowest point in the cave, but also the warmest (Burgess et al. 1997). According to Burgess et al. (1997), this maternity roost was estimated to have around 100 individuals. More recently (2010), a survey estimated this roost to have a population of over 300 individuals (Horrocks, written communication, 15 April 2016). The available literature did mention the existence of maternity roosts for the Brazilian free-tailed bat; however, no information on the exact locations or total numbers was included. For the purposes of this assessment, this measure is considered to be a data gap.

Threats and Stressor Factors

Threats to CAVE's bat populations identified by park natural resource staff include land use changes (i.e., development), pesticides, white-nose syndrome (WNS), wind turbines, and park infrastructure (e.g., lighting). Conversion of land from natural habitat to agriculture and other anthropogenic development is impacting bats and other species throughout the world (Medlin et al. 2010). Habitat fragmentation, as well as reduction in patch size and density, has been shown to reduce both the abundance and richness of bat communities (Medlin et al. 2010). Tracking the rate of anthropogenic development in the area around CAVE, along with regular monitoring and inventory of the bat community in the park, would help managers make informed decisions on bat conservation strategies.

Being near the top of the food chain, bats are at risk of increased levels of chemical pollutants that concentrate in lower plants and animals (Graham 2007). While the relationship between DDT and the Brazilian free-tailed bat population at CAVE is less clear than once thought, DDT is found in higher concentrations in the CAVE populations than elsewhere in the country (Graham 2007). Elevated concentrations of DDT at CAVE may have resulted from an improperly stored, large batch of DDT in a shed near the park that was discovered in 1994 (Graham 2007).

Bats are nocturnal predators of many types of insects and have a significant impact on insect numbers, as they are able to consume vast quantities (Graham 2007). Crops along the Pecos and Black Rivers near CAVE are parasitized by several moth species, a primary food source for bats (Graham 2007). Agricultural practices near the park may involve pesticides, posing a major threat to bat health through consuming insects laced with these possibly toxic chemicals (Graham 2007).

WNS is presumed to be caused by a fungus called *Pseudogymnoascus destuctans*, resulting in a skin infection (Castle and Cryan 2010, Baker et al. 2015). The recent appearance (discovered in 2007 in upstate New York) and fast spread of WNS in North America poses a threat to the bats in the park (Castle and Cryan 2010). Bat mortalities from the infection are estimated at six million in the eastern United States and Canada (Baker et al. 2015). Though it has not yet been detected within CAVE, it has been spreading westward, having reached bat populations in Iowa, Missouri, and recently jumped to the Pacific Northwest to the state of Washington, and implicated in devastating mortalities among hibernating bat populations (Castle and Cryan 2010). WNS causes bats to arouse from hibernation more frequently or for longer periods than usual, depleting their body fat prematurely and causing them to starve (Foley et al. 2011). NPS managers hope to prevent the disease from spreading to colonies within CAVE, or at the very least, early detection may provide a chance to manage the spread of the disease by cave closures, education to cavers and visitors, and monitoring.

Bats are known to be sensitive to noise and light, and the park has taken steps to reduce disturbance by infrastructure such as lighting, elevators, and pumps (NPS 2009). Bats have been known to turn around and go back to their roost rather than fly through lighted areas, so park staff are careful to turn off all lighting in the evenings to avoid this disturbance (NPS 2009). Any maintenance or construction activity on the surface is conducted during daytime hours (when feasible) to avoid disturbance of the bats' feeding activities (NPS 2009). Other maintenance actions have been undertaken to facilitate bat maneuverability in and out the caves, including moving a chain link fence originally constructed near the pit (NPS 2009).

Wind energy turbines that are becoming increasingly common upon the landscape and are known to be responsible for the fatality of large numbers of bats (Kunz et al. 2007). Fatalities have been especially prominent with utility-scale wind turbines located along forested ridges (Kunz et al. 2007). Migratory bat species are most commonly involved, and this mortality has become a major threat, meriting multi-year monitoring and research (Kunz et al. 2007). There are currently eight utility-scale wind power plants in the state of New Mexico (ECMD 2015). None are currently located within

Eddy County where the park is located, but turbines in other areas may have impacts on the migratory bat colonies that travel to and from CAVE. In the State of New Mexico, wind energy initiatives are expanding. The city of Carlsbad has a developing wind support sector which services wind developments in Texas (BBCRC 2000). In Eddy County there is a prototype facility under consideration with a desired capacity of 40 megawatts (MW) (BBCRC 2000). With an average turbine size of 700 kilowatt (kW), this facility would have 58 turbines (BBCRC 2000). This project would require a total land area of 708-809 ha (1,750 -2,000 ac), and the proposed site (Mescalero Ridge) is located approximately 97-113 km (60-70 mi) northeast of CAVE (BBCRC 2000). It is unknown if this site plans to monitor bat mortalities resulting from the wind turbines.

Cell phone towers are an additional concern and threat to bats. Cell phone towers emit radio-frequency electromagnetic fields (RF-EMF) that may disrupt or change neurotransmitter function and the electrophysiology in living things (Sivani and Sudarsanam 2012). Some studies have suggested that the presence of RF-EMFs from cell phone towers can result in bat colony roost abandonment (Sivani and Sudarsanam 2012). Proximity thresholds for bats are not well studied and would require further investigation to understand impacts that may affect the bats in CAVE.

Data Needs/Gaps

With the exception of species richness, the selected measures are considered to be data gaps. There is literature available documenting the number of species observed in the park to date, but additional bat species may also occur based on distribution ranges (Cryan 2003). Population estimates for all 17 documented species are not available. In addition, there is incomplete recorded documentation for the total number of caves utilized by bats in the park, as well as the number of maternity roosts for each species. In order to maintain and provide long-term protection and conservation in the park, a routine bat census may be useful.

Overall Condition

Species Richness

Species richness was assigned a *Significance Level* of 3 by the project team. There are 17 bat species confirmed as occurring within the park. Without a reference condition to compare this to, it is difficult to ascertain if this number has changed over time. Due to a lack of a reference number of species, a *Condition Level* cannot be assigned at this time.

Species Abundance

The measure of abundance was assigned a *Significance Level* of 3. There are many estimates for the colony of Brazilian free-tailed bats starting in 1928. However, the first two estimates, which numbered in the millions, are now considered to be inaccurate. Hristov et al. (2010) found that the colony of Brazilian free-tailed bats has large number fluctuations from year to year, season to season, and even day to day, making accurate estimation difficult. Based on available estimates from 1957 through 2005 (Table 15), the abundance of Brazilian free-tailed bats a concern at CAVE. However, other bat species are understudied and their abundance is a data gap. Due to the data gap, a *Condition Level* could not be assigned for bat populations in the park.

Number of Caves Utilized

The number of caves utilized by bats was assigned a *Significance Level* of 2. A total of 120 caves and 168 karst features have been documented in the park, but the total number used by bats is unknown. Combining research on bats in the park, there are four caves that are known to support bat roosts (Northup 2013). There is an additional cave with a very old guano pile that is believed to be no longer inhabited by bats. It is possible that additional caves are utilized by bats, but this has not been confirmed. Due to a lack of documentation over time regarding cave use by bats, a *Condition Level* cannot be assigned at this time.

Number of Maternity Roosts per Species

The measure for number of maternity roosts per species was assigned a *Significance Level* of 3. There are many studies of the colony of Brazilian free-tailed bats that migrate to Carlsbad Cavern each spring. These studies have identified maternity roosting throughout the parks cave system for this species. There is also limited information on the single maternity roost of fringed myotis within Carlsbad Cavern. It is unknown if any other species have maternity roosts in park caves and how many maternity roosts occurred in the park historically. Due to this limited amount of information, a *Condition Level* cannot be assigned at this time.

Weighted Condition Score

Due to the lack of historic data (or reference conditions) and limited current information for the measures, a *Weighted Condition Score* cannot be calculated at this time. Monitoring and inventory activities in CAVE for the current bat colonies would be useful to establish a baseline data set for assessing any trends in the coming years.

Bats			
Measures	**Significance Level**	**Condition Level**	**WCS=N/A**
Species Richness	3	N/A	
Species Abundance	3	N/A	
Number of Caves Utilized	2	N/A	
Number of Roost Sites/Species	3	N/A	

4.3.6. Sources of Expertise

- Rod Horrocks, CAVE Physical Scientist.
- Kent Schwarzkopf, CAVE Chief of Resource Stewardship and Science.

4.3.7. Literature Cited

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4.4. Birds

4.4.1. Description

Bird populations often act as excellent indicators of an ecosystem's health (Hutto 1998, Morrison 1998, NABCI 2009). Birds are typically highly visible components of ecosystems, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). The unique ecosystems and physical formations in CAVE provide bird species with a wealth of habitat types and food sources. While CAVE is most notable for its expansive cave formations and habitats, a habitat type that is heavily utilized by cave swallows (*Petrochelidon fulva*; Photo 12), the park is also home to several stretches of grassland habitats as well as the desert riparian oasis in the Rattlesnake Springs Unit. Of particular note are the rugged and remote high elevation mesic vegetation communities in CAVE (West 2012).

Photo 12. Two cave swallows hover by a salsify plant (*Tragopogon dubius*; a non-native) to grab the fluff from seeds to line their nests in the twilight zone of the natural entrance to Carlsbad Cavern (NPS Photo).

The NPS Certified Species List (NPS 2015) confirms the presence of 362 bird species within the park (Appendix E), with another five species that have been identified as probably occurring in the park (NPS 2015). An additional species, the wood thrush (*Hylocichla mustelina*), is slated to be added to this list in 2016, which would bring the total number of confirmed or probably present bird species in the park to 378 (Steve West, Borderlands Environmental Education and Research Consortium, written communication, 25 May 2016). Among the confirmed species are several birds designated as species of concern by at least one agency (Appendix F). Four bird species in CAVE are listed under the Endangered Species Act (ESA) as either threatened or endangered: the southwestern willow flycatcher (endangered), yellow-billed cuckoo (*Coccyzus americanus*; threatened), lesser prairie chicken (threatened), and the Mexican spotted owl (*Strix occidentalis lucida*; threatened). The Rattlesnake Springs area of CAVE is of particular importance to several bird species of conservation concern, especially riparian obligate species such as the Bell's vireo (*Vireo bellii*; state-threatened species) and the yellow-billed cuckoo. The southwestern willow flycatcher also frequents this location, and has been observed breeding there as well (Powell 2009; West, written communication, 25 May 2016).

4.4.2. Measures

- Species richness
- Trends in abundance in species of conservation concern

4.4.3. Reference Conditions/Values

A reference condition for the birds in CAVE was not established. CHDN monitoring of landbirds in the park has been ongoing for the past 5 years, and a summary report is due out in 2016. The results of those surveys would likely serve as an excellent baseline for future surveys and assessments of condition. At this time, the best professional judgment of NPS staff, in combination with the available data, will be used to assess the overall condition of this resource.

4.4.4. Data and Methods

West (2012) surveyed six breeding bird transects in CAVE, each with 14 sampling points, from May through July 2003 (Figure 32). The Yucca Mesa transect was spatially limited due to the length of the mesa and only had 13 sampling points. All transects were located in the western half of the park, which represented an area of the park that lacked previous avian abundance/presence data. Additionally, each transect was located on or near a ridge top or a canyon bottom.

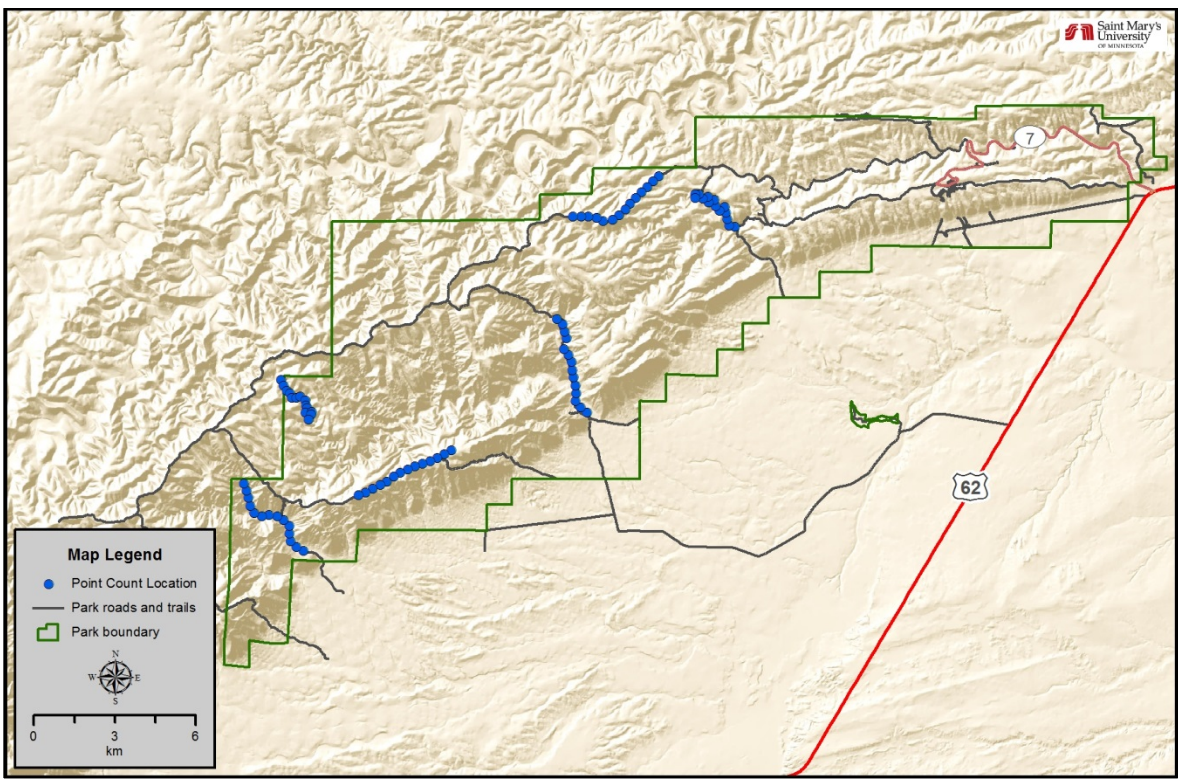

Figure 32. Point count locations within CAVE that were sampled by West (2012) during 2003 survey efforts.

West (2012) surveyed each transect twice, and visits to the same site were spaced by at least 7 days. Observers began surveys at approximately 0530 hours, and recorded all birds that were detected at each point along the transect. Other information collected at the sampling points included the distance the bird was seen from the observer (e.g., 0-50 m [0-164 ft]), type of detection (e.g., flyover), life stage (e.g., adult, juvenile), and global positioning system (GPS) location. Additionally, observers recorded information such as slope, aspect, dominant landform, dominant understory and overstory vegetation, maximum tree height, and brush and herbaceous layer height during a visit to the transect on the day before the survey (West 2012).

From 2004-2006, Meyer and Griffin (2011) surveyed four low elevation riparian sites in CAVE. The objectives of this study were to:

1. Apply survey methodologies in spring, summer, and fall seasons in riparian habitat study sites to document species presence, species richness, and relative abundances.
2. Relate the project findings to existing information on the avifauna at each of the sampling areas and update species lists.
3. Provide the baseline data and site evaluations necessary for the development of monitoring programs in the CHDN (Meyer and Griffin 2011, p. 1).

Survey sites chosen in the park included: Rattlesnake Springs, Walnut Canyon, Grammer Seep, and Oak Spring. Meyer and Griffin (2011) visited these sites before monitoring efforts began in order to assess the habitat, terrain, and what type of survey type would be best suited for each site. After these preliminary visits, Meyer and Griffin (2011) determined that point counts would be used at the Rattlesnake Springs and Walnut Canyon sites, while timed area searches would be used at Grammer Seep and Oak Spring.

Point counts occurred along transects at minimum intervals of 200 m (656 ft), with surveys beginning no earlier than 15 minutes before sunrise. Point counts lasted 5 minutes, and all birds that were detected during this period were recorded. The timing of bird observation (i.e., first 3 minutes of survey, or last 2 minutes of the survey) and the distance of detection (similar to the distances used in West [2012]) were also recorded. Observations were treated as incidental if they included a bird that was detected flying over a site that was not associated with their preferred habitat type, birds that were flushed before or after the beginning of a count, or birds that were detected between survey points.

The timed area searches performed by Meyer and Griffin (2011) followed a general route, but also allowed the observer the freedom to deviate from the route if a bird needed to be pursued. All bird species that were detected were recorded, with observations being separated based on the location where the bird was observed (i.e., inside or outside the survey area). All birds that were observed in flight and did not originate from the surveyed habitat type were considered flyovers.

CHDN Landbird Monitoring

As part of a network-wide landbird monitoring project, the Rocky Mountain Bird Observatory (RMBO), in partnership with the CHDN, began monitoring birds in CAVE in the spring of 2010. The overall objective of the project was to detect potential changes in population parameters over time (White 2011).

The RMBO land bird monitoring in CAVE closely paralleled the RMBO's "Integrated Monitoring in Bird Conservation Regions (IMBCR)" program, which utilizes a spatially-balanced sampling design during survey efforts (White et al. 2011). Across a landscape, the RMBO establishes a series of strata and super-strata (White et al. 2011). Within these strata, the RMBO and its partners utilize generalized random-tessellation stratification (GRTS) to select sample units (Stevens and Olsen 2004, White et al. 2011). According to White et al. (2011, p. 8):

> *The IMBCR design defined sampling units as 1-km^2 cells that were used to create a uniform grid over the entire [Bird Conservation Region] BCR. Within each grid cell we established a 4 x 4 grid of 16 points spaced 250 m apart* (Figure 33).

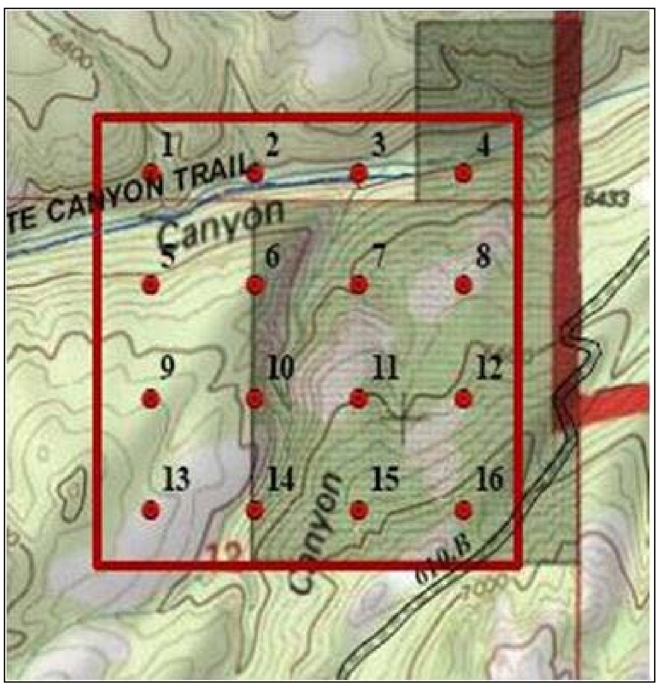

Figure 33. Example of a grid cell created by the RMBO using the IMBCR design. Reproduced from White et al. (2011).

During monitoring efforts in the CHDN, RMBO survey points were stratified across grassland and riparian habitats. When sample points followed a linear feature such as a riparian corridor transects were utilized, and when points were along an area feature a grid pattern was used (Figure 33). In CAVE, eight grids were used to sample the grassland habitat and one transect was used to survey the riparian corridor in Rattlesnake Springs (Figure 34). Grassland survey points were visited once during May in CAVE, while riparian points were visited twice (late-April and mid-May). During surveys, researchers recorded all birds detected at a given point in a 6-minute interval.

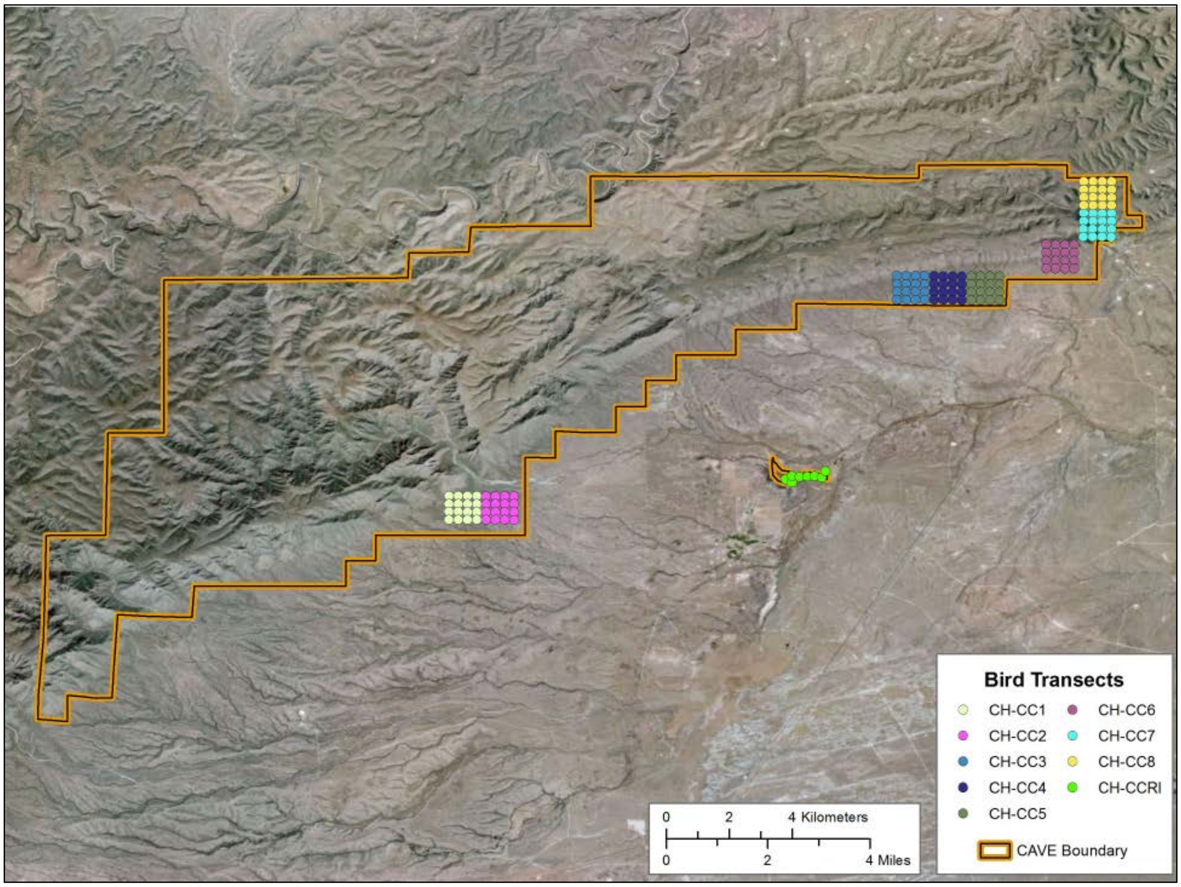

Figure 34. Point count locations used by the RMBO during CHDN landbird monitoring in CAVE from 2010-2014. Reproduced from Ali and Valentine-Darby (2014).

4.4.5. Current Condition and Trend

Species Richness

The species richness measure can indicate overall habitat suitability for breeding birds, and is vital to understand the effects of changing landscapes on native biodiversity. However, there may be undetected changes in species richness of native species compared to non-native species, or in Neotropical migrant species compared to resident species. Such changes would not be apparent in the tables and figures presented in this document. The various studies that have occurred in CAVE have all used unique methodologies, occurred at varying times of the year, and have been conducted in locations that often do not overlap. These variations make comparisons across studies problematic, and it is likely impossible to draw accurate conclusions by comparing the studies to one another. Also of note is the fact that none of the studies summarized in this assessment accounted for detectability differences among species and habitats or sampling sites. Because of this, species richness as reported here reflects only the number of species observed and not the actual number of species that were present.

West (2012)

During breeding bird surveys in CAVE in 2003, West (2012) documented 55 bird species. Overall, species richness values (including only species observed on transects) between survey sites were consistent, with values ranging from 29 species (North Slaughter Canyon) to 22 species (Guadalupe Ridge; Table 16); the average number of species observed on-transect at a site during West (2012) was 25.8.

Table 16. On-transect species richness values for the six survey locations in West (2012).

Survey Location	# of Species Detected
North Slaughter Canyon	29
Rattlesnake Canyon	26
Yucca Mesa	28
Guadalupe Ridge	22
Open Hollow Gulch	26
North Double Canyon	24
Average	**25.8**

West (2012) also documented two unique species during the 2003 survey: an elf owl (*Micrathene whitneyi*), which had not previously been identified in the park, and a Montezuma quail (*Cyrtonyx montezumae*), a species previously thought to be extirpated from the area. In addition to documenting species presence and abundance, West (2012) also made efforts to observe the nesting species in the area of the point counts. Active nests or nesting behavior (e.g., nest defense, dependent young) were found for 16 species (Table 17). The records of nesting for the plumbeous vireo (*Vireo plumbeus*) and the gray vireo were the first instances observed in CAVE.

Table 17. Nesting bird species observed in CAVE during West (2012) surveys in 2003.

Nesting Bird Species	Active Nest	Nesting Behavior
ash-throated flycatcher		X
Bewick's wren		X
blue-gray gnatcatcher		X
canyon towhee		X
Cassin's kingbird	X	
gray vireo	X	
mourning dove	X	

Table 17 (continued). Nesting bird species observed in CAVE during West (2012) surveys in 2003.

Nesting Bird Species	Active Nest	Nesting Behavior
northern mockingbird	X	
phainopepla	X	
plumbeous vireo	X	
rock wren		X
rufous-crowned sparrow		X
Say's phoebe		X
Scott's oriole		X
varied bunting		X
white-winged dove	X	

Meyer and Griffin (2011)

During 2004-2006 surveys of four low elevation riparian sites in CAVE, Meyer and Griffin (2011) observed 151 unique avian species (Table 18). The average species richness value at the four survey sites was 67 species. The Rattlesnake Springs survey site had the highest species richness value, and accounted for 133 species. No other site had more than 100 species; Walnut Canyon had the second highest species richness estimate (81), while Grammer Seep (34) and Oak Spring (20) both yielded comparatively lower richness estimates (Table 18). However, it should be noted that Grammer Seep and Oak Spring were only formally visited once during Meyer and Griffin (2011), while the remaining two sites were sampled six or seven times.

Table 18. Species richness values observed at four study sites in CAVE from 2004-2006 (Meyer and Griffin 2011).

Survey Location	# of Species Detected
Rattlesnake Springs	133
Oak Spring	20
Grammer Seep	34
Walnut Canyon	81
Average	**67**
Total	**151**

The Rattlesnake Springs site produced by far the largest species richness value of any CHDN survey site/NPS unit sampled by Meyer and Griffin (2011), and also had the highest number of both obligate and facultative riparian species. Additionally, the Rattlesnake Springs surveys documented a high number of incidental birds (birds observed off or between transects). Four species were detected during this survey that were not included on the park's certified species list at the time of Meyer and Griffin's (2011) publication: common raven (*Corvus corax*), Eurasian collared-dove (*Streptopelia decaocto*), gray hawk (*Buteo nitidus*), and greater pewee (*Contopus pertinax*). The common raven (2003), Eurasian collared dove (2003), and gray hawk (2006, although unconfirmed sighting occurred in 1998) had been noted in the park before Meyer and Griffin (2011), but had not yet been included on the Certified Species List; the greater pewee observation was indeed the first observation for the park.

In total, the 133 species documented at Rattlesnake Springs represented 39% of all species known to occur in the park. The NPS Certified Species List (NPS 2015) has been updated since Meyer and Griffin (2011), and the total species observed during this study would represent 37% of all species using the updated list.

CHDN Monitoring

CHDN landbird monitoring in CAVE has occurred annually since 2010, although data are only available through 2014 at this time. The average number of species observed per year in the park has been 67 species, with an average of 46 species and 41.6 species observed in the grassland and riparian habitats, respectively (Figure 35). It should again be noted that the number of transects in the grassland habitat (eight) was much higher than the number in the riparian habitat (one). The highest observed species richness value for the park occurred in 2013 when 80 species were observed. Species richness values have ranged from 46 in 2010 to 80 species in 2013.

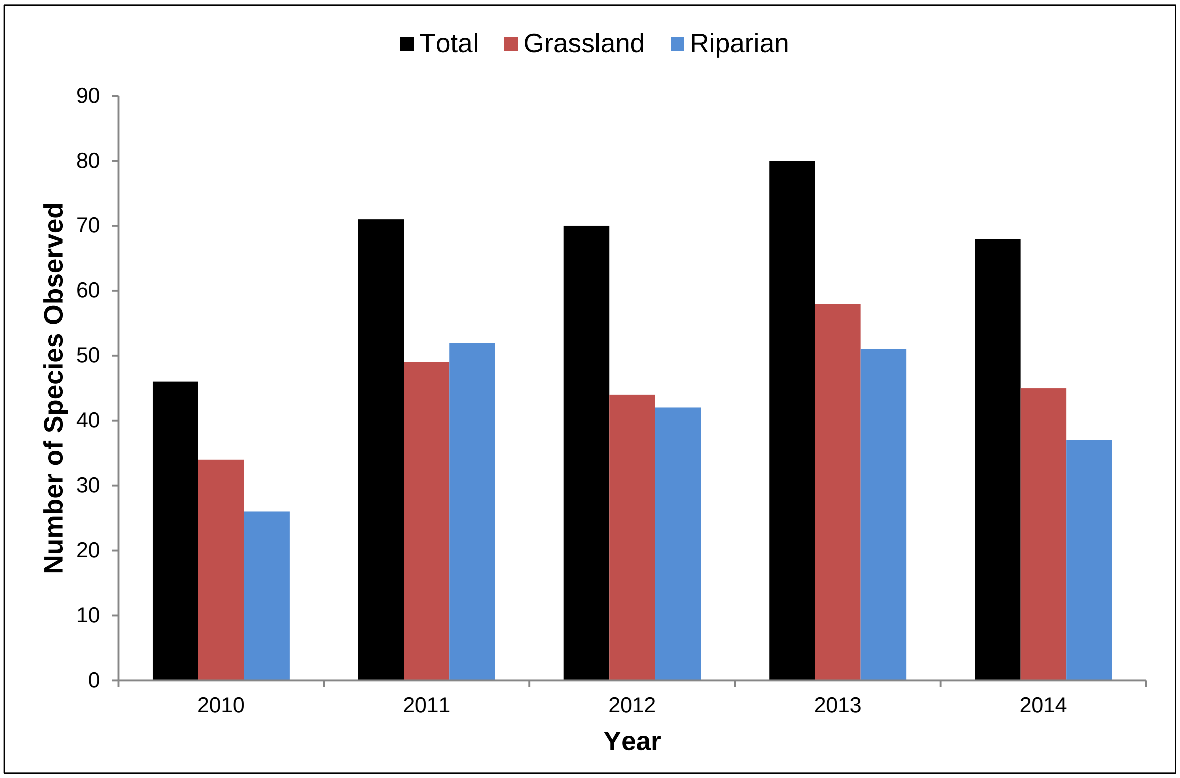

Figure 35. Species richness values observed at CAVE during annual CHDN landbird monitoring from 2010-2014 (White 2011, White and Valentine-Darby 2012, 2013, 2014, Ali and Valentine-Darby 2014).

The grassland sites in CAVE had slightly higher species richness estimates in most years, although the difference between the two sites was generally small (± eight species). Richness estimates at grassland sites ranged from 34 (2010) to 58 species (2013), while richness estimates at riparian sites ranged from 26 (2010) to 52 (2011) (Figure 35). No new species to the park were detected during the survey efforts; however, an incidental observation of a streak-backed oriole (*Icterus pustulatus*) was detected and was verified by observers and park staff. This species has not yet been added to the certified species list (NPS 2015).

Trends in Abundance in Species of Conservation Concern

For this component, a species was considered a species of concern if it appeared on one of the following conservation lists:

- USFWS Birds Species of Conservation Concern (BCC) for BCR 35 (Chihuahuan Desert) (USFWS 2008);
- Listed by Partners in Flight (PIF) on the:
- North American Landbird Conservation Plan (NA LCP) (Rich et al. 2004);
- Saving our Shared Birds (SOS) shared species list;
- Threatened and endangered species of New Mexico: 2014 biennial review (NMDGF 2014);
- USFWS Endangered Species List;
- Comprehensive wildlife conservation strategy for New Mexico: Chihuahuan Desert (NMDGF 2006).

According to the NPS Certified Bird Species List (NPS 2015), 89 species that have been confirmed in CAVE are listed by at least one of the above agencies as a species of conservation concern (Appendix F). However, there are no established monitoring protocols or programs that specifically track the population trends of these species. The various bird surveys have documented several of these species during their respective monitoring efforts. With the exception of the CHDN monitoring, which has annually monitored abundance using the same methodology; it is difficult to determine trends in abundance for these species. The results of each individual survey effort, as they pertain only to species of conservation concern, are discussed below. Outside of the CHDN monitoring, comparisons between studies will not be made due to differences in survey methodology, timing, and location.

West (2012)

During 2003 surveys of six breeding bird transects in the park, West (2012) documented 18 bird species that were identified as species of conservation concern by one of the aforementioned lists; two state-listed threatened species (gray vireo, varied bunting [*Passerina versicolor*]), and one federally threatened species (yellow-billed cuckoo) were observed (Table 19). The most abundant species that were observed included the Scott's oriole (*Icterus parisorum*; 168 observations), gray vireo (136 observations), the rock wren (*Salpinctes obsoletus*; 81 observations), and the mourning dove (*Zenaida macroura*; 74 observations). Together these four species made up 81% of all observations of species of conservation concern. The North Double Canyon (122 individuals) and

Rattlesnake Canyon (121 individuals) sites had the highest abundance estimate for species of conservation concern (Table 19).

Table 19. Priority species abundance as observed during the West (2012) surveys in six habitat types in CAVE. NSCA=North Slaughter Canyon, RASP=Rattlesnake Canyon, YUME=Yucca Mesa, GURI=Guadalupe Ridge, OHGU=Open Hollow Gulch, NDCA=North Double Canyon. Species without abundance values were observed off transect and did not have values reported.

Species	**NSCA**		**RASP**		**YUME**		**GURI**		**OHGU**		**NDCA**	
	5/3/ 2003	**6/10/ 2003**	**5/25/ 2003**	**6/30/ 2003**	**6/2/ 2003**	**6/29/ 2003**	**6/6/ 2006**	**6/24/ 2003**	**6/13/ 2003**	**6/26/ 2003**	**6/20/ 2003**	**7/3/ 2003**
scaled quail	2	5	1	2			2	2				
Montezuma quail												
golden eagle			1									
mourning dove	8	9	9	1	2	12	2		14	13	2	2
yellow-billed cuckoo		1								2		
elf owl												
common nighthawk			2	1		1	1	7				
white-throated swift								2	1		1	
olive-sided flycatcher												
gray vireo	2	9	15	17	13	18		2	6	12	19	23
cactus wren	8	7										
rock wren	4	2	10	10	3	21	1	6	2	3	8	11
phainopepla	4		1									
canyon towhee	1	1	1	1		3	3	2			2	1
black-chinned sparrow					2	1			1	4	1	4

Table 19 (continued). Priority species abundance as observed during the West (2012) surveys in six habitat types in CAVE. NSCA=North Slaughter Canyon, RASP=Rattlesnake Canyon, YUME=Yucca Mesa, GURI=Guadalupe Ridge, OHGU=Open Hollow Gulch, NDCA=North Double Canyon. Species without abundance values were observed off transect and did not have values reported.

Species	**NSCA**		**RASP**		**YUME**		**GURI**		**OHGU**		**NDCA**	
	5/3/ 2003	**6/10/ 2003**	**5/25/ 2003**	**6/30/ 2003**	**6/2/ 2003**	**6/29/ 2003**	**6/6/ 2006**	**6/24/ 2003**	**6/13/ 2003**	**6/26/ 2003**	**6/20/ 2003**	**7/3/ 2003**
black-throated sparrow	2	3	7				1	2				
varied bunting	1	1	4	3							2	2
Scott's oriole	9	38	20	15	15	8	5	1	10	3	11	33
Total Abundance	**41**	**76**	**71**	**50**	**35**	**64**	**15**	**24**	**34**	**37**	**46**	**76**
Total Point Count Richness	**10**	**10**	**11**	**8**	**5**	**7**	**7**	**8**	**6**	**6**	**8**	**7**
Site Abundance	**117**		**121**		**99**		**39**		**71**		**122**	
Site Richness	**11**		**11**		**7**		**9**		**7**		**8**	

Meyer and Griffin (2011)

During 2004-2006 surveys of four low level riparian areas in CAVE, Meyer and Griffin (2011) identified 41 species of conservation concern. Of the four sampling sites, Rattlesnake Springs had the highest species richness value for species of conservation concern (32 species), while Walnut Canyon had the highest overall abundance estimate (909 individuals). For the purpose of this measure, all of the individuals detected, not just those observed on transect, are reported.

The Grammer Seep survey site supported 11 species of conservation concern during Meyer and Griffin (2011)'s single visit to the area (Table 20). The rock wren was the most abundant species (17 individuals), followed by the migratory yellow-headed blackbird (*Xanthocephalus xanthocephalus*; 16 individuals), and the black-throated sparrow (*Amphispiza bilineata*; 10 individuals). No state or federally listed species were observed at this site.

Table 20. Species of conservation concern abundance values as documented by Meyer and Griffin (2011) at the Grammer Seep survey site in 2004.

Species	**Fall Abundance**
black-chinned sparrow	4
black-tailed gnatcatcher	2
black-throated sparrow	10
cactus wren	1
canyon towhee	3
golden eagle	1
mourning dove	8
rock wren	17
Scott's oriole	2
Wilson's warbler	5
yellow-headed blackbird	16
Total Abundance	**69**
Total Richness	**11**

The Oak Spring survey site only had three species of conservation concern in 2004. These species were the mourning dove (identified as a species of concern by NMDGF [2006]; 68 individuals), rock wren (eight individuals), and black-throated sparrow (one individual). There were no state or federally listed species identified at this site.

Rattlesnake Springs had 32 species of conservation concern identified during Meyer and Griffin's (2011) transect surveys from 2004-2006. Most of these species were detected during the migratory periods (fall and spring), although a fair number remained during the breeding and summer seasons

(Table 21). The most abundant species observed for the duration of the surveys included the mourning dove (130 observations), Bell's vireo (76 observations), and the Wilson's warbler (*Cardellina pusilla*; 42 observations). The southwestern willow flycatcher was observed in both the fall and summer surveys, albeit in low numbers; this species is currently federally and state-listed as endangered. The Bell's vireo and yellow-billed cuckoo both appear on New Mexico's threatened species list, and were observed in comparatively high numbers compared to other priority species at this site (Table 21).

Table 21. Species of conservation concern observed at the Rattlesnake Springs site by season during 2004-2006 surveys conducted by Meyer and Griffin (2011).

Species	Breeding	Fall	Spring	Summer	Winter
Bell's vireo	17	16	41	2	
belted kingfisher		1			
black-tailed gnatcatcher		1			
black-throated sparrow		3	5	1	
Brewer's sparrow		4	7		1
cactus wren		1	5		
Cassin's sparrow		2	1	1	
common nighthawk	1		6	1	
crissal thrasher		2	1		
green-tailed towhee		6			
hooded oriole			9		
lark bunting		13			
loggerhead shrike		5			
Lucy's warbler	4	1	10	2	
mourning dove	10	38	79	3	
northern bobwhite		1			
northern flicker		5	2		1
northern harrier		1			
olive-sided flycatcher		2	5		
painted bunting	7	2	11	1	
phainopepla			1		
pine siskin	1	4	29		

Table 21 (continued). Species of conservation concern observed at the Rattlesnake Springs site by season during 2004-2006 surveys conducted by Meyer and Griffin (2011).

Species	Breeding	Fall	Spring	Summer	Winter
pyrrhuloxia	1	1		1	
rock wren		1			
scaled quail	3	6	14		1
Swainson's hawk	2	3	9		
verdin	1	13	9	1	
Virginia's warbler		1			
white-throated swift		1	2		
willow flycatcher		2		1	
Wilson's warbler		14	28		
yellow-billed cuckoo	7	11	8	3	
Total Abundance	**54**	**161**	**282**	**17**	**3**
Richness by Season	**11**	**29**	**21**	**11**	**3**
Total Richness - 32 species					

The Walnut Canyon survey site had 27 species of conservation concern during Meyer and Griffin (2011) (Table 22). The migratory period (spring and fall) had the highest species abundance totals, with the fall season having more observations than the spring (421 observations compared to 321, respectively) (Table 22). The most abundant species of conservation concern that were observed during these surveys included the black-throated sparrow (176 observations), rock wren (168 observations), cactus wren (*Campylorhynchus brunneicapillus*; 117 observations), and the Scott’s oriole (101 observations). Three species were observed that were listed as threatened by New Mexico: gray vireo, peregrine falcon (*Falco peregrinus*), and the varied bunting. The yellow-billed cuckoo was the only federally threatened species identified at this site.

Table 22. Species of conservation concern observed at the Walnut Canyon site during 2004-2006 surveys conducted by Meyer and Griffin (2011).

Species	Breeding	Fall	Spring
black-chinned sparrow		3	
black-throated sparrow	26	79	71
Brewer's sparrow		12	
cactus wren	77	17	23
canyon towhee	10	49	17
Cassin's sparrow		8	
golden eagle	1		
gray vireo	6		12
green-tailed towhee		13	2
lark bunting		1	
loggerhead shrike		9	
mourning dove	17	23	21
olive-sided flycatcher			1
peregrine falcon	2		
phainopepla	2		20
pine siskin			3
pyrrhuloxia		19	7
rock wren	30	85	53
sage thrasher		2	
scaled quail	18	15	44
Scott's oriole	23	49	29
varied bunting	*	1	4
verdin		1	5
Virginia's warbler		1	
white-throated swift	1		1
Wilson's warbler		34	1
yellow-billed cuckoo	10		7

Table 22 (continued). Species of conservation concern observed at the Walnut Canyon site during 2004-2006 surveys conducted by Meyer and Griffin (2011).

Species	Breeding	Fall	Spring
Richness by Season	**13**	**19**	**18**
Total Abundance	**223**	**421**	**321**
Richness by Season	**13**	**19**	**18**
Total Richness - 27 species			

* Species was detected outside of the formal survey

CHDN Monitoring

From 2010-2014, CHDN and RMBO landbird monitoring efforts surveyed the grassland (eight transects) and riparian habitats (one transect) of CAVE. The total number of bird species of conservation concern observed during all survey efforts was 35; 30 species were observed on the grassland surveys and 21 species were observed on the riparian surveys (Table 23). The number of priority species observed at grassland sites was generally greater than at the riparian sites, with the highest number of priority species observed at grassland sites in a year being 21 (2013) and the highest number observed at a riparian site being 14 (2011) (Table 23).

Table 23. Species of conservation concern observed at eight grassland (G) transects and one riparian (R) transect during CHDN landbird monitoring form 2010-2014 (White 2011, White and Valentine-Darby 2012, 2013, 2014, Ali and Valentine-Darby 2014).

Species	2010		2011		2012		2013		2014	
	G	R	G	R	G	R	G	R	G	R
Bell's vireo		7	7	20		11		16		9
black-chinned sparrow	1				2					
black-tailed gnatcatcher	2									
black-throated sparrow	152		87	1	218		190		75	
Brewer's sparrow			50		2		11		8	1
cactus wren	1		1		12		2		2	
canyon towhee	16		10	2	17		16	1	8	
Cassin's sparrow	56		35	1	10		31		51	
common nighthawk	2			3						
curve-billed thrasher			11		6		1			
eastern meadowlark			2							

Table 23 (continued). Species of conservation concern observed at eight grassland (G) transects and one riparian (R) transect during CHDN landbird monitoring form 2010-2014 (White 2011, White and Valentine-Darby 2012, 2013, 2014, Ali and Valentine-Darby 2014).

Species	**2010**		**2011**		**2012**		**2013**		**2014**	
gray vireo					1		1	1		
green-tailed towhee			17	5			2	1	12	1
hooded oriole				1						1
lark bunting					1		131	1		
lark sparrow									20	
loggerhead shrike			1		1		1		1	
Lucy's warbler						4		5		2
mourning dove	32	3	26	1	34	4	35	13	17	7
northern bobwhite					4					1
northern harrier			1				1			
painted bunting	1	12		3		5	1			2
phainopepla				11					1	
pine siskin							1	5		1
pyrrhuloxia	19		22		39		26		2	
rock wren	3		1		10		11		7	
scaled quail	36		26		67		75		82	
Scott's oriole	13		27	3	25		13		4	
Swainson's hawk				1						
varied bunting							7			
verdin	3		1				7			
white-throated swift					1					
willow flycatcher						4				
Wilson's warbler			4	3		1	1	4	2	6
yellow-billed cuckoo				1		2				
Total Abundance	**337**	**22**	**329**	**56**	**450**	**31**	**564**	**47**	**292**	**31**
Yearly Habitat Richness	**14**	**3**	**18**	**14**	**17**	**7**	**21**	**9**	**15**	**10**
Yearly Richness	**15**		**24**		**23**		**23**		**21**	
Total Richness - 35 species										

Total priority species abundance estimates during the landbird monitoring ranged from 323 individuals (2014) to 611 individuals (2013), with a substantially higher number of individuals being observed in the grassland habitats (Table 23). The most abundant species of conservation concern that were observed for the duration of the landbird surveys included the black-throated sparrow (723 individuals), scaled quail (*Callipepla squamata*; 286 individuals), and the Cassin's sparrow (*Peucaea cassinii*; 184 individuals). These three species were observed almost exclusively in grassland habitats (Table 23).

Five species were observed during the landbird monitoring efforts that were either federally or state-listed as threatened or endangered. These species included: Bell's vireo (state-listed threatened), gray vireo (state-listed threatened), varied bunting (state-listed threatened), southwestern willow flycatcher (state and federally listed endangered), and the yellow-billed cuckoo (federally listed threatened). Most of these species were observed either exclusively, or in greater numbers, in riparian areas, although the gray vireo was observed in low numbers at both sites and the varied bunting was exclusive to grassland habitats.

Of the state and federally listed species observed from 2010-2014, the Bell's vireo was observed in the highest numbers (Figure 36). Abundance estimates fluctuated annually (Figure 36), with 2011 representing the highest abundance estimate of the study. This species has been documented as breeding in the Rattlesnake Springs area, and was the only state/federally listed species that was observed during every year of the landbird monitoring in the park.

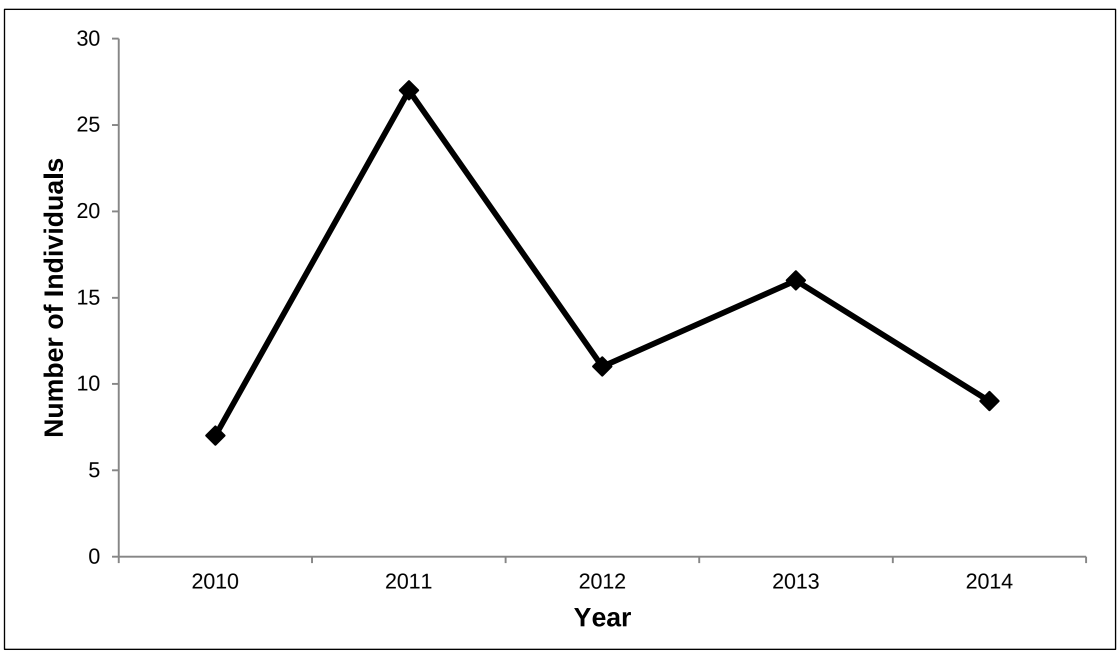

Figure 36. Number of Bell's vireos observed at both riparian and grassland sites during landbird monitoring in CAVE from 2010-2014 (White 2011, White and Valentine-Darby 2012, 2013, 2014, Ali and Valentine-Darby 2014).

Threats and Stressor Factors

Avian brood parasite species (e.g., brown-headed cowbird [*Molothrus ater*]) represent a threat to several avian species in CAVE. Brood parasites are species that lay their eggs in the nests of other breeding species, which then in turn incubate and care for the young (Photo 13; Payne 1977). Brood parasitism generally reduces the reproductive success of the host species, as host species typically fledge fewer young compared to non-parasitized parents of the same species (Payne 1977).

Photo 13. Brown-headed cowbird egg (mottled color), that has been laid in a chipping sparrow (*Spizella passerina*) nest (NPS Photo).

Brown-headed cowbirds are a native species in CAVE, and can directly contribute to the reduced nesting success of host species, as they will often puncture or remove host species eggs (Friedmann 1963). Brown-headed cowbirds often hatch earlier than host species eggs, and grow larger and faster than the host species, which often results in the death of the host chicks due to starvation, neglect, overcrowding, or direct mortality by trampling or removal from the nest (Friedmann 1963, Payne 1977). Many breeding species are targeted by brood parasites, although warblers, blackbirds, and vireos are among the most commonly parasitized species.

In CAVE, the Bell's vireo (a state-threatened species) has been targeted particularly aggressively by cowbirds, and in 1997 and 1998, 32 of the 40 (80%) monitored Bell's vireo nests were parasitized by cowbirds (NPS 1999). Eleven of these nests were completely abandoned by the vireos. Further, researchers documented approximately two cowbird eggs per vireo nest in 1998 (NPS 1999). Cowbird parasitism is a particular concern in the Rattlesnake Springs area, as this area is home to several breeding species of conservation concern, and contains nesting habitat for the endangered southwestern willow flycatcher.

While a natural phenomenon, brood parasitism can be actively managed against; instances of cowbird egg removal from host nests has resulted in increases in reproductive success in various parts of the species' home range (Mayfield 1960, Walkinshaw 1972, Payne 1977). CAVE managers have taken some action in the Rattlesnake Springs area to minimize the impacts that cowbirds may have. Managers have also removed buried powerline boxes that were commonly used as perches by the cowbirds, and there has been active removal and addling of cowbird eggs in Bell's vireo nests (NPS 1999).

Fire is a natural process in CAVE and was historically an important source of disturbance in mixed conifer forests throughout the southwestern U.S. (Sakulich and Taylor 2007, NPS 2008). Fire influences the park's vegetation communities and ecosystem processes, which in turn impacts wildlife habitat (NPS 2008). In 2011, the loop fire burned approximately 3,343 ha (8,261 ac) of land in CAVE, primarily in the steep, rugged terrain of the Walnut Canyon area. Habitats that burned during the loop fire included juniper (*Juniperus* spp.), brush, common stool (*Dasylirion wheeleri*), yucca (*Yucca* spp.), and grasslands. White and Valentine-Darby (2014) implied that the areas that burned during the loop fire were not as well populated by birds as they had been in years past. The presence of a high fuel load in critical bird areas represents a significant threat to the bird populations in the park. A catastrophic fire (in terms of size and severity) could reduce the amount of bird habitat for several seasons and reduce the availability of suitable nesting sites for cavity-nesting species. While fire is necessary and probably overdue in the Rattlesnake Springs area, the timing of it is critical, as any fire in the breeding season could have dramatic impacts on the priority bird species in the area.

While the threat of predation is a natural occurrence for avian species, there are several instances of predation from non-native predators that represent a more substantial threat. Domestic and feral cats (*Felis catus*) are one of the largest causes of bird mortality in the United States. According to Loss et al. (2012), annual bird mortality caused by outdoor cats is estimated to be between 1.4 and 3.7 billion individuals. The median number of birds killed by cats was estimated at 2.4 billion individuals, and almost 69% of bird mortality due to cat predation was caused by un-owned cats (i.e., strays, barn cats, and completely feral cats) (Loss et al. 2012). While CAVE is located in a relatively remote setting, the possibility of predation from feral cats is still a threat, as Whites City and Carlsbad are near the park and feral cats have been observed in the Rattlesnake Springs area.

The non-native eastern fox squirrel has become more established in CAVE, and represents a predation threat to many of the nesting bird species in the park, particularly in the Rattlesnake Springs area. This species has moved into the area, and has out-competed other native small mammals such as the rock squirrel (*Spermophilus variegatus*) (West, written communication, 25 May 2016). The rock squirrel was a common mammal species in the Rattlesnake springs area as recently as the early 2000s, but it has been over 10 years since the species has been observed in that area (West, written communication, 25 May 2016). While no studies have currently documented the predation rates of squirrels in the park, it is likely that the fox squirrel consumes bird eggs in the area, and an increase in population size for the squirrel could have impacts on the nesting community of this priority area of the park.

With Rattlesnake Springs representing the largest riparian portion of the park, there is substantial concern over the fluctuation in water levels in this area. Several bird species that have been documented in the park are riparian-dependent, such as herons, egrets, and duck species, and significant fluctuations in water level could result in the loss of appropriate habitat for many of the park's confirmed species. The increase in oil and gas drilling operations in the area, combined with the increased use of groundwater for agricultural purposes could result in fluctuations of water levels in Rattlesnake Springs. While Doser and Kaip (2008) investigated how underground channels might feed the springs in the park, additional research is needed to evaluate to what degree fluctuations in the park may occur, and how they may affect the many priority avian species of the area.

Recent efforts to develop alternative energy sources have resulted in more wind farm development across the planet (de Lucas et al. 2008). Collisions with wind turbines are likely more frequent among raptors and Neotropical migrants. However, the exact effects that these wind farms have on birds are still poorly understood. Some studies have found that wind farms are responsible for no more mortalities than other human-made structures (e.g., buildings, communication towers) (Osborn et al. 2000), while other studies have found that turbines are responsible for unusually high numbers of bird mortalities (Smallwood and Thelander 2007). A small wind farm consisting of 139 wind turbines is located to the south of GUMO (approximately 62 km [38 mi] from CAVE) (USDA 2010); future research could be focused on the mortality caused by these turbines if population declines are noticed in the CAVE area. A more understood threat to bird species is collisions with other human-made structures. Bird collisions with buildings, power lines, communication towers, and windows may result in between 97-976 million bird deaths across the globe (USFWS 2002).

Data Needs/Gaps

Continuation of the grassland and riparian bird monitoring efforts by the RMBO are essential for monitoring not only the health of habitat-specific bird species, but also for monitoring the health of the riparian communities of the park. By utilizing a spatially balanced sample design with skilled observers, the survey efforts should yield an excellent baseline for future comparisons. Additional study efforts that highlight the use of the park by wintering grassland bird species may also be useful to track potential trends in migration and overwintering populations.

Increased sampling (more than one sample per year) using the White (2011) spatially-balanced land bird protocol would allow for density and occupancy estimates in the future. These estimates could provide baseline values that would serve as sources of comparison for future studies. Visits in the winter would also allow for a more accurate description of the overwintering species that use the park.

Populations of avian species of conservation concern are monitored by various agencies on a global scale. However, monitoring of these species' abundance in the park would help managers to understand how many species and individuals are present in the park, and would also provide approximate estimates of what seasons the species are present in CAVE. The riparian corridor of Rattlesnake Springs represents a vital bird habitat for both migratory and resident species. Monitoring the health of the bird populations in this area more closely would provide managers with insights into the health of many bird communities, and the overall health of the riparian area. A management strategy related to the ongoing cowbird and fox squirrel issues in this area is also needed to promote continued growth of the park's priority bird communities.

Overall Condition

Species Richness

The project team assigned the species richness measure a *Significance Level* of 2 during project scoping. As has been mentioned previously, a comparison between survey efforts is difficult due to differing methodologies and timing. However, the five most recent surveys of the park (White 2011, White and Valentine-Darby 2012, 2013, Ali and Valentine-Darby 2014, White and Valentine-Darby 2014) have all utilized the same methodology and survey locations and allow for a more accurate picture of the current health and trends of species richness in the park. Species richness estimates for CAVE have remained variable yet relatively stable during the five years of RMBO monitoring (Figure 35). The annual species richness values have ranged from 46-80 species, with an average of 67 species observed each year.

The park serves as an important migratory stop over site for many species, and the Rattlesnake Springs area continues to be a critical desert oasis for many species. The importance of this area, and the tremendous diversity of bird species observed here, is supported by the large number of birders that gather yearly in this region to watch for new or rare species. CAVE has an incredible number of species on its NPS Certified Species List (367; NPS 2016), and new species continue to be added. For example, in 2014 a streak-backed oriole, a Mexican and Central American resident, was observed on several occasions by RMBO and NPS staff. The piratic flycatcher (*Legatus leucophaius*) has been observed at seven locations in the U.S., and one of those locations was Rattlesnake Springs. The species was observed in 2012, and much like with the streak-backed oriole sighting, visitors from around the world travelled to CAVE to see the vagrant species (West, written communication, 25 May 2016).

Due in part to the diversity of species observed annually in the park, and also due to the relatively consistent number of species observed in recent years, this measure was assigned a *Condition Level* of 0, indicating no concern at this time. Continued monitoring of priority areas in the park, including grassland and riparian habitat sites, will allow for a more accurate analysis of potential trends in the avifauna of the park.

Trends in Abundance in Species of Conservation Concern

The trend in abundance in species of conservation concern measure was assigned a *Significance Leve*l of 3 during project scoping. While West (2012) and Meyer and Griffin (2011) both documented the presence of several species of conservation concern during their respective surveys, their data are limited in time scope and do not allow for an analysis of trends. CHDN and RMBO monitoring in the past five years has identified 35 species of conservation concern, and has also identified five species that are state or federally threatened/endangered. Of the state and federally listed species identified, only the Bell’s vireo has been identified during every year of monitoring; this highlights how critically important the Rattlesnake Springs area is to this species for breeding. The Bell’s vireo is further threatened in the park by brood-parasitism from the brown-headed cowbird, and nesting failure has been directly attributed to the cowbird in the past decade (NPS 1999).

With only 5 years of continuous data for these species, it is difficult to determine potential trends. This is further complicated by the fact that many of the priority species observed in the park are migratory and may only pass through the park, or be observed in the park, infrequently. However, the fact that so many priority species rely on the park at some stage of their life history is critically important. Additionally, the Rattlesnake Springs area represents a breeding habitat for the endangered southwestern willow flycatcher, and is a known breeding location for the state-listed Bell's vireo. It is primarily for these reasons that this measure was assigned a *Condition Level* of 2, indicating moderate concern. Continued monitoring of the priority species in the park is needed to more accurately determine long-term trends for this group of birds. Close attention should be paid to the effects of brood parasitism on nesting species such as the Bell's vireo and the southwestern willow flycatcher.

Weighted Condition Score

A Weighted Condition Score of 0.40 was calculated for the bird component, indicating moderate concern. A trend arrow was not assigned, as no long-term data are available at this time; only recent data (2010-2014) are available for comparison. A medium confidence border was assigned due to relative uncertainty regarding the current trends in species of conservation concern.

Birds			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.40**
Species Richness	2	0	
Trends in Abundance in Species of Conservation Concern	3	2	

4.4.6. Sources of Expertise

- Steve West, Borderlands Environmental Education and Research Consortium.

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4.5. Herpetofauna

4.5.1. Description

Herpetofauna, especially reptiles, are diverse in the semi-arid Chihuahuan Desert. This region includes the eastern-most edge of the relatively wide geographic range of ponderosa pine (*Pinus ponderosa*) forests and just enough permanent water to provide aquatic habitat (Photo 14) (Prival and Goode 2011). The aquatic habitats found within CAVE support four semi-aquatic turtle species and also the aquatic life stages of several amphibians (NPS 2015).

Photo 14. The presence of aquatic habitat supports amphibian and turtle species in CAVE (Photo by Kevin Benck, SMUMN GSS 2015).

The park has established several management priority species including the gray-banded kingsnake and blotched water snake, both of which are state-listed endangered species (NPS 2015). The state-listed threatened mottled rock rattlesnake (Photo 15) and Rio Grande cooter are also priority species (NPS 2015). Additional priority species include the arid land ribbon snake (*Thamnophis proximus diabolicus*) and the Texas horned lizard (*Phrynosoma cornutum*) (NPS 2015). A third state-listed endangered species, the Great Plains narrow mouthed toad (*Gastrophryne olivacea*), is thought to occur in the park as well (NPS 2015). Overall, a total of 88 herptile species have either been documented or are suspected to occur in the park (based on voucher records or individual distribution ranges and habitat preferences) (NPS 2015). The American bullfrog (*Lithobates catesbeianus*) is also a management priority, since it is a non-native species and considered a threat to native fauna in the park (NPS 2015). Its presence in the park was documented in the herpetofauna inventory conducted by Prival and Goode (2011).

Photo 15. The New Mexico state threatened mottled rock rattlesnake occurs within the park (Photo by Mike Woolman, Prival and Goode 2011).

4.5.2. Measures

- Species richness
- Species abundance
- Trends in species of concern

4.5.3. Reference Conditions/Values

A reference condition for herpetofauna at the park was not defined by CAVE natural resource staff. Ideally, the reference condition would be based on the known, historical condition of each measure identified for analysis. Due to the parks establishment in 1923, it could be assumed that at that time, the native flora and fauna was minimally impacted (if at all) by non-native species. However, specific data on herpetofauna within CAVE is very limited. Without reference data the identification of change or trends in abundance, richness, and in species of concern is not possible. However, this assessment could serve as a baseline to compare with subsequent studies and surveys in order to determine possible trends in the future.

4.5.4. Data and Methods

Gehlbach (1964) provides a summary of distributions of amphibians and reptiles in the CAVE area and the adjacent Guadalupe Mountains, based on records from previous works. While this study is a historic record of herpetofauna in the region, detailed information specific to findings within the boundaries of the park is not provided. For this reason, this report cannot serve as a baseline condition.

Prival and Goode (2011) conducted an inventory of herpetofauna within the CHDN parks. The inventory at CAVE was conducted during 2003 and 2004. Searches were primarily conducted on foot in pre-defined areas where the likelihood of observing rare herpetofauna was greatest (Prival and

Goode 2011). Foot searches targeting diurnal species were conducted between the hours of 0730 and 1200, while those targeting amphibians and nocturnal reptile species were done between 1800 and 2400 hours (Prival and Goode 2011). Although searches on foot occasionally included trails, most were conducted off-trail (Prival and Goode 2011). These off-trail surveys concentrated on canyons and riparian areas, as well as other habitat types preferred by herpetofauna (Prival and Goode 2011). Road cruising was conducted at night by driving slowly along available roadways (Prival and Goode 2011). In addition, pitfall trap arrays were set up using 19 liter (5 gallon) buckets set in-ground to the rim. These pitfall arrays were combined in groups of three, connected by 10 m (32.8 ft) silt fence walls that direct animal movement into the pitfall trap (Prival and Goode 2011). All herpetofauna observations were located by GPS coordinates and data on genus and species (subspecies if able), time, habitat, substrate, and approximate age or life stage were recorded (Prival and Goode 2011). Incidental observations, consisting of individuals observed outside of formalized search efforts, were also recorded (Prival and Goode 2011).

NPSpecies is a web-based system that provides standardized information on the occurrence of species within a park including scientific names (and synonyms), common names, abundance, residency, and nativity among other attributes (NPS 2014b). This information is based on documented evidence that substantiates the presence of a species within a park. This evidence can be in the form of a report or publication, documented observations, or collected specimens or vouchers (NPS 2014b).

4.5.5. Current Condition and Trend

<u>Species Richness</u>

A summary of past records of herpetofauna in both CAVE and the adjacent Guadalupe Mountains area was compiled by Gehlbach (1964). It contained 41 species of herpetofauna that had been previously documented in the park and surrounding areas (Appendix G). This summary included a total of six frog and toad species, 18 snake species, 15 lizard and skink species, and two turtle species (Gehlbach 1964). Dates of collection of each species are not documented and the summary also does not specify whether the listed species were documented within CAVE or the adjacent Guadalupe Mountains. Although the Guadalupe Mountains are near the park, it is unlikely that all these same species would inhabit the park due to the large disparity in elevation; the mountains reach 914 m (3,000 ft) in some parts and have much different habitat than the park (Schwarzkopf, written communication, 15 April 2016).

The most recent herpetofauna survey was conducted in 2003 and 2004 (Prival and Goode 2011). During that survey, 46 species of herpetofauna were documented including two New Mexico state level threatened species, the Rio Grande cooter and the mottled rock rattlesnake (Prival and Goode 2011). Additionally, the state level endangered gray-banded kingsnake was also documented in CAVE (Prival and Goode 2011). In all, there were eight frog and toad species, 18 snake, three turtle, and 17 lizard and skink species documented in CAVE by this study (Appendix G) (Prival and Goode 2011).

According to the NPSpecies database, the herpetofauna present in CAVE consist of 51 species, including 43 reptiles (17 lizards and skink, 22 snakes, four turtle) and eight amphibians (frog and toad) species (Appendix G) (NPS 2015). NPSpecies also lists an additional 20 reptile (six lizards and skink, 11 snakes, three turtle) and five amphibian species that are likely to be found within the park, but their presence has not been confirmed (Appendix G) (NPS 2015). One species, Blanchard's cricket frog (*Acris crepitans*), is identified as historically being found within the park, but not currently (Appendix G) (NPS 2015).

Species Abundance

Prival and Goode (2011) collected herpetofauna in 2003 and 2004 for a CHDN reptile and amphibian inventory of the park. The full listing of species and counts collected by Prival and Goode (2011) are shown in Table 24. Of the collected species, lizards were most abundant. The southwestern fence lizard (*Sceloporus cowlesi*) was the most abundant of all species collected, with 546 individuals captured during the surveys (Table 24) (Prival and Goode 2011). Other lizard species collected in the hundreds included the Chihuahuan spotted whiptail (*Cnemidophorus exsanguis*), common checkered whiptail (*Cnemidophorus tesselatus*), Big Bend tree lizard (*Urosaurus ornatus*), northern crevice spiny lizard (*Sceloporus poinsettii*), Trans-Pecos striped whiptail (*Cnemidophorus inornatus heptagrammus*), and the Chihuahuan greater earless lizard (*Cophosaurus texanus*) (Prival and Goode 2011). Amphibians collected by Prival and Goode (2011) included 235 Couch's spadefoot (*Scaphiopus couchii*), 212 Texas toads (*Anaxyrus speciosus*), and 125 western green toads (*A. debilis insidior*) (Table 24).

The NPSpecies database does include information on abundance levels for species that have been confirmed as present within a park. However, with the exception of the American bullfrog, southwestern fence lizard, Chihuahuan spotted whiptail, and the common checkered whiptail, all listed as common, the abundance of the remaining species is listed as unknown (NPS 2015).

Table 24. Number of individuals collected during 2003 and 2004 surveys (Prival and Goode 2011).

Scientific Name	Common Names	Prival and Goode (2011)
Frogs and Toads		
Scaphiopus couchii	Couch's spadefoot	235
Anaxyrus speciosus	Texas toad	212
Anaxyrus debilis insidior	western green toad	125
Anaxyrus punctatus	red-spotted toad	40
Lithobates berlandieri	Rio Grande leopard frog	26
Spea multiplicata	Mexican spadefoot	22
Lithobates catesbeianus	American bullfrog	10
Anaxyrus cognatus	Great Plains toad	2

Table 24 (continued). Number of individuals collected during 2003 and 2004 surveys (Prival and Goode 2011).

Scientific Name	Common Names	Prival and Goode (2011)
Lizards and Skinks		
Sceloporus cowlesi	southwestern fence lizard	546
Cnemidophorus exsanguis	Chihuahuan spotted whiptail	468
Cnemidophorus tesselatus	common checkered whiptail	463
Urosaurus ornatus	Big Bend tree lizard	294
Sceloporus poinsettii	northern crevice spiny lizard	222
Cnemidophorus inornatus heptagrammus	Trans-Pecos striped whiptail	184
Cophosaurus texanus	Chihuahuan greater earless lizard	146
Crotaphytus collaris	eastern collared lizard	82
Coleonyx brevis	Texas banded gecko	40
Uta stansburiana	common side-blotched lizard	35
Eumeces obsoletus	Great Plains skink	21
Masticophis flagellum testaceus	western coachwhip	21
Cnemidophorus gularis	Texas spotted whiptail	20
Phrynosoma cornutum	Texas horned lizard	18
Eumeces multivirgatus	variable skink	11
Phrynosoma modestum	round-tailed horned lizard	5
Snakes		
Crotalus lepidus lepidus	mottled rock rattlesnake	55
Crotalus atrox	western diamond-backed rattlesnake	43
Crotalus molossus	northern black-tailed rattlesnake	31
Coluber taeniatus	striped whipsnake	28
Pituophis catenifer	Sonoran gopher snake	18
Salvadora grahamiae	mountain patch-nosed snake	16
Bogertophis subocularis	Trans-Pecos rat snake	13
Elaphe guttata emoryi	Great Plains rat snake	10
Tantilla hobartsmithi	Smith's black-headed snake	8

Table 24 (continued). Number of individuals collected during 2003 and 2004 surveys (Prival and Goode 2011).

Scientific Name	Common Names	Prival and Goode (2011)
Snakes (continued)		
Diadophis punctatus	ring-necked snake	7
Rhinocheilus lecontei	Texas long-nosed snake	5
Leptotyphlops dissectus	New Mexico threadsnake	4
Hypsiglena torquata	Texas nightsnake	3
Thamnophis cyrtopsis	western black-necked garter snake	3
Gyalopion canum	Chihuahuan hook-nosed snake	2
Heterodon nasicus	Mexican hog-nosed snake	2
Sonora semiannulata	variable groundsnake	2
Thamnophis marcianus	Marcy's checkered garter snake	2
Lampropeltis alterna	gray-banded kingsnake	1
Turtles		
Pseudemys gorzugi	Rio Grande cooter	65
Terrapene ornata	ornate box turtle	7
Kinosternon flavescens	yellow mud turtle	2

Trends in Species of Concern

Existing data on herpetofauna species of concern for the park specifically are limited. There is a high concern for the widespread, illegal collection of the state-level endangered gray-banded kingsnake in southeast New Mexico (Painter et al. 2002). While this species hasn't been well studied in CAVE or elsewhere, it is present in the park (Prival and Goode 2011). Considering the behavior and habitat preferences of this rare snake, the park likely serves as a refuge area (Painter et al. 2002). Although unlikely to be abundant anywhere within its assumed range, this snake seeks areas with access to deep crevices and fissures for hunting and shelter, making the park a likely preferred habitat (Painter et al. 2002). These snakes feed primarily on lizards and skinks (Painter et al. 2002, Prival and Goode 2011, NPS 2015).

Other species of concern that have been documented in the park include the Rio Grande cooter and the mottled rock rattlesnake (NPS 2015). The blotched water snake and the Great Plains narrow mouthed toad may also occur (NPS 2015). During the surveys in 2003 and 2004, a total of 23 and 42 Rio Grande cooters were documented in CAVE, respectively (Prival and Goode 2011). Though there are no previous or subsequent studies to compare these numbers to, this information will be a useful baseline for future surveys (Prival and Goode 2011). Prival and Goode (2011) do clarify that this number is likely inflated, since some of these individuals were likely recounted during the survey.

There were 37 mottled rock rattlesnakes counted in 2003 and 18 in 2004 (Prival and Goode 2011). Future monitoring focused on determining areas of preference for these species will help inform conservation decisions that are most effective for protection of at-risk and priority herpetofauna.

Threats and Stressors

Herpetofauna are susceptible to a wide array of threats and stressors within their native geographical ranges. Herpetofauna life strategies place limitations, or constraints, on where they can live and feed (Valentine-Darby 2010). This leaves them vulnerable to landscape changes, climate change, and other anthropogenic disturbances to their habitats (Valentine-Darby 2010).

Oil and gas developments that occur across the New Mexico landscape are a concern to herpetofauna health since they can potentially degrade the regional water quality with chemical contamination. Concerns with water contamination in the park are merited due to the karst nature of the area and proximity to numerous oil and gas wells. Leakage from improperly constructed or capped oil and gas wells has the potential to contaminate underground aquifers and surface water, even though they may be miles away. Since karst terrain is formed by dissolution of carbonate within evaporate bedrock beneath the earth's surface, it is difficult to predict drainage patterns (Land et al. 2013). Under these terrain conditions, contaminated water often moves a great distance very quickly, without any opportunity to become naturally filtered as it would in other geologic structures (e.g., sandstone, granite) (NPS 2014a).

Amphibians are especially sensitive to drought or other changes to hydrology that may cause a drop in the water table, ultimately resulting in loss of crucial wetland habitat (USGS 2015). Water tables often are lowered by excessive pumping to meet the demands of agriculture or municipalities, as well as by extensive periods of drought (USGS 2015). Groundwater depletion is a concern to managers at CAVE, partly due to the presence of sensitive amphibian species. Depletion of groundwater can also cause land subsidence, loss of riparian vegetation, and salinization of groundwater; all these are threats to the herpetofauna at CAVE (USGS 2015).

Climate change impacts on herpetofauna are difficult to predict, although there is conjecture that some species would respond to warmer temperatures by moving to higher elevations (Prival and Goode 2011). Concerns with water withdrawals from the Rattlesnake Springs area have been expressed by park management as a possible threat or stressor to herpetofauna. Rattlesnake Springs provides aquatic habitat relied upon by herpetofauna for breeding and spawning. This water source has been utilized for many years for irrigation, public supply, and fish and wildlife propagation (Cox 1963). An investigation into the impact of pumping by three irrigation wells in the area of Rattlesnake Springs was conducted between 1961 and 1962 by the United States Geological Survey (USGS) (Cox 1963). The wells were found to be impacting water flows, pool level, and spring levels (Cox 1963). The current use of the wells is unknown, but any pumping may have negative impacts on the herpetofauna relying on these pools, riparian habitat, and surrounding soil moisture.

A Fire Management Plan (FMP) for the park was completed in 2005 in order to outline several goals and objectives: protecting people, property and natural and cultural resources; suppress unwanted fire, allow fire to assume its natural and ecological role, use wildfire and prescribed fire in order to manage resources; manage fire cooperatively with adjacent stakeholders; and coordinate fire activities with all park divisions and the public (McMahill 2005). Impacts on herpetofauna during prescribed fires have been researched and have direct (mortality) and indirect (community structure) impacts (Gebow and Halvorson 2004, Weiss 2014). In certain circumstances, burning has been followed by increased herpetofauna diversity, since fire can restore and rejuvenate areas if timed and conducted properly (Gebow and Halvorson 2004, Weiss 2014). However, too frequent, poorly timed, or severe fires are more likely to result in high mortality of herpetofauna (Gebow and Halvorson 2004, Weiss 2014).

Feral hogs (*Sus scrofa*), an invasive species, are known for their destructive wallowing behavior and voracious, indiscriminate appetites (NMWS 2010). They are also directly connected to declines in threatened and endangered species in the State of New Mexico (NMWS 2010). There are both direct and indirect impacts to herpetofauna from feral hogs. Direct predation has been well documented, including an instance where 49 spadefoot toads were extracted from a single hog stomach (NMWS 2010). Feral hogs consume all genera of herpetofauna, including venomous snakes (NMWS 2010). Indirect impacts from the rooting and wallowing behavior include decreased canopy cover, introduction of invasive plant seeds, and native habitat/vegetation destruction (NMWS 2010). Currently, there are no feral hogs inhabiting the park, but populations are confirmed within Eddy County and in GUMO (WSNM 2010, NPS 2015).

Roadways can have a variety of ecological impacts on herpetofauna, including direct vehicle-related mortality and possible behavioral influences on various species (Andrews and Jochimsen 2007). Some research suggests that roadway mortality from direct vehicular impact among herpetofauna is significant and a serious threat to populations (Andrews and Jochimsen 2007). Habitat fragmentation and population isolation are indirect effects of roadways on herpetofauna, which are variable depending on species (Andrews and Jochimsen 2007). There are limited roadway accesses within the park, but highway 180/62 may impact herpetofauna populations associated with CAVE due to proximity. Roadway impacts for the park are not generally known, since there hasn't been an effort to collect data on the number and species of road kills.

<u>Data Needs/Gaps</u>

There is a data gap regarding the abundances of herpetofauna species in CAVE. With the Prival and Goode (2011) data, future surveys will now have a baseline for comparison when counting the number of individuals of each species. With this inventory in place, subsequent surveys following Prival and Goode (2011) methodology will make this data useful to determine any trends in abundance, richness, or species of concern within CAVE.

<u>Overall Condition</u>

Species Richness

The species richness measure was given a *Significance Level* of 3. The reference condition for this measure is currently undefined and considered to be a data gap. Although there is a species list from the Gehlbach (1964) summary, the subsequent surveys in 2003 and 2004 were not conducted with a similar methodology and, therefore, the results are not comparable. Since there were additional species observed during the second year of the Prival and Goode (2011) survey, there are likely additional species within the park that have yet to be detected. Based on this observation, there is not adequate information to determine a *Condition Level* at this time.

Species Abundance

Species abundance was assigned a *Significance Level* of 3 by the project team. The reference condition for this measure is also considered to be a data gap. The data from Prival and Goode (2011) are available but for the same reasons outlined above, the information available does not have the level of completeness necessary to assign a *Condition Level* at this time.

Trends in Species of Concern

Trends in species of concern were given a *Significance Level* of 3. This measure also lacks a reference condition and has not been directly assessed in the park. The presence of two state-level endangered and two state-level threatened species has been confirmed in the park. Until further surveys are completed, any trends in these species will not be clear. A *Condition Level* was not assigned due to this data gap.

Weighted Condition Score

A *Weighted Condition Score* could not be calculated for CAVE's herpetofauna due to the lack of data for the selected measures. The current condition and trend of this resource are unknown.

Herpetofauna			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Species Abundance	3	N/A	
Species Richness	3	N/A	
Trends in Species of Concern	3	N/A	

4.5.6. Sources of Expertise

- This assessment relied on the published literature and best professional judgment as the primary sources of expertise.

4.5.7. Literature Cited

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4.6. Air Quality

4.6.1. Description

Air pollution can significantly affect natural resources and their associated ecological processes, as well as the health of park visitors. In the Clean Air Act (CAA), Congress set 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 (42 U.S.C. §7470(2)). This goal applies to all units of the National Park System. The act includes special provisions for the 48 park units, including CAVE identified as "Class I"; all other NPS areas are designated as Class II. Class I airshed designations must be made by Congress and have only been done once, in the 1977 revisions to the CAA. For Class II airsheds, the increment ceilings for additional air pollution above baseline levels are slightly greater than for Class I areas. Additional authority to consider and protect air quality in national parks is provided by Title 54 (54 USC 100101(a) et seq.), commonly known as the NPS Organic Act, and the Wilderness Act.

Parks designated as Class I and II airsheds typically use the EPA's National Ambient Air Quality Standards (NAAQS) for criteria air pollutants as the ceiling standards for allowable levels of air pollution. EPA standards are designed to protect human health and the health of natural resources (EPA 2015a). The CAA also establishes that current visibility impairment in Class I areas must be remedied and future impairment prevented (NPS 2015d). To comply with CAA and NPS Organic Act mandates, the NPS established a monitoring program that measures air quality trends in many park units for key air quality indicators, including atmospheric deposition, ozone (O_3), and visibility (NPS 2015d).

Located in southeastern New Mexico near the border of Texas, the primary pollutants likely to affect air quality at CAVE include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3], ammonium [NH_4], and sulfate [SO_4]); ground-level ozone; haze-causing particles; and airborne toxics (NPS 2016). These challenges to air quality are generated by a variety of sources including; local emissions generated by traffic and development, air inversions, and through contaminants carried into the region via prevailing seasonal winds. Air pollution may impair the scenic views that many visitors come to CAVE to enjoy.

4.6.2. Measures

- Atmospheric deposition of nitrogen
- Atmospheric deposition of sulfur
- Ozone
- Particulate matter
- Visibility
- Atmospheric deposition of mercury

Atmospheric Deposition of Nitrogen and Sulfur

Nitrogen and sulfur are emitted into the atmosphere primarily through the burning of fossil fuels, industrial processes, and agricultural activities (EPA 2012). While in the atmosphere, these emissions form compounds that may be transported long distances and settle out of the atmosphere in the form of pollutants such as particulate matter (e.g., SO_4, NO_3, NH_4) or gases (e.g., nitrogen dioxide, sulfur dioxide [SO_2], nitric acid [HNO_3], ammonia[NH_3]) (NPS 2008, EPA 2012). Atmospheric deposition can be in wet (i.e., pollutants dissolved in atmospheric moisture and deposited in rain, snow, low clouds, or fog) or dry (i.e., particles or gases that settle on dry surfaces as with windblown dusts) form (EPA 2012). Deposition of N and S can have significant effects on ecosystems including acidification of water and soils, excess fertilization or increased eutrophication, changes in the chemical and physical characteristics of water and soils, and accumulation of toxins in soils, water and vegetation (NPS 2008, reviewed in Sullivan et al. 2011a, b).

Ozone Concentration

Ozone occurs naturally in the earth's upper atmosphere, where it protects the earth's surface against ultraviolet radiation (EPA 2012). However, it also occurs at the ground level (i.e., ground-level O_3) where it is created by a chemical reaction between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of heat and sunlight (NPS 2008). Precursors to O_3 are emitted from a variety of source types, including power plants, industry, motor vehicles, oil and gas development, and others. Forest fires also emit O_3 precursors (EPA 2014a).

Ozone is one of the most widespread pollutants affecting vegetation in the U.S. (NPS 2008). Considered phytotoxic, O_3 can cause significant foliar injury and growth effects for sensitive plants in natural ecosystems (NPS 2008, EPA 2016c). Specific effects include reduced photosynthesis, premature leaf loss, and reduced biomass; prolonged exposure can increase vulnerability to insects and diseases or other environmental stresses (NPS 2008). Plant species occurring in CAVE that are known to be sensitive to O_3 include white sagebrush (*Artemisia ludoviciana*), common dogbane (*Apocynum cannabinum*), green ash (*Fraxinus pennsylvanica*), Goodding's willow (*Salix gooddingii*), common chokecherry (*Prunus virginiana*), Virginia creeper (*Parthenocissus quinquefolia*), ponderosa pine (*Pinus ponderosa*), and skunkbush sumac (*Rhus trilobata*) (NPS 2006, NPS 2015c).

At high concentrations, O_3 can aggravate respiratory and cardiovascular diseases in humans, through reduced lung function, acute respiratory problems, and increased susceptibility to respiratory infection (EPA 2016c, d, e). Visitors and staff engaging in aerobic activities in the park, such as hiking, as well as children, the elderly, and people with heart and lung diseases are especially sensitive to elevated ozone levels.

Particulate Matter and Visibility

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets that become suspended in the atmosphere. PM largely consists of acids (such as NO_3 and SO_4), organic chemicals, metals, and soil or dust particles (EPA 2014a, EPA 2016e). There are two particle size classes of concern: $PM_{2.5}$ – fine particles found in smoke and haze, which are 2.5 micrometers in diameter or less; and PM_{10} – coarse particles found in wind-blown dust, which have diameters between 2.5 and 10 micrometers (EPA 2012). Fine particles are a major cause of reduced visibility (haze) in many national parks and wildernesses (EPA 2012). $PM_{2.5}$ can be directly emitted from sources such as forest fires or they can form when gases emitted from power plants, industry and/or vehicles react with air (EPA 2014a, EPA 2016e). Particulate matter either absorbs or scatters light. As a result, humans see less clarity, color, and distance, especially during humid conditions when additional moisture is present in the air (EPA 2012, EPA 2016e). $PM_{2.5}$ is also a concern for human health as these particles can easily pass through the throat and nose and enter the lungs (EPA 2012, EPA 2014a, EPA 2016e). Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation (EPA 2012, EPA 2016e).

Atmospheric Deposition of Mercury

Sources of atmospheric mercury (Hg) include fuel combustion and evaporation (especially coal-fired power plants), waste disposal, mining, industrial sources, and natural sources such as volcanoes and evaporation from enriched soils, wetlands, and oceans (EPA 2008). Atmospheric deposition of Hg from coal-burning power plants has been identified as a major source of Hg to remote ecosystems (Landers et al. 2008). Hg is a potential problem for ecosystems in regions with heavy current or historic coal use due to the already high concentrations of Hg pollution.

Mercury deposited into rivers, lakes, and oceans can accumulate in various aquatic species, resulting in exposure to wildlife and humans that consume them (EPA 2008). Hg exposure can cause liver, kidney, and brain (neurological and developmental) damage (EPA 2008). High Hg concentrations in birds, mammals, and fish can result in reduced foraging efficiency, survival, and reproductive success (Mast et al. 2010, Eagles-Smith et al. 2014).

4.6.3. Reference Conditions/Values

The NPS Air Resources Division (ARD) developed an approach for rating air quality conditions in national parks, based on the current NAAQS, ecosystem thresholds, and visibility improvement goals (NPS 2015d). This approach is discussed by indicators in the following paragraphs and the ratings are summarized in Table 25 and Table 26.

Table 25. National Park Service Air Resources Division air quality index values for wet deposition of nitrogen (N) or sulfur (S), ozone (O_3), particulate matter (PM), and visibility (NPS 2015d).

Condition Level	Wet Deposition of N or S (kg/ha-yr)	Human Health Risk from O_3 (ppb)	Vegetation Health Risk from O_3 (ppm-hrs)	Human Health Risk from PM2.5 (ppb)	Visibility (dv*)
Significant Concern	>3	≥71	>13	≥35.5	>8
Moderate Concern	1–3	55–70	7-13	12.1–35.4	2–8
Good Condition	<1	≤55	<7	≤12	<2

*A unit of visibility proportional to the logarithm of the atmospheric extinction; one deciview represents the minimal perceptible change in visibility to the human eye.

Table 26. National Park Service Air Resources Division air quality assessment matrix for mercury status (NPS 2015d). Green = Good condition, yellow = Moderate Concern, and Red = Significant Concern.

Predicted Methylmercury Concentration Rating	Mercury Wet Deposition Rating				
	Very Low (<3 µg/m2/yr)	**Low (≥3–<6 µg/m2/yr)**	**Moderate (≥6–<9 µg/m2/yr)**	**High (≥9–<12 µg/m2/yr)**	**Very High (≥ 12 µg/m2/yr)**
Very Low (< 0.038 ng/L)					
Low (≥0.038–< 0.053 ng/L)					
Moderate (≥0.053–<0.075 ng/L)					
High (≥0.075–<0.12 ng/L)					
Very High (≥0.12 ng/L)					

Atmospheric Deposition of Nitrogen and Sulfur

Assessment of current condition of atmospheric deposition of N and S is based on wet (rain and snow) deposition. Wet deposition is used as a surrogate for total deposition (wet plus dry), because wet deposition is the only nationally available monitored source of nitrogen and sulfur deposition data (NPS 2015d). Values for N (from NH_4 and NO_2) and sulfur (from SO_4) wet deposition are expressed as amount of N or S in kilograms deposited over a one-hectare area in one year (kg/ha/yr). The NPS ARD selected a wet deposition threshold of 1.0 kg/ha/yr as the level below which natural ecosystems are likely protected from harm, based on studies linking early stages of aquatic health decline correlated with 1.0 kg/ha/yr wet deposition of N both in the Rocky Mountains (Baron et al. 2011), and in the Pacific Northwest (Sheibley et al. 2014). Parks with less than 1 kg/ha/yr of atmospheric wet deposition of N or S compounds are assigned *Good Condition*, those with 1–3 kg/ha/yr are assigned *Moderate Concern*, and parks with depositions greater than 3 kg/ha/yr are assigned *Significant Concern* (NPS 2015d).

Ozone Concentration

The primary NAAQS for ground-level O_3 is set by the EPA, and is based on human health effects. The 2008 NAAQS for O_3 was a 4th-highest daily maximum 8-hour O_3 concentration of 75 ppb (parts per billion) (NPS 2015d). On October 1, 2015, the EPA strengthened the national O_3 standard by setting the new level at 70 ppb (EPA 2015a). The NPS ARD recommends a benchmark for *Good Condition* O_3 status in line with the updated Air Quality Index (AQI) breakpoints (NPS2015d).

Current condition for human health risk from O_3 is based on the estimated 5-year 4th-highest daily maximum 8-hour O_3 average concentration in ppb (NPS 2015d). O_3 concentrations ≥ 71 ppb are assigned a *Significant Concern* (NPS 2015d). O_3 concentrations from 55–70 ppb are assigned *Moderate Concern* (NPS 2015d). A *Good Condition* is identified when O_3 concentrations are < 55 ppb (NPS 2015d).

In addition to being a concern to human health, long-term exposures to O_3 can cause injury to ozone-sensitive plants (EPA 2014b). The W126 metric relates plant response to O_3exposure and is a better predictor of vegetation response than the metric used for the primary (human-health based) standard (EPA 2014b). The W126 metric measures cumulative O_3 exposure over the growing season in "parts per million-hours" (ppm-hrs) and is used for assessing the vegetation health risk from O_3levels (EPA 2014b).

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

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

NPS ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation. Levels below this guideline are considered *Good Condition*; 7-13 ppm-hrs to is *Moderate Concern* and > 13 ppm-hrs is considered to be of *Significant Concern* (NPS 2015d).

Particulate Matter

The PM condition is based on the NAAQS for $PM_{2.5}$ and PM_{10}, which are established by EPA to protect human health (NPS 2015d). NPS units that are in EPA designated nonattainment areas for PM are assigned *Significant Concern* condition for PM (NPS 2015d). The NAAQS primary standard for $PM_{2.5}$ is an annual 98th percentile mean of 35 µg/m^3 (µg/m^3 = ppb) for a 24-hour period over a 3-year average or a weighted annual mean of 15.0 µg/m^3 in a 24-hour period over a 3-year average (EPA 2011). The primary and secondary NAAQS for PM_{10} measured over a 24-hour period is set at 150 µg/m^3 (EPA 2011).

For NPS units that are outside PM nonattainment areas, EPA AQI breakpoints for 24-hour average are used to assign a PM condition (NPS 2015d). $PM_{2.5}$ concentrations ≥ 35.5 ppb are assigned a *Significant Concern* (NPS 2015d). $PM_{2.5}$ concentrations from 35.4–12.1 ppb are assigned *Moderate Concern* (NPS 2015d). *Good Condition* is when $PM_{2.5}$ concentrations are ≤ 12 ppb (NPS 2015d).

Visibility

Visibility conditions are assessed in terms of a Haze Index, a measure of visibility (dv) that is derived from calculated light extinction and represents the minimal perceptible change in visibility to the human eye (NPS 2011). Conditions measured near 0 dv are clear and provide excellent visibility, and as dv measurements increase, visibility conditions become hazier (NPS 2011). NPS ARD assesses visibility condition status based on the deviation of the estimated current visibility on mid-range days from estimated natural visibility on mid-range days (i.e., those estimated for a given area in the absence of human- caused visibility impairment) (NPS 2015d). The NPS ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network (NPS 2015d). Visibility on mid-range days is defined as the mean of the visibility observations falling within the range of the 40th through the 60th percentiles (NPS 2015d). A visibility condition estimate of less than 2 dv above estimated natural conditions indicates a *Good Condition*, estimates ranging from 2–8 dv above natural conditions indicate *Moderate Concern*, and estimates greater than 8 dv above natural conditions indicate *Significant Concern* (NPS 2015d).

Visibility trends are computed from the Haze Index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the CAA and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days (NPS 2015d). Although this legislation provides special protection for NPS areas designated as Class I, the NPS applies these standard visibility metrics to all units of the NPS. If the Haze Index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating (NPS 2015d). Otherwise, the Haze Index trend on the 20% haziest days is reported as the overall visibility trend (NPS 2015d).

Atmospheric Deposition of Mercury

The condition of Hg was assessed using estimated 3-year average Hg wet deposition (micrograms per meter squared per year [$\mu g/m^2/yr$]) and the predicted surface water methylmercury concentrations (nanograms per liter [ng/L]) at NPS I&M parks (NPS 2015d). It is important to consider both Hg deposition inputs and ecosystem susceptibility to mercury methylation when assessing Hg condition because atmospheric inputs of elemental or inorganic Hg must be methylated before it is biologically available and able to accumulate in food webs (NPS 2015d). Thus, Hg conditions cannot be assessed according to Hg wet deposition alone. Other factors like environmental conditions conducive to mercury methylation (e.g., dissolved organic carbon, wetlands, and pH) must also be considered (NPS 2015d). Hg wet deposition and predicted methylmercury concentrations are considered concurrently in the mercury status assessment matrix displayed above in to identify one of three park-specific mercury/toxics status categories: *Good Condition, Moderate Concern*, and *Significant Concern* (NPS 2015d).

4.6.4. Data and Methods

<u>Monitoring in the Park</u>

Air quality monitoring in the park has been limited. O_3 was monitored from June 2007 through September 2015 using a portable ozone monitoring station (POMS) located near the Visitor's Center (Figure 37) (EPA 2016b). Atmospheric deposition of N, S, or Hg, visibility, and $PM_{2.5}$ have not been measured within CAVE (NPS 2015b).

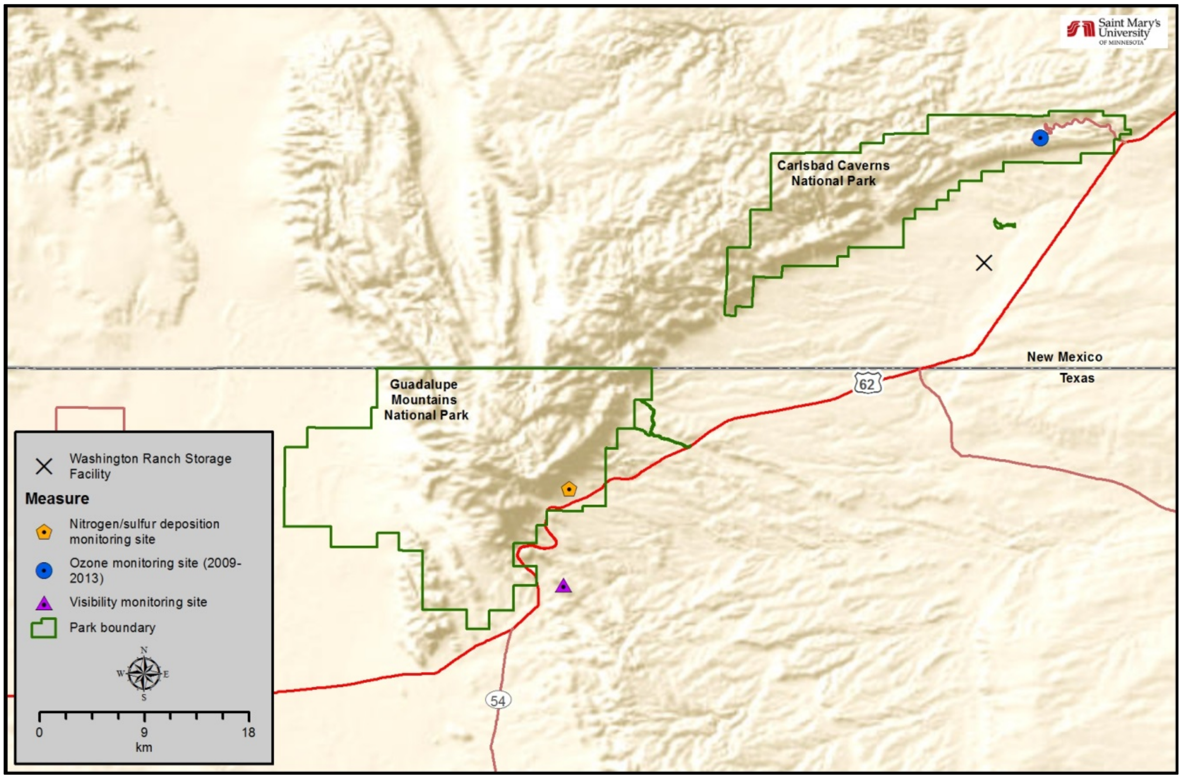

Figure 37. Location of air quality monitoring sites that provided data used in the air quality analysis for CAVE.

NPS Data Resources
Although data on some air quality parameters are not actively collected within park boundaries, data collected at several regional monitoring stations for various parameters can be used to estimate air quality conditions in CAVE (Figure 37). For parks not actively collecting air quality parameters, the NPS ARD provides estimates of O_3, wet deposition (N, S, and Hg), and visibility that are based on interpolations of data from regional air quality monitoring stations operated by NPS, EPA, various states, and other entities, averaged over the most recent 5 years (2009–2013). Estimates and conditions data for CAVE were obtained from the NPS Air Quality by Park data products page.

On-site or nearby data are needed for a statistically valid trends analysis. There are no on-site or nearby representative monitors to assess PM or N, S and Hg deposition trends. For visibility trend analysis, monitoring data from an Interagency Monitoring of Protected Visual Environments Program (IMPROVE) station is required (NPS 2015d). The IMPROVE GUMO site (GUMO1; operational since March 1988) meets this criterion and was used to represent CAVE (Figure 38) (NPS 2015d).

Other Air Quality Data Resources
The EPA Air Emission Sources database provides measures of state-level air pollutants (carbon monoxide [CO], lead [Pb], NO_x, VOCs, PM, and SO_2) grouped by major source sectors such as fires, agriculture, and industrial (EPA 2016a).

The National Atmospheric Deposition Program–National Trends Network (NADP-NTN) database provides annual average summary data for N and S concentration and deposition across the United States (US) (NADP 2016b). The NADP-NTN monitoring site closest to CAVE is located at GUMO Frijole Ranger Station in western Texas (Site ID: TX22) (Figure 37), approximately 40 km (25 mi) southwest of the park. This site is currently active and has collected data for the region since 1984 (NADP 2016b). Data summaries for this monitor are available on the NAPD-NTN website (NADP 2016b).

The NADP Mercury Deposition Network (MDN) provides weekly summary data for Hg deposition and concentration (NADP 2016a). Wet Hg deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trend analyses. Trends are computed for parks with a representative NADP MDN wet deposition monitor that is within 16 km (9.94 mi) of park boundaries (NPS 2015d). Predicted methylmercury concentrations in surface water were obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the US based on relevant water quality characteristics (pH, SO_4, and total organic carbon [TOC]) and wetland abundance (USGS 2015). At this time, there are no on-site or nearby representative monitors to assess wet mercury deposition trends.

Special Air Quality Studies

Sullivan et al. (2011a) identified ecosystems and resources at risk to acidification and excess N enrichment in national parks. These reports provide a relative risk assessment of acidification and nutrient enrichment impacts from atmospheric N and S deposition for parks in 32 I&M networks. Ecosystem sensitivity ratings to acidification from atmospheric deposition were based on percent sensitive vegetation types, number of high-elevation lakes, length of low-order streams, length of high-elevation streams, average slope, and acid-sensitive areas within the park (Sullivan et al. 2011a). Ecosystem sensitivity ratings to nutrient enrichment effects were based on percent sensitive vegetation types and number of high-elevation lakes within the park (Sullivan et al. 2011b).

Kohut (2007) employed a biologically-based method to evaluate the risk of foliar injury from O_3 at parks within the 32 Vital Signs Networks, the Appalachian National Scenic Trail, and the Natchez Trace National Scenic Trail. The assessment allows resource managers at each park to better understand the risk of O_3 injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of O_3 on plants.

Pardo et al. (2011) synthesizes current research relating atmospheric N deposition to effects on terrestrial and aquatic ecosystems in the U.S. and to identify empirical critical loads for atmospheric N deposition.

4.6.5. Current Condition and Trend

Atmospheric Deposition of Nitrogen

Five-year interpolated averages of N (from NO_3 and NH_4) wet deposition from the NPS ARD are used to estimate condition for deposition (NPS 2015a). The most recent 5-year average (2009-2013) estimates wet deposition of N at CAVE as 2.0 kg/ha/yr (NPS 2015a), which suggests atmospheric deposition of N in the moderate concern category (Figure 38) (See Table 23 for rating values). According to Sullivan et al. (2011b), ecosystems in the park were rated as having very high sensitivity to nutrient enrichment effects relative to all I&M parks, thus putting atmospheric deposition of N in the *Significant Concern* category (NPS 2015a).

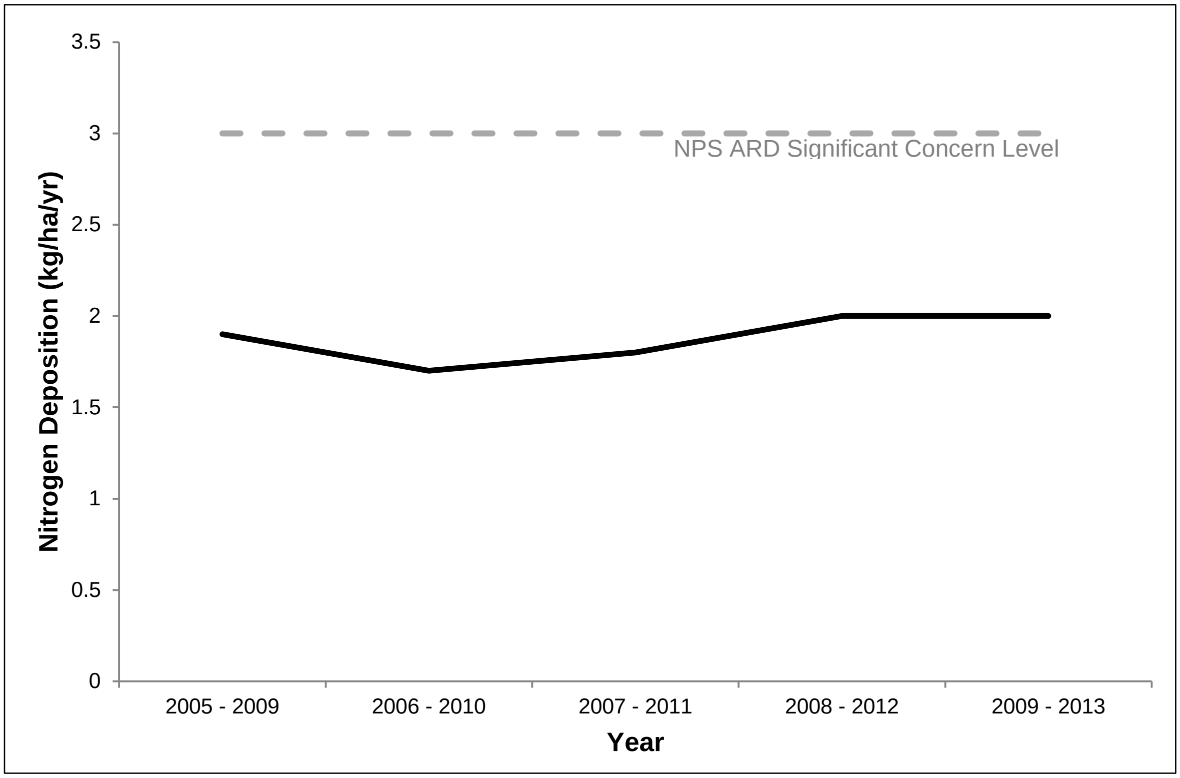

Figure 38. Estimated 5-year averages of nitrogen wet deposition (kg/ha/yr) at CAVE from the NPS ARD (NPS 2015a).

In addition to assessing wet deposition levels, critical loads can also be a useful tool in determining the extent of deposition impacts (i.e., nutrient enrichment) to park resources (Pardo et al. 2011). A critical load is defined as the level of deposition below which harmful effects to the ecosystem are not expected (Pardo et al. 2011). For CAVE, which falls into the North American Desert and Temperate Sierras (Level 1) ecoregions (Figure 39), NPS (2014) ARD suggested following critical load ranges for total N deposition (wet plus dry):

- 3.0 kg/ha/yr to protect lichens (North American Desert [4.0-7.0 kg/ha/yr for Temperate Sierra])
- 3.0-8.4 kg/ha/yr to protect shrubland, woodland, and desert grassland (North America Desert)

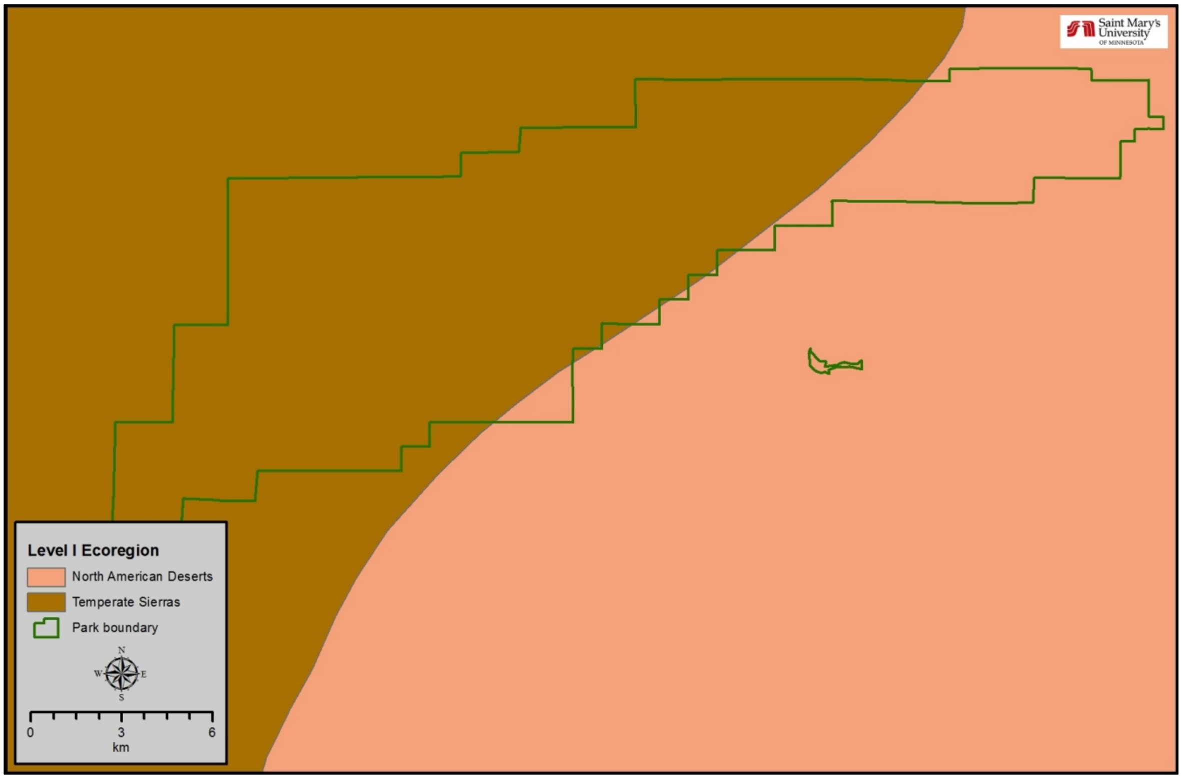

Figure 39. Two Level I ecoregions fall inside CAVE boundaries: Temperate Sierras and North American Deserts.

The lowest critical load level (3.0 kg/ha/yr) is identified as an appropriate management goal because it will protect the full range of vegetation in the park (Pardo et al. 2011). The estimated 2011–2013 average for total (wet plus dry) N deposition was 3.0 kg/ha/yr for the area where CAVE is located (NADP 2014). Therefore, the total N deposition level in the park is at the minimum ecosystem critical load for some park vegetation communities, suggesting that lichen and shrubland, woodland, and desert grasslands are at risk for harmful effects.

Concentrations of N compounds in wet deposition can be used to evaluate trends in deposition of N. Since atmospheric wet deposition can vary greatly depending on the amount of precipitation that falls in any given year, it can be useful to examine concentrations of pollutants, which factor out the variation introduced by precipitation. Figure 40 shows that NO_3 concentration has been slowly decreasing since the early 2000s, while NH_4 concentration varies between years (Figure 41).

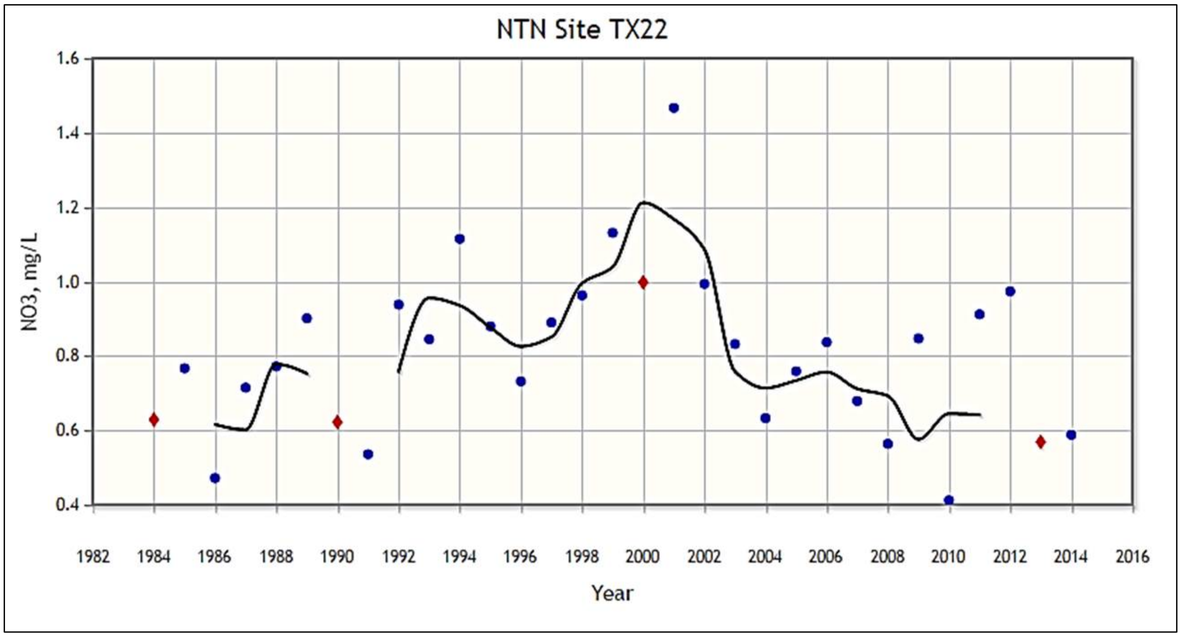

Figure 40. Annual weighted mean concentration of NO_3 in wet deposition from GUMO Frijole Ranger Station (NTN Site TX22) (NADP 2016b). The black line represents a smoothed 3-yr moving average.

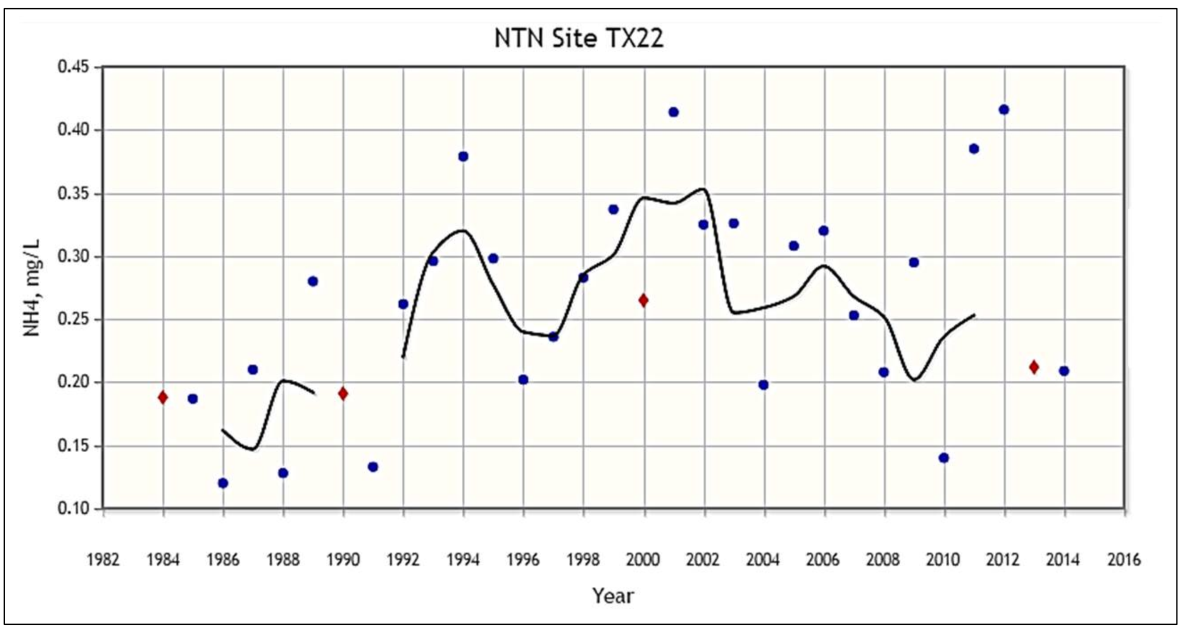

Figure 41. Annual weighted mean concentration of NH_4 in wet deposition from GUMO Frijole Ranger Station (NTN Site TX22) (NADP 2016b). The black line represents a smoothed 3-yr moving average.

Atmospheric Deposition of Sulfur

Five-year interpolated averages of S (from SO_4) wet deposition from the NPS ARD are used to estimate condition for deposition (NPS 2015a). The most recent 5-year average (2009-2013) estimates wet deposition of S at CAVE as 1.6 kg/ha/yr (NPS 2015a), which suggests atmospheric deposition of S in the moderate concern category (Figure 42) (See Table 23 for rating values).

According to Sullivan et al. (2011a), ecosystems in the park were rated as having very high sensitivity to acidification effects relative to all I&M parks, thus putting atmospheric deposition of S in the *Significant Concern* category (NPS 2015a).

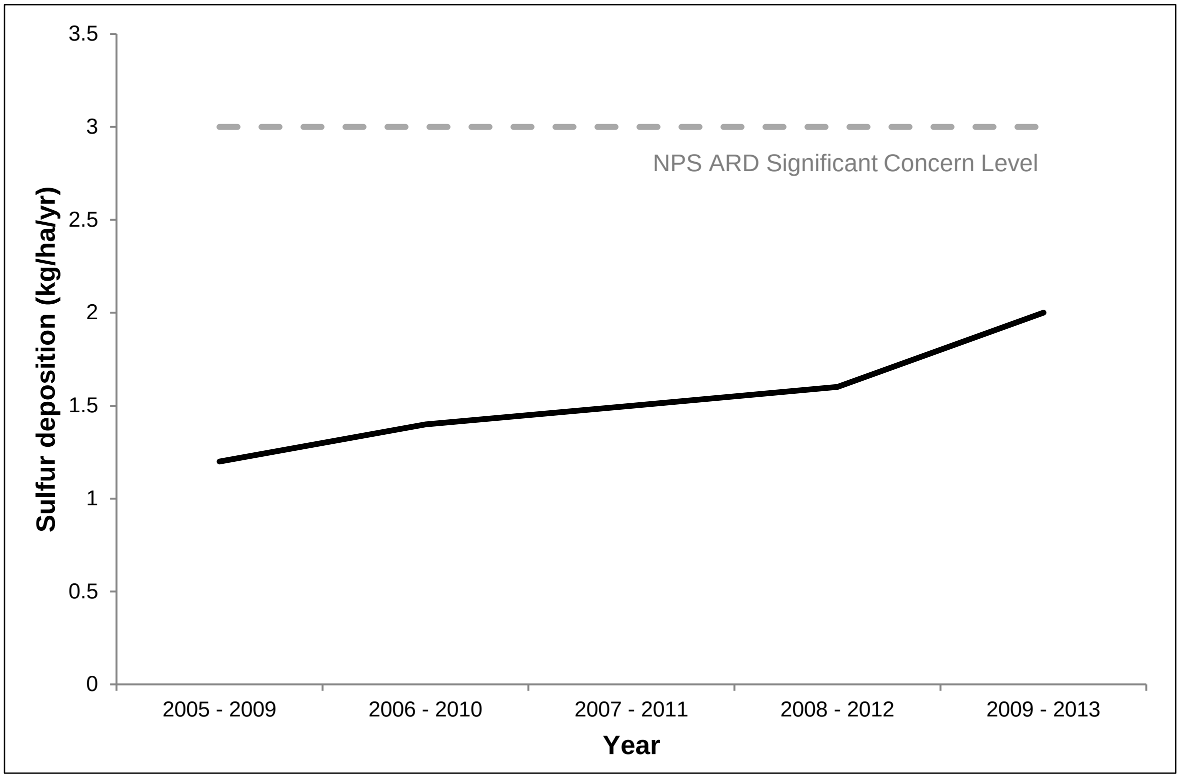

Figure 42. Estimated 5-year averages of S wet deposition (kg/ha/yr) at CAVE from the NPS ARD (NPS 2015a).

Concentrations (ng/L) of S compounds in wet deposition can be used to evaluate trends in deposition of S. Since atmospheric wet deposition can vary greatly depending on the amount of precipitation that falls in any given year, it can be useful to examine concentrations of pollutants, which factor out the variation introduced by precipitation. Figure 43 shows that SO_4 concentration levels showed a decrease around 2001, but levels then increased between 2008 and 2011 (NADP 2016b).

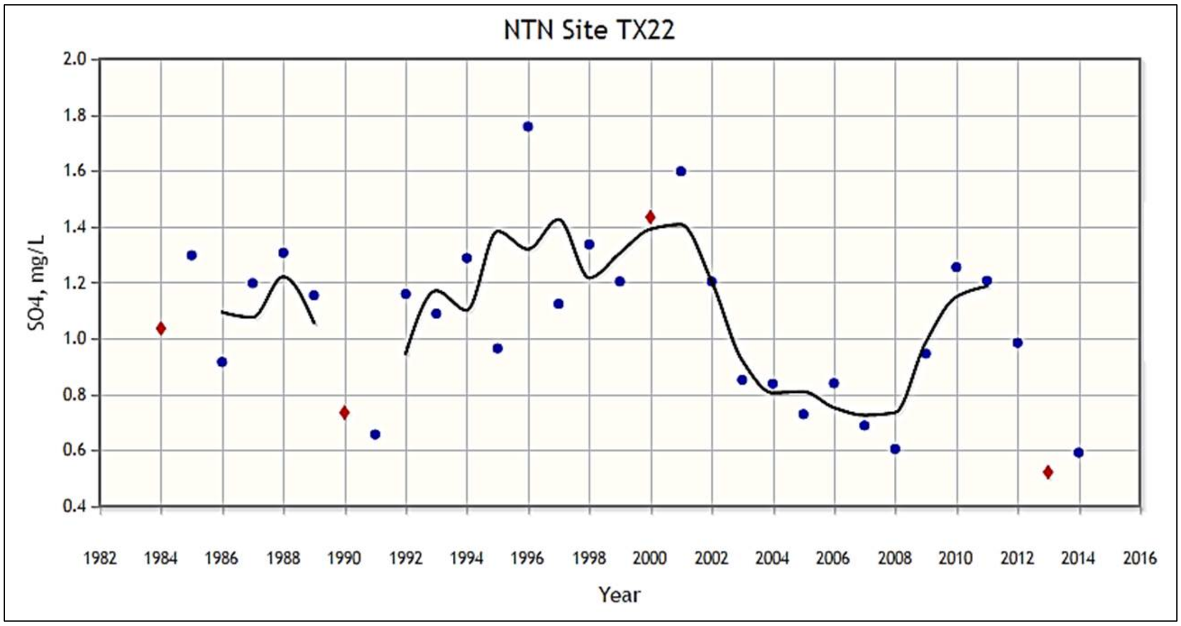

Figure 43. Annual weighted mean concentration of SO_4 in wet deposition from GUMO Frijole Ranger Station (NTN Site TX22) (NADP 2016b). The black line represents a smoothed 3-yr moving average.

Ozone Concentration

The condition of human risk from O_3 in NPS units is determined by calculating the 5-year average of the fourth-highest daily maximum of 8-hour average O_3 concentrations measured at each monitor within an area over each year (NPS 2015a). The most recent 5-year (2009–2013) estimated average for 4th highest 8-hour O_3 concentration at CAVE is 68.1 ppb (NPS 2015a), which is considered *Moderate Concern*.

Vegetation health risk from ground-level O_3 condition is determined by estimating a 5-year average of annual maximum 3-month 12-hour W126 values. The 2009–2013 estimated W126 metric of 10.5 ppm-hrs falls in the *Moderate Concern* category (NPS 2015a).

Ozone was monitored at CAVE from June 2007 to September 2015 (NPS 2015a, EPA 2016b). Figure 44 illustrates the trend in annual fourth-highest daily maximum 8-hour values during this period. For 2007-2015, O_3 concentration fluctuated (no statistically significant trend) (NPS 2015a, EPA 2016b). Concentrations ranged from 63.0 ppb in 2009 and 2010 to 72.0 ppb in 2012 but seem to be declining since (NPS 2015a, EPA 2016b). All measurements were below the 2008 national standard considered protective of human health, although 2 years (2008, 2012) were above the newly adopted 2015 O_3 standard (Figure 45).

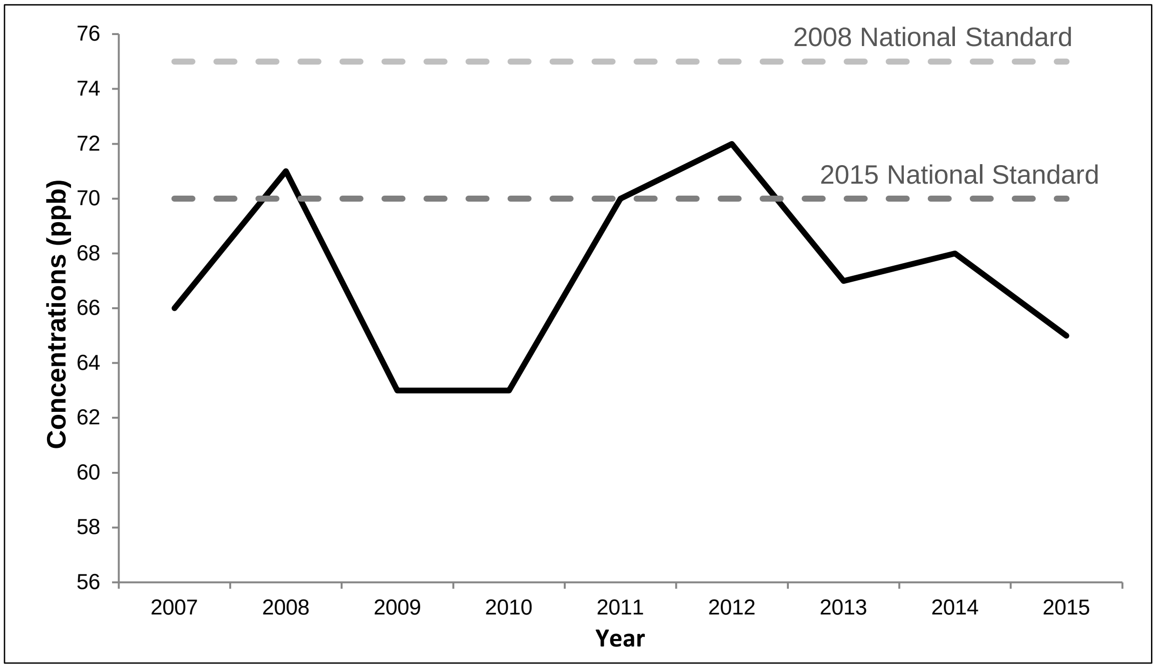

Figure 44. Annual 4th highest 8-hour maximum O_3 concentrations (ppb) at CAVE, 2007-2015 (NPS 2015a, EPA 2016b).

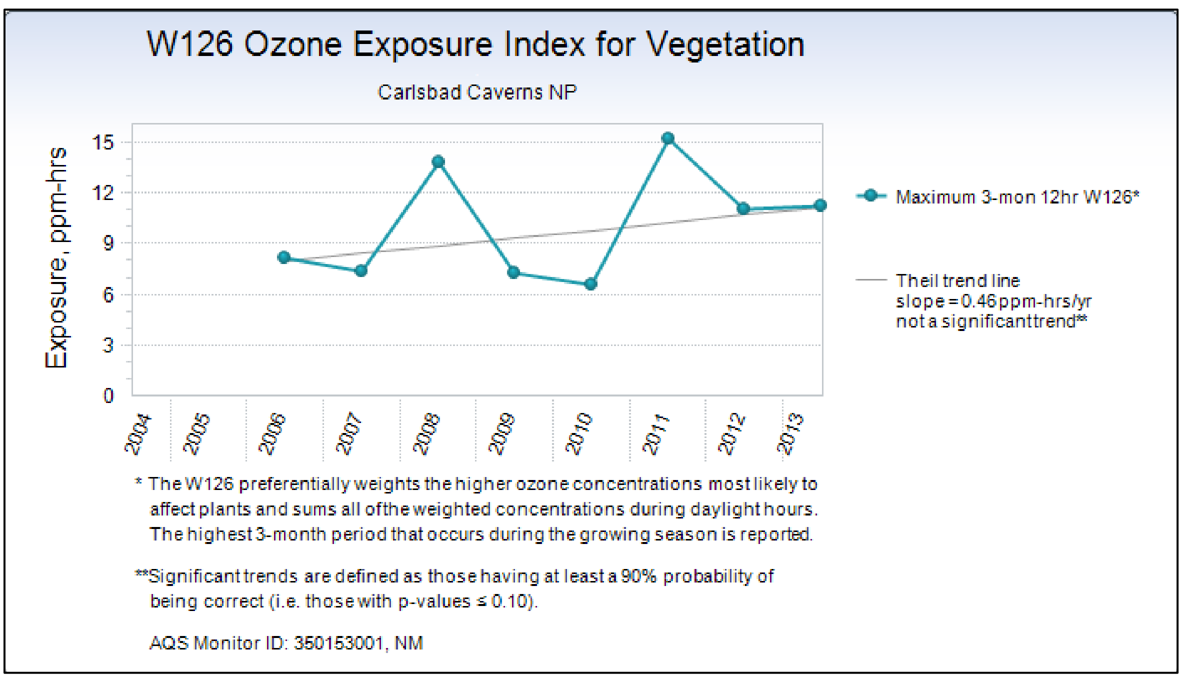

Figure 45. W126 O_3 exposure index for vegetation concentration (ppm-hrs) at CAVE (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

For 2006–2013, the trend in the W126 metric at CAVE also fluctuated between years (NPS 2015a). Values ranged from 6.6 to 15.2 ppm-hrs and two years had values greater than 13 ppm-hr, which falls in the *Significant Concern* category (NPS 2015a).

Kohut (2007) assessed O_3 concentrations in the CHDN and the risk of injury to plant species that are sensitive to sustained O_3 exposure. Estimations by kriging indicate that, from 1995-1999, ambient O_3 concentrations in CAVE frequently exceeded 60 ppb but only occasionally exceeded 80 ppb; concentrations exceeding 100 ppb rarely occurred (no more than 8 hours across 5 years of monitoring) (Kohut 2007). Sensitive plant species begin to experience foliar injury when exposed to O_3 concentrations of 80-120 ppb/hour for extended periods of time (8 hours or more). Drier soil conditions can decrease the ability of plants to absorb O_3, reducing the risk of foliar injury during drought conditions (Kohut 2007). However, the infrequent incidences of concentrations higher than 80 ppb in CAVE and rare or mild drought conditions made the risk of foliar injury from O_3 low at that time (Kohut 2007). If the level of risk increases in the future, foliar damage may be assessed using ozone-sensitive plant species as indicators (NPS 2006).

Particulate Matter

In 2011, Eddy County, New Mexico had between 0.70-1.60 tons per square miles of $PM_{2.5}$ emissions (EPA 2006). The majority of these emissions came from dust (23.3%) and fire (14.5%) (Table 27) (EPA 2006).

Table 27. 2011 $PM_{2.5}$ emissions for Eddy County listed by source sector; emissions are given in total tons versus tons per square mile (EPA 2006).

Source Sector	**Emissions (Short Tons)**	**Source Sector**	**Emissions (Short Tons)**
Unpaved road dust	1,786	Waste Disposal	66
Paved road dust	78	Commercial Cooking	21
Construction dust	64	Non-Industrial NEC	0
Dust Total	**1,928**	**Miscellaneous Total**	**87**
Wildfires	1,119	On-road	47
Prescribed Fires	64	Non-road	25
Agricultural Field Burning	15	Locomotives	2
Fires Total	**1,198**	Aircraft	1
NEC	257	**Mobile Total**	**75**
Oil and Gas Production	242	Industrial Boilers, ICEs	30
Mining	169	Residential	26
Petroleum Refineries	38	Comm/Institutional	9
Storage and Transfer	2	Industrial Boilers	7
Industrial Processes Total	**708**	Electric Generations	0
Agriculture Total (Crop and Livestock Dust)	**131**	**Fuel Combustion Total**	**72**

Despite data available at the state and county level, due to a lack of particulate matter monitors near CAVE and no data available from representative monitors (Ksienya Pugacheva, NPS ARD Natural Resource Specialist, written communication, 2 June 2016), an accurate assessment of PM concentrations for the park could not be completed at this time.

Visibility

Five-year estimated averages of visibility on mid-range days minus natural condition visibility on mid-range days are used to estimate condition for visibility. The 2009–2013 estimated visibility on mid-range days was 7.0 dv above estimated natural conditions (NPS 2015a). This estimate falls into the *Moderate Concern* category based on NPS criteria for air quality assessment.

For 2004-2013, the trend in visibility at the GUMO1 IMPROVE monitor remained relatively unchanged (no statistically significant trend) on the 20% clearest days (Figure 46) and remained relatively unchanged (no statistically significant trend) on the 20% haziest days (Figure 47) (NPS 2015a). The primary visibility impairing pollutants on the clearest days from 2009–2013 were ammonium sulfate, ammonium nitrate, coarse mass, and organic carbon (Figure 48), and pollutants on the haziest days from 2009-2013 were ammonium sulfate, coarse mass, organic carbon, and fine soil (Figure 49) (NPS 2015a).

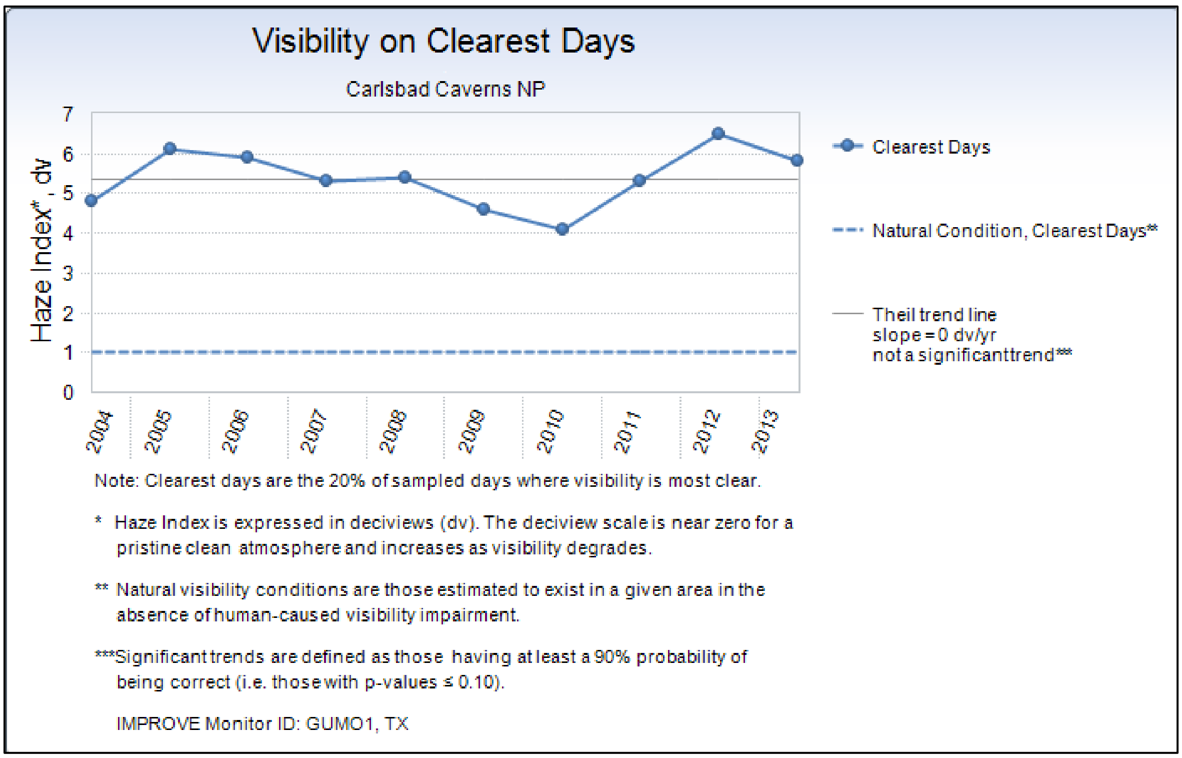

Figure 46. 10-year trend (2004-2013) in visibility for the 20% clearest days (dv) for CAVE. Values were interpolated from conditions at GUMO1, TX (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

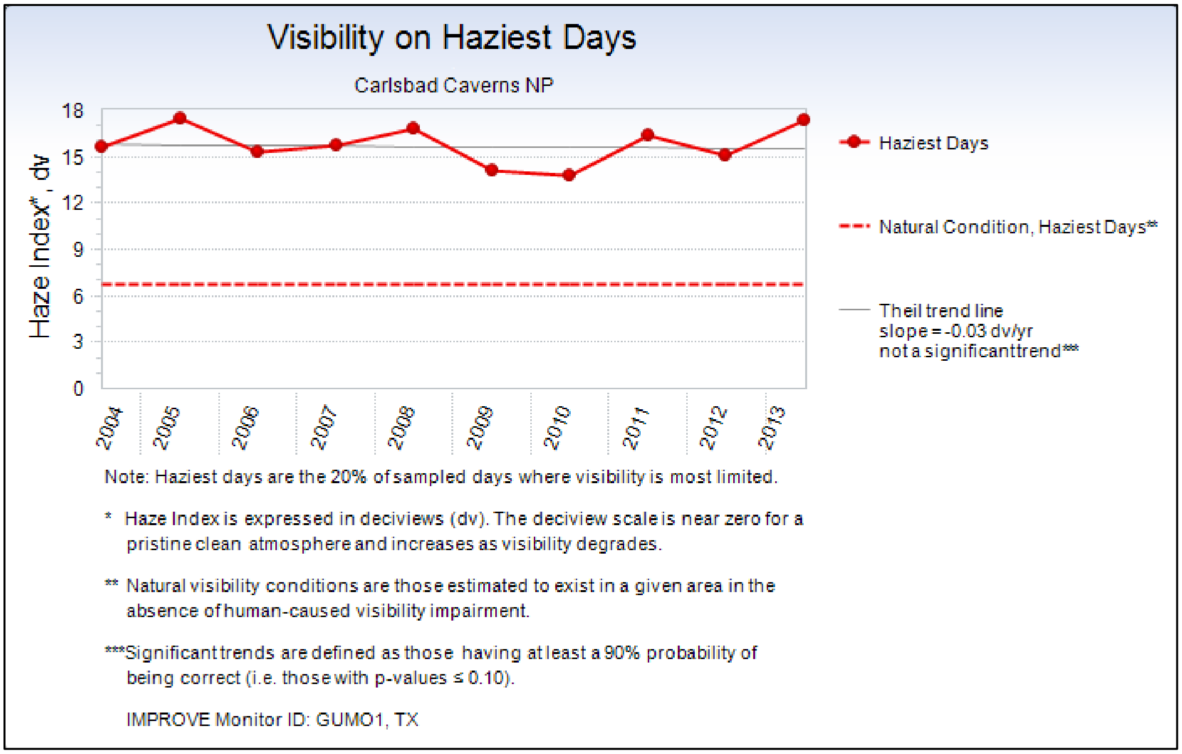

Figure 47. 10-year trend (2004-2013) in visibility for the 20% haziest days (dv) for CAVE. Values were interpolated from conditions at GUMO1, TX (NPS 2015a). Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

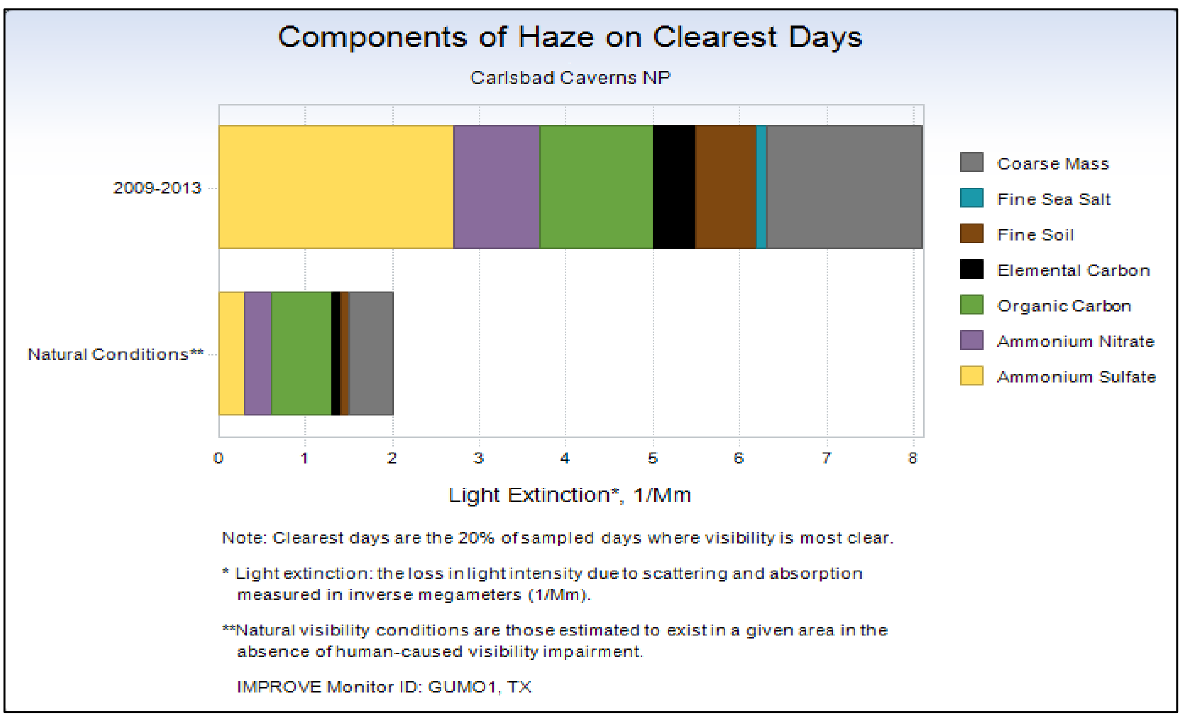

Figure 48. Composition of haze on clearest days (2009-2013) for CAVE (NPS 2015a). Data were interpolated from GUMO1, TX. Graph was produced by the NPS ARD Air quality conditions and trends website (NPS 2015a).

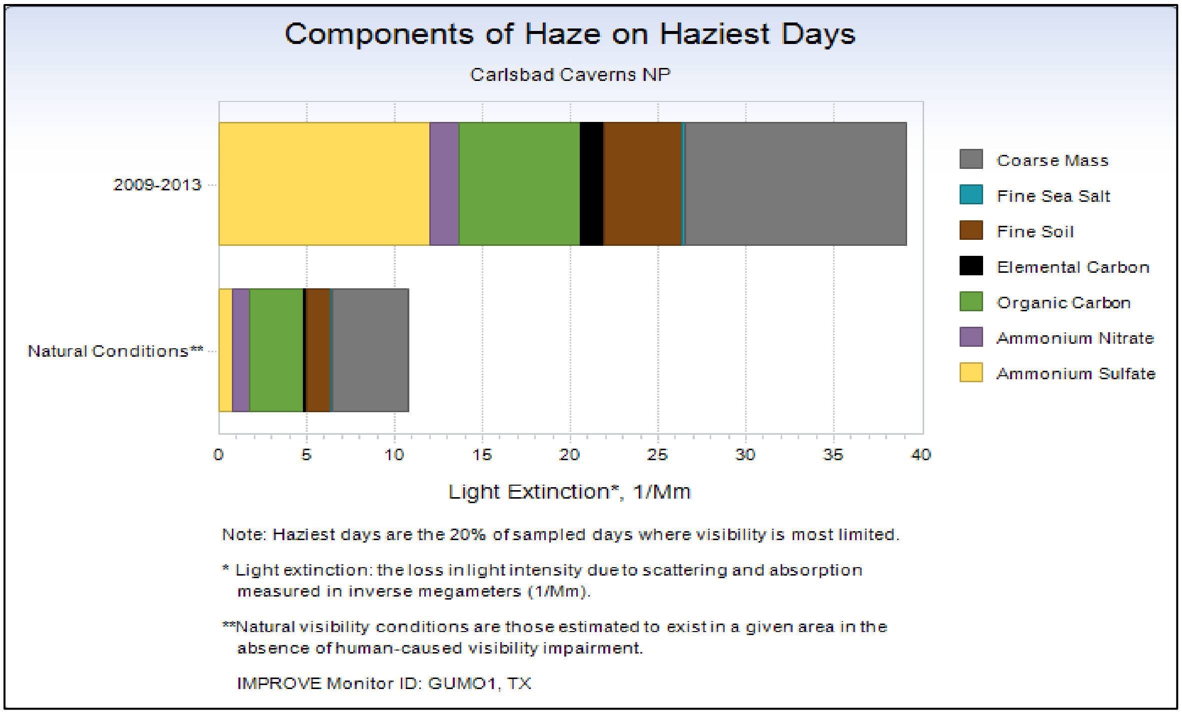

Figure 49. Composition of haze on the haziest days (2009-2013) for CAVE (NPS 2015a). Data were interpolated from GUMO1, TX. Graph was produced by the NPS ARD Air quality and trends website (NPS 2015a).

Atmospheric Deposition of Mercury

Both Hg deposition inputs and ecosystem susceptibility to mercury methylation inputs are required when assessing overall Hg conditions because atmospheric inputs of elemental or inorganic Hg must be methylated before it is biologically available and able to accumulate in food webs (NPS 2015d). Despite a lack of Hg monitoring data, an estimated wet mercury deposition range and predicted level of methylmercury concentration are used as a base for this measure (NPS 2015b). Due to landscape factors influencing the uptake of Hg in an ecosystem, the estimated wet Hg deposition for surface waters in CAVE ranges from 5.9 to 8.5 µg/m^2/yr (NPS 2015d) and the predicted methylmercury concentration is estimated at 0.18 (Pugacheva, written communication, 2 June 2016). These estimates, when combined, fall into the *Significant Concern* category based on NPS criteria for this measure.

Threats and Stressor Factors

CAVE natural resource managers identified several potential threats to the parks air quality, including oil and gas development from the El Paso natural gas facility, vehicle emissions from both highway traffic and the oil industry, air pollution from the cities of El Paso (Texas) and Juárez (Mexico), and smoke from wildfires.

CAVE is located within the Permian oil and gas basin, an area with extensive historic and ongoing oil and gas development (RRC 2016). The basin underlies most of west Texas and extreme southeastern New Mexico; it covers an area approximately 402 km (250 mi) wide and 483 km (300 mi) long (RRC 2016). The basin has produced over 29 billion barrels of oil and 75 trillion cubic feet of gas (RRC 2016). CAVE is located in the Bone Spring Formation of this basin (Figure 50), a formation that has been increasing in thousand-barrel-per-day production from January 2000 to May 2014 (Budzik and Perrin 2014).

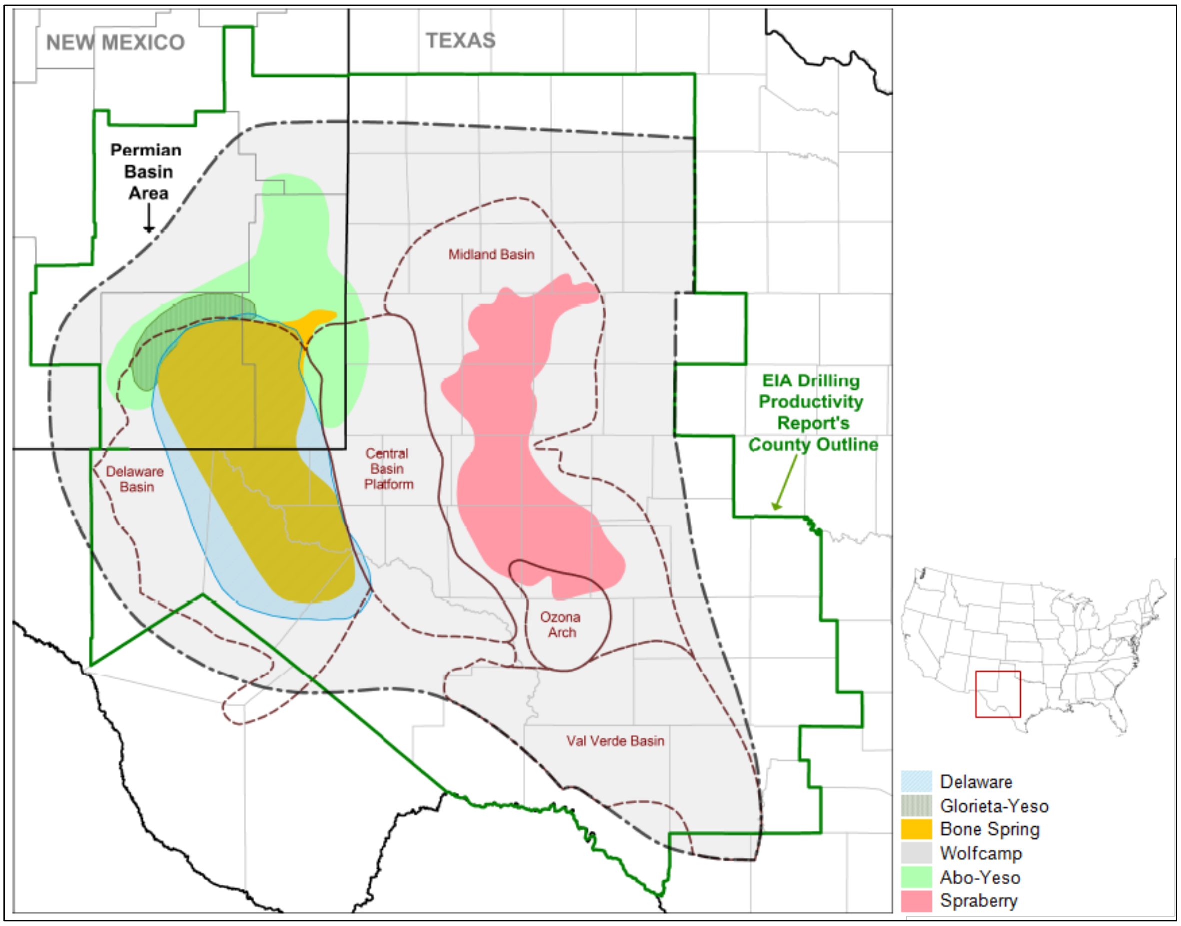

Figure 50. A few of the oil-producing formations found in the Permian Basin. CAVE is found on top of the Bone Spring formation; this formation has been increasing in thousand-barrel-per-day production from January 2000 to May 2014 (Budzik and Perrin 2014). Map was produced by the U.S. Energy Information Administration (Budzik and Perrin 2014).

The Washington Ranch Storage Facility (Figure 37) is owned by the El Paso Natural Gas Company, LLC and is located approximately 8 km (5 mi) south of CAVE. The main purpose of the facility is to store natural gas and oil (NMED 2015). An emissions report was conducted in 2015 by the New Mexico Environment Department (NMED); according to their report, the facility produced the following amounts of greenhouse gases (GHGs): 10,293 metric tons of carbon dioxide (CO_2), 6,799 metric tons of methane (CH_4), and 27 metric tons of N_20 (NMED 2015). These gases all contribute to accelerated climate change and reduce the overall air quality (EPA 2012). The report conducted by NMED (2015) also stated that the facility produced the following criterial pollutants, hazardous air pollutants (HAPs), and VOC emissions: 59 tons of CO, 60 tons of nitrous oxide (N_2O), 46 tons of VOCs, 7 tons of HAPs, 3 tons of PM, and 1 ton of SO_2. HAPs are considered toxic pollutants that cause cancer or other serious health impacts such as reproductive effects or birth defects (EPA

2015b). VOCs are carbon-based chemicals that, depending on the length and concentration of exposure, can be problematic for people with respiratory issues such as asthma or sensitivities to chemicals (MDH 2016).

There are also numerous types of equipment associated with oil and gas development and production, such as drill rigs, fracturing engines, compressors, heaters/treaters, separators, dehydration units, and tanks. Each of these individually small “sources” emit air pollutants (NOx, VOCs, GHGs, hydrogen sulfide [H_2S], PM, and HAPs) that cumulatively contribute to regional air quality concerns (Pugacheva, written communication, 11 December 2015). In addition, exhaust and dust from motor vehicles on and near CAVE emit N_2O, VOCs, and PM (Pugacheva, written communication, 11 December 2015). Along with the oil and gas industry’s emissions, vehicle traffic can contribute to air pollution as well (HEI 2010). Motorized vehicles produce CO_2, CO, hydrocarbons (HC), NOx, PM, and mobile-source air toxins (MSATs) (HEI 2010).

Other than oil and gas development, urban development could be a potential contributor to decreased air quality. The City of El Paso, Texas had a population of 649,121 in 2010 (USCB 2016) and Juárez City is the second most populated city on the U.S.-Mexico border, with a population of 1.3 million in 2010 (CIHRE 2011). Both urban areas are approximately 177 km (110 mi) southwest of CAVE (Figure 51).

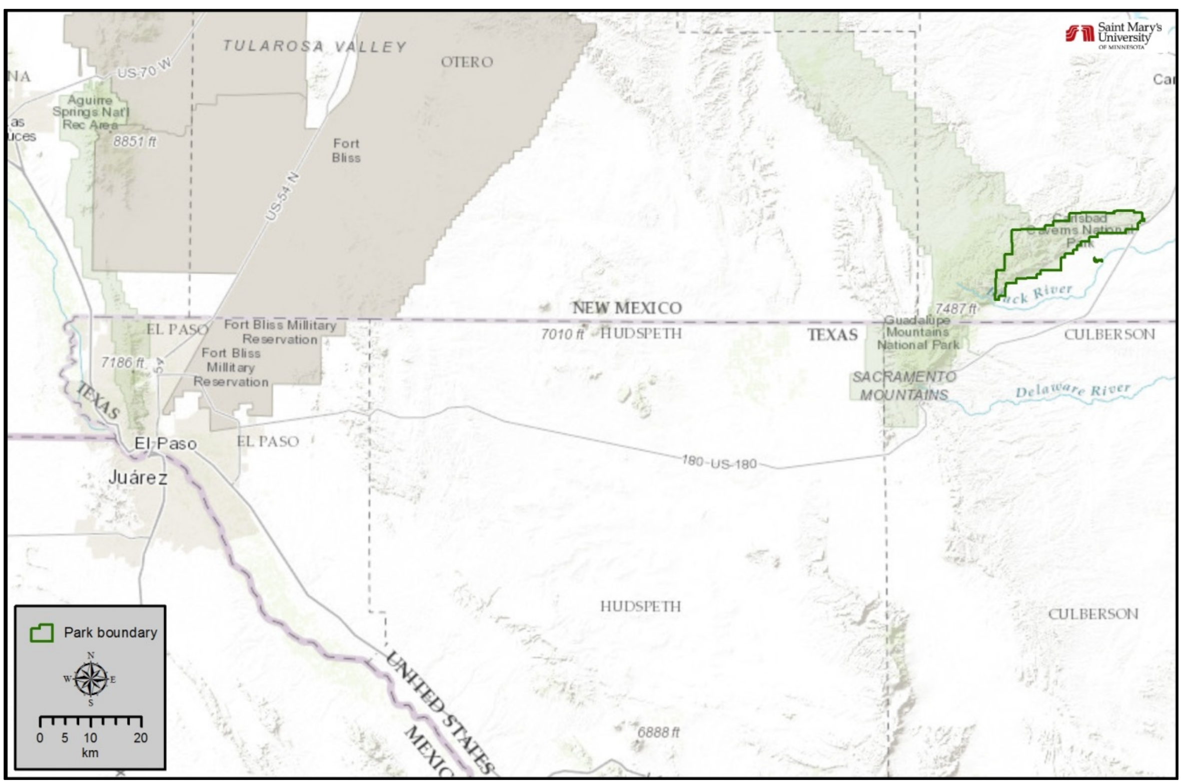

Figure 51. El Paso, Texas and Juárez City in Mexico are approximately 177 km (110 mi) southwest of the park.

The Renewable and Appropriate Energy Laboratory (RAEL) at the University of California-Berkeley is a climate change research group that created a nation-wide interactive carbon footprint map based on zip codes (RAEL 2016). According to this “CoolClimate Map,” the city of El Paso generates on average 47.6 tons of CO_2 emissions a year; this mainly comes from transportation and housing emissions (RAEL 2016). CAVE may be impacted by air pollution from this major metropolitan area to the west. The degree and timing of these impacts depend on prevailing wind directions, which can vary with season. Based on wind speed and direction data for El Paso (from 1984-1992), a high percentage of the prevailing winds (approximately 20%) come from the west or southwest (Figure 52) and could eventually blow the city’s air pollution toward CAVE (TCEC 2015).

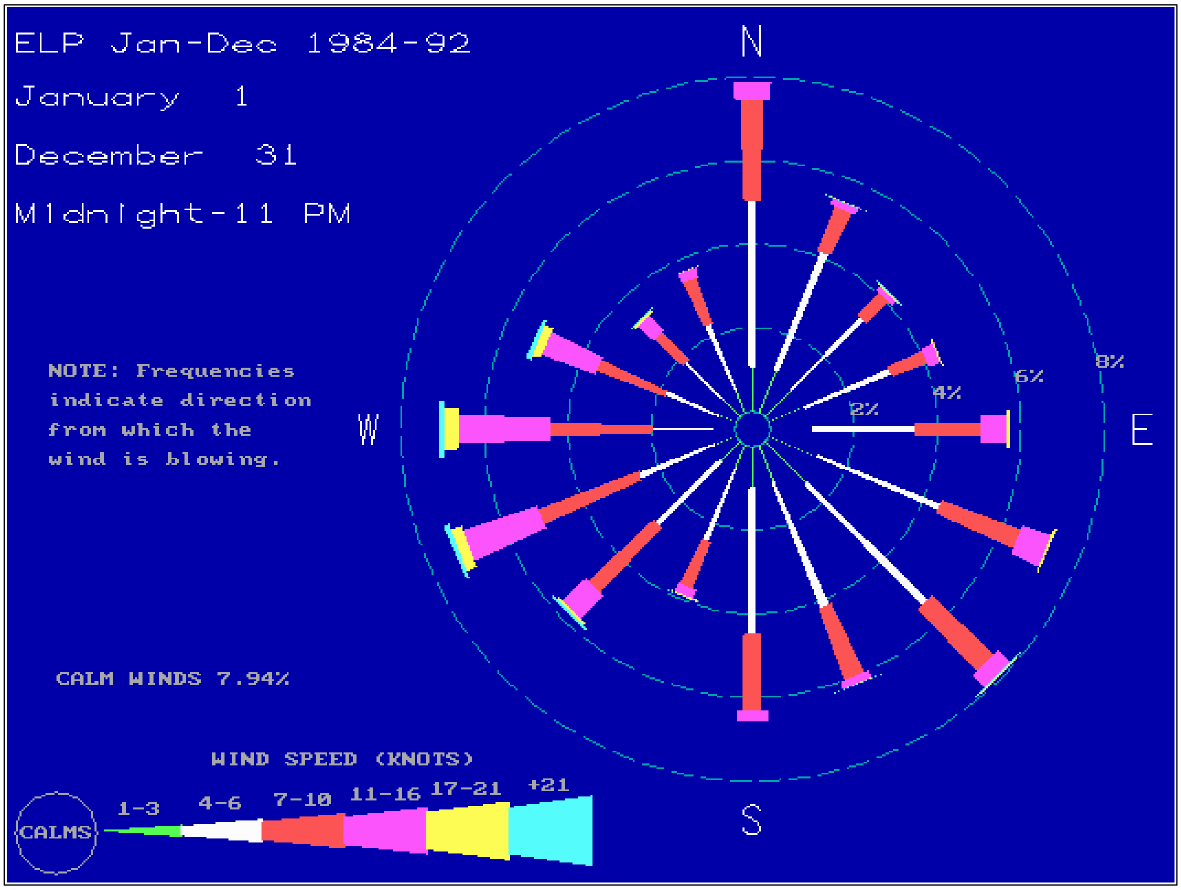

Figure 52. A wind rose plot for El Paso, Texas that measures wind speed and direction. A high percentage of the wind comes from the west and southwest (TCEQ 2015).

Droughts throughout the west have increased the frequency and severity of wildfires, which produce particulates and can significantly impair visibility (Westerling et al. 2006, NPS 2010). Wildfires may also become more frequent if plant biomass increases as a result of nutrient enrichment from N deposition. Research in the arid environment of California’s Joshua Tree National Park showed that N deposition as low as 3 kg/ha/yr increased wildfire risk in pinyon-juniper communities, due to increased growth of fine fuels such as annual grasses (Rao et al. 2010).

Data Needs/Gaps

There are no Hg wet deposition or PM air quality monitors within an acceptable distance to accurately represent conditions in the park. No Hg wet deposition or methylation data is available at the time of this writing and the nearest active NADP-MDN monitor that provides annual averages for mercury deposition is located nearly 282 km (175 mi) northwest of CAVE (Site ID: NM 10). Periodic or consistent monitoring of atmospheric deposition and PM would help managers better understand the local air quality conditions in and around CAVE and how they may affect other park resources.

Overall Condition

Atmospheric Deposition of Nitrogen

The *Significance Level* for this measure was defined as a 3 by the project team. Current NPS estimated averages for N depositions are considered to be of *Significant Concern*, based on NPS criteria for rating air quality and ecosystem effects stated by Sullivan et al. (2011b). The most recent total N deposition estimates (wet plus dry) for CAVE are at the minimum ecosystem critical load for some park vegetation communities (as defined by Pardo et al. [2011] and NPS ARD [2014]), suggesting lichen and shrubland, woodland, and desert grasslands are at risk for harmful effects. Overall, atmospheric deposition of N was assigned a *Condition Level* of 3, or of significant concern.

Atmospheric Deposition of Sulfur

The *Significance Level* for this measure was also defined as a 3 by the project team. Current NPS estimated averages for S depositions are considered to be of *Significant Concern*, based on NPS criteria for rating air quality and ecosystem effects stated by Sullivan et al. (2011a). In addition, with concentrations of SO_4 increasing since 2008, atmospheric deposition of S was assigned a *Condition Level* of 3, or of significant concern.

Ozone Concentration

The *Significance Level* for O_3 was defined as a 2 by the project team. Current human health and vegetation risk from ground-level O_3 falls into the *Moderate Concern* category based on NPS criteria for rating air quality condition. Annual 4th highest 8-hour maximum concentrations from 2007 through 2015 were below the EPA's 2008 standard protective of human health (NPS 2015a, EPA 2016b). Although two years (2008, 2012) were above the new 2015 O_3 standard, O_3 levels seem to be in decline since 2012 (NPS 2015a, EPA 2016b). Despite that, the *Condition Level* for O_3 concentration was assigned a 2, indicating moderate concern, based on the rating according to NPS ARD standards.

Particulate Matter

A *Significance Level* of 3 was assigned PM by the project team. Due to a lack of particulate matter monitors near CAVE and no data available from representative monitors, a *Condition Level* cannot be assigned at the time of this writing.

Visibility

The *Significance Level* for visibility was also defined as a 3 by the project team. Current interpolated average visibility estimates for CAVE fall into the *Moderate Concern* category based on NPS criteria. Estimated visibility on the 20% clearest days also falls just within the moderate concern category (close to good condition), while visibility on the 20% haziest days falls into the significant concern category (NPS 2015a). The *Condition Level* for visibility was assigned a 2, indicating that visibility is of moderate concern, based on NPS ARD standards.

Atmospheric Deposition of Mercury

This measure was assigned a *Significance Level* of 2. Despite a lack of Hg monitoring data, the estimated wet Hg deposition for surface waters in CAVE ranges from 5.9 to 8.5 µg/m^2/yr (NPS 2015d) and the predicted methylmercury concentration is estimated at 0.18 (Pugacheva, written communication, 2 June 2016). Due to the aforementioned factors, a *Condition Level* of 3, or significant concern, was assigned.

Weighted Condition Score

The *Weighted Condition Score* for CAVE air quality is 0.87, which is on the higher end of the significant concern range. A trend was not assigned, due to the lack of data from within or near the park itself. Because of the use of interpolated air quality estimates for most measures rather than on-site data, the confidence in this condition assessment is medium.

Air Quality			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.87**
Atmospheric Deposition of Nitrogen	3	3	
Atmospheric Deposition of Sulfur	3	3	
Ozone Concentration	2	2	
Particulate Matter	3	N/A	
Visibility	3	2	
Atmospheric Deposition of Mercury	2	3	

4.6.6. Sources of Expertise

- Ksienya Pugacheva, NPS ARD Natural Resource Specialist.
- Cheryl McIntyre, CHDN Physical Scientist.

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4.7. Dark Night Skies

4.7.1. Description

A lightscape is a place or environment characterized by the natural rhythm of the sun and moon cycles, clean air, and of dark nights unperturbed by artificial light (NPS NSNSD 2015a). The NPS directs each of its units to preserve, to the greatest extent possible, these natural lightscapes (NPS 2006). Natural cycles of dark and light periods during the course of a day affect the evolution of species and other natural resource processes such as plant phenology (NPS 2006, NPS NSNSD 2015a). Several species require darkness to hunt, hide their location, navigate, or reproduce (NPS NSNSD 2015a). In addition to the ecological importance of dark night skies, park visitors expect skies to be free of light pollution and allow for star observation.

CAVE is located in a rather remote portion of southeast New Mexico, near the New Mexico–Texas border. The closest anthropogenic light source is Whites City, New Mexico (Figure 53). Whites City is located approximately 6 km (3.7 mi) to the east of the park (Duriscoe and Magargal 2007). Other locations that have a negative impact on the natural lightscape at CAVE are Carlsbad, Artesia, and Roswell, New Mexico, and El Paso, Texas (Figure 53) (Duriscoe and Magargal 2007). Additional anthropogenic light sources in the vicinity include a drilling rig and two outdoor lights located to the southeast of the park (Duriscoe and Magargal 2007).

Figure 53. Location of the park and nearby sources of anthropogenic light.

The resource of a dark night sky is important to the NPS for a variety of reasons. First, the preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photic environment within the range of natural variability. Excursions outside this natural range may result in a modification to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals (NPS NSNSD 2015a). The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved. Second, the “scenery” of national park areas does not just include the daytime hours (NPS NSNSD 2015a). A natural starry sky absent of anthropogenic light is a key scenic resource, especially at large wilderness parks remote from major cities. Third, the history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes (NPS NSNSD 2015a). As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present. Fourth, the recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire or “sleeping under the stars” (NPS NSNSD 2015a). And lastly, night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology (NPS NSNSD 2015a).

4.7.2. Measures

The dark night sky condition will be assessed using the data collected by the NPS Natural Sounds and Night Sky Division (NSNSD). During field visits the NSNSD collects data for a suite of measures in order to define the current condition of dark night skies in a park unit. These measures typically include:

- Sky luminance over the hemisphere in high resolution (thousands of measurements comprise a data set), reported in photometric luminance units (V magnitudes per square arc second [mag/arcsec^2] or milli-candela per square meter [mcd/m^2]) or relative to natural conditions, often shown as a sky brightness contour map of the entire sky. V magnitude (mags) is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a “Johnson-Cousins V” filter. It is similar to the “CIE photopic” broadband function for wavelengths of light to which the human eye is sensitive (Bessell 1990);
- Integrated measures of anthropogenic sky glow from selected areas of sky that may be attributed to individual cities or towns (known as city light domes), reported in milli-Lux of hemispheric illuminance or vertical illuminance;
- Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispheric (or horizontal) illuminance, V-magnitudes of the integrated hemisphere, or ratio of anthropogenic illuminance to natural illuminance;
- Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as the Wilderness boundary), in milli-Lux;
- Visual observations by a human observer, such as Bortle Class and Zenith limiting magnitude (ZLM);
- Integrated synthesized measure of the luminance of the sky within 50 degrees of the Zenith, as reported by the Unihedron Sky Quality Meter (SQM), in mag/arcsec^2.

4.7.3. Reference Conditions/Values

Park staff identified the absence of anthropogenic light as the preferred reference condition. This condition can be defined as the absence of artificial light in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows:

> *No portion of the sky background brightness exceeds natural levels by more than 200 percent, and the sky brightness at the Zenith does not exceed natural Zenith sky brightness by more than 10 percent. These values correspond to readings of 2.0 and 0.1. The ratio of anthropogenic hemispheric illuminance to natural hemispheric illuminance from the entire night sky does not exceed 20 percent. The observed light from a single visible anthropogenic source (light trespass) is not observed as brighter than the planet Venus (0.1 milli-Lux) when viewed from within any area of the park designated the naturally dark zone* (Dan Duriscoe, NPS NSNSD, pers. comm., 2011).

Achieving this reference condition for preserving natural night skies is well summarized in the NPS Management Policies (NPS 2006, p. 57) as follows in section 4.10:

> *The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light.*

Implementing this directive in CAVE requires that facilities within the park meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park:

- produce zero light trespass beyond the boundary of their intended use;
- be of an intensity that meets the minimum requirement for the task, but does not excessively exceed that requirement;
- be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow;
- be controlled intelligently, preventing unnecessary dusk to dawn bright illumination of areas.

4.7.4. Data and Methods

Data were collected for dark sky documentation in CAVE from the northeast corner of the old tennis court on two separate occasions, the night of 17 April 2007 and the nights of 31 January and 1 February 2008 (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). Data were collected for a suite of measures during each visit. Figure 54 displays the data collection site (tennis court) in relation to the Visitor Center.

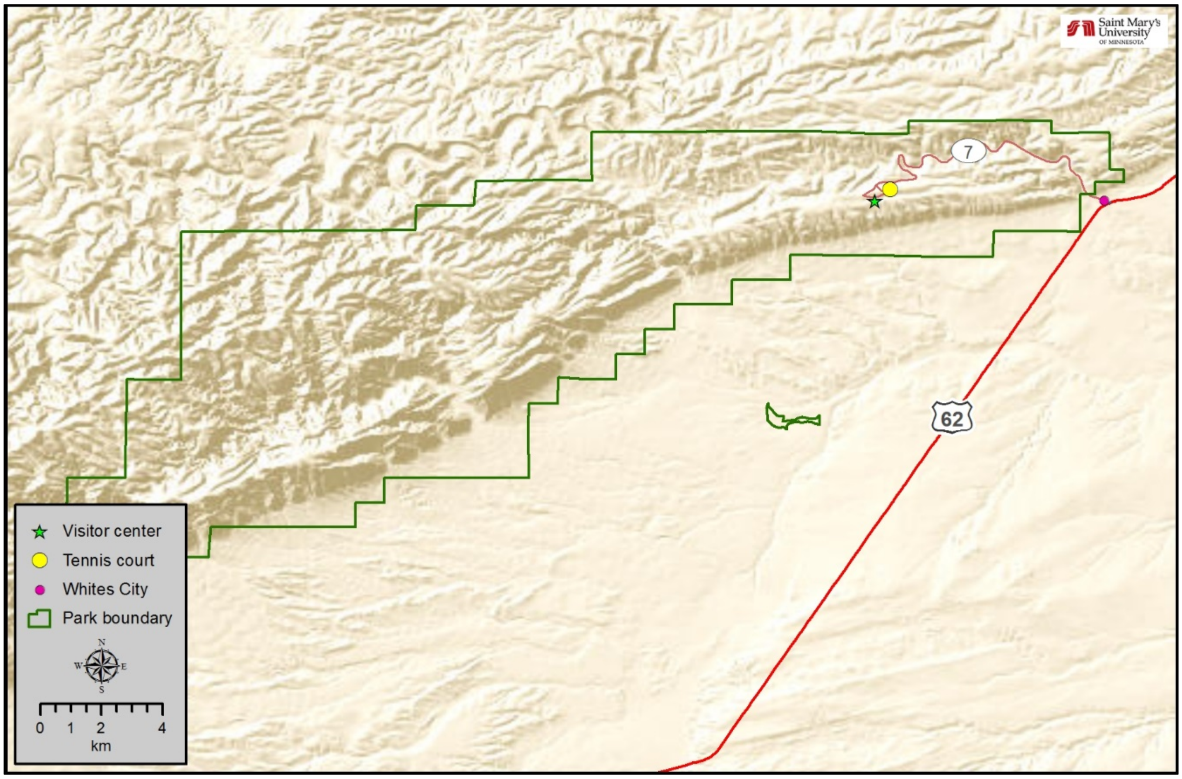

Figure 54. Location of Dark Night Sky sample site at CAVE.

4.7.5. Current Condition and Trend

Background for NPS Night Sky Division's Suite of Measures

Anthropogenic light in the night environment can be very significant, especially on moonless nights. Unshielded lamps mounted on tall poles have the greatest potential to cause light pollution, since light directly emitted by the lamp has the potential to follow an unobstructed path into the sky or the distant landscape. This type of light spill has been called glare, intrusive light, or light trespass (Narisada and Schreuder 2004). The dark-adapted human eye will see these individual light sources as extremely bright points in a natural environment. These sources also have the potential to illuminate the landscape, especially vertical surfaces aligned perpendicular to them, often to a level that approaches or surpasses moonlight. The brightness of such objects may be measured as the amount of light per unit area striking a "detector" or a measuring device, or entering the observer's pupil. This type of measure is called illuminance (Ryer 1997).

Illuminance is measured in lux (metric) or foot-candles (English), and is usually defined as luminous flux per unit area of a flat surface (1 lux = 1 lumen/m^2). However, different surface geometries may be employed, such as a cylindrical surface or a hemispheric surface. Integrated illuminance of a hemisphere (summed flux per unit area from all angles above the horizon) is a useful, unbiased metric for determining the brightness of the entire night sky. Horizontal and vertical illuminance are also used; horizontal illuminance weights areas near the Zenith much greater than areas near the horizon, while vertical illuminance preferentially weights areas near the horizon, and an azimuth of orientation must be specified (Ryer 1997).

Direct vertical illuminance from a nearby anthropogenic source will vary considerably with the location of the observer, since this value varies as the inverse of the square of the distance from light source to observer (Ryer 1997). Therefore, measures of light trespass are usually made in sensitive areas (such as public campgrounds).

Anthropogenic light which results in an upward component will be visible to an observer as "sky glow." This is because the atmosphere effectively scatters light passing through it. The sky is blue in daytime because of Rayleigh scattering by air molecules, which is more effective for light of shorter wavelengths. For this reason, bluish light from outdoor fixtures will produce more sky glow than reddish light. Larger particles in the atmosphere (aerosols and water vapor droplets) cause Mie scattering and absorption of light, which is not as wavelength-dependent and is more directional. When the air is full of larger particles, this process gives clouds their white appearance and produces a whitish glow around bright objects (e.g., the sun and moon). The pattern of sky glow as seen by a distant observer will appear as a dome of light of decreasing intensity from the center of the city on the horizon. As the observer moves closer to the source, the dome gets larger until the entire sky appears to be luminous (Garstang 1989).

Light propagated at an angle near the horizon will be effectively scattered and the sky glow produced will be highly visible to an observer located in the direction of propagation. Predictions of the apparent light dome produced by a sky glow model demonstrate this (Luginbuhl et al. 2009). Light reflected off surfaces (e.g., a concrete road or parking area) becomes visible light pollution when it is scattered by the atmosphere above it, even if the light fixture has a "full cutoff" design and is not visible as glare or light trespass to a distant observer. For this reason, the intensity and color of outdoor lights must be carefully considered, especially if light-colored surfaces are present near the light source.

Light domes from many cities, as they appear from a location within Joshua Tree National Park, are shown in Figure 55 and Figure 56, as a grayscale and in false color. This graphic demonstrates that the core of the light dome may be tens or hundreds of times brighter than the extremities. A logarithmic scale for sky luminance and false color are commonly used to display monochromatic images or data with a very large dynamic range, and are used extensively in reports of sky brightness by the NSNSD.

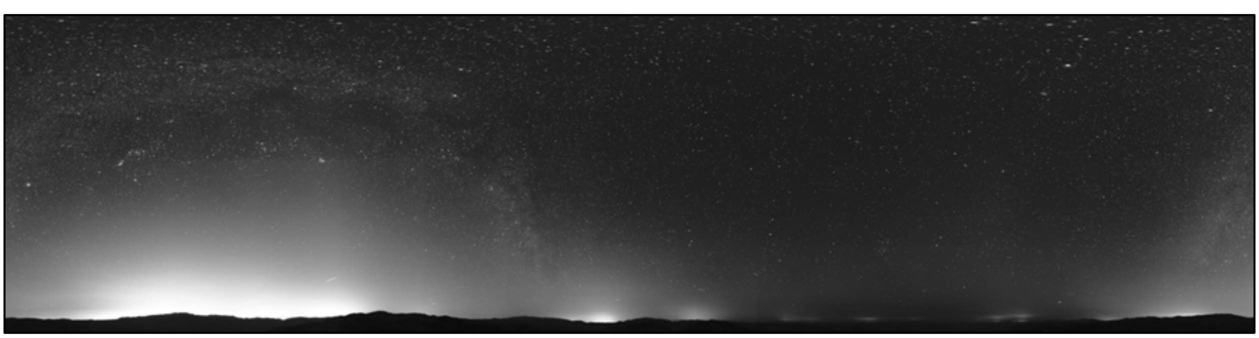

Figure 55. Grayscale representation of sky luminance from a location in Joshua Tree National Park (Figure provided by Dan Duriscoe, NPS NSNSD).

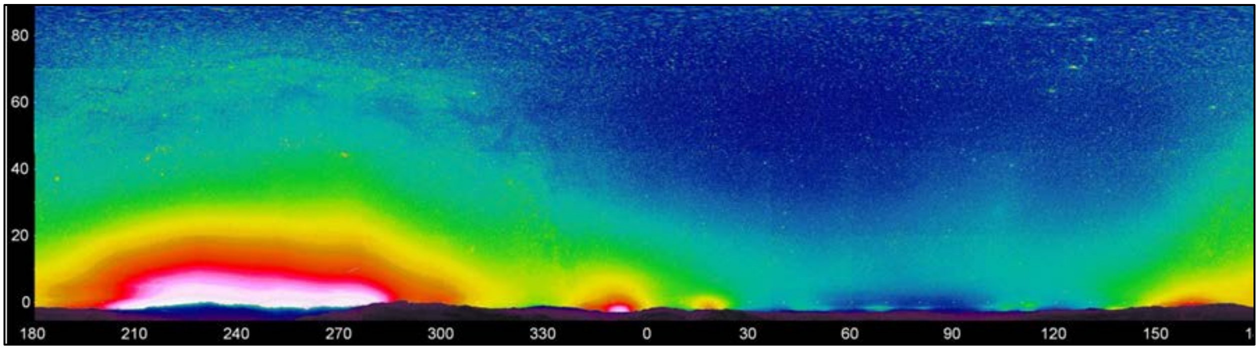

Figure 56. False color representation of Figure 55 after a logarithmic stretch of pixel values (Figure provided by Dan Duriscoe, NPS NSNSD).

The brightness (or luminance) of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The NSNSD utilizes a digital camera with a large, dynamic range, monochromatic charge-coupled device (CCD) detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data and the image scale in arc seconds per pixel is accurately known. Sky luminance is reported in astronomical units of V-magnitudes per square arc second, and in engineering units of milli-candela per square meter. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These data sets may be used for both resource condition assessment and long-term monitoring.

Figure 55 and Figure 56 contain information on natural sources of light in the night sky as well as anthropogenic sources. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date, time, and the relative brightness of the natural airglow (the so-called "permanent aurora" which varies in intensity over time) (Roach and Gordon 1973). The NSNSD has constructed such a model, and uses it in analysis of data sets to remove the natural components. This results in a more accurate measure of anthropogenic sky glow (Figure 57). Figure 56 represents "total sky brightness" while Figure 57 displays "anthropogenic sky glow" or "net light pollution." This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

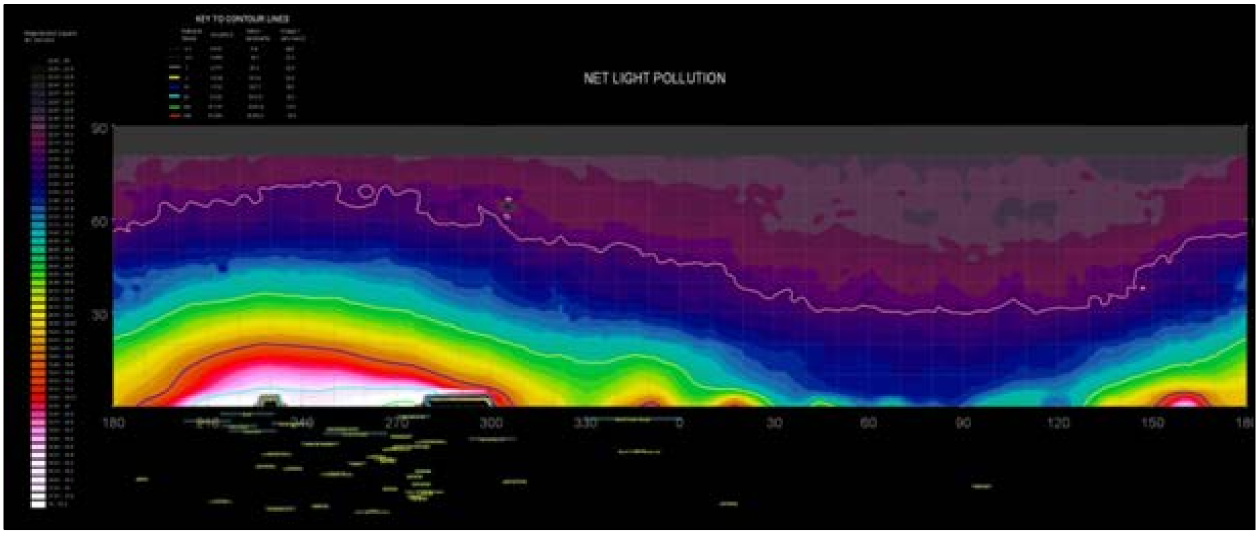

Figure 57. Contour map of anthropogenic sky glow at a location in Joshua Tree National Park, analogous to Figure 56 with natural sources of light subtracted (Figure provided by Dan Duriscoe, NPS Night Sky Division).

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition - a ratio of anthropogenic to natural light. Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2009). This so-called “light pollution ratio” is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NSNSD data, the atmospheric conditions determined from each individual data set.

A quick and moderately accurate method of quantifying sky brightness near the Zenith is the use of a Unihedron SQM. The Unihedron SQM is a single-channeled hand-held photometric device. A single number in magnitudes per square arc second is read from the front of the device after its photodiode and associated electronics are pointed at the Zenith and the processor completes its integration of photon detection. Because the meter is relatively inexpensive and easy to use, a database of measures has grown since its introduction (see http://unihedron.com/projects/darksky/database/index.php). The NSNSD produces values from each data set as both a synthesized value derived from the high-resolution images and by hand held measures with a Unihedron SQM. The performance of the SQM has been tested and reviewed by Cinzano (2005) and while fairly accurate and easy to use, the value it produces is biased toward the Zenith. Therefore, the robustness of data collected in this manner is limited to areas with relatively bright sky glow near the Zenith, corresponding to severely light polluted areas. While not included in the reference condition, a value of about 21.85 would be considered “pristine,” providing the Milky Way is not overhead and/or the natural airglow is not unusually bright when the reading is taken (Moore et al. 2013).

Visual observations are important in defining sky quality, especially in defining the aesthetic character of night sky features. A published attempt at a semi-quantitative method of visual observations is described in the Bortle Dark Sky Scale (Bortle 2001). Observations of several features of the night sky and anthropogenic sky glow are synthesized into a 1-9 integer interval scale, where class 1 represents a "pristine sky" filled with easily observable features and class 9 represents an "inner city sky" where anthropogenic sky glow obliterates all the features except a few bright stars. Bortle Class 1 and 2 skies possess virtually no observable anthropogenic sky glow (Bortle 2001).

Another visual method for assessing sky quality is the ZLM, which is the apparent brightness or magnitude of the faintest star observable to the unaided human eye, which usually occurs near the Zenith. This method involves many factors, the most important of which is variability from observer to observer. A ZLM of 7.0-7.2 is usually considered "pristine" or representing what should be observed under natural conditions; observation of ZLM is one of the factors included in the Bortle Dark Sky Scale. The ZLM is often referenced in literature on the quality of the night sky, and is the basis for the international "Globe at Night" citizen-scientist program (see http://www.globeatnight.org/index.html). The NSNSD has experimented with the use of this observation in predicting sky quality, and has found that it is a much coarser measure and prone to much greater error than accurate photometric measures over the entire sky. For these reasons, it is not included in the reference conditions section.

NPS Night Sky Division Suite of Measures

As stated earlier, the NSNSD documented baseline dark night sky conditions based on data collected during field visits in 2007 and 2008. Sky conditions during the 2007 visit were relatively clear with a slight breeze, with a haze developing as the winds died down during the night (Duriscoe and Magargal 2007). Clear conditions were recorded for the night of 31 January 2008, with some haze over El Paso, Texas (Magargal and Jiles 2008a). Conditions on the night of 1 February 2008 were windy in the early evening, and improved as the winds died down during the night (Magargal and Jiles 2008b). During these visits, the extinction coefficients (measure of air opacity) measured by the NPS NSNSD were 0.13 for both nights during the 2008 visit and 0.20 on the night visit in 2007 (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). Extinction coefficient values between 0.14 and 0.2 suggest that the sky was relatively clear (Jeremy White, NPS Night Skies Program Physical Science Technician, written communication, 21 September 2015) and the results from CAVE fall into this category. The following is a summary of the data collected during the field visits. The nightly data report for the two visits in 2008 can be found in Appendix H and Appendix I.

Table 28 shows the observed values and light pollution ratio (LPR) for the average natural sky luminance measures from the three nights NSNSD visited CAVE. The "observed" result corresponds to what an observer on the ground would see, and the LPR expresses the amount of artificial light above the natural condition (NPS NSNSD 2015b). The LPR is expressed as a percentage, for example a value of 0.10 = 10% above natural conditions (NPS NSNSD 2015b). The zenith value is one of the more widely reported sky quality indicators. This measure is calculated based on a one degree diameter circle centered on the zenith (NPS NSNSD 2015b). Values lower than 21.3 mag/arcsec^2 generally indicate a degraded sky quality (NPS NSNSD 2015b). The mean all-sky indicator is an unbiased measure of the amount of light reaching the observer from sky luminance (NPS NSNSD 2015b). The natural moonless reference condition for this indicator is 21.6

mag/arcsec^2 (NPS NSNSD 2015b). The median value is the middle sky brightness value for the entire sky; a view of the entire sky will reveal most areas to be near this value (NPS NSNSD 2015b). The median value can also be referenced to the natural moonless condition (NPS NSNSD 2015b). The measured values for each of these indicators at CAVE was near or below the reference condition value and the LPR ranged from a low of <3% to 46% (Table 28). These values indicate that there was some degradation to the quality of the night sky at CAVE at the time of the field visits.

Table 28. Select sky luminance measures for the NSNSD field visits to CAVE (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b).

Sky Quality Indicators	17 April 2007		31 January 2008		1 February 2008	
	Observed (mag/arcsec^2)	LPR	Observed (mag/arcsec^2)	LPR	Observed (mag/arcsec^2)	LPR
Zenith	21.97	0.11	21.78	< 0.10	21.59	< 0.10
Mean all-sky	21.23	0.46	21.29	0.34	21.20	0.29
Median	21.44	0.21	21.49	0.05	21.40	<0.03

Results for the illuminance from city light domes measure for each night is shown graphically in the false color estimated artificial sky glow mosaics Figure 58. These graphics represent the sky luminance from artificial sky glow. Land features and individual light trespass sources have been removed, leaving an at-a-glance representation of the amount of light pollution from sky glow observed from the tennis court (NPS NSNSD 2015b). In these figures, light intrusions from local light sources can be seen. The sky glow from El Paso, Texas appears at an azimuth of 259° and the sky glow from Carlsbad, New Mexico can be seen at an azimuth of 36° and Whites City, New Mexico is at an azimuth of 92° (Magargal and Jiles 2008a, b). Other light sources visible in the imagery are summarized in Appendix I. The most dominant feature is the sky glow between azimuth 330° and 125°, this is comprised of the lights from a number of sources including Albuquerque (328°), Carlsbad (36°), and Roswell (356°) in New Mexico and Amarillo (35°), Lubbock (56°), Midland (94°), and Odessa (99°) in Texas (Magargal and Jiles 2008a, b) In comparing the false color mosaics for the three visits, although there is some slight variation in the images due to atmospheric conditions the images are fairly consistent. Specific data on the brightness of these light domes were available for the 17 April 2007 field visit and is given in Table 29. Values for these observations are given in V magnitudes (mags); the lower the value (smaller or more negative), the brighter the object (Duriscoe and Magargal 2007).

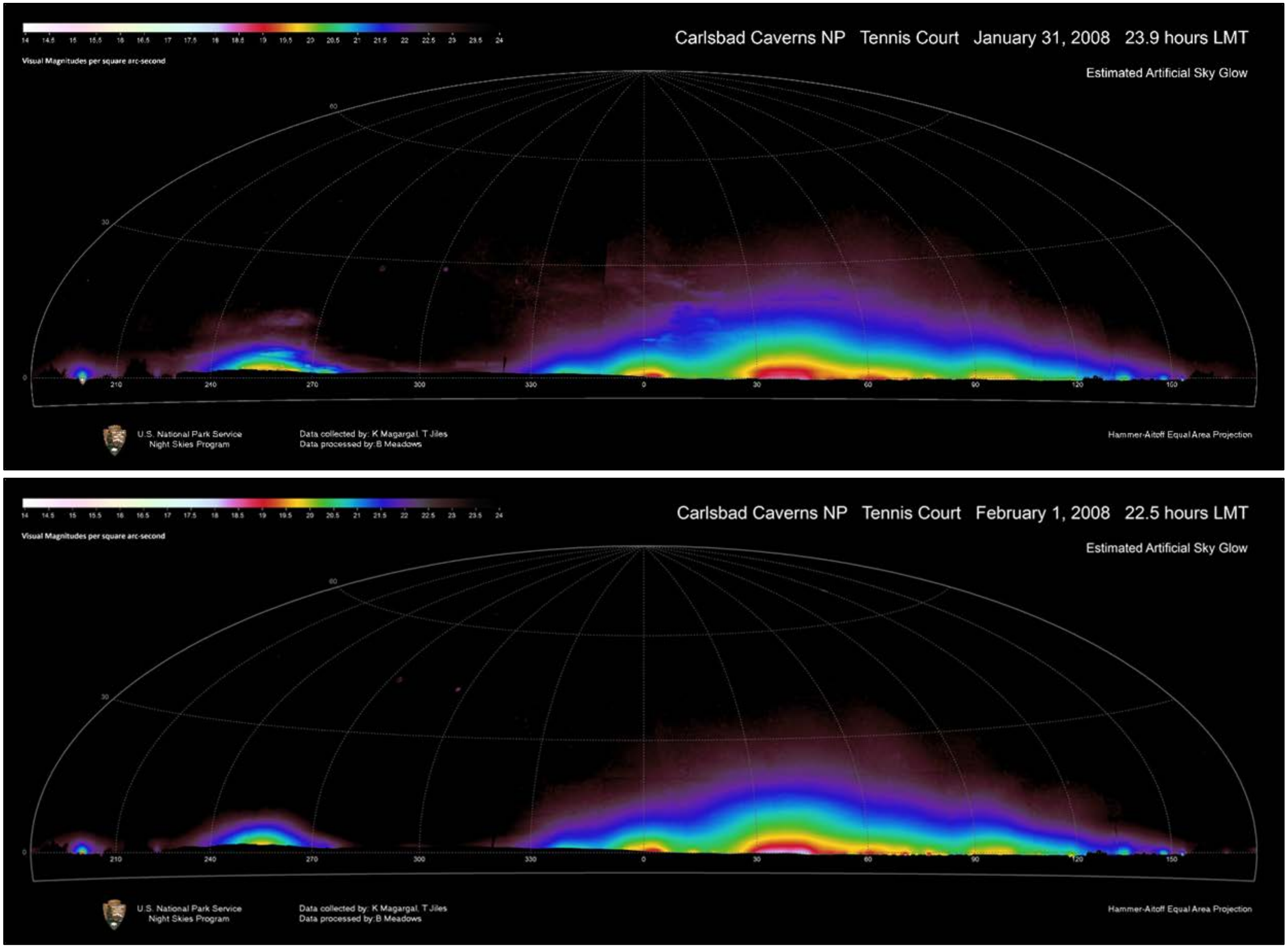

Figure 58. False color mosaic images of the CAVE night sky on the nights of (A) 17 April 2007, (B) 31 January 2008, and (C) 1 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

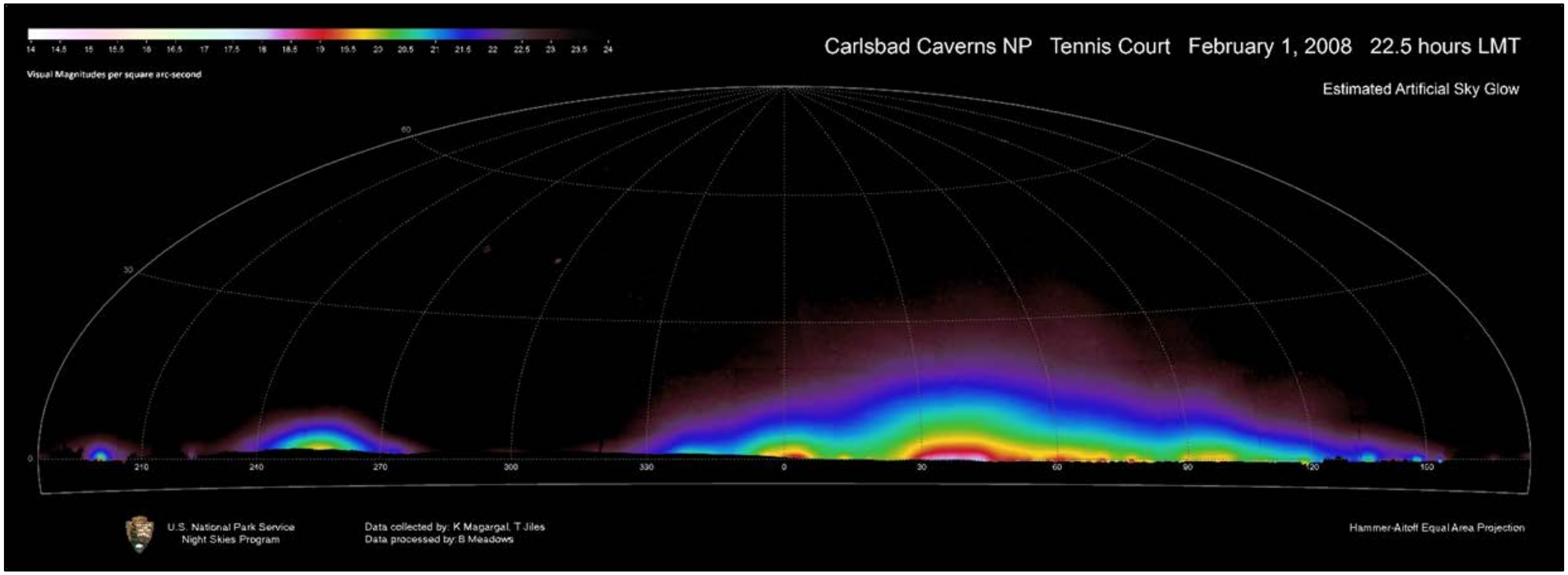

Figure 58 (continued). False color mosaic images of the CAVE night sky on the nights of (A) 17 April 2007, (B) 31 January 2008, and (C) 1 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD). Figures 59A and 59B are on the previous page

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Table 29. Light dome data from 18 April 2007 night visit (Duriscoe and Magargal 2007).

City, State	Brightness (mags)
Carlsbad, NM	-4.41
Whites City, NM	-1.48
Artesia, NM	-2.58
Roswell, NM	-2.58
El Paso, TX	-1.95
Total	**-5.09**

The illuminance measures are an indication of the amount of light that is striking the ground (horizontal) or a vertical plane (vertical) (NPS NSNSD 2015b). The natural reference condition for moonless nights for the horizontal is 0.8 milli-Lux and 0.4 milli-Lux for the vertical (NPS NSNSD 2015b). The horizontal values for the three NSNSD visits to CAVE ranged from 0.80 0.90 milli-Lux (Table 30) (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). The vertical value ranged from 0.760.80 milli-Lux (Table 30) (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). The LPR for the horizontal ranged from 0.06 to 0.19 and the vertical values ranged from 0.87 to 1.03 (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). These values indicate that there was minor degradation to the quality of the night sky at CAVE at the time of the field visits.

Table 30. Select illuminance measures for the NSNSD field visits to CAVE (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b).

	17 April 2007		31 January 2008		1 February 2008	
Direction of Light Strike	Observed (milli-Lux)	LPR	Observed (milli-Lux)	LPR	Observed (milli-Lux)	LPR
Horizontal	0.82	0.19	0.80	0.09	0.90	0.06
Max vertical	0.80	1.03	0.76	0.93	0.80	0.87

The SQM values for the NSNSD field visits ranged from 21.5221.77 mag/arcsec^2 (Table 31) (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). The Bortle Class and ZLM were also collected for these visits. A Bortle Classes of 3 was recorded on 17 April 2007 and 31 January 2008, with a Bortle Class of 4 recorded on 1 February 2008 (Table 31) (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). ZLM values ranged from 6.5–7.2 (Table 31) (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b). SQM values of 21.3 (Bortle Class 1-3) and greater are within the range of natural skies, 19.5-21.3 (Bortle Class 4-6) could be considered significantly degraded, while values less than 19.5 (Bortle Class 7-9) are considered severely degraded (NPS NSNSD 2015b). The SQM and Bortle Class values collected at CAVE generally fall within the range of natural skies.

Table 31. Additional sky quality measures from the NSNSD field visits to CAVE (Duriscoe and Magargal 2007, Magargal and Jiles 2008a, b).

Sky Quality Measures	17 April 2007	31 January 2008	1 February 2008
SQM (mag/arcsec^2)	21.77	21.67	21.52
Bortle Class	3.00	3.00	4.00
ZLM	7.20	6.90	6.50

Threats and Stressor Factors

CAVE is subjected to low levels of anthropogenic light pollution. This light pollution comes from oil and gas drilling operations and urban areas north, northeast, and west of the park (see Figure 59). Currently there are very few light fixtures within the park (i.e., limited to the visitor center area) and it is particularly important that within-park sources of light be contained, eliminating light trespass and minimizing anthropogenic sky glow. Lorenz (2006) and Danko (2015) re-created a light pollution map that displays the level of light pollution in the US. A subset of that map featuring the light pollution occurring in CAVE and surrounding areas is shown in Figure 59. The park is located in two levels of light pollution ranging from two to three on the Bortle Scale, which means the dark night sky is slightly impaired. Sources of light pollution in CAVE are primarily from the Carlsbad area.

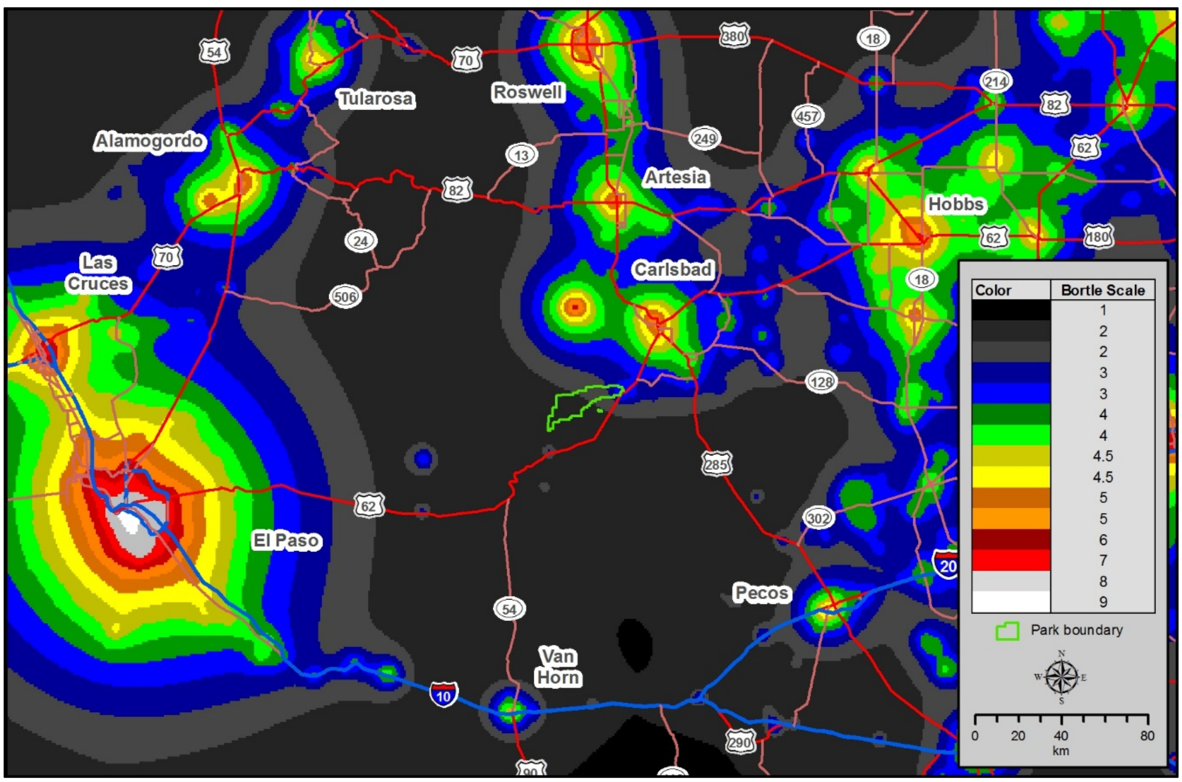


Figure 59. Levels of light pollution occurring in CAVE, and in surrounding areas (Lorenz 2006, Danko 2015).

Further the NPS NSNSD has developed a GIS model derived from data from the 2001 World Atlas of Night Sky Brightness (Cinzano et al. 2001), which depicts *zenith* sky brightness (the brightness of the sky directly above the observer). A neighborhood analysis is then applied to the World Atlas to determine the anthropogenic sky brightness over the *entire* sky. Finally, the modeled anthropogenic light over the entire sky is presented as a ratio (ALR) over the natural sky brightness (Duriscoe In preparation). Based on this GIS model, the all sky anthropogenic ratio ranges from 0.25 to 0.5 within the park boundary, indicating a sky 25% to 50% brighter than average natural conditions, based primarily on the proximity to Carlsbad (Figure 60).

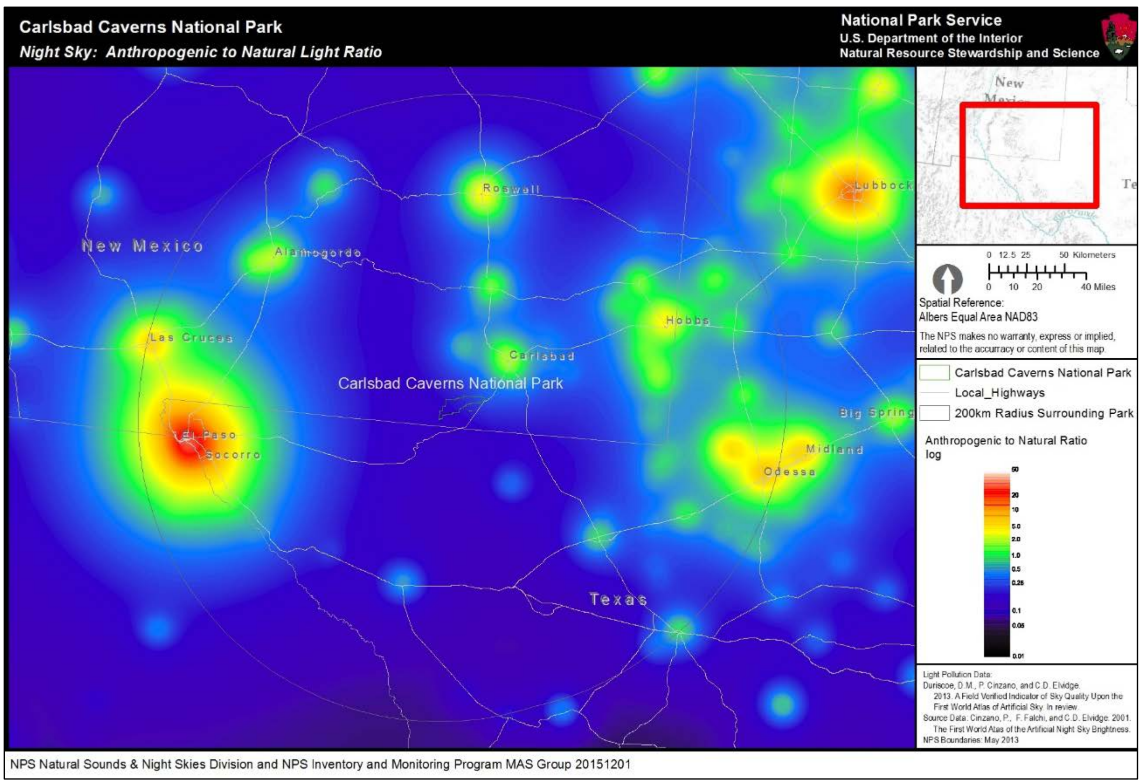


Figure 60. Regional view of anthropogenic light near CAVE expressed as an all-sky anthropogenic light pollution ratio.

Data Needs/Gaps

A draft plan for natural lightscape management in CAVE, which could include zoning the park area to indicate where outdoor lighting is required and where the naturally dark zone occurs, would greatly benefit park managers and researchers. Continued measurement of the entire sky brightness condition should occur on a periodic basis, about once every 5 years, with the tennis court as the preferred observation site, in order to track external threats.

Overall Condition

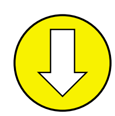
NPS NSNSD's Suite of Measures (3)

During scoping meetings, the CAVE NRCA team assigned the NPS NSNSD suite of measures a *Significance Level* of 3. Based on the interpretation of the data available from the NSNSD's 2007 and

2008 field visits, all of the measures were determined to be either in the “degraded” range or right on the border between “natural” and “degraded.” The data clearly indicate that the dark night skies are negatively impacted by anthropogenic light sources and urbanization of the areas surrounding CAVE. Based on these factors, a *Condition Level* of 2, meaning moderate concern was assigned to maximum vertical illuminance and average anthropogenic sky glow measures. The remaining measures were given a *Condition Leve*l of 1, low concern. While a population study was not conducted as part of this analysis, it can be assumed that the impact from the urban light domes, especially the Carlsbad, NM and El Paso, TX areas, will increase as these urban areas continue to grow. Continued gas and oil exploration occurring in close proximity to CAVE threatens the natural dark night sky quality. Based on this assumption, a downward or continuing degradation trend was assigned. It should be noted that the scoring and trends analysis for this component represents the conditions of the dark night sky at CAVE as of 2007 and 2008, and may or may not accurately reflect the current conditions.

Weighted Condition Score

The dark night sky component was assigned a *Weighted Condition Score* of 0.4, indicating moderate concern. The downward trend was assigned based on the expected population growth in the Carlsbad and El Paso areas. Further, no known light pollution mitigation measures have been taken by local communities or industrial or commercial facilities adjacent to the park. A moderate confidence level was assigned, primarily due to the fact that the data used was from 2007 and 2008 and it is unknown if this represents the current condition of dark night skies at CAVE.

Dark Night Skies			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.4**
Average Natural Sky Luminance	3	1	
Average Anthropogenic Light Dome	3	2	
Horizontal Illuminance	3	1	
Maximum Vertical Illuminance	3	2	
Sky Quality Meter/Bortle Class	3	0	

4.7.6. Sources of Expertise

- Dan Duriscoe, NPS Natural Sounds and Night Skies Division.
- Jeremy White, NPS Night Skies Program Physical Science Technician.

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4.8. Infrastructure Impacts on Caves

4.8.1. Description

The primary purpose of the national park system is to provide opportunities for the public to experience and enjoy the natural and cultural features of those parks; cave ecosystems can provide a unique level of natural and cultural resource education (Baker et al. 2015). A major reason for park establishment was the discovery of the many complex underground features in such a small space (Barnett 1981). Over the years, visitors and cave scientists have been attracted to the caves because of their unusual origin, massive size, unusual features, and highly decorated cave rooms (NPS 1995). With that, it is important for park management and park visitors to take the necessary measures to preserve these resources in the best possible manner, while still allowing for exploration (Burger and Pate 2001). For the park to support the number of visitors they receive, approximately 400,000 per year (NPS 2015), an extensive infrastructure system has been put in place above and below ground (van der Heijde et al. 1997). Above ground infrastructure includes a visitor center, multiple parking lots, offices, maintenance facilities, and staff quarters, while below ground there is a snack bar (known as the Lunch Room), two passenger and two freight elevators, that travel from the visitor center into the cave, restrooms, artificial trails, handrails, and an electrical lighting system (Photo 16). The potential impact of infrastructure found in and directly above the cave has become a concern for park management (van der Heijde et al. 1997).

Photo 16. This photo displays the Natural Entrance into Carlsbad Caverns. An artificial trail and handrail were put in place to provide easier access to the caves for visitors (Photo by Kevin Benck, SMUMN GSS).

4.8.2. Measures

- Pool water quality
- Cave air quality
- Cave climatic conditions
- Nutrient loading
- Groundwater quality

4.8.3. Reference Conditions/Values

The reference condition for this component in the park was defined as the condition before the construction of infrastructure and any anthropogenic influence (pre-1920s).

4.8.4. Data and Methods

Two studies completed in 2007 analyzed the water quality of the Lechuguilla Cave pools. One focused specifically on the areas of Lake Chandalar, Lake of the Blue Giants, Lake Margaret, and Lake of the White Roses (Levy 2007a) (Figure 61). The other focused on Lake Lechuguilla (entrance), Lake Louise (western branch), Pearlsian Gulf water supply (southwestern branch), and Tower Place water supply (southwestern branch) (Levy 2007b) (Figure 62). The pools were chosen because chemical changes had been discovered there in the past, they were designated drinking pools for cavers, results could be compared with historical trends (Levy 2007b), and to provide insight into the geochemical origin and evolution of water (Levy 2007a). Samples were collected between 2005 and 2006 and analyzed for properties such as N and pH levels, temperature (°C), and TDS (Levy 2007b).

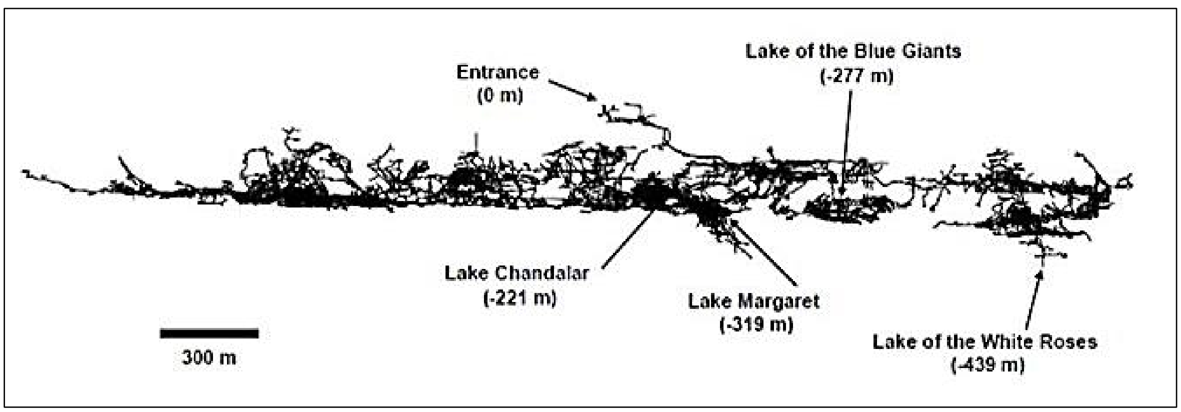

Figure 61. A profile view map of the locations of cave pools sampled in the Lechuguilla Cave (Levy 2007a).

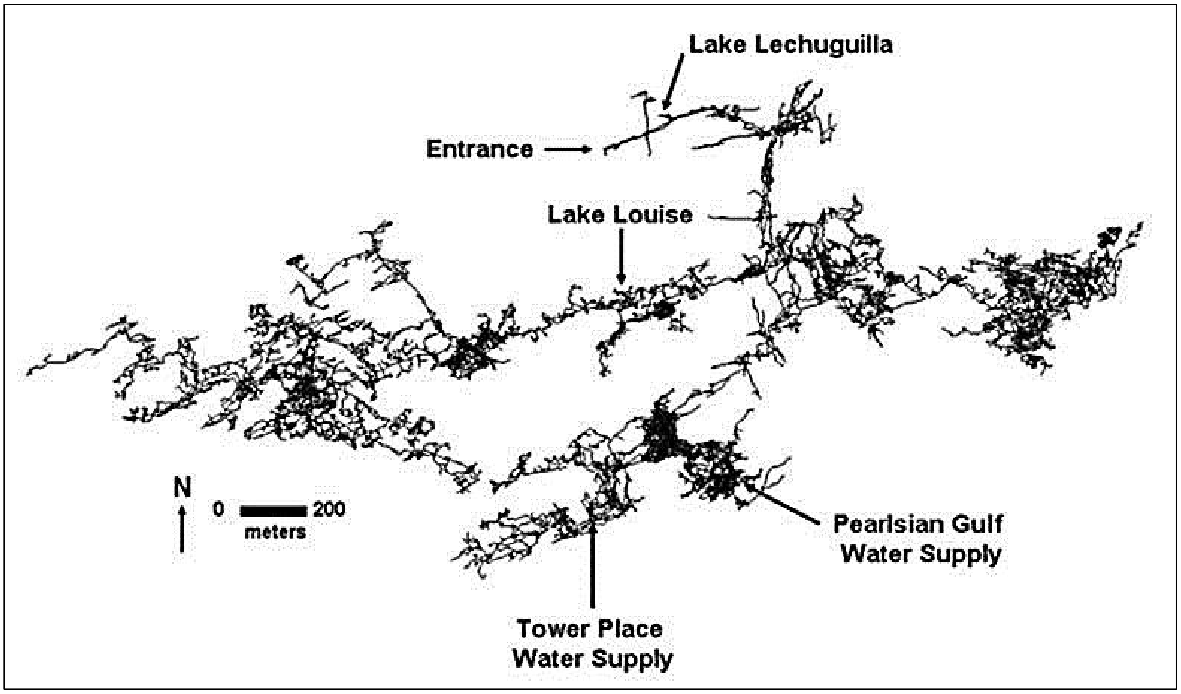

Figure 62. A plan view map of the locations of cave pools sampled in the Lechuguilla Cave (Levy 2007b).

Hunter et al. (2004) completed a study in Lechuguilla Cave that looked at whether or not there were coliform bacteria in the cave pools, which are an indicator of fecal contamination. Indications of coliform contamination appeared in 1995 near urine disposal areas, nearby trails, and several soil and drinking source locations (Hunter et al. 2004). Sampling occurred at pools in and near Red Lake, Lake Louise, Deep Secrets, Liberty Bell, Snow White Passage, and Oasis (Hunter et al. 2004) (Figure 63).

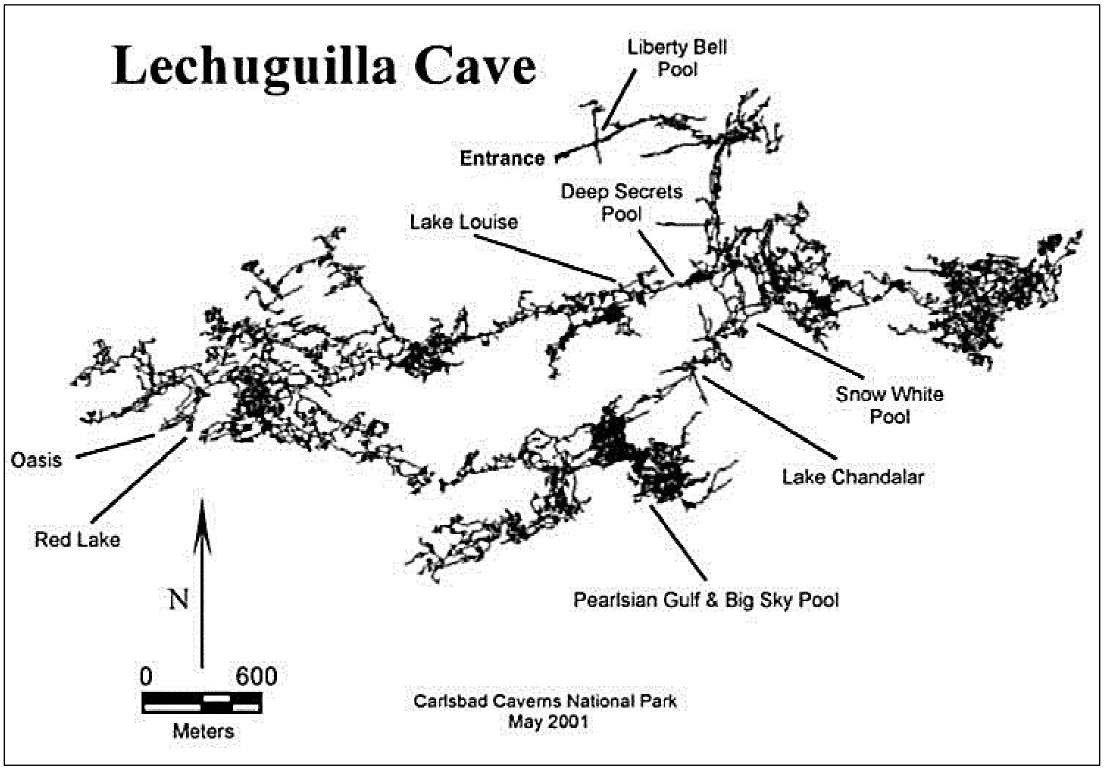

Figure 63. The locations where samples were taken in Lechuguilla Cave pools for coliform testing (Hunter et al. 2004).

Forbes (2000) performed water quality sampling at 13 pools inside Carlsbad Caverns; a total of 55 samples were collected. Parameters measured included concentration levels of major ions in the water, along with cave atmosphere conditions in terms of air temperature, humidity, and CO_2 levels (Forbes 2000).

van der Heijde et al. (1997) completed a water infiltration study to determine the areas in caves, specifically Carlsbad Caverns that were most vulnerable to contamination from above ground park infrastructure. The major objectives of the study were to: 1) identify and characterize potential contaminant sources; 2) determine the presence and nature of contaminant pathways from these potential contaminant sources at or near the land surface to the caverns; 3) determine present impacts from these anthropogenic sources on the hydrology and water quality of the cave system, and 4) evaluate likelihood of future contamination of the cave system (van der Heijde et al. 1997).

Water quality data for both the Lechuguilla Cave and Carlsbad Caverns pools were obtained through the EPA's STORET data warehouse (http://www.epa.gov/storet/dw_home.html). This database contains water quality measurements collected by various federal and state agencies and included data for over 2,500 sampling points (EPA 2015). Data available from EPA STORET was from the years 1984–2001.

With the park being designated as a Class I airshed, according to the 1977 CAA standards, there are specific guidelines and monitoring protocols that must occur in the park, such as monitoring trends in atmospheric deposition, O_3, and visibility (Prenni et al. 2015). The IMPROVE monitoring station located within park boundaries only monitors surface air and does not monitor air quality inside the caves, thus no underground air quality data could be found for the caves.

Air temperature is a key driver of climatic processes inside the caves and can be a useful parameter with the diverse climate conditions between chambers, tunnels, and remote areas (Pflitsch et al. 2014a). A recent study by Pflitsch et al. (2014b) monitored air temperature at specific monitoring points inside Carlsbad Caverns and described the overall climate conditions. Data loggers were placed throughout cavern to record the air temperature every five minutes; to draw comparisons, one data logger was placed outside the caves near the office buildings. A total of seven locations were used in this study: Devil's Spring (floor), Devil's Spring (ceiling), Left Hand Tunnel (front), Left Hand Tunnel (back), King's Palace, Big Room, and Lower Cave (Pflitsch et al. 2014b).

4.8.5. Current Condition and Trend

Pool Water Quality

Water temperatures for all sample points in Lechuguilla Cave (1984-2001) ranged from 16-20.3 °C (60.8-68.5 °F) with an average of 18.8 °C (65.8 °F) (EPA 2015), and when comparing levels for the specific Lechuguilla Cave pools sampled in both of the Levy (2007a, b) studies, temperatures stayed relatively constant (Appendix J). In the EPA STORET dataset, levels of pH ranged from 7-8.6 with an average of 7.9; this excludes an outlier pool that had a pH level of 9.7, caused by the presence of batteries as stated in the database (EPA 2015). In comparing these pH values with Levy's (2007a, b) pH values, the majority of pH levels have slightly decreased as the years progressed (Appendix K). Levels of TDS in the EPA STORET dataset range from 81-2,370 mg/l with an average of 1,077.1 mg/l; this excludes three outlier pools that had TDS values of 39,600 mg/l, 43,100 mg/l, and 46,483.05 mg/l (EPA 2015). When comparing these TDS values with Levy's (2007a, b), the majority of values have increased (Appendix L).

The temperatures in the EPA STORET dataset for Carlsbad Caverns (1989-1995) had values ranging from 9.5-20.3 °C (49.1-68.5 °F) with an average of 15.5 °C (59.9 °F) (EPA 2015). According to Forbes (2000), of all the samples locations in Carlsbad Caverns, temperature values were fairly similar in range and average: 9.5-19.2 °C (49.1-66.6 °F) with an average temperature of 14.8 °C (58.6 °F) (Appendix M). Also in the EPA STORET dataset for Carlsbad Caverns, pH levels ranged from 6-9.14, with an average pH of 7.67 (EPA 2015); while in Forbes (2000), the pH range was 7.23-9.14 with an average of 8.23 (Appendix N). Forbes (2000) also measured TDS levels and found ranges to be from 298-5,971 mg/l with an average of 1,270.88 mg/l; of the 55 samples collected in this study, only 16 provided TDS values. Levels of TDS in the EPA STORET dataset range from 130-15,000 mg/l with an average of 1,272.27 mg/l; this excludes an outlier pool that had a TDS value of 108,000 mg/l (EPA 2015) (Appendix O). Overall, Forbes (2000) and the EPA STORET dataset had similar pool water quality data inside Carlsbad Caverns.

The results from Hunter et al. (2004) determined that coliform was present in Red Lake, Lake Louise, Deep Secrets, and the Oasis drinking-water pools within Lechuguilla Cave, but was not present in the Liberty Bell and Snow White Passage (Table 32). However, Hunter et al. (2005)

cautioned that the results may be misleading, in that "coliform" is too general of a term and it can describe many different kinds of bacteria that are not related to fecal matter.

Table 32. Results of coliform sampling from Lechuguilla Cave drinking water pools (#positive/#total tests) (Hunter et al. 2004).

Date	Red Lake[b]	Lake Louise[a, c]	Deep Secrets[a, b]	Liberty Bell	Snow White Passage	Oasis[c]
15 January 1999	(3/8) Sm Pool					
15 January 2000	(1/5) Lg Pool	(4/5)	(0/5) Lg Pool			
18 November 2000	(0/5) Lg Pool	(4/5)	(1/7) Sm Pool (3/5) Lg Pool			
26 January 2001	(2/4) Lg Pool	(4/6)	(4/6) Lg Pool	(0/5)	(0/5)	(1/5)

a. Denotes current drinking water source as of 2004. Others have been used in the past during early exploration and rescue situations or have been closed for research purposes or contamination.

b. Represents pools with water siphoning hoses during 2001.

c. Represents pools with water pitchers or dipping cups during 2001.

<u>Cave Air Quality</u>

The air quality of a cave ecosystem can depend on components such as temperature, humidity, and levels of CO_2 (Kim et al. 2012). Multiple factors (e.g., topography, vapors, temperature, etc.) can influence CO_2 levels inside a cave, but studies have shown that a large player in increased CO_2 levels is human respiration (Kim et al. 2012). Accumulated levels of CO_2 can affect stalagmite growth rates, and induce stagnant air (Sanchez-Canete et al. 2013). The quality of the air inside a cavern can be affected by the overall air composition (Pflitsch et al. 2014b). No air quality information within the caves was identified at this time, therefore the component is considered to be a data gap.

<u>Cave Climatic Conditions</u>

Climate conditions inside of caves are unique and diverse throughout; some parts are affected by immediate outside weather conditions and other parts show long–term seasonal patterns. Another important influence on climatic processes is the natural convective ventilation system, also known as dominant air currents (Figure 64). Anthropogenic influence on cave climate is a factor, with the visitors themselves and the infrastructure (lights, elevators, cafeteria) having an impact (Pflitsch et al. 2014b). Specifically, infrastructure impacts on cave climate includes artificial lighting heating up and drying the air, enlarged and artificial entrances and access routes altering air flow, and respiration and body heat from the visitors changing the air composition (Pflitsch et al. 2014b). While average air temperature inside Carlsbad Caverns is roughly 13 °C (55 °F), the temperature can fluctuate throughout, with Left Hand Tunnel averaging 17 °C (63 °F) and Devil's Spring averaging 11 °C (51 °F) (Pflitsch et al. 2014b).

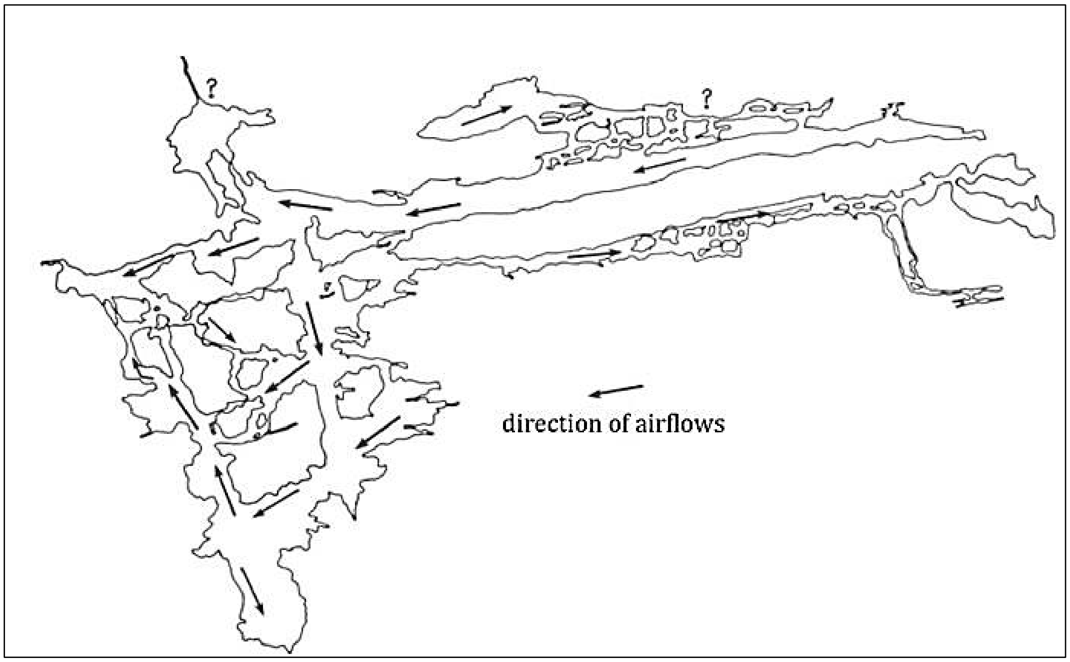

Figure 64. The arrows above indicate dominant air flow directions within Carlsbad Caverns (Pflitsch et al. 2014b).

Left Hand Tunnel is considered to be a contained environment, or to have compartmentalized topography (Pflitsch et al. 2014b). This causes air temperature (from surrounding anthropogenic influence) and barometric pressure changes to "stay in place" inside Left Hand Tunnel, and over time has caused the air movement to change (Pflitsch et al. 2014b). Pflitsch et al. (2014b) had a unique opportunity during their study. A federal government shutdown occurred causing closing of the park to visitors for two weeks in October 2013, providing a more natural temperature baseline for Carlsbad Caverns (Pflitsch et al. 2014b). From this baseline, it was concluded that temperatures inside King's Palace (Figure 65) and the Big Room (Figure 66), sites of frequent visitor activities, have permanently increased and, in addition, the normal convective air flow has been altered (Figure 67) (Pflitsch et al. 2014b).

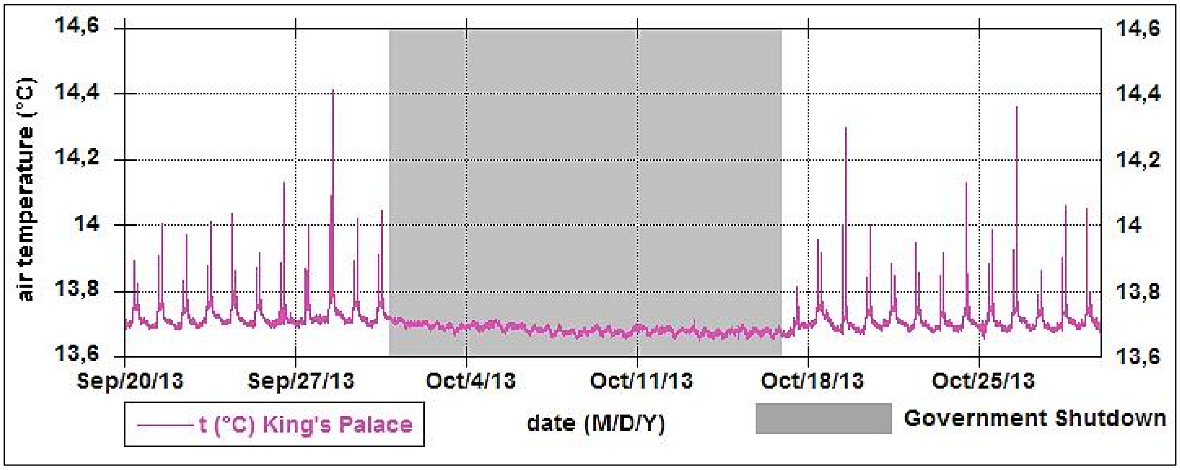

Figure 65. The profile of the air temperatures monitored in King's Palace inside Carlsbad Caverns. During the 2013 federal government shutdown, baseline temperatures provided a measure to gauge temperature changes due to anthropogenic influences (Pflitsch et al. 2014b).

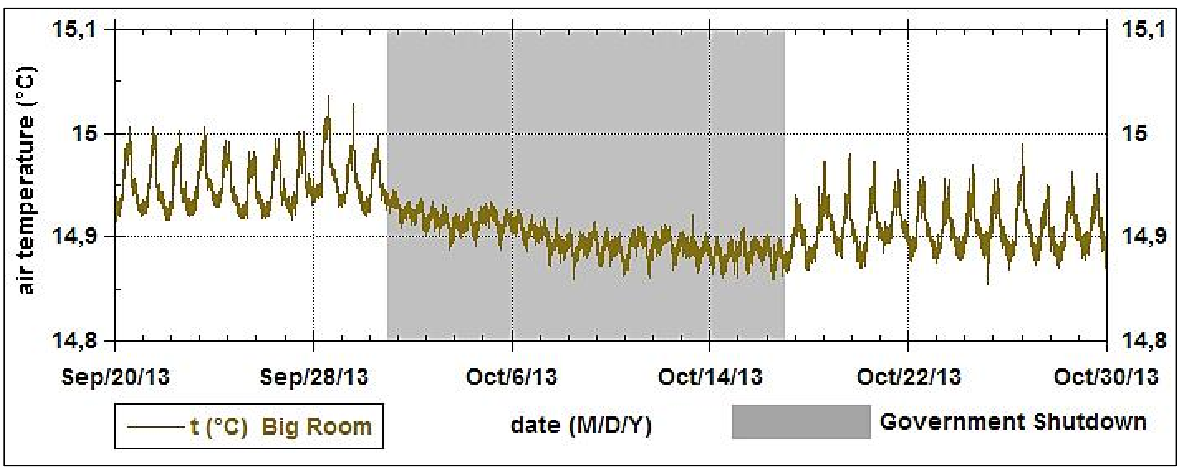

Figure 66. The profile of the air temperatures monitored in the Big Room inside Carlsbad Caverns. During the 2013 federal government shutdown, baseline temperatures provided a measure to gauge temperature changes due to anthropogenic influences (Pflitsch et al. 2014b).

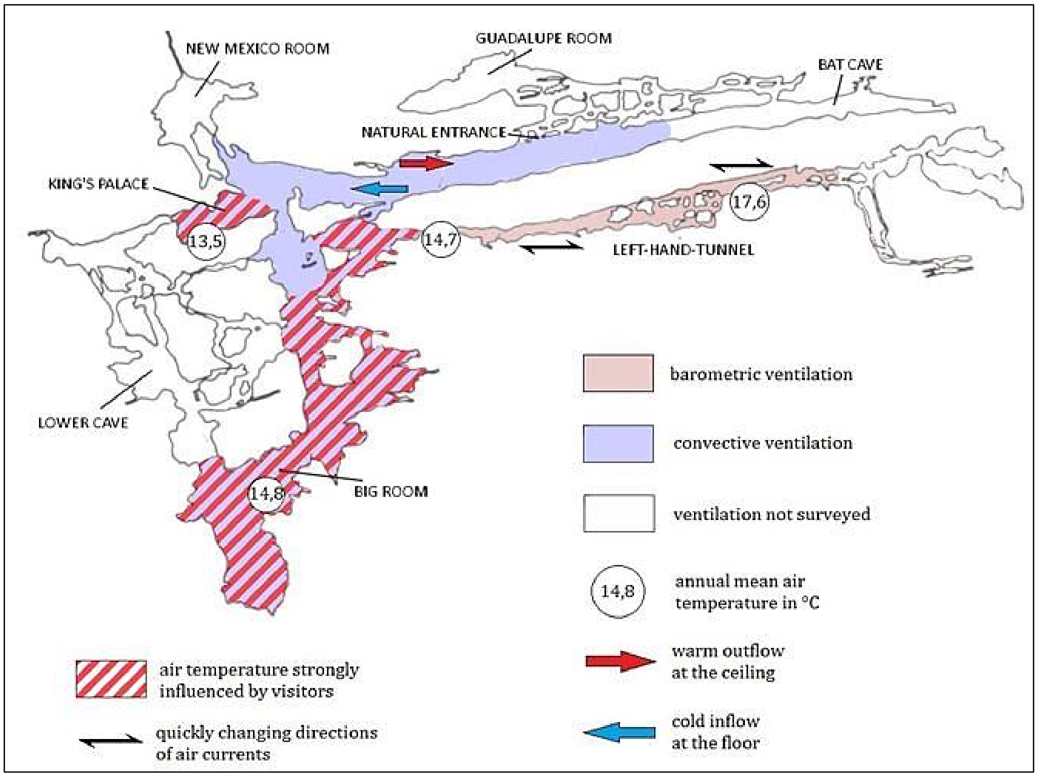

Figure 67. Results from the Carlsbad Caverns climate condition study are displayed spatially, showing the areas of concern in red stripes (Pflitsch et al. 2014b).

<u>Nutrient Loading</u>

N and phosphorus (P) are found naturally in the environment and are essential nutrients for many life forms. Phosphorus tends to bind to sediment particles, while N dissolves in water (Mueller and Helsel 2013). Increased levels of these nutrients, specifically N, can cause harm to a normally N-limited cave environment through breaking down into NH_3 and fueling the growth of exotic microbial communities (Boston and Welch 2004). Sources of potential pollution can come from agriculture fields (through excess spraying of N and/or manure for fertilizer), and acid rain caused by automobile emissions (Graham 2007, Mueller and Helsel 2013).

Available EPA STORET data (1984-2001) for pools sampled in Lechuguilla Cave showed NO_3 levels ranging from 0.57–8.7 mg/l with an average of 1.32 mg/l (EPA 2015). This is excluding the sample taken at Golden Road Pit because of its $N0_3$ level at 800 mg/l (EPA 2015). NH_4 levels ranged from 0.01-0.12 mg/l with an average of 0.05 mg/l; 11 samples could not be included due to their non-detection limit, which was either ~0.02 mg/l or ~0.05 mg/l (EPA 2015). Twenty-one pools were tested for nitrate (NO_2) and all samples were below the detection limit (~0.02 mg/l) (EPA 2015). NO_3 levels for samples from Lechuguilla Cave ranged from 1.3-57.46 mg/l with an average of 7.96 mg/l. This excludes two samples, one taken from Stud Lake (3,900 mg/l) and one from Helictite Pool in Pellucidar Room (4,195 mg/l) (EPA 2015). Thirty-four pools were sampled for phosphate (PO_4) with all but one sample regarded as non-detections due to any levels present being below the detection limit (~0.05 mg/l) (EPA 2015). The sample from the first pool from the entrance in the Liberty Bell Room exhibited a PO_4 level of 0.08 mg/l (EPA 2015).

The EPA STORET dataset also provides information on both NO_3 and PO_4 levels inside Carlsbad Caverns pools. NO_3 ranged from 2-238 mg/l with an average of 44.7 mg/l. Of the 64 samples listed in the dataset, eight could not be included due to their non-detection limit (~2 mg/l) (EPA 2015) PO_4 levels ranged from 0.05-1.89 mg/l with an average of 0.36 mg/l; of those 65 samples, 42 were below the detection limit (~0.05 mg/l) (EPA 2015).

Due to the spatially and temporally limited nature of the available data (e.g., most locations have been sampled only once or twice between the years 1984-2001), a comparison of nitrogen and phosphorous levels cannot be completed at this time.

Groundwater Quality

Due to its location within the Chihuahuan Desert, water is a limiting factor for the park's ecosystems. (NPS 2010). Even though the park's caves are relatively dry and have minimal amounts of flowing water, speleothem development and organisms living inside the cave depend on this limited resource (Graham 2007). If the desert climate happens to become wetter in the future, speleothem growth will accelerate; conversely if the climate happens to become drier, speleothem growth will decrease (Graham 2007). Because of the critical nature of groundwater in a semi-arid environment, understanding where the groundwater is and how it moves can provide insight into the overall function and integrity of cave ecosystems (NPS 2010). For more information on the park's groundwater quality, please refer to Chapter 4.10.

Threats and Stressor Factors

CAVE resource managers identified several potential threats and/or stressors to the environment of the parks cave system. These include infrastructure located on the surface and within the various cave systems in the park, herbicide and chemical control practices on park lands, and the park visitors.

All infrastructure necessary for administering park business and providing access to Carlsbad Caverns is located more or less directly above the cave system. This includes parking lots, the visitor center, park offices, etc. This development creates potential sources of contamination for Carlsbad Caverns ecosystem, specifically water contamination (van der Heijde et al. 1997). A study completed in 1996 discovered elevated concentrations of zinc, aluminum, and TOC in Carlsbad Caverns cave pools; all three of these chemical compounds are associated with vehicle use in the parking lots (Bremer 1998). Increased development in and around all caves inside the park could raise the levels of water contamination and cause more disruption to the cave ecosystem (Graham 2007).

Herbicide has been sprayed in the past around the parking lots and in the mescal pits near the natural cave entrance into Carlsbad Caverns (Bremer 1998). However, there has been no indication of these, or any surrounding vegetation control practices, having an impact on cave ecosystem health. As of now, there is little data articulating the impact that spraying of unwanted vegetation on park lands or on adjacent lands has had on the caves in the park.

The elevator and utility shafts located in the caves below the visitor center create easy transportation from the surface to underground and vice versa, but they also cause unnatural water infiltration to the upper formations of the caves through the downward conduits (Graham 2007). A sewage pump is also necessary to support visitor and staff restrooms, but the potential for contamination from the sewage through equipment failure, rusted pipes, or spills poses a threat to the cave ecosystem (Graham 2007). A study completed by Elliot (1998) looked at ecologically disturbed areas inside Carlsbad Caverns. Woodpiles found throughout the cavern had been likely deposited around the 1920's and have become home to many microbial and invertebrate communities. Even though these woodpiles have harbored many species (some identified as native), Elliot (1998) recommends carefully removing portions of these woodpiles enough as to not disturb the adapted environment.

Bats are known to be sensitive to light and noise, so park staff has taken steps to reduce the disturbance from infrastructure inside the caves, like turning off all lights in the evening and avoiding construction activities during the day (NPS 2009). Artificial light coming from infrastructure inside the caves could potentially dry out normally moist areas and decrease humidity. The park recently replaced the incandescent and fluorescent lights in Carlsbad Cavern ,with LED (light-emitting diode) lights in the cave, as they give off significantly less light and heat (Horrocks, written communication, 15 July 2016). Excess light could also cause higher amounts of photosynthetic organisms such as algae, moss, and fungus to grow, and could draw unwanted animals farther into the cave, which could disrupt the overall cave ecosystem (Olson 2002, Graham 2007). For example the park has created a twilight zone above Devils Spring in the Main Corridor of Carlsbad Cavern, to discourage cave swallows from venturing further into the cave (Horrocks, written communication, 15 July 2016). Also, vandalism and graffiti potential increases when visitors are able to see more of the natural features of the cave (Olson 2002). Along with light pollution, impacts of uncontrolled lint accumulation in cave environments include degradation of the appearance of cave formations, introduced food sources for unwanted organisms, and potentially dissolving cave surfaces (Jablonsky et al. 2003). As people travel inside the caves, they bring in lint mainly through their clothing fibers, along with remnants from skin and hair (Graham 2007).

The Lunch Room is a large feature found inside Carlsbad Caverns. It provides visitors with a concession stand and a place to sit. This feature has been known to generate large amounts of waste (Graham 2007), harbor unwanted microbial communities (Griffin et al. 2014), contribute to water contamination (van der Heijde et al. 1997, Graham 2007), and produce excessive lighting that disrupts the surrounding environment (Graham 2007).

Gates are used to restrict access to vulnerable parts, or the entirety, of a cave. These gates can be positive in preserving natural and cultural resource, but they can also cause harm through disruption of natural process, such as bat hibernation. Gates can block entrances, change the air temperature, prevent air flow, and influence natural humidity levels, all of which can make a cave unsuitable for hibernating bats (Barber et al. 2007). Bat-friendly cave gates have been designed and implemented in many caverns to help minimize this problem. The decision of whether or not to install a cave gate is not taken lightly; the American Cave Conservation Association, Bat Conservation International, and the Missouri Department of Conservation have constructed a flow chart to help make an informed decision on cave gating (Fant et al. 2009) (Appendix P).

Data Needs/Gaps

An abundance of air quality data is available outside the caves, but none could be found for inside. To complete a full assessment of air quality inside the caves, adequate data need to be developed to create a baseline. Up-to-date and routine pool water quality sampling could be completed to detect any changes from the Levy (2007a, b) and Forbes (2000) studies. These findings could also shed light on nutrient loading effects inside the cave pools. Additionally, since nutrient loading is often linked to runoff (van der Heijde et al. 1997), monitoring water quality after rainfall events is suggested to gain a better understanding of what type and how many nutrients come from surface infrastructure of the park.

Overall Condition

Pool Water Quality

The *Significance Level* for pool water quality was assigned a 3. Levy (2007a, b) and Forbes (2000) provide the most up-to-date measurements of pool water quality and levels of nutrients inside both Lechuguilla Cave and Carlsbad Caverns. Park staff is aware of the need to monitor and manage pool water quality. Debate regarding coliform bacteria sampling results has led to some uncertainty regarding the significance of concern over their presence. Due to these factors, the *Condition Level* for this measure was assigned a 2, or of moderate concern.

Cave Air Quality

A *Significance Level* of 3 was assigned for air quality within the caves. The park is designated as a Class I airshed with an abundance of air quality data available outside the caves. Without adequate data representing air quality inside the caves, a *Condition Level* cannot be assigned at this time and this measure is considered to be a data gap.

Cave Climatic Conditions

The *Significance Level* for cave climatic conditions was assigned a 3. Anthropogenic influence on the cave structure, such as increased artificial light and altered entrance and access routes, has altered the climate inside the caves. Especially in highly trafficked areas like Big Room and King's Palace, increased temperatures, reduced humidity, and changes in air flow directions have disrupted the natural ecosystem (Pflitsch et al. 2014a). Due to these factors, the *Condition Level* for this measure was assigned a 2, or of moderate concern.

Nutrient Loading

This measure was assigned a *Significance Level* of 3. This measure is considered to be a data gap at this time. Comprehensive and consistent analysis of nutrient levels of pools within the park cave systems are needed in order to evaluate the impacts of nutrient levels inside caves. Thus, a *Condition Level* for this measure cannot be assigned at this time.

Groundwater Quality

The *Significance Level* for groundwater quality was assigned a 3. The park's groundwater quality is discussed in detail in Chapter 4.10 of this NRCA. Since a *Weighted Condition Score* for the groundwater component could not be assigned at this time due to three of the four measures providing data gaps, this measure is considered a data gap here as well. Even though water is generally in high quality, due to a lack of depth to groundwater data and current recharge rates and withdrawal amounts, the groundwater in CAVE cannot be accurately assessed and needs further research for support.

Weighted Condition Score

A *Weighted Condition Score* for this component could not be assigned at this time due to over 50% of the measures being data gaps. Of the measures that did provided sufficient information for a condition level (i.e., pool water quality and cave climate conditions), conditions for these measures are considered to be of moderate concern. Due to the lack of historical data dating back to pre-1920s (before the opening of the park), no reference condition was available. Despite that, the impacts from excess artificial lighting, altered cave landscapes, and elevator and sewer systems are causing disruption to the cave ecosystem thus causing a deteriorating trend for this condition.

Infrastructure Impacts on Caves			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Pool Water Quality	3	2	
Cave Air Quality	3	N/A	
Cave Climate Conditions	3	2	
Nutrient Loading	3	N/A	
Groundwater Quality	3	N/A	

4.8.6. Sources of Expertise

- This assessment relied on the published literature and best professional judgment as the primary sources of expertise.

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4.9. Human Impacts on Caves

4.9.1. Description

Along with providing biological and geological information, caves can tell stories of paleontology, climate change, and human culture, thus causing more people outside the scientific community to become interested in them (Baker et al. 2015). The primary purpose of the national park system is to provide opportunities for people to experience and enjoy the natural and cultural features of those parks (Photo 17). However, it is important for park management and park visitors to take the necessary measures to preserve those resources in the best possible manner for future visitors (Burger and Pate 2001).

Photo 17. Accessibility and experience to the caves for visitors is important to the NPS for education and awareness of the unique ecosystem (NPS Photo).

4.9.2. Measures

- Number of broken formations
- Annual lint accumulation
- Number of visitors annually
- Photo monitoring of lower use areas
- Introduced microbes and pathogens

4.9.3. Reference Conditions/Values

The reference condition for this component in the park was defined as in the condition before the construction of infrastructure and any anthropogenic influence (pre-1920s).

4.9.4. Data and Methods

The most recent survey of cave formation condition was in 1983 and surveyed the following areas in Carlsbad Cavern: Main Corridor (Gate to Bate Cave seating area, Bat Cave to auditorium, auditorium to Devil's Spring, Devil's Spring to Taffy Hill, Taffy Hill to Devil's Den, Devil's Den bench to Witches Finger, Witches Finger to Iceberg Rock, and Iceberg Rock to shortcut), Green Lake Room, King's Palace, Queen's Chamber, Papoose Room, and Appetite Hill through Boneyard to Big Room

Junction (Paris and Giananntonio 1983 p. 3). Each speleothem discovered vandalized was marked and tallied (Paris and Giananntonio 1983).

Impacts of uncontrolled lint accumulation in cave environments include degradation of the appearance of cave formations, introduced food sources for unwanted organisms, and potentially dissolving cave surfaces (Jablonsky et al. 2003). As people travel inside the caves, they bring in lint mainly through their clothing fibers, along with remnants from skin and hair (Graham 2007). In 1988, a group of volunteers worked to remove as much lint and litter as possible inside the Carlsbad Caverns. This initial cleanup occurred over the span of four years, comprised 5.99 km (3.72 mi), and utilized over 2,500 volunteers (Jablonsky et al. 2003). The cleanup was done using hand tools such as brushes, tweezers, and a type of synthetic “feather dusters” to help get in between cracks and crevices (Jablonsky et al. 2003). The lint generated from these cleanups was analyzed by Jablonsky et al. (2003) to see how much of it was synthetic versus natural. The two sample locations used in this study include the Men’s Room Corridor (relatively dry setting) and the Queen’s Chamber (damp setting) (Jablonsky et al. 2003).

The IRMA Portal provides visitor use statistics for all national parks. Multiple reports can be generated from these statistics including, but not limited to, annual park recreation visitation (1904-last calendar year), monthly public use, and traffic counts. For this component, annual park recreation visitation and monthly public use statistics were used as part of the analysis (NPS 2016). The NPS monthly public use report (2015) counts the number of visitors to multiple features inside CAVE such as: campgrounds, bat flights, bus passengers, entrance vehicles, main cave (from now on referred to Carlsbad Caverns), Rattlesnake Canyon, Slaughter Canyon Cave, and total caves.

Werker and Hildreth-Werker (1995) assisted CAVE staff in the design and implementation of permanent photo monitoring stations throughout Left Hand Tunnel, New Mexico Room, Lower Cave, and Hall of the White Giant in Carlsbad Caverns. These permanent site locations were selected based on potential visitor impacts, fragile and unique features, and trail maintenance concerns. Along with the photographs, water levels and speleothem characteristics (i.e. moisture presence, growth, corrosion, etc.) were monitored (Werker and Hildreth-Werker 1995).

Cave environments support unique and sensitive microbial communities (Burger and Pate 2001). A study completed in 2004 inside Carlsbad Caverns looked at whether or not human visitation inside the caves was a probable cause for the introduction of non-indigenous microorganisms (Griffin et al. 2014). Multiple bacterial samples were collected in 2004, 2005, and 2009 along the paved visitor trail that descends from the Natural Entrance of Carlsbad Caverns to and around the Big Room, the Lunch Room, and less-frequented off-trail areas (e.g., Sand Passage, Hall of the White Giant, New Mexico Room Overlook, and Left Hand Tunnel) for contrast (Griffin et al. 2014). The sample sites used in the 2009 study included sites A, E, Lunch Room A, H, and Left Hand Tunnel (Griffin et al. 2014) (Figure 68).

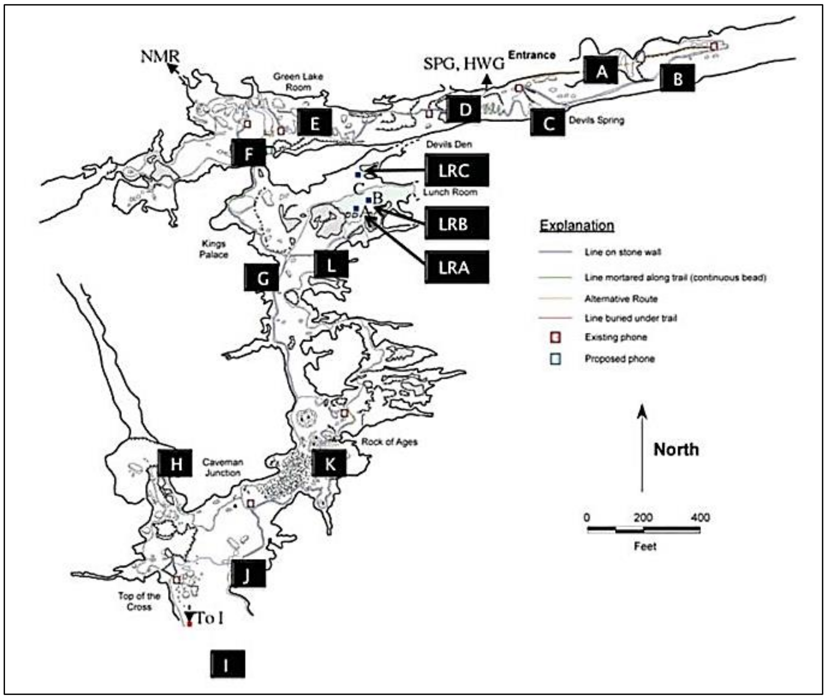


Figure 68. 2004 and 2005 sample sites used in the Griffin study. Black boxes represent the trail sample sites A through L, and Lunch Room A, B, and C. NMR = route to the New Mexico Overlook; SPG, HWG = route to Sand Passage and the Hall of the White Giant (Griffin et al. 2014).

4.9.5. Current Condition and Trend

Number of Broken Formations

Even with successful guided tours being implemented in 1982 (Paris and Giananntonio 1983), stainless steel railings installed along visitor trails, and staffing limits implemented (Dayton 1975), vandalism and misuse of natural resources still remains an issue for the park (Paris and Giananntonio 1983, Graham 2007). The 1983 vandalism survey is the most recent data available to demonstrate this (Paris and Giananntonio 1983) (Table 33). According to the survey, the majority of vandalized speleothems occurred inside Queen's Chamber (31%) and Papoose Room (26%); popular areas for visitor tours. The Queen's Chamber is known for its unique helictites formations (Graham 2007).

Table 33. Vandalized speleothem count and the associated location inside the caverns of CAVE (Paris and Giananntonio 1983).

Location in Carlsbad Cavern	Number of vandalized speleothems
Main Corridor	
gate to Bat Cave seating area	16
Bat Cave to auditorium	9
auditorium to Devil's Spring	190
Devil's Spring to Taffy Hill	48

Table 33 (continued). Vandalized speleothem count and the associated location inside the caverns of CAVE (Paris and Giananntonio 1983).

Location in Carlsbad Cavern	Number of vandalized speleothems
Main Corridor	
Taffy Hill to Devil's Den	112
Devil's Den (excluding right wall at top of stairs)	74
Devil's Den bench to Witches Finger	61
Witches Finger to Iceberg Rock	9
Iceberg rock to shortcut	4
Subtotal	**533**
Green Lake Room Total	**789**
King's Palace	
entrance to 1st corner, left side of trail	27
entrance to 1st corner, right side of trail	645
corner to keyhole, left side of trail	16
corner to keyhole, right side of tail	58
wall, keyhole to tunnel	234
tunnel to bottom of Appetite Hill, right side of trail	282
entrance wall to broken formations	85
Subtotal	**1347**
Queen's Chamber	
Keyhole	38
Keyhole to 1st corner, right side of trail	231
1st corner to 2nd corner (and path to Mys. Room)	673
2nd corner to draperies, right side of trail	71
draperies to exit	649
keyhole wall to exit	57
entrance to exit, left side of trail	143
island with backlit drapery	81
island with 1st draperies	242
Subtotal	**2185**

Table 33 (continued). Vandalized speleothem count and the associated location inside the caverns of CAVE (Paris and Giananntonio 1983).

Location in Carlsbad Cavern	Number of vandalized speleothems
Papoose Room	
south wall	407
east wall	388
north wall and center	1019
Subtotal	**1814**
Appetite Hill through Boneyard to Big Room Junction	**372**
Total speleothems counted	**7040**

NPS (1996) proposed actions to reduce visitor impacts. These proposed actions included limiting visitor access to certain areas of the cave that hold fragile resources such as in Green Lake Room and King's Palace, and to also emphasize the significance of natural resources in the cave through interpretive messages to park visitors (NPS 1996). As of this time, there are no current studies or documentation articulating whether or not these proposed actions have impacted the number of broken formations; according to the draft foundation document (NPS 2014), visitor impacts on the cave ecosystem and formation breakage studies still need to occur in the park.

Annual Lint Accumulation

An effort was made in 1988 by the park staff and volunteers to clean up lint in the caves (called "Lint Camps"); as a result, over 70 kg (154 lbs) of lint was removed. (Graham 2007). An additional 20.7 kg (45.6 lbs) was removed in the following years up through 1992 (Griffin et al. 2014). It was discovered that after a period of time, the accumulated lint had started to deteriorate and become a source of organic material for microbes, mites, and spiders. These introduced microbes and organisms that normally thrive in high-organic-energy environments are a threat to the native, low-organic-energy microbes that thrive in the cave environment (Graham 2007). A similar problem also occurs in the Lehman Caves at Nevada's Great Basin National Park, also a cave environment. According to Marech (2014), 22.7 kg (50 lbs) of lint was gathered during one lint camp weekend. Horrocks and Ohms (2006) pointed out that a year after lint cleaning inside Lehman's Cave, noticeable lint started accumulating again.

Jablonsky et al. (2003) determined that 68% of the fibers found at the two sample sites within Carlsbad Caverns (Men's Room Corridor and Queen's Chamber) were synthetic or coming from anthropogenic sources such as clothing. Also, lint deposition likely increases as visitors travel throughout the caves. Therefore, ensuring visitors are "clean" before entering the cavern will reduce the amount of lint at the entrance but not necessarily through the entire cave system (Jablonsky et al. 2003). Possible solutions to lint accumulation are installing air showers and foot cleaning features for voluntary use, creating lint drop zones alongside trails, reviewing of custodial cleaning techniques

(Jablonsky et al. 2003), and constructing 45.7 cm (18 in) high lint curbs alongside the trails (Horrocks, written communication, 9 May 2016).

Horrocks and Ohms (2006) also identified that many factors influence lint accumulation: number of cave visitors, gravity, air movement, cave wall contours and textures, trail design, heat, and humidity (Horrocks and Ohms 2006 p. 353). Generally speaking, lint accumulation is found to be more prevalent in areas where visitors stop and sit down, on lower portions of walls adjacent to trails (Horrocks and Ohms 2006), and along stairs and steep slopes where visitor's legs and arms rub against their clothing (Horrocks, written communication, 9 May 2016).

<u>Number of Visitors Annually</u>

CAVE received 407,265 visitors on average between 2005 and 2015; that is a 12% increase from the first ten years of park establishment (1924-1934) (NPS 2016) (Figure 69). Although the number of visitors to the park has increased since its establishment, the most popular time for the park was during the 1970's when average number of visitors was at 787,643 each year (NPS 2016). It is identified in Public Law 92-625 that national parks are required to address carrying capacity of the number of visitors at one time (NPS 1996). At the time of the 1996 General Management Plan, the park did not have a carrying capacity in place for visitors inside the caves.

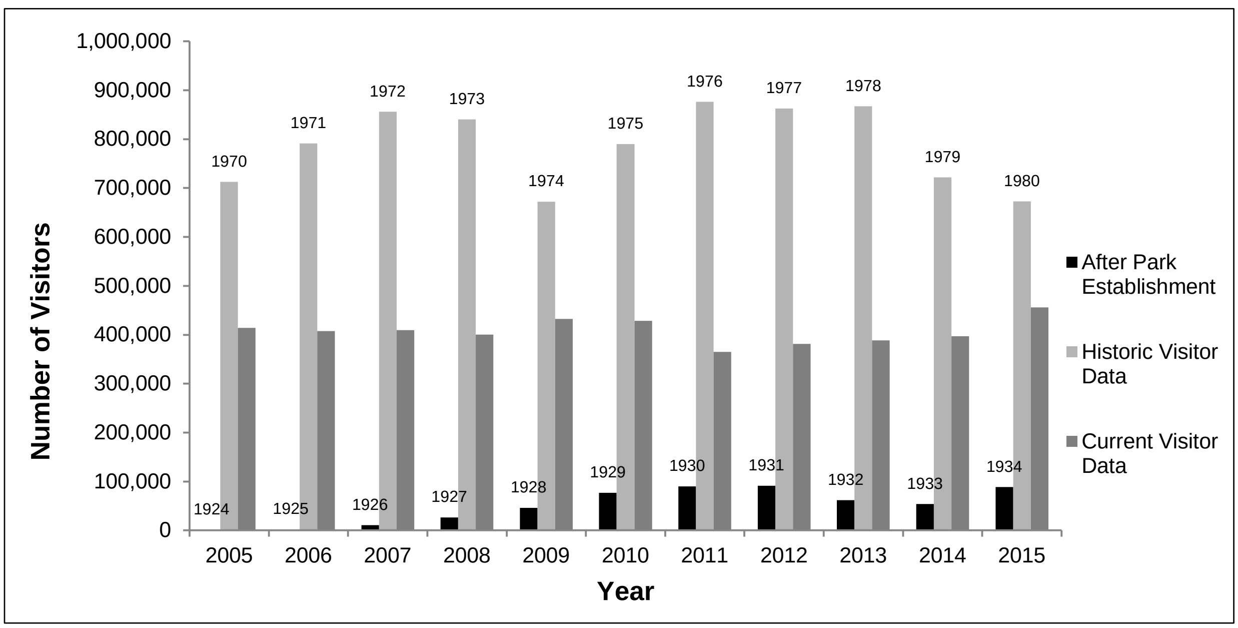


Figure 69. Average annual visitor statistics for CAVE from 2005-2015 compared to historic visitor statistics from 1970-1980 and after park establishment from 1924-1934 (NPS 2015). Medium gray represents current visitor trends, light gray represents historic visitor trends, and black represents visitor trends after park establishment.

According to the NPS monthly public use report (2015), in 2015, 416, 928 people visited Carlsbad Caverns with the most popular months being June (50,546) and July (70,170). Popular attractions, such as Rattlesnake Canyon, had a total of 25,098 visitors in 2015, and Slaughter Canyon Cave had 628 visitors in the same year (NPS 2015).

Photo Monitoring of Lower Use Areas

Using permanent stations for photo monitoring can allow for consistent and accurate photos for the same location on subsequent shooting sessions (Werker and Hildreth-Werker 1995). Proper photo monitoring can provide park staff and research with information sequences through visual documentation. Being able to monitor changes, growth, and impacts of cave resources, information decisions can be made in regards to management of the unique cave environment (Werker and Hildreth-Werker 1995). Due to a lack of photo monitoring data, this measure is considered to be a data gap.

Introduced Microbes and Pathogens

Anthropogenic impacts inside the cave, from visitors and cave explorers, have introduced non-native, competitive microbes (Griffin et al. 2014). Human hair and skin contain an abundance of bacteria and fungi (Grice et al. 2009); one study found 205 genera of bacteria on human skin and 14 genera of fungi were observed within the human toe web environment (Griffin et al. 2014). The bacteria and fungi found on humans are introduced as invasive into the cave environment, and potentially cause harm to the native microbial community through competition and killing of populations (Graham 2007, Griffin et al. 2014). Griffin et al. (2014) found prevalent bacteria and fungi, measured by colony-forming units (CFUs), in Carlsbad Caverns. *Staphylococcus* spp. (18% of the CFU) was found near a visitor paved trail, and *Knoellia* spp. (40.1% of CFU) was found at off-trail locations (Griffin et al. 2014). *Eupenicillium* is a fungus generally associated with food (Vanderwolf et al. 2013) and it was found near the Lunch Room concessions area. Air-borne fungi such as *Cladosporium* and *Alternaria* were found near the Natural Entrance (Griffin et al. 2014). *Cladosporium* are fairly common throughout the world and are active in low temperatures and high humidity. This particular fungus can cause harm to plants and humans through asthma (Ogórek et al. 2014).

Threats and Stressor Factors

Cave ecosystems are delicate in nature and with continual human use, development, and exploration, the impact from humans on the natural resources of the parks caves can be detrimental (Graham 2007). As of 1983, the cave systems at CAVE were in a period of stability and any subsequent impact or change discovered in speleothems is likely a direct cause of human impact (Paris and Giananntonio 1983).

Speleothems provide a geological timeline for a cave, including seismic (vibrations in the earth) activities, whether they are caused naturally or by human impact (Akgöz and Eren 2015). Anthropogenic disruptions on speleothems can be direct (e.g., touching, breaking, tipping) or indirect (e.g., vibrations caused by underground blasting, driving heavy machinery above ground). Dating of seismic events can be seen on speleothems through the growth-axis angle and through referencing occurrences in time; using this information, it is often possible to determine the source of disturbances (Akgöz and Eren 2015).

In 1992, the BLM proposed gas and oil drilling sites in southeastern New Mexico in an area called Dark Canyon, which is located just north of CAVE, near Lechuguilla Cave (Figure 70) (BLM 1992). Even through drilling or extraction has not occurred, partially due to the Lechuguilla Cave Protection

Area (BLM 1992), on this leased land, the potential for drilling could indirectly degrade cave resources through water contamination (Graham 2007), increased soil erosion, and increased potential for cave passage and room collapse (Goodbar nd). Substantial hydrocarbon reserves have been discovered just north of the park and, if drilled, the risk of toxic and flammable contamination could potentially harm the unique cave environment (Graham 2007).

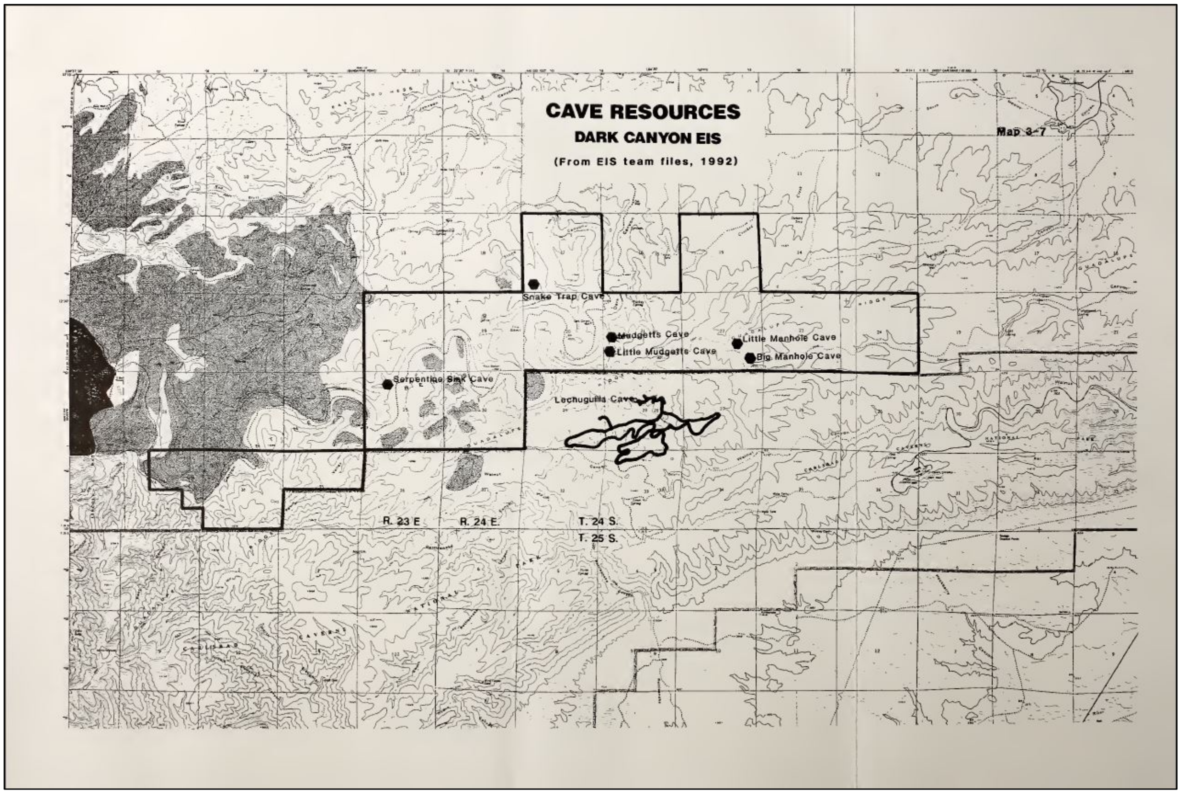


Figure 70. The area known as Dark Canyon is the thick black line at the top of the map (the black dots represent locations of caves), while Lechuguilla Cave is located just south of the study area. (Figure taken from the Dark Canyon Environmental Impact Statement (BLM 1992).

Human waste has become a problem in the caves, whether it is garbage generated from visitors at the Lunch Room in Carlsbad Caverns, or human waste, specifically urine, generated from visitors along unguided trails (Graham 2007). Cave research in backcountry caves is important to help understand the unique environment, but when expeditions take more than four days and low impact cave camping is used, urine disposal becomes an issue. Cavers can only carry out up to four days of human waste; cave camps in Lechuguilla Cave often last 6-8 days (Horrocks, written communication, 9 May 2016). Food and fecal waste is packaged and taken out by each researcher, but urine has been dumped inside the caves at designated sites to create lighter carrying packs. On an average research expedition, a person can generate approximately 2 liters (0.5 gallons) of urine per day, which could amount to an additional 10 kg (22 lbs) on an individual's pack that already weighs 14 – 27 kg (30 – 50 lbs) (Boston and Welch 2004). This additional urine inside the cave environment results in an excess of N in the water. This excess N gets broken down into NH_3 which can upset the natural balance of native cave microbial species, and potentially fuel exotic species that thrive on higher N levels to outcompete the native species (Boston and Welch 2004). Boston and Welch (2004) tested different methods to help reduce the amount of urine waste without having the researcher carry out the extra weight. One possible solution was to burn off the NH_3 with an alcohol or hydrogen fueled heat pump (Boston and Welch 2004). Other suggestions included chemical processing and biofiltration (Boston and Welch 2004).

The fungus that causes WNS has not been detected in in the park caves, although a strain in the same genus (*Pseudogymnoascus*) was discovered (Horrocks, written communication, 9 May 2016). It does not grow in temperatures above 20 °C (68 °F), which makes cave environments potential long-term incubation sites (Lorch et al. 2013). A recent study showed that the fungus spores can be found in a cave environment, specifically the sediment, even if present bats do not have the disease. Once introduced, the fungus' spores can survive for a substantial period of time (Lorch et al. 2013). Human-assisted transmission does not seem to be a frequent event, but the fungus' spores have been found on equipment and clothing on a researcher, especially from a cave located in the eastern United States (Castle and Cryan 2010).

Research and exploration in caves are necessary to fully understand the health of the cave ecosystem (Graham 2007). Research expeditions can take up many days and through that process, it has been discovered that careless travel has broken formations and tracked mud and dirt in previously pristine locations (Graham 2007). Park management has implemented more stringent guidelines that focus on leaving minimal impact during exploration and research (Graham 2007). Such guidelines include flagging trails, closing sensitive areas, and using aqua socks on flowstones (Horrocks, written communication, 9 May 2016).

Data Needs/Gaps

While this assessment provided some baseline for assessing human impacts inside the caves of the park, additional and up-to-date data would provide a more comprehensive analysis. With the last vandalism study completed in 1983, a more current inventory could provide information on whether or not certain implementations such as the steel railing installation and the use of guided tours have succeeded in reducing vandalism. Also, an updated analysis of current lint accumulation could provide a more thorough analysis. According to the Werker and Hildreth-Werker (1995) study, permanent photo monitoring stations were installed in the Left Hand Tunnel, New Mexico Room, Lower Cave, and Hall of the White Giant. Data from this report was not available at the time of this assessment. If those stations are still in place, current photo monitoring could provide visual information on certain cave resources.

Overall Condition

Number of Broken Formations

The *Significance Level* for number of broken formations was assigned a 3. With the most recent vandalism survey completed in in 1983 (Paris and Giananntonio 1983), and no other current data available, a *Condition Level* cannot be assigned at this time.

Annual Lint Accumulation

The *Significance Level* for annual lint accumulation was also assigned a 3. The Jablonsky et al. (2003) study discovered that 68% of the lint was generated from synthetic fibers with most of the remaining being natural fibers, both originating from clothing. In an effort to reduce the amount of lint accumulation, park management has implemented annual week long “Lint Camps” where volunteers come and remove lint from inside the cave, as well as enlisting other volunteer groups for half-day projects. Due to re-occurring lint presence and no other measures implemented to reduce lint accumulation, a *Condition Level* for this measure was assigned a 2, or of moderate concern.

Number of Visitors Annually

This measure was assigned a *Significance Level* of 2. The park does not have a visitor carrying capacity set in place to help keep the visitor impact on the cave ecosystem to a minimum. With a constant stream of visitors, especially to Carlsbad Caverns (NPS 2015), and no carrying capacity set in place, visitor impact is a potential threat to the cave ecosystem; thus the *Condition Level* for this measure was assigned a 2, or of moderate concern.

Photo Monitoring of Lower Use Areas

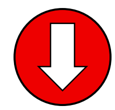
The *Significance Level* for photo monitoring of lower use areas was assigned a 3. Photo monitoring can provide visual sequential information about specific cave resources. Being able to monitor changes, growth, and impacts can provide park staff with the proper resource management for the unique cave environment (Werker and Hildreth-Werker 1995). Due to the photo monitoring data for the park being over 20 years old, accurate current data are not available at this time and a *Condition Level* cannot be assigned.

Introduced Microbes and Pathogens

This measure was also assigned a *Significance Level* of 3. Human beings carry microbial communities on their hair, clothes, and skin. These exotic microbial communities get introduced into a cave environment and can disrupt or replace the native microbial communities (Griffin et al. 2014). Also, research occurring in a cave, especially in more delicate parts, can disrupt the native microbial communities through tracking mud (Burger and Pate 2001). Park staff is working on efforts to reduce these exotic introductions, but it remains difficult to stop the natural shedding of human hair and skin. Exotic microbial communities are also being introduced through the underground Lunch Room concession area and have been found to disrupt the native communities (Griffin et al. 2014). Due to the factors listed above, the *Condition Level* for this measure was also assigned a 2, or of moderate concern.

Weighted Condition Score

The *Weighted Condition Score* for this component is 0.67, indicating human impacts are of high concern, and the condition is deteriorating. Due to the lack of historical data dating back to pre-1920s (before the opening of the park), no reference condition was available. Also, with no current photo monitoring and broken formations monitoring data, a complete assessment could not be completed at this time. Despite that, impacts from lint accumulations negatively affecting the cave speleothems, introduced microbes and pathogens from cave infrastructure and visitor traffic, and no visitor carrying capacity set in place for the caves, disruption to the unique cave ecosystem is occurring thus a high confidence border is used.

Human Impacts on Caves			
Measures	**Significance Level**	**Condition Level**	**WCS = 0.67**
Number of Broken Formations	3	N/A	
Annual Lint Accumulation	3	2	
Number of Visitors Annually	2	2	
Photo Monitoring of Lower Use Areas	3	N/A	
Introduced Microbes and Pathogens	3	2	

4.9.6. Sources of Expertise

- Kent Schwarzkopf, CAVE Chief of Resource Stewardship and Science.
- Rod Horrocks, CAVE Physical Scientist.

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4.10. Groundwater

4.10.1. Description

When studying groundwater, both occurrence and movement of the resource can vary between locations; most groundwater moves at a slower pace than surface water (Heath 1983). Due to many factors, including slower pace, groundwaters are often considered reservoirs, thus making them readily accessible for anthropogenic uses (Heath 1983). However, groundwater systems found near lava flows, coarse gravels, and karst areas are considered to be conduits and water moves at a more rapid pace (Heath 1983); the park falls into this category. The park is part of a karstic environment, meaning the geology of the area provides high porosity and permeability for water in a soluble rock (Uliana 2001). This karst environment was created from the historic formation of the area known as the Capitan Reef Complex, which is an ancient reef that formed around the perimeter of the Permian-aged Delaware Basin (Graham 2007). Over time, the basin was filled in with evaporate deposition and the area was uplifted and eroded, leaving parts of the Capitan Reef exposed; the Guadalupe Mountains are a remnant of those ancient reefs (Photo 18).

Photo 18. The Guadalupe Mountains display remnants of the ancient Capitan Reef (Photo by Kathy Allen, SMUMN GSS).

The Capitan Aquifer occurs in the Capitan Reef Complex; it is this aquifer that is associated with the parks groundwater (Uliana 2001). The aquifer has both confined (overlain by another layer that limits groundwater flow) and unconfined (in direct contact with the surface water or water table) components (Jonena Hearst, GUMO geologist, written communication, 4 October 2012). Due to the high permeability and porosity of the limestone and dolomite environment, groundwater in the Capitan Aquifer tends to flow northeast to east (Uliana 2001) (refer to Figure 73) along the outside of the reef. Discharge would occur in the Pecos River, and eventually in the Gulf of Mexico (Uliana 2001).

Due to its location within the Chihuahuan Desert, water is a limiting factor for the park's ecosystems. (NPS 2010). Even though the park's caves are relatively dry and have minimal amounts of flowing water inside (like most caves in the desert do), speleothem development and organisms living inside the cave depend on this limited resource (Graham 2007). If the desert climate happens to become wetter in the future, speleothem growth will accelerate; conversely if the climate happens to become drier, speleothem growth will decrease (Graham 2007). Because of the critical nature of groundwater in a semi-arid environment, understanding where the groundwater is and how it moves can provide insight into the overall function and integrity of cave ecosystems (NPS 2010).

4.10.2. Measures

- Depth to groundwater
- Water quality
- Recharge area
- Human use/withdrawal

4.10.3. Reference Conditions/Values

Lake of the White Roses was discovered and identified as the deepest point (393 m [1,289 ft] below surface) in Lechuguilla Cave in 1989 (Figure 71). This body of water is situated about 30 m (98 ft) above the regional water table and extends to depths that likely intersect the Capitan Aquifer (Land and Burger 2008). The water chemistry of this water body more closely resembles an average aquifer sample than other pool waters in the Lechuguilla Cave (Land and Burger 2008).

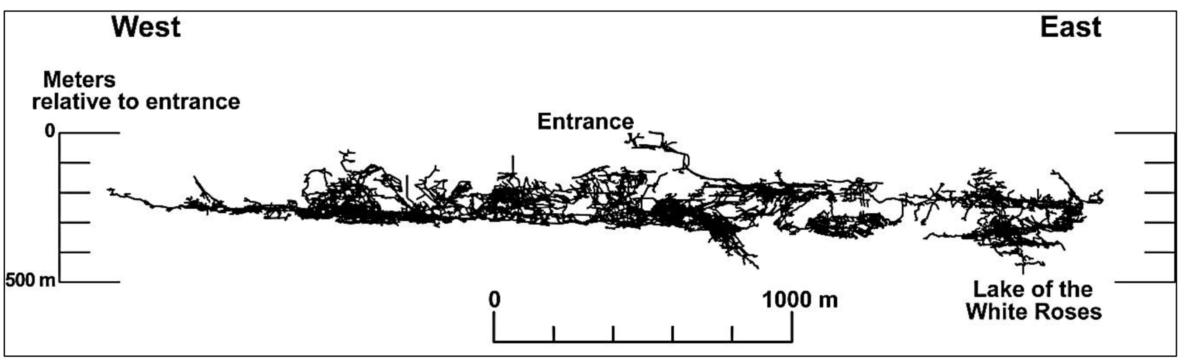

Figure 71. Lake of the White Roses is considered to be the deepest point so far discovered in Lechuguilla Cave. Discovered in 1989, it sits 30m (98 ft) above the regional water table and more closely resembles an average aquifer sample than any other pools in Lechuguilla Cave (Land and Burger 2008).

As 1989 represents the year of discovery, and the first year of data for the deepest point in Lechuguilla Cave, initial measurements from this location serve as the reference condition for this component. Subsequent measurements will be compared to this period. In the absence of data from this time related to the selected measures for this assessment, comparisons will be made using more recently collected data or current trends.

4.10.4. Data and Methods

van der Heijde et al. (1997) completed a water infiltration study to determine areas in the parks cave systems, specifically Carlsbad Cavern, that were most vulnerable to contamination from above ground park infrastructure. The major objectives of the study were to: 1) identify and characterize potential contaminant sources; 2) determine the presence and nature of contaminant pathways from these potential contaminant sources at or near the land surface to the caverns; 3) determine present impacts from these anthropogenic sources on the hydrology and water quality of the cave system, and 4) evaluate likelihood of future contamination of the cave system (van der Heijde et al. 1997). Hydrologic system domains were determined, based on hydrogeological characterization, to represent a characteristic set of infiltration pathways. Using a GIS and computer-aided design (CAD)-based overlay techniques, these hydrologic system domains were analyzed against the potential contamination sources to determine where the surface runoff could potentially end up inside Carlsbad Caverns (van der Heijde et al. 1997).

Forbes (2000) conducted water quality sampling at 13 pools inside Carlsbad Caverns; taking a total of 55 samples. Parameters measured included concentration levels of major ions in the water, along with atmospheric conditions of air temperature, humidity, and CO_2 levels. Bromide (Br) levels in the pools were also studied due to their ability to be a conservation tracer. Br can exist in water without being affected by other ions (Forbes 2000).

Land and Burger (2008) determined the rate of groundwater recharge in Lechuguilla Cave, specifically Lake of the White Roses. A datalogger was submerged into the lake and water levels were recorded every two hours; this sampling occurred from 7 May 2003 through 5 May 2005. During this time of sampling, extreme precipitation events occurred that helped articulate the recharge rate for Lake of the White Roses (Land and Burger 2008); while these data may provide some insight into recharge rates, each cave within the park will be different (Horrocks, written communication, 15 July 2016).

According to Bjorklund and Motts (1959), the Capitan Aquifer supplies municipal water to the City of Carlsbad, New Mexico, a major potash company, and to nearby ranches and farms (Rice-Snow and Goodbar 2012) due to high water quality near areas of recharge. The data available at the time of this writing articulating withdrawal amounts is from the mid-1950s (Table 34). Even though the study is almost 60 years old, Bjorklund and Motts (1959) also provides in-depth analysis on the geological and hydrogeological composition of the Carlsbad area.

Table 34. Some of the uses and amounts of groundwater pumped from the Capitan Aquifer in 1954 for municipal and agricultural purposes (Bjorklund and Motts 1959).

Groundwater Use	Quantity pumped in 1954 (acres)
City of Carlsbad	6,120
Happy Valley*	50
White City*	100
Irrigation	7,500
Industrial	2,310
Domestic and stock	200
Total	16,280

*Source from a privately owned well (Bjorklund and Motts 1959)

4.10.5. Current Condition and Trend

Depth to Groundwater

Water table elevations tend to follow the elevation of the land surface (Heath 1983); Williams (1983) speculated that a large groundwater storage area is found in the vadose (or unsaturated) zone at Carlsbad Caverns. Due to the park's caves being a karstic environment and groundwater moving rapidly throughout, the water table tends to fluctuate dramatically in short periods of time (IAH 2013). At this time, there are no reference data available on groundwater levels for the Capitan Aquifer within park boundaries.

Water Quality

CAVE has a semi-arid climate, where only small amounts of water infiltrate from the surface into the caves. Only during heavy rainstorms is there the potential that excess water and contaminants can enter the caves, thus causing concern (van der Heijde et al. 1997). Potential sources of surface contamination were identified by van der Heijde et al. (1997) and included buildings for park maintenance, staff, and visitors, sewer lines from staff housing, the maintenance yard and offices, visitor and staff parking lots, and storage tanks used for diesel and propane. The most threatened areas within Carlsbad Cavern are 1) the Quintessential Right, 2) Left Hand Tunnel, 3) New Section, 4) the Main corridor between Devil's Spring and Iceberg Rock, and 5) the locations in Chocolate High, the New Mexico Room, the Scenic Rooms, and the Big Room area (van der Heijde et al. 1997) (Figure 72). During the van der Heijde et al. (1997) study, it was concluded that although areas of Carlsbad Cavern are highly vulnerable to surface contamination, few indicators suggest massive contamination is occurring (Appendix Q).

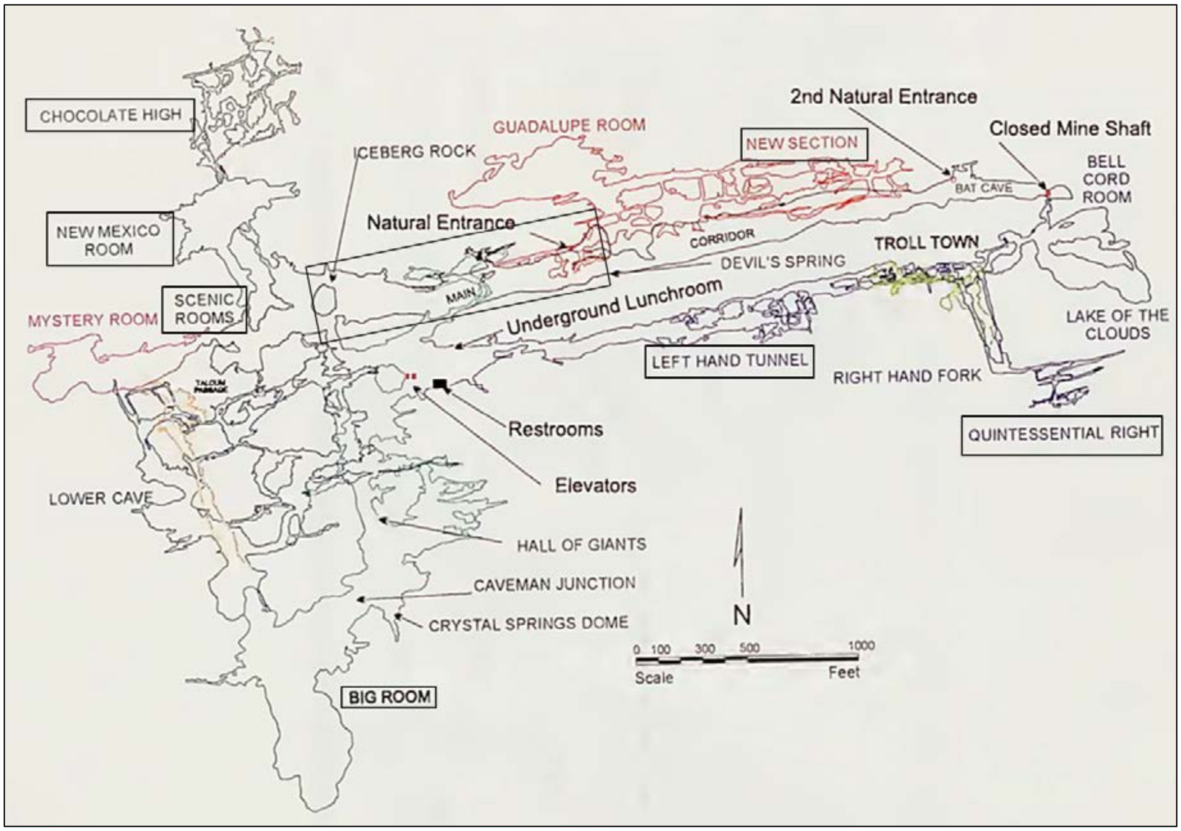

Figure 72. A few named locations found within Carlsbad Cavern. The conclusions of the van der Heijde et al. (1997) study stated that the most threatened cave areas in the park are 1) the Quintessential Right, 2) Left Hand Tunnel, 3) New Section, 4) the Main corridor between Devil's Spring and Iceberg Rock, and 5) the locations in Chocolate High, the New Mexico Room, the Scenic Rooms, and the Big Room area (black outlines display these areas).

According to Forbes (2000), large differences in water quality were discovered between pools in Carlsbad Caverns, but minor variations occurred in the same pool between different sampling years (Forbes 2000). Most of the pools discovered in the study contained fresh water with minimal amounts of salt buildup. It was concluded that any high levels of ion concentrations discovered were related to the surrounding geology. For example, Longfellows Bathtub and Iron Pools were found to have higher concentrations of calcium and SO_4 (TDS 2,500 mg/l) from the surrounding dissolution of the gypsum mineral present in Carlsbad Caverns (Forbes 2000). Climate conditions within Carlsbad Caverns (i.e., temperature, humidity) did not seem to have an effect on the water quality of the pools sampled (Forbes 2000).

In terms of water quality for the Capitan Aquifer, distance from recharge areas has an effect on water quality (Uliana 2001). Portions of the aquifer located in Texas have been found to have lower quality while areas closer to groundwater recharge in New Mexico (i.e., where the reef is exposed at the surface in the Guadalupe and Glass Mountains) contain higher quality water (Uliana 2001). The park and the city of Carlsbad fall into this area of higher quality (Uliana 2001, Rice-Snow and Goodbar 2012), thus making the resource suitable for municipal drinking water.

Recharge Area

In drier, more semi-arid regions, recharge conditions are more complex than other climate regions. Recharge events can vary from year to year based on precipitation, seasonal distributions, air temperatures, and land use (Heath 1983). The Capitan Reef is recharged by infiltration from precipitation, seepage from streams, arroyos, reservoirs, canals, and by subsurface inflow from the adjacent aquifers (Bjorklund and Motts 1959). When measuring the water levels in the Lake of the White Clouds after two major rainfall events, Land and Burger (2008) concluded that the Capitan Reef has very high transmissivity and porosity levels. With recharge rates occurring intermittently following precipitation events and discharge events being a continuous process, recharge rates are inversely related to discharge rates. As recharge increases, groundwater heads decline causing the rate of discharge to decrease (Heath 1983). Pool water inside caves tends to have higher residence time. Excess water from the cave pools will eventually percolate into the Capitan Aquifer as recharge (van der Heijde et al. 1997). Forbes (2000) also articulates that pools inside the caves discharge through leaking water into the aquifer system rather than evaporation; this was demonstrated by the lack of dissolved bromide in the pools. Despite information on how recharge occurs in the aquifer, there is no current data available on how much recharge or where exactly in the cave ecosystem groundwater recharge is occurring.

Human Use/Withdrawal

As stated in the Bjorklund and Motts (1959) study, agriculture and irrigation have had a presence in the Carlsbad area since the late 1800s. During the 1954 growing season, 12,342.93 ha (30,500 ac) of land was irrigated and of that, 9,793.41 ha (24,200 ac) was largely irrigated by groundwater (Bjorklund and Motts 1959). Potash ore refineries were also mentioned as a source of withdrawal; high quantities were used in refinery ponds and when water from those ponds seep back into the earth, it created increased levels of salinity (Bjorklund and Motts 1959). Oil refineries are also found in and around the Carlsbad area and according to Bjorklund and Motts (1959), had drilling depths ranging from 152.4-1,219.2 m (500 to 4,000 ft) below ground. In 1959, the City of Carlsbad utilized nine wells for withdrawing groundwater from the Capitan Aquifer and in 1954 7,402,721 kl (kiloliters) (1,955,592,000 gal) of water was pumped from these wells for various uses throughout the city (Bjorklund and Motts 1959). The unincorporated community, Happy Valley, utilizes one privately owned well (100.3 m [329ft]) that taps into the reef aquifer as well. In 1954, the Happy Valley pumped anywhere from 2,309.10 kl (610,000 gal) to 54,942.8 kl (14,517,000 gal) for various uses (Bjorklund and Motts 1959). Two more privately owned wells are located in the unincorporated community of White City; together these two wells pumped anywhere from 325.55 kl (86,000 gal) to 598.10 kl (158,000 gal) (Bjorklund and Motts 1959). Even though Bjorklund and Motts (1959) provides an abundance of data on the pumping and withdrawal of the Capitan Aquifer, at the time of this writing, there is no current data available on similar findings.

Threats and Stressor Factors

Threats to the groundwater resources in the park identified by park resource managers include climate change, historic overgrazing, pumping for human and agricultural use, and oil and gas development. Groundwater levels are continually adjusting due to the effects of weather, well pumping, and land use (Porter et al. 2009) With the naturally arid climate, the ecosystem already supports minimal water movement (van der Heijde et al. 1997). Potential impacts of climate change in the region around CAVE include increased temperatures, changes in the amount and timing of precipitation, and more extreme weather events (Davey et al. 2007). Climate conditions for the park are already shifting and getting warmer (Monahan and Fisichelli 2014) and groundwater levels in the CHDN are showing vulnerabilities to drought (Porter et al. 2009). Extreme rainfall events are also increasing at a rate of 51% more per century (Gonzalez 2014). This increased rainfall could lead to more water contamination in caves as more surface runoff leaches underground (Gonzalez 2014).

In areas of lower quality near Texas, oil and gas well development occurs (Uliana 2001) and is increasing the potential for groundwater contamination (Rice-Snow and Goodbar 2012). In areas where the Capitan Aquifer is being drained or pumped for anthropogenic uses, hydraulic gradients and flow paths are changing. Specifically, the oil and gas well development during the past 80 years has drained groundwater to the extent of affecting the gradient so much that it altered the original discharge area (Figure 73).

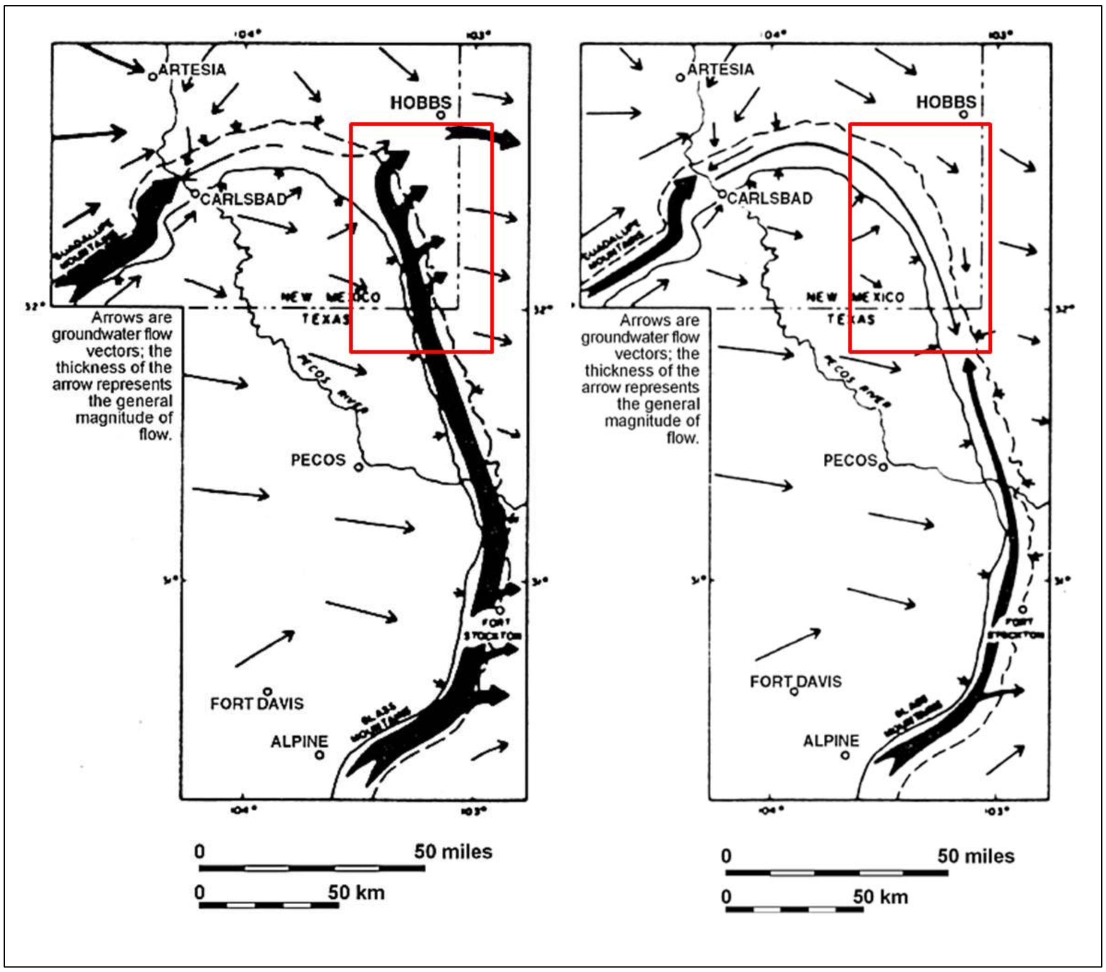

Figure 73. Image on the left displays groundwater flow in the Capitan Aquifer before oil and gas well development and pumping, while the image on the right displays the altered groundwater flow due to the oil and gas well development and pumping. Notice area of terminal discharge has been completely altered (red box) (Uliana 2001).

Even though proposed gas and oil drilling, in an area called Dark Canyon (see Figure 70), put in place by the BLM have not been very active, partially due to the Lechuguilla Cave Protection Area (BLM 1992), the potential for drilling could indirectly degrade cave resources through water contamination (Graham 2007), increased soil erosion, and increased potential for cave passage and room collapse (Goodbar nd). Substantial hydrocarbon reserves have been discovered just north of the park and, if drilled, the risk of toxic and flammable contamination could potentially harm the unique cave environment (Graham 2007).

Overgrazing of vegetation occurs when too much livestock is in one area for a long period of time and proper monitoring of their grazing habits is not in place. This phenomenon can affect the surrounding soil properties, which can reduce infiltration, accelerate runoff, and contribute to soil erosion (Czeglédi and Radácsi 2005). There is no historic grazing practices information specific to the park, but livestock grazing has been embedded in the social and political fabric of the West for centuries. According to the 2011 National Land Cover Dataset (NLCD), land cover suitable for grazing and holding livestock include:

- Grassland/Herbaceous: areas dominated by graminoid and herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tiling, but can be utilized for grazing.
- Pasture/Hay: areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation (USGS 2011).

An 80-km (50-mi) buffer was used to determine the land cover in close-proximity to CAVE; both the grassland/herbaceous and pasture/hay land cover types fall inside this buffer (Figure 74). Even though exact correlation between grazing lands and the park are not highlighted, the NLCD can provide insight as to the relative distance and direction grazing lands are found to the park.

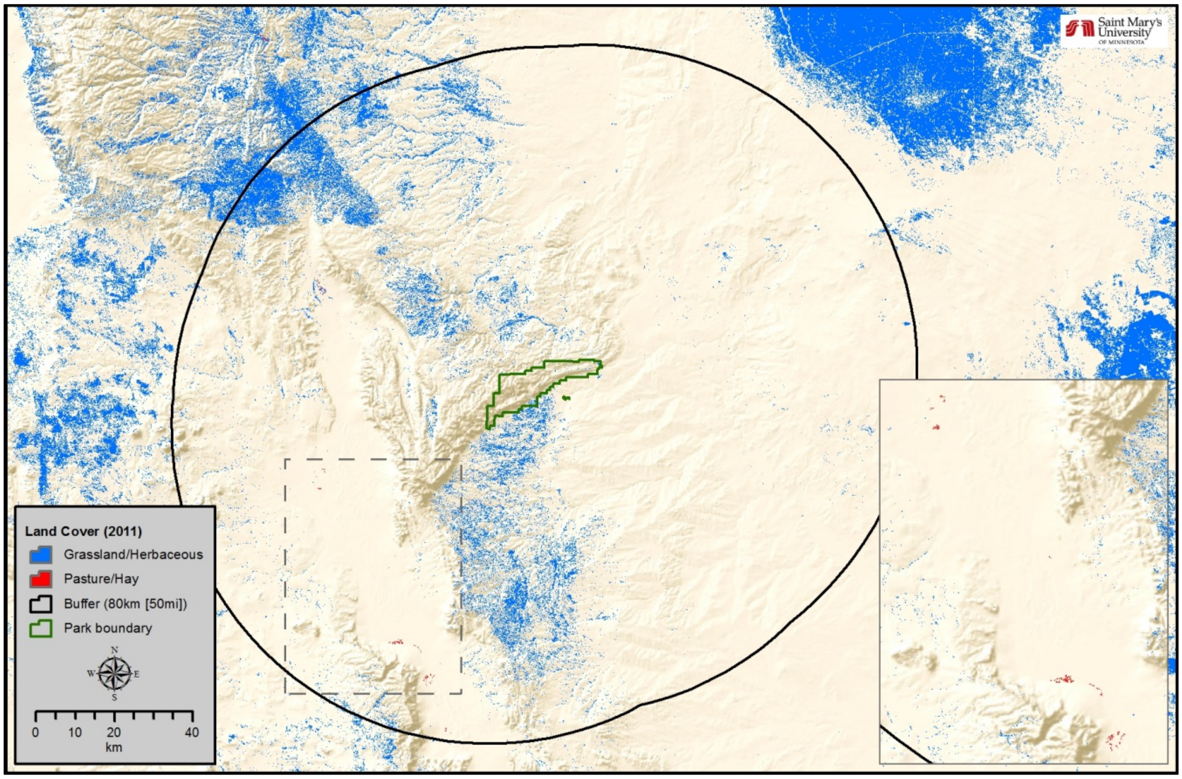

Figure 74. According to the 2011 NLCD, livestock and grazing practices can be found on both grassland/herbaceous and pasture/hay land cover types (USGS 2011). Within an 80-km (50-mi) buffer around CAVE, both land cover types are found. Pasture/Hay is minimal but found in the west to southwest area of the buffer.

Not until recently have the environmental impacts of grazing on public lands become a serious and widespread concern; approximately 70% of western states support livestock grazing (Floyd et al. 2003). It is possible, however, for the landscape to recover after overgrazing by improving the grazing distribution habits of livestock (Czeglédi and Radácsi 2005).

<u>Data Needs/Gaps</u>

More data monitoring of groundwater depth and recharge for the Capitan Aquifer inside the park would be beneficial for rating the overall condition of the resource. It can also provide insight for determining the impacts from groundwater withdrawals and external pumping from the aquifer. Development (municipal, agricultural, industrial) surrounding the park has been withdrawing groundwater for a long time, but these cumulative withdrawals have not been documented since 1954 (Bjorklund and Motts 1959). There are limited data available on how these withdrawals are affecting the groundwater inside the caves.

<u>Overall Condition</u>

Depth to Groundwater

The *Significance Level* for depth to groundwater was assigned a 3. Due to the lack of data on depth to groundwater inside the caves, a *Condition Level* cannot be assigned at this time.

Water Quality

A *Significance Level* of 3 was assigned for water quality. van der Heijde et al. (1997) study on contamination sources provides a good baseline for determining how pollutants enter Carlsbad Caverns ecosystem. It concluded that there are areas in the cave system that are highly vulnerable to surface contamination, but overall, little contamination has occurred inside the cave ecosystem (van der Heijde et al. 1997). According to Forbes (2000), the surface water quality entering Carlsbad Caverns is posing little threat to the overall ecosystem. Due to these studies, the *Condition Level* for this measure was assigned a 1, or of low concern.

Recharge Area

The *Significance Level* for recharge area was assigned a 3. Water moves fairly quickly inside the park due to the karst environment. The Land and Burger (2008) study reached this conclusion through studying the Lake of the White Roses inside Lechuguilla Cave, particularly by measuring pool depth after large rainfalls. Water coming from the surface percolates quickly into the caves and overall groundwater system. Water does have a long residence time inside the cave pools, but eventually evaporates or drains below into the water table (Land and Burger 2008). Despite information on how recharge occurs in the aquifer, there is no current data available on how much recharge or where exactly in the cave ecosystem groundwater recharge is occurring; thus a *Condition Level* cannot be assigned at this time.

Human Use/Withdrawal

This measure was assigned a *Significance Level* of 3. Development surrounding the park is using groundwater from the Capitan Aquifer; this includes municipalities, farming and ranching, and oil and gas well development (Graham 2007). No data are available at the time of writing this component that articulates the impact from anthropogenic uses of groundwater through withdrawal and pumping, thus no *Condition Level* could be assigned.

Weighted Condition Score

A *Weighted Condition Score* for the groundwater component cannot be assigned at this time due to three of the four measure providing data gaps. Even though water is generally in high quality, due to a lack of depth to groundwater data and current recharge rates and withdrawal amounts, the groundwater levels in CAVE cannot be accurately assessed and needs further research for support.

Groundwater			
Measures	**Significance Level**	**Condition Level**	**WCS = N/A**
Depth to Groundwater	3	N/A	
Water Quality	3	1	
Recharge Area	3	N/A	
Human Use/Withdrawal	3	N/A	

4.10.6. Sources of Expertise

- Cheryl McIntyre, CHDN Physical Scientist.
- Colleen Filippone, NPS Regional Hydrologist.

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Chapter 5. Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the park.

5.1. Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but are needed to help inform the status or overall condition of a key resource component in the park. Data gaps exist for nearly all the resource components assessed in this NRCA. Only birds and dark night skies had adequate information available to assign a condition level to all of the identified measures for these two components. The remaining components had varying degrees of data needs, ranging from one to all of the identified measures. Table 35 provides a detailed list of the key data gaps by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 35. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Rattlesnake Springs community	➢ Evaluation of the quality and suitability of the vegetation structure within this unit in terms of Southwestern willow flycatcher nesting habitat. ➢ Monitoring of cottonwood size class distribution and regeneration. ➢ Future hydrologic and ecologic analysis to identify best management practices for the wetlands in the unit (Muldavin et al. 2012). ➢ Development of a wetlands management plan for the unit. ➢ Further research on the relationship between surface water and groundwater within the region.
Seeps and springs	➢ Comprehensive inventory of vegetation community composition of the park's seep- and spring-associated habitats and, to the degree possible, monitoring of the areal extent of these resources. ➢ Continued monitoring of the park's water table levels and groundwater flow paths. ➢ Long-term consistent monitoring of the water quality and discharge of the park's seeps and springs. ➢ Further research on the relationship between surface water and groundwater within the region.

Table 35 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Bats	➢ Research on the abundance of bat species within the park. ➢ Further research on the number of caves utilized by the park's bat population. ➢ Further research on the number of maternity roosts (by species) within the park's caves.
Birds	➢ Continuation of the grassland and riparian bird monitoring by the RMBO will provide park resource managers with a long-term data set that can be used to identify trends in abundance, density, and species richness of the habitat-specific bird species, as well as the health of the park's riparian vegetation communities. ➢ Future monitoring of avian species of concern would help managers to understand how many species and individuals are present in the park, and would also provide approximate estimates of what seasons the species are present in CAVE. ➢ Closer monitoring of the health of the bird populations in the Rattlesnake Springs area would provide managers with insights into the health of many bird communities, and the overall health of this riparian area. ➢ Addition of bird surveys during the spring and fall migration period and in winter would provide resource managers with a better understanding of the trends and status of year-round bird species in the park. These surveys should employ the White (2011) spatially-balanced landbird protocol in order to be comparable with existing bird density and occupancy data. ➢ Development of a management strategy related to the ongoing cowbird and fox squirrel issues in this area is also needed to promote continued growth of the park's priority bird communities.
Herpetofauna	➢ Continued population inventories and studies following Prival and Goode (2011) methodology to update the composition and distribution of the herpetofauna community at CAVE. ➢ Development and implementation of a long-term monitoring program that would assist park resource managers in assessing the condition of the park's herptiles and to understand trends in population and distribution.
Air quality	➢ No active air quality monitors, with the exception of the on-site POMS station, are within the distance (16 km [10 mi]) necessary to accurately represent conditions in the park. ➢ Periodic or consistent monitoring of atmospheric deposition of nitrogen, sulfur, and mercury deposition, as well as ozone, particulate matter, and visibility would help managers better understand the local air quality conditions in and around CAVE and how they may affect other park resources.

Table 35 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Dark night skies	➢ The last visit by the NPS NSNSD was approximately 10 years ago. Given the analysis of that data and current conditions, another visit by the NPS NSNSD is recommended. ➢ Continued monitoring by the NPS NSNSD on a regular basis is recommended given the degraded quality of the night skies. This would provide data that could determine if the light intrusion has stabilized or continues to degrade. ➢ Development of a natural lightscape management plan for the park.
Infrastructure impacts on caves	➢ Currently, no active air quality monitoring is conducted within the caves. Monitoring air quality within the cave environments will benefit resource managers in assessing and managing for infrastructure and visitor impacts on the caves. ➢ Periodic or consistent monitoring of the water quality of pools within the caves would provide information to resource managers on managing stormwater runoff impacts to the cave environments.
Human impacts on caves	➢ Update to 1983 vandalism survey. ➢ A comprehensive inventory of cave formations is needed in order to determine if management practices put in place have reduced the incidents of vandalism. ➢ Continued monitoring and analysis of lint accumulation. ➢ Continued photo monitoring of cave resources using the photo-monitoring stations installed by Werker and Hildreth-Werker (1995).
Groundwater	➢ Continued monitoring of the park's water table levels and groundwater flow paths. ➢ Long-term consistent monitoring of the water quality of groundwater within the park. ➢ Further research on the relationship between surface water and groundwater within the region.

Several of the park's data gaps involve the need for comprehensive inventories and continued monitoring in order to accumulate data to assess and evaluate the condition and trends over time for many of the resources included in this analysis. This is evident by the high number of measures that could not be assigned a current condition due to either recent data gaps or lack of historic data to quantify the identified reference condition. The hydrologic resources reviewed during this assessment would benefit from research on the relationship between surface water and groundwater in the region, along with consistent monitoring and record-keeping of water table levels. Other components, such as birds and herpetofauna, would benefit from more consistent sampling efforts (both timing and methodology).

5.2. Component Condition Designations

Table 36 displays the conditions assigned to each resource component presented in Chapter 4 (definitions of condition graphics are located in Table 37 following Table 36). It is important to remember that the graphics represented are simple symbols for the overall condition and trend assigned to each component. Because the assigned condition of a component (as represented by the symbols in Table 36) is based on a number of factors and an assessment of multiple literature and data sources, it is strongly recommended that the reader refer back to each specific component assessment in Chapter 4 for a detailed explanation and justification of the assigned condition. Condition designations for some components are supported by existing datasets and monitoring information and/or the expertise of NPS staff, while other components lack historic data, a clear understanding of reference conditions (i.e., what is considered desirable or natural), or even current information. Condition could not be determined for five of the ten selected components: seeps and springs, bats, herpetofauna, infrastructure impacts on caves, and groundwater.

For featured components with available data and fewer information gaps, assigned conditions varied. None of the components assessed by this review was considered to be in good condition. Two components (birds and dark night skies) were of moderate concern, and three components (Rattlesnake Springs' community, air quality, and human impacts on caves) were considered to be of significant concern. The NPS NSNSD data for dark night sky conditions at CAVE is nearly ten years old, and it is likely that this component would fall into the significant concern category if current data were available. The air quality component was assessed as being of significant concern, even though the individual measures all fell within the moderate concern category. The rating was elevated to the significant concern primarily due to the fact that the ecosystems at CAVE may be very highly sensitive to nitrogen-enrichment and acidification effects relative to all I&M parks (Sullivan et al. 2011a, b, Sullivan et al. 2011c, d, NPS 2015). This finding was consistent with the results from the NPS ARD. The significant concern for the Rattlesnake Springs community was primarily due to declines in the measured discharge rates for the spring, and the loss of historic wetland areas.

Table 36. Summary of current condition and condition trend for featured NRCA components.

Component	WCS	Condition
Biological Composition		
Ecological communities		
Rattlesnake Springs community	0.89	
Seeps and springs	N/A	
Mammals		
Bats	N/A	

Table 36 (continued). Summary of current condition and condition trend for featured NRCA components.

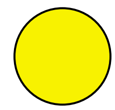
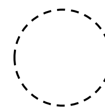
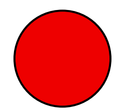
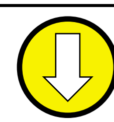
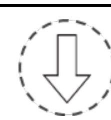
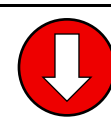
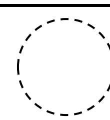
Component	WCS	Condition
Biological Composition		
Birds		
Birds	0.40	
Reptiles		
Herpetofauna	N/A	
Environmental Quality		
Air quality	0.87	
Dark night skies	0.40	
Physical Characteristics		
Geologic and Hydrologic		
Infrastructure impacts on caves	N/A	
Human impacts on caves	0.67	
Groundwater	N/A	

Table 37. Indicator symbols used to indicated condition, trend, and confidence in the assessment.

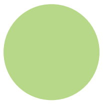
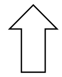
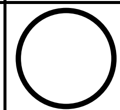
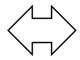
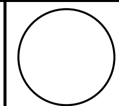
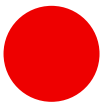
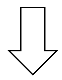
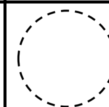
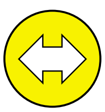
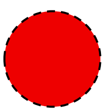
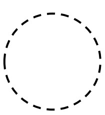
Condition Status		**Trend in Condition**		**Confidence in Assessment**	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Table 38. Examples of indicator symbols and descriptions of how to interpret them.

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.

5.3. Park-wide Condition Observations

5.3.1. Ecological Communities

The wetland and riparian vegetation communities of CAVE are vital resources for the park, providing habitat and water for wildlife and performing critical ecological functions. They are found mainly in the Rattlesnake Springs Unit and associated with isolated seeps and springs found throughout the park. Given a lack of data, a condition assessment could only be completed for the Rattlesnake Springs community. This resource was scored in the significant concern category. This community should be closely monitored so that management actions can be put into place if the condition continues to deteriorate.

5.3.2. Other Biotics

Other biotic components included in the NRCA were bats, birds, and herpetofauna. Due to data gaps in the identified measures or in defining the reference condition, condition could not be assigned for bats and herpetofauna. Birds were considered to be in moderate condition; however, a trend could not be assigned due to the lack of long-term monitoring data.

5.3.3. Environmental Quality

Environmental quality is important in maintaining healthy functioning ecosystems. The health of terrestrial and aquatic organisms in parks can be affected substantially by air and water quality conditions. Visitor experience may be diminished by the impact the surrounding land use has on the views from the park during both the day and night. The data collected by the NPS NSNSD for CAVE is approximately 10 years old. In reality, this data does not reflect the current impacts on the night skies at the park. The analysis of the data collected in 2007 and 2008 shows that there was some degradation to the night sky at that time. Another visit by the NPS NSNSD is recommended to assess the current condition of the night skies at the park.

The condition of the park's air quality was determined to be of significant concern by this assessment. Data for the atmospheric deposition of nitrogen, sulfur, and mercury measures fell within the highest concern levels as defined by the NPS ARD. Ozone concentration and visibility data indicated that these measures, while in the moderate category, were at the lower end of that range. However, in terms of haziest days, the visibility data fell into the significant concern category. Due to the lack of on-site data or from a monitoring station within an accepted distance, the particulate matter measure could not be assessed. Due to the sensitive ecosystems and vegetation present within the park, these measures warrant close monitoring in the future.

5.3.4. Physical Characteristics

CAVE was established due to its wealth of cave and karst structures and as a means to protect these resources. Three of the components assessed in this analysis can be used to provide an indication of the overall health of the cave communities within the park (infrastructure impacts on caves, human impacts on caves, and groundwater). Complete information was available to calculate an overall condition level for only the human impacts on caves component. The data and literature reviewed for this component indicated that there has been considerable impact on the caves by park visitors, as would be expected. This component was concluded to be of significant concern at this time. However, park resource managers have undertaken steps and management activities that will stabilize or lower these impacts in the future. Adequate information was available to determine a deteriorating trend for the infrastructure impacts on caves component, even though data was not available to determine an overall condition score. The groundwater component could not be assessed due to a general lack in current or baseline data.

5.3.5. Park-wide Threats and Stressors

Several threats and stressors influence the condition of multiple resources within CAVE. These include oil and gas development in the area, adjacent land uses, drought, climate change, and the impacts associated with visitor use. The park is located in the State of New Mexico's major oil producing region (NM EMNRD 2014). The impacts from oil and gas drilling activities can have wide-ranging effects on several of the park's natural resources, from degrading groundwater quality to decreased air quality and dark night sky visibility. Impacts from visitors are fairly widespread across the park's natural resources. This is in part due to the amount of access visitors have to the park's resources, both above and below ground.

5.3.6. Overall Conclusions

CAVE supports an extremely diverse ecosystem, supporting a range of unique features, from fragile cave environments to a number of plant and animal species that are near the geographic limits of their ranges. This assessment serves as a review and summary of available data and literature for featured natural resources within the park. Current condition could not be determined for half of the components due to data gaps. For those resources where a current condition could not be assessed due to the lack of data or defined reference conditions, the information presented here may serve as a baseline against which any changes in condition of components in the future may be compared. For resources where condition could be assessed, the majority warranted significant concern. In general, through the understanding of the condition of these resources, park resource managers can prioritize management objectives and better focus conservation strategies to maintain the health and integrity of park ecosystems.

5.4. Literature Cited

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Appendices

Appendix A. Wetted extent measurements for CAVE springs gathered by the CHDN (NPS 2016).

CAVE springs	Date	Brook length (m)	Wetted width (cm)	Depth (cm)
Able Seep	3/30/2012	2.0	50.00	5.00
Angels Bath Spring	10/23/2010	62.0	105.45	2.34
Crown Rock	11/5/2010	25.0	100.00	1.00
Cut Log Seep	11/5/2010	75.0	76.00	0.01
Dog Pen Seep	11/6/2010	20.0	800.00	0.01
Forgetful Seep	10/26/2010	107.0	79.56	0.81
Grammer Seep	10/22/2010	144.0	111.27	0.78
Iron Pipe Spring	11/5/2010	22.0	1.50	2.00
Kids Spring	10/25/2010	---		4.00
Kirkland Spring	3/29/2012	3.0	100.00	3.00
Longview Spring	11/5/2010	13.0	10.00	2.00
Maple Spring	11/20/2010	8.0	2,000.00	0.01
Minolith Spring	4/2/2012	0.2	30.00	15.00
No Name Seep 1	11/19/2010	8.0	30.00	0.01
No Name Seep 10	11/6/2010	3.0	150.00	0.01
No Name Seep 3	10/21/2010	5	---	0.00
No Name Seep 4	10/9/2014	24.8	202.00	4.00
	2/26/2015	26.5	205.00	11.00
No Name Seep 5	10/23/2010	20.0		
No Name Seep 6	10/25/2010	50.0	75.75	0.01
No Name Seep 7	10/24/2010	29.0	64.29	0.41
No Name Spring 9	3/29/2012	5.0	200.00	0.10
Oak Spring	10/23/2010	44.0	107.20	3.54
Oak Spring 2	10/23/2010	25.0	280.00	2.00
Previously Unknown Seep	10/23/2010	3.0	30.00	0.01
	10/10/2014	12.2	10.00	0.15
Putman Tank	3/31/2012	30.0	100.00	2.50
Rock Wren	11/20/2010	14.0	100.00	0.01
Slaughter Pot Hole	11/20/2010	---	45.00	150.00
	10/9/2014	2.1	177.20	---
	2/26/2015	2.7	262.00	---
Spider Cave Seep	10/23/2010	49.0	9.00	0.01
Stone Ranch Spring	10/24/2010	13.4	39.00	0.55
Upper East Grammer Seep	10/22/2010	42.0	146.77	3.60

CAVE springs	Date	Brook length (m)	Wetted width (cm)	Depth (cm)
Upper Lechuguilla	11/8/2010	49.0	37.56	2.39
Upper Lowe Ranch Spring	11/19/2010	118.0		
Upper Middle Grammer Spring	10/23/2010	22.0	1,700.00	0.01
Upper West Grammer Seep	10/23/2010	13.0	1,300.00	0.00
West Lechuguilla Seep	11/8/2010	120.0	138.39	3.22
Wild Calf Seep	4/1/2012	3.0	1.00	0.00

Appendix B. Available discharge measurements for Oak Spring (EPA 2015).

Date	Flow rate (lpm)	Date	Flow rate (lpm)	Date	Flow rate (lpm)
7/1931	19.4	9/1970	0.2	10/1982	4.7
7/1932	8.0	6/1972	0.2	2/1983	2.2
12/1932*	9.5	12/1972	5.7	1/28/1984	2.5
3/1937*	7.9	2/1973	5.7	4/1984	4.2
1/1939	5.0	4/1974	2.8	6/1985	3.5
4/1960	4.1	6/1974	2.5	2/1987	2.3
1/1/1963	1.9	2/1977	2.8	2/1988	4.7
4/1969	0.3	5/1978	3.8	11/1990	4.0
10/1969	0.1				

*Measurements noted in a 1959 memo from A. V. Dunn (Dunn 1959).

Appendix C. Available discharge measurements for Longview Spring (EPA 2015).

Date	Flow rate (lpm)	Date	Flow rate (lpm)	Date	Flow rate (lpm)
5/1953	0.6	9/1971	0.6	4/1978	0.5
9/1961	0.5	11/1971	0.5	2/1983	0.2
2/1962	0.3	10/1972	3.8	3/1984	1.9
11/1962	0.1	6/1972	0.5	4/1985	5.0
8/1966	0.6	1/1973	3.9	7/1985	2.8
4/1969	0.3	8/1973	0.3	3/1986	0.5
8/1969	0.6	1/1974	2.3	4/1987	0.4
9/1969	0.3	4/1974	2.9	2/1988	2.8
4/1971	0.3	5/1974	1.0	1/1991	0.7
8/1971	0.8	1/1975	8.8	7/1991	3.8
		3/1977	0.6	4/2000	0.4

Appendix D. Available discharge measurements in lpm for other seeps and springs within CAVE (NPS 1972, 2016; EPA 2015).

Spring/Date	Discharge	Spring/Date	Discharge	Spring/Date	Discharge
Able Seep		**Grammer Seep**		**Rock Wren**	
3/1972	0.63	4/1969	<0.1	4/1962	0.2
12/1990	0.22	7/1986	2.0	6/1962	0.3
3/2012	0.01	1/1991	0.6	11/1962	0.3
Big Hill Seep		10/2010	0.0	5/1969	0.3
4/1960	0.4	**Iron Pipe Spring**		7/1969	0.3
9/1969	0.1	1/1972	0.5	1/1970	0.3
7/1970	0.2	6/1972	0.4	3/1991	0.2
9/1970	0.1	2/1973	0.7	11/2010	0.01
9/1971	0.2	4/1974	0.2	**Spider Cave Seep**	
2/1978	0.1	3/1977	0.3	12/1971	0.2
1/1983	0.4	2/1983	0.1	2/1972	0.2
1/1984	0.4	4/1985	0.2	3/1974	0.1
4/1984	1.4	7/1985	0.3	2/1987	<0.1
6/1985	0.7	1/1991	1.3	4/1987	0.4
4/1986	1.9	7/1991	3.8	8/1987	0.5
4/1987	0.6	3/2000	0.1	11/1990	0.5
2/1989	0.3	11/2010	2.0	**Stone Ranch Spring**	
2/1991	0.6	**Kids Spring**		1/1953	0.6
7/1991	0.3	3/1962	0.3	9/1961	0.9
4/2000	<0.1	8/1962	0.5	9/1969	0.5
Clemond Ranch Spring		10/1962	0.5	3/1971	0.6
3/1962	0.3	9/1969	0.5	8/1971	0.7
5/1969	0.1	1/1970	1.3	6/1972	0.9
4/1970	0.3	9/1972	0.6	8/1972	0.5
9/1971	0.1	4/1974	0.3	1/1973	0.5
8/1972	0.1	2/1983	0.2	6/1974	0.8
8/1985	1.0	1/1984	0.2	3/1977	0.9
4/1987	4.7	6/1985	0.2	7/1981	0.8
2/1988	4.0	6/1988	4.2	3/1983	0.4
1/1991	0.21	1/1991	0.7	4/1985	0.9
Crown Rock		10/2010	2.0	6/1985	4.4
3/1962	Dry	**Kirkland Spring**		6/1986	0.9
11/1962	Wet	6/1969	0.2	4/1987	1.6

Spring/Date	Discharge	Spring/Date	Discharge	Spring/Date	Discharge
4/1969	0.4	10/1970	0.3	1/1988	4.7
9/1969	0.2	12/1990	0.2	1/1991	1.3
10/1969	0.5	3/2012	1.0	4/2000	0.8
6/1972	0.4	**Log Cabin Seep**		10/2010	1.6
2/1973	0.3	3/1972	0.1	**Upper Lechuguilla Seep**	
8/1973	0.2	12/1990	0.1	11/1969	3.2
1/1974	0.2	3/2012	0.0	12/1971	0.5
Crown Rock (cont.)		**Maple Spring**		**Upper Lechuguilla Seep (cont.)**	
4/1974	0.2	4/1962	Low	9/1972	0.9
5/1974	0.5	5/1969	0.3	2/1977	0.5
3/1977	0.2	1/1970	0.3	11/1980	0.3
1/1991	1.3	4/1974	0.3	1/1984	0.3
7/1991	0.4	3/1991	0.4	2/1988	0.4
5/2000	0.5	11/2010	2.0	11/1990	0.1
11/2010	1.5	**Lowe Ranch Spring**		11/2010	0.0
Cut Log Spring		4/1960	<0.1	**Upper Lowe Ranch Seep**	
2/1973	9.5	10/1961	0.1	5/1970	2.0
4/1985	0.1	8/1962	Dry	7/1970	<0.1
3/1986	0.1	2/1963	Dry	11/1990	0.4
1/1991	0.1	8/1969	0.1	**Upper Middle Grammer Seep**	
7/1991	0.2	1/13/1970	0.2	4/1969	<0.1
5/2000	Dry	1/15/1970	0.3	7/1970	0.1
11/2010	1.0	2/1970	0.3	4/1974	0.2
Dead Man Seep		5/1970	0.2	2/1977	<0.1
1/1972	0.4	4/1971	0.2	3/1979	0.1
2/1989	0.3	5/1971	0.1	1/1991	0.5
1/1991	0.2	9/1971	<0.1	**West Upper Grammer Seep**	
Dog Pen Seep		8/1972	Dry	4/1969	0.1
3/1953	0.1	1/1973	0.2	7/1970	0.2
3/1969	0.2	1/23/1983	0.6	2/1977	0.1
9/1969	0.5	1/31/1983	0.5	3/1979	0.1
3/1971	0.4	2/1984	0.5	2/1983	0.1
8/1971	0.6	4/1984	0.5	2/1986	7.2
11/1971	0.6	6/1985	1.5	7/1986	26.5
6/1972	0.4	4/1986	0.3	1/1991	5.7
2/1973	1.0	4/1987	0.4	**West Lechuguilla Seep**	
8/1973	0.3	2/1988	0.3	10/1969	0.3
1/1974	0.2	2/1989	0.4	1/1970	0.3

Spring/Date	Discharge	Spring/Date	Discharge	Spring/Date	Discharge
3/1974	0.1	11/1990	0.1	1/1973	1.0
5/1974	0.1	7/1991	0.1	5/1980	0.9
4/1974	0.1	4/2000	0.1	6/1985	1.7
2/1977	0.1	**Old Quaker**		4/1987	1.4
4/1985	0.3	10/1970	Dry	2/1988	1.1
7/1985	0.1	11/1970	Dry	2/1989	0.4
3/1986	0.1	2/1991	0.01	11/1990	0.6
1/1991	0.2	11/2010	0.0	11/2010	0.0
7/1991	0.7	**Oak Spring 2**		**Unnamed Seep #6**	
4/2000	<0.1	10/2010	2.9	4/1987	2.1
11/2010	2.0			11/1990	0.1
				10/2010	0.0
East Lechuguilla Seep		**Pine Cove Spring**		**Unnamed Seep #35**	
10/1969	0.3	2/1972	0.4	3/1980	0.5
1/1970	0.3	10/1972	0.4	**Unnamed Seep #36**	
5/1970	0.2	2/1973	6.3	3/1970	0.3
1/1973	1.0	3/1977	0.3	**Unnamed Seep #38**	
6/1985	1.7	**Putnam Tank**		2/1991	0.2
2/1988	1.9	8/1962	0.5	**Unnamed Seep #43**	
East Upper Grammer Seep		6/1969	0.1	2/1991	<0.1
4/1969	<0.1	1/1970	0.3	4/2000	Dry
7/1970	Dry	4/1970	0.4	**Unnamed Seep #45**	
7/1986	<0.1	4/1971	0.4	2/1972	0.1
2/1988	0.4	3/1972	0.3	11/1990	0.1
1/1991	0.2	7/1972	0.2	**Unnamed Seep #46**	
10/2010	0.0	4/1974	0.1	1/1972	0.3
Forgetful Seep		12/1990	0.2	**No Name Seep 4**	
10/2010	3.5	3/2012	0.01	10/2014	5.0
Minolith Spring		**No Name Spring 9**		2/2015	3.8
4/2012	0.01	3/2012	0.01		
Previously Unknown Seep		**Wild Calf Seep**			
10/2014	<1.0	4/2012	0.01		
		Slaughter Pothole			
		10/2014	0.0		

Appendix E. All bird species confirmed or observed in CAVE from 2003-2014, as observed by their respective study.

Bolded species indicate a species of conservation concern, while species marked “P” are probably present in the park but not confirmed. A detailed list of priority species and their respective status is provided in Appendix F.

Common Names	NPS (2016)	West (2012)	Meyer and Griffin (2011)	CHDN (2010-2014)
acorn woodpecker	X	X		
American avocet	X			
American bittern	X			
American coot	X			
American crow	X			
American dipper	X			
American goldfinch	X		X	X
American kestrel	X	X	X	
American pipit	X			X
American redstart	X		X	
American robin	X			
American tree sparrow	X			
American white pelican	X			
American wigeon	X			
American woodcock	X			
Anna's hummingbird	X			
ash-throated flycatcher	X	X	X	X
Baird's sandpiper	X			
Baird's sparrow	X			
bald eagle	X			

*It was suggested that the wood thrush be added to the NPS (2015) list in 2016. This addition is not yet live on the NPS web portal, but would bring the total to 368 species.

Bolded species indicate a species of conservation concern, while species marked “P” are probably present in the park but not confirmed. A detailed list of priority species and their respective status is provided in Appendix F.

Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
Baltimore oriole	X		X	
band-tailed pigeon	X	X		
bank swallow	X			
barn owl	X			
barn swallow	X		X	X
bay-breasted warbler	X			
Bell's vireo	X		X	X
belted kingfisher	X		X	
Bewick's wren	X	X	X	X
black phoebe	X		X	X
black tern	X			
black vulture	P			
black-and-white warbler	X			
black-bellied whistling-duck	X			
black-billed cuckoo	X			
black-billed magpie	X			
blackburnian warbler	X			
black-capped vireo	X			
black-chinned hummingbird	X	X	X	X
black-chinned sparrow	X	X	X	X
black-crowned night-heron	X			
black-headed grosbeak	X	X	X	X
black-necked stilt	X			
blackpoll warbler	X			

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Common Names	NPS (2016)	West (2012)	Meyer and Griffin (2011)	CHDN (2010-2014)
black-tailed gnatcatcher	X		X	X
black-throated blue warbler	X			
black-throated gray warbler	X			
black-throated green warbler	X			
black-throated sparrow	X	X	X	X
blue grosbeak	X	X	X	X
blue jay	X			
blue-gray gnatcatcher	X	X	X	X
blue-headed vireo	X			
blue-throated hummingbird	X	X		
blue-winged teal	X			X
blue-winged warbler	X			
bobolink	X			
Brewer's blackbird	X		X	X
Brewer's sparrow	X		X	
broad-billed hummingbird	X			
broad-tailed hummingbird	X		X	X
broad-winged hawk	X			
bronzed cowbird	X		X	
brown creeper	X			
brown thrasher	X		X	X
brown-headed cowbird	X	X	X	X
bufflehead	X			
Bullock's oriole	X	X	X	X

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Common Names	NPS (2016)	West (2012)	Meyer and Griffin (2011)	CHDN (2010-2014)
burrowing owl	X			
bushtit	X	X	X	
cactus wren	X	X	X	X
calliope hummingbird	X			
Canada goose	X			
Canada warbler	X			
canvasback	X			
canyon towhee	X	X	X	
canyon wren	X	X	X	
Cape May warbler	X			
Carolina wren	X			
Cassin's finch	X			
Cassin's kingbird	X	X	X	X
Cassin's sparrow	X		X	X
Cassin's vireo	X		X	
cattle egret	X			
cave swallow	X	X	X	X
cedar waxwing	X		X	X
cerulean warbler	X			
chestnut-collared longspur	X			
chestnut-sided warbler	X			
Chihuahuan raven	X			X
chimney swift	X			
chipping sparrow	X		X	X

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Bolded species indicate a species of conservation concern, while species marked “P” are probably present in the park but not confirmed. A detailed list of priority species and their respective status is provided in Appendix F.

Common Names	NPS (2016)	West (2012)	Meyer and Griffin (2011)	CHDN (2010-2014)
cinnamon teal	X			
Clark's nutcracker	X			
clay-colored sparrow	X		X	X
cliff swallow	X		X	X
common black-hawk	X			
common goldeneye	X			
common grackle	X			
common ground-dove	X			
common merganser	X			
common moorhen	X			
common nighthawk	X	X	X	X
common poorwill	X	X	X	
common raven	X		X	X
common yellowthroat	X		X	X
Connecticut warbler	X			
Cooper's hawk	X		X	X
cordilleran flycatcher	X	X	X	X
Costa's hummingbird	P			
crissal thrasher	X		X	
curve-billed thrasher	X			X
dark-eyed junco	X		X	
dickcissel	X		X	
double-crested cormorant	X			
downy woodpecker	X			

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
dusky flycatcher	X		X	X
dusky-capped flycatcher	X			
eared grebe	X			
eastern bluebird	X			
eastern kingbird	X			
eastern meadowlark	X			X
eastern phoebe	X		X	
eastern screech-owl	P			
eastern towhee	X			
eastern wood-pewee	X			
elf owl	X	X		
Eurasian collared-dove	X		X	X
European starling	X			
evening grosbeak	X			
ferruginous hawk	X			
field sparrow	X			
flammulated owl	X			
fox sparrow	X			
gadwall	X			
golden eagle	X	X	X	
golden-crowned kinglet	X			
golden-crowned sparrow	X			
golden-winged warbler	X			
Grace's warbler	X			

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Common Names	NPS (2016)	West (2012)	Meyer and Griffin (2011)	CHDN (2010-2014)
grasshopper sparrow	X			
gray catbird	X		X	
gray flycatcher	X	X		X
gray hawk	X		X	X
gray vireo	X	X	X	X
gray-cheeked thrush	X			
great blue heron	X		X	
great crested flycatcher	X			
great egret	X			
great horned owl	X	X		X
great kiskadee	X			
greater pewee	X		X	
greater roadrunner	X		X	X
greater yellowlegs	X			
great-tailed grackle	X		X	X
green heron	X			
green-tailed towhee	X		X	X
green-winged teal	X			
groove-billed ani	X			
hairy woodpecker	X			
Hammond's flycatcher	X	X	X	
Harris's hawk	X			
Harris's sparrow	X			
hepatic tanager	X	X	X	

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
hermit thrush	X	X	X	X
hermit warbler	X			
hooded merganser	X			
hooded oriole	X		X	X
hooded warbler	X			
horned lark	X			
house finch	X	X	X	X
house sparrow	X		X	X
house wren	X		X	X
Hutton's vireo	X			
Inca dove	X			
indigo bunting	X		X	X
juniper titmouse	X			
Kentucky warbler	X			
killdeer	X		X	X
ladder-backed woodpecker	X	X	X	X
lark bunting	X		X	X
lark sparrow	X		X	X
lazuli bunting	X			X
Le Conte's sparrow	X			
least bittern	X			
least flycatcher	X			
least sandpiper	X			
lesser goldfinch	X		X	X

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
lesser nighthawk	X	X	X	X
lesser prairie-chicken	X			
lesser scaup	X		X	
lesser yellowlegs	X			
Lewis's woodpecker	X			
Lincoln's sparrow	X		X	
loggerhead shrike	X		X	X
long-billed curlew	X			
long-billed dowitcher	X			
long-billed thrasher	X			
long-eared owl	X			
Louisiana waterthrush	X			
Lucifer hummingbird	X			
Lucy's warbler	X		X	X
MacGillivray's warbler	X		X	X
magnificent hummingbird	X			
magnolia warbler	X		X	
mallard	X		X	
marsh wren	X		X	X
McCown's longspur	X			
merlin	X			
Mississippi kite	X		X	
Montezuma quail	X	X		
mountain bluebird	X			

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
mountain chickadee	X		X	
mourning dove	X	X	X	X
Nashville warbler	X		X	
neotropic cormorant	X			
northern beardless-tyrannulet	X			
northern bobwhite	X		X	X
northern cardinal	X		X	X
northern flicker	X		X	
northern goshawk	X			
northern harrier	X		X	X
northern mockingbird	X	X	X	X
northern parula	X		X	
northern pintail	X			
northern rough-winged swallow	X		X	X
northern shoveler	X			
northern waterthrush	X		X	
olive-sided flycatcher	X	X	X	
orange-crowned warbler	X		X	X
orchard oriole	X		X	X
osprey	X			
ovenbird	X			
Pacific-slope flycatcher	P			
painted bunting	X		X	X
painted redstart	X			

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
palm warbler	X			
peregrine falcon	X		X	
phainopepla	X	X	X	X
Philadelphia vireo	X			
pied-billed grebe	X			
pine siskin	X		X	X
pine warbler	X			
pinyon jay	X			
piratic flycatcher	X			
plumbeous vireo	X	X	X	X
prairie falcon	X			
prairie warbler	X			
prothonotary warbler	X			
purple finch	X			
purple martin	X			
pygmy nuthatch	X			
pyrrhuloxia	X		X	X
red crossbill	X			
red-bellied woodpecker	X			
red-breasted nuthatch	X			X
red-eyed vireo	X			
red-faced warbler	X			
redhead	X			
red-headed woodpecker	X			

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Common Names	NPS (2016)	West (2012)	Meyer and Griffin (2011)	CHDN (2010-2014)
red-naped sapsucker	X		X	
red-necked phalarope	X			
red-shouldered hawk	X			
red-tailed hawk	X	X	X	
red-winged blackbird	X		X	X
ring-billed gull	X			
ringed turtle-dove	P			
ring-necked duck	X		X	
ring-necked pheasant	X			
rock pigeon	X			
rock wren	X	X	X	X
rose-breasted grosbeak	X		X	
rough-legged hawk	X			
ruby-crowned kinglet	X		X	X
ruddy duck	X			
ruddy ground-dove	X			
rufous hummingbird	X			
rufous-crowned sparrow	X	X	X	X
rusty blackbird	X			
sage sparrow	X			
sage thrasher	X		X	
sandhill crane	X			
savannah sparrow	X			X
Say's phoebe	X	X	X	X

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
scaled quail	X	X	X	X
scarlet tanager	X			
scissor-tailed flycatcher	X			
Scott's oriole	X	X	X	X
sedge wren	X			
semipalmated sandpiper	X			
sharp-shinned hawk	X		X	
short-eared owl	X			
short-tailed hawk	X			
snow goose	X			
snowy egret	X			
solitary sandpiper	X			
song sparrow	X		X	
sora	X			
spotted owl	X			
spotted sandpiper	X			X
spotted towhee	X	X	X	X
Sprague's pipit	X			
Steller's jay	X			
summer tanager	X		X	X
Swainson's hawk	X		X	X
Swainson's thrush	X		X	
Swainson's warbler	X			
swamp sparrow	X			

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
Tennessee warbler	X			
thick-billed kingbird	X			
Townsend's solitaire	X			X
Townsend's warbler	X		X	X
tree swallow	X		X	X
tricolored heron	X			
tropical parula	X			
tundra swan	X			
turkey vulture	X	X	X	X
upland sandpiper	X		X	
varied bunting	X	X	X	X
varied thrush	X			
verdin	X		X	X
Vermilion flycatcher	X		X	X
vesper sparrow	X			X
violet-green swallow	X	X		X
Virginia rail	X			
Virginia's warbler	X		X	
warbling vireo	X		X	X
western bluebird	X			
western grebe	X			
western kingbird	X	X	X	X
western meadowlark	X		X	
western sandpiper	X			

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
western screech-owl	X			
western scrub-jay	X			X
western tanager	X		X	X
western wood-pewee	X	X	X	X
whip-poor-will	X			
white ibis	X			
white-breasted nuthatch	X		X	
white-crowned sparrow	X		X	X
white-eyed vireo	X			
white-faced ibis	X			
white-tailed kite	X			
white-throated sparrow	X			
white-throated swift	X	X	X	X
white-winged dove	X	X	X	X
wild turkey	X		X	X
willet	X			
Williamson's sapsucker	X			
willow flycatcher	X		X	X
Wilson's phalarope	X			
Wilson's snipe	X		X	
Wilson's warbler	X		X	X
winter wren	X			
wood duck	X			
worm-eating warbler	X			

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Common Names	**NPS (2016)**	**West (2012)**	**Meyer and Griffin (2011)**	**CHDN (2010-2014)**
yellow warbler	X		X	X
yellow-bellied sapsucker	X		X	
yellow-billed cuckoo	X	X	X	X
yellow-breasted chat	X		X	X
yellow-crowned night-heron	X			
yellow-green vireo	X			
yellow-headed blackbird	X		X	
yellow-rumped warbler	X		X	X
yellow-throated vireo	X			
yellow-throated warbler	X			
zone-tailed hawk	X			
Total	**367***	**55**	**145**	**112**

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Appendix F. Bird species of conservation concern that have been confirmed in CAVE.

X = Included on list; IA = immediate action is the recommended conservation action (Rich et al. 2004); NB = non-breeding in selected BCR; M = continued active management is the recommended conservation action (Rich et al. 2004); PR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004); T = Threatened, Federal and State listing category; E = Endangered, Federal and State listing category; DL = Delisted, but being monitored, Federal listing category; C =Federal candidate species; Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010); Steep Decline = % population loss based on BBS or CBC trend since mid-1960s, or on PT score (>50%) if no reliable trend data; SOC = Species of Concern, Federal listing category.

		USFWS (2008); BCR 35	Rich et al. (2004)		Federal/State Listings		NMDGF (2006)
Common Name	**Park Status**	**Chihuahuan Desert**	**NA LCP**	**Saving our Shared Birds (SOS)**	**New Mexico Listed**	**Federal Listed**	**Chihuahuan Desert**
Baird's sparrow	Present	NB	IA	TRI-NATIONAL	T		X
bald eagle	Present	DL			T		X
bank swallow	Present			STEEP DECLINE			
Bell's vireo	Present	a	IA	TRI-NATIONAL	T		
belted kingfisher	Present			STEEP DECLINE			
black-billed cuckoo	Present			STEEP DECLINE			
black-capped vireo	Present			TRI-NATIONAL			
black-chinned sparrow	Present	X	M	STEEP DECLINE[c]			
black-tailed gnatcatcher	Present		PR[b]				
black-throated sparrow	Present		M[a]				
bobolink	Present			STEEP DECLINE			
Brewer's sparrow	Present		M	STEEP DECLINE[c]			
broad-billed hummingbird	Present				T		

a. Non-listed subspecies or population of Threatened or Endangered species.
b. Stewardship species with > 75% of population found in BCRs 20, 35, and 36.
c. Species endemic to the Tri-National area (Berlanga et al. 2010).

X = Included on list; IA = immediate action is the recommended conservation action (Rich et al. 2004); NB = non-breeding in selected BCR; M = continued active management is the recommended conservation action (Rich et al. 2004); PR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004); T = Threatened, Federal and State listing category; E = Endangered, Federal and State listing category; DL = Delisted, but being monitored, Federal listing category; C =Federal candidate species; Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010); Steep Decline = % population loss based on BBS or CBC trend since mid-1960s, or on PT score (>50%) if no reliable trend data; SOC = Species of Concern, Federal listing category.

		USFWS (2008); BCR 35	Rich et al. (2004)		Federal/State Listings		NMDGF (2006)
Common Name	**Park Status**	**Chihuahuan Desert**	**NA LCP**	**Saving our Shared Birds (SOS)**	**New Mexico Listed**	**Federal Listed**	**Chihuahuan Desert**
burrowing owl	Present	X					X
cactus wren	Present		PR[b]				
Canada warbler	Present			TRI-NATIONAL			
canyon towhee	Present		PR				
Cassin's finch	Present			STEEP DECLINE[c]			
Cassin's sparrow	Present	X	M[b]				
cerulean warbler	Present			TRI-NATIONAL			
chestnut-collared longspur	Present	NB		TRI-NATIONAL			
chimney swift	Present			STEEP DECLINE			
common black-hawk	Present	X			T		
common ground-dove	Present				E		X
common nighthawk	Present			STEEP DECLINE			
Connecticut warbler	Present			STEEP DECLINE			
Costa's hummingbird	Probably Present		PR		T		
crissal thrasher	Present		PR[b]				
curve-billed thrasher	Present		PR				

a. Non-listed subspecies or population of Threatened or Endangered species.

b. Stewardship species with > 75% of population found in BCRs 20, 35, and 36.

c. Species endemic to the Tri-National area (Berlanga et al. 2010).

X = Included on list; IA = immediate action is the recommended conservation action (Rich et al. 2004); NB = non-breeding in selected BCR; M = continued active management is the recommended conservation action (Rich et al. 2004); PR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004); T = Threatened, Federal and State listing category; E = Endangered, Federal and State listing category; DL = Delisted, but being monitored, Federal listing category; C =Federal candidate species; Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010); Steep Decline = % population loss based on BBS or CBC trend since mid-1960s, or on PT score (>50%) if no reliable trend data; SOC = Species of Concern, Federal listing category.

		USFWS (2008); BCR 35	Rich et al. (2004)		Federal/State Listings		NMDGF (2006)
Common Name	**Park Status**	**Chihuahuan Desert**	**NA LCP**	**Saving our Shared Birds (SOS)**	**New Mexico Listed**	**Federal Listed**	**Chihuahuan Desert**
eastern meadowlark	Present			STEEP DECLINE			
elf owl	Present	X	PR				
ferruginous hawk	Present	NB					X
field sparrow	Present			STEEP DECLINE[c]			
flammulated owl	Present	X	PR				
golden eagle	Present	X					X
golden-winged warbler	Present			TRI-NATIONAL			
Grace's warbler	Present	X	M				
grasshopper sparrow	Present			STEEP DECLINE			X
gray vireo	Present	X	PR		T		X
green-tailed towhee	Present		PR[b]				
Harris's sparrow	Present			STEEP DECLINE[c]			
hermit warbler	Present		M				
hooded oriole	Present						X
horned lark	Present			STEEP DECLINE			
lark bunting	Present	NB		STEEP DECLINE[c]			

a. Non-listed subspecies or population of Threatened or Endangered species.

b. Stewardship species with > 75% of population found in BCRs 20, 35, and 36.

c. Species endemic to the Tri-National area (Berlanga et al. 2010).

X = Included on list; IA = immediate action is the recommended conservation action (Rich et al. 2004); NB = non-breeding in selected BCR; M = continued active management is the recommended conservation action (Rich et al. 2004); PR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004); T = Threatened, Federal and State listing category; E = Endangered, Federal and State listing category; DL = Delisted, but being monitored, Federal listing category; C =Federal candidate species; Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010); Steep Decline = % population loss based on BBS or CBC trend since mid-1960s, or on PT score (>50%) if no reliable trend data; SOC = Species of Concern, Federal listing category.

		USFWS (2008); BCR 35	Rich et al. (2004)		Federal/State Listings		NMDGF (2006)
Common Name	**Park Status**	**Chihuahuan Desert**	**NA LCP**	**Saving our Shared Birds (SOS)**	**New Mexico Listed**	**Federal Listed**	**Chihuahuan Desert**
lesser prairie-chicken	Present			TRI-NATIONAL		T	X
Lewis's woodpecker	Present		M				
loggerhead shrike	Present	X		STEEP DECLINE[c]			X
long-billed curlew	Present	NB					
Lucifer hummingbird	Present	X	PR[b]		T		
Lucy's warbler	Present		M				
McCown's longspur	Present	NB	PR				
Mexican spotted owl (spotted owl)	Present		IA	TRI-NATIONAL		T	
Montezuma quail	Present		M				X
mourning dove	Present						X
northern beardless-tyrannulet	Present				E		
northern bobwhite	Present			STEEP DECLINE			
northern flicker	Present			STEEP DECLINE			
northern harrier	Present						X
olive-sided flycatcher	Present			TRI-NATIONAL			
painted bunting	Present	X	M				
peregrine falcon	Present	DL			T		
phainopepla	Present		PR[b]				
pine siskin	Present			STEEP DECLINE			

Common Name	Park Status	USFWS (2008); BCR 35	Rich et al. (2004)		Federal/State Listings		NMDGF (2006)
		Chihuahuan Desert	NA LCP	Saving our Shared Birds (SOS)	New Mexico Listed	Federal Listed	Chihuahuan Desert
pinyon jay	Present			TRI-NATIONAL			
prairie warbler	Present			STEEP DECLINE			
pyrrhuloxia	Present		M[b]				
red-faced warbler	Present	X	PR				
red-headed woodpecker	Present			STEEP DECLINE[c]			
rock wren	Present			STEEP DECLINE			
rufous hummingbird	Present			STEEP DECLINE[c]			
rusty blackbird	Present			STEEP DECLINE[c]			
sage thrasher	Present						X
sandhill crane	Present						X
scaled quail	Present		M				X
Scott's oriole	Present		PR[b]				
short-eared owl	Present			STEEP DECLINE			
Sprague's pipit	Present	NB	M	TRI-NATIONAL			X
Swainson's hawk	Present		M				
thick-billed kingbird	Present		PR		E		
varied bunting	Present	X	M		T		X
verdin	Present		M[b]	STEEP DECLINE[c]			
Virginia's warbler	Present	X	PR				
white-throated swift	Present		M				
whip-poor-will	Present			STEEP DECLINE			

a. Non-listed subspecies or population of Threatened or Endangered species.

b. Stewardship species with > 75% of population found in BCRs 20, 35, and 36.

c. Species endemic to the Tri-National area (Berlanga et al. 2010).

X = Included on list; IA = immediate action is the recommended conservation action (Rich et al. 2004); NB = non-breeding in selected BCR; M = continued active management is the recommended conservation action (Rich et al. 2004); PR = long-term planning and responsibility is the recommended conservation action (Rich et al. 2004); T = Threatened, Federal and State listing category; E = Endangered, Federal and State listing category; DL = Delisted, but being monitored, Federal listing category; C =Federal candidate species; Tri-National = Temperate breeders of high tri-national concern (Berlanga et al. 2010); Steep Decline = % population loss based on BBS or CBC trend since mid-1960s, or on PT score (>50%) if no reliable trend data; SOC = Species of Concern, Federal listing category.

		USFWS (2008); BCR 35	Rich et al. (2004)		Federal/State Listings		NMDGF (2006)
Common Name	**Park Status**	**Chihuahuan Desert**	**NA LCP**	**Saving our Shared Birds (SOS)**	**New Mexico Listed**	**Federal Listed**	**Chihuahuan Desert**
willow flycatcher (southwestern)	Present				E	E	
Wilson's warbler	Present			STEEP DECLINE			
yellow-billed cuckoo	Present	C		STEEP DECLINE		T	
yellow-headed blackbird	Present		PR[b]				
	TOTAL:	**26**	**38**	**42**	**14**	**4**	**19**
	IA:		**3**				
	M/SS:		**17/4**				
	PR/SS:		**18/9**				
	STEEP DECLINE/ ENDEMIC:			**30/11**			
	TRI-NATIONAL:			**12**			

d. Non-listed subspecies or population of Threatened or Endangered species.

e. Stewardship species with > 75% of population found in BCRs 20, 35, and 36.

f. Species endemic to the Tri-National area (Berlanga et al. 2010).

Appendix G. Herpetofauna species listed by NPSpecies (NPS 2015) that are documented or thought to occur within CAVE correlated with the surveys conducted by Gehlbach (1964) and Prival and Goode (2011).

(U = unconfirmed, P = present, NP = not in park, H = historical).

Scientific Name	Common Name	Gehlbach (1964)	Prival and Goode (2011)	NPS (2015)
		Frogs and Toads		
Acris crepitans	Blanchard's cricket frog			NP/H
Anaxyrus cognatus	Great Plains toad		X	P
Anaxyrus debilis insidior	western green toad		X	P
Anaxyrus punctatus	red-spotted toad	X	X	P
Anaxyrus speciosus	Texas toad	X	X	P
Anaxyrus woodhousii	Woodhouse's toad			U
Craugastor augusti	Balcones barking frog			U
Gastrophryne olivacea	Great Plains narrow mouthed toad			U
Lithobates berlandieri	Rio Grande leopard frog	X	X	P
Lithobates blairi	plains leopard frog			U
Lithobates catesbeianus	American bullfrog	X	X	P
Scaphiopus couchii	Couch's spadefoot	X	X	P
Spea bombifrons	plains spadefoot			U
Spea multiplicata	Mexican spadefoot	X	X	P
		Lizards and Skinks		
Ambystoma tigrinum	barred tiger salamander			U
Cnemidophorus exsanguis	Chihuahuan spotted whiptail		X	P
Cnemidophorus gularis	Texas spotted whiptail	X	X	P
Cnemidophorus inornatus heptagrammus	Trans-Pecos striped whiptail	X	X	P
Cnemidophorus tesselatus	common checkered whiptail	X	X	P
Cnemidophorus tigris	marbled whiptail			U

Scientific Name	Common Name	Gehlbach (1964)	Prival and Goode (2011)	NPS (2015)
		Lizards and Skinks		
Coleonyx brevis	Texas banded gecko	X	X	P
Cophosaurus texanus	Chihuahuan greater earless lizard	X	X	P
Crotaphytus collaris	eastern collared lizard	X	X	P
Eumeces multivirgatus	variable skink	X	X	P
Eumeces obsoletus	Great Plains skink	X	X	P
Gambelia wislizenii	long-nosed leopard lizard			U
Gyalopion canum	Chihuahuan hook-nosed snake	X	X	P
Holbrookia maculata	common lesser earless lizard			U
Masticophis flagellum testaceus	western coachwhip	X	X	P
Phrynosoma cornutum	Texas horned lizard	X	X	P
Phrynosoma hernandesi	Hernandez's short-horned lizard			U
Phrynosoma modestum	round-tailed horned lizard	X	X	P
Sceloporus cowlesi	southwestern fence lizard		X	P
Sceloporus magister	desert spiny lizard			U
Sceloporus poinsettii	northern crevice spiny lizard	X	X	P
Urosaurus ornatus	Big Bend tree lizard	X	X	P
Uta stansburiana	common side-blotched lizard	X	X	P
		Snakes		
Arizona elegans	glossy snake			U
Bogertophis subocularis	Trans-Pecos ratsnake	X	X	P
Coluber constrictor	eastern racer			U
Coluber taeniatus	striped whipsnake	X	X	P
Crotalus atrox	western diamond-backed rattlesnake	X	X	P
Crotalus lepidus lepidus	mottled rock rattlesnake	X	X	P
Crotalus molossus	northern black-tailed rattlesnake	X	X	P
Crotalus scutulatus scutulatus	Northern Mohave rattlesnake			U

Scientific Name	Common Name	Gehlbach (1964)	Prival and Goode (2011)	NPS (2015)
		Snakes		
Crotalus viridis	green prairie rattlesnake			U
Diadophis punctatus	ring-necked snake	X	X	P
Elaphe guttata emoryi	Great Plains ratsnake	X	X	P
Heterodon nasicus	Mexican hog-nosed snake		X	P
Hypsiglena torquata	Texas night snake	X	X	P
Lampropeltis alterna	gray-banded kingsnake		X	P
Lampropeltis getula	desert kingsnake			P
Lampropeltis triangulum	New Mexico milksnake			U
Leptotyphlops dissectus	New Mexico threadsnake	X	X	P
Leptotyphlops humilis	Trans-Pecos threadsnake			U
Nerodia erythrogaster transversa	blotched water snake	X		P
Opheodrys vernalis	smooth green snake			U
Pituophis catenifer	Sonoran gopher snake	X	X	P
Rhinocheilus lecontei	Texas long-nosed snake	X	X	P
Salvadora deserticola	Big Bend patch-nosed snake	X		P
Salvadora grahamiae	mountain patch-nosed snake	X	X	P
Sistrurus catenatus	desert massasauga			U
Sonora semiannulata	variable groundsnake		X	P
Tantilla hobartsmithi	Smith's black-headed snake	X	X	P
Tantilla nigriceps	plains black-headed snake	X		P
Thamnophis cyrtopsis	western black-necked garter snake	X	X	P
Thamnophis marcianus	Marcy's checkered garter snake	X	X	P
Thamnophis proximus diabolicus	arid land ribbon snake			U
Thamnophis sirtalis	common garter snake			U
Trimorphodon biscutatus	western lyre snake			U

Scientific Name	Common Name	Gehlbach (1964)	Prival and Goode (2011)	NPS (2015)
		Turtles		
Apalone spinifera	Texas spiny softshell			U
Chelydra serpentina	snapping turtle			U
Chrysemys picta	painted turtle			U
Kinosternon flavescens	yellow mud turtle	X	X	P
Pseudemys gorzugi	Rio Grande cooter		X	P
Terrapene ornata	ornate box turtle	X	X	P
Trachemys scripta	red-eared slider			P

Appendix H. Night sky quality monitoring report data collected at the tennis court near the CAVE Visitors Center for night of 31 January 2008.

NPS NIGHT SKIES PROGRAM DATA NIGHT REPORT

CAVE080201 Carlsbad Caverns NP **Tennis Court** **1-Feb-08**

Data Night Attributes

Longitude:	-104.43975	Camera:	IMG 2	Air temp. (C):	-0.6	ZLM:	7.00	OBS_1:	K Magargal
Latitude:	32.17881	# of sets:	3	R. H. (%):	16.0	BORTLE:	3	OBS_2:	T Jiles
Elevation (m):	1344	Exposure (secs):	10	Wind Speed (mph):	1	SQM:	21.64	OBS_3:	

NARRATIVE: A clear and steady night with minimal haze over El Paso, TX. Multiple light domes visible. Very faint shadows observed by light of the domes. The Milky Way was clearly visible in detail. M31 and the M44 were visible by direct vision. SQM 21.64. LZM 6.8 (Kate), 7.0 (Teresa).

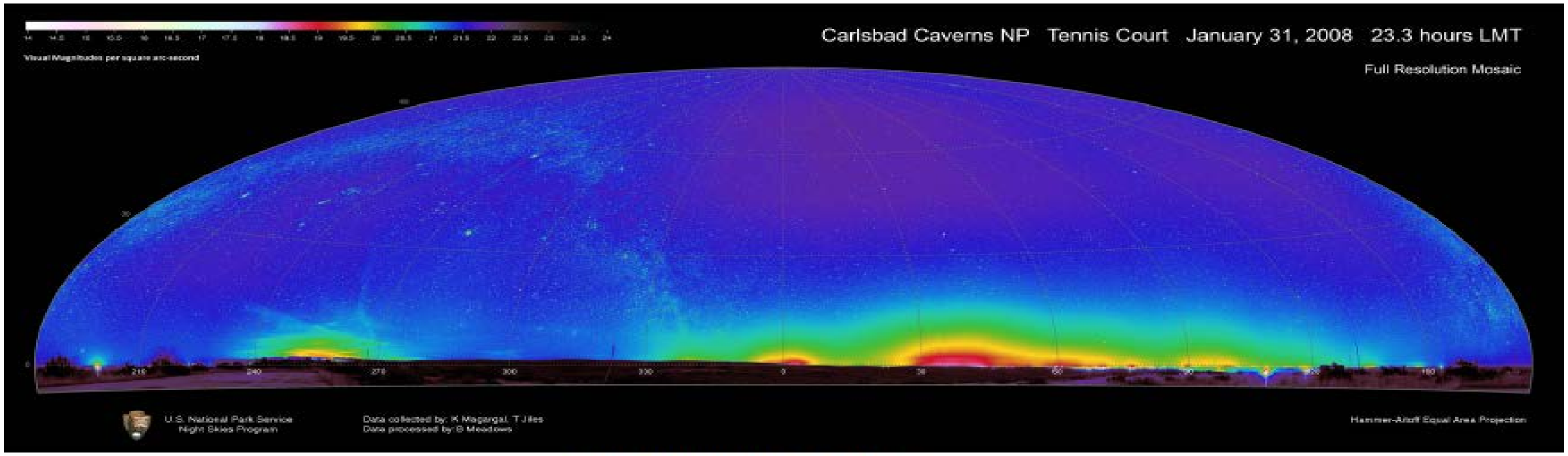
Data Set Attributes

	Quality Flags				Natural Sky Model			Extinction				Collection Properties			
Data Set	Use-able	Col-lection	Pro-cessing	Atmo-sphere:	Zenith airglow (μcd/m²)	Fit quality	Natural sky model fit notes	Ext. coeff. (mag/airmass)	Std err Y	# stars used	# stars reject	% Clouds	Ave. Point Error	Max Point Error	total bias drift
1	Y	4	4	3	57	5	Excellent subtraction	0.122	0.04	97	6	5	0.54	0.66	2.9
2	Y	4	4	4	60	5	Excellent subtraction	0.132	0.05	91	4	3	0.49	0.62	5.9
3	Y	4	4	3	60	5	Excellent subtraction	0.121	0.04	93	3	5	0.45	0.58	4.3

Populated Places

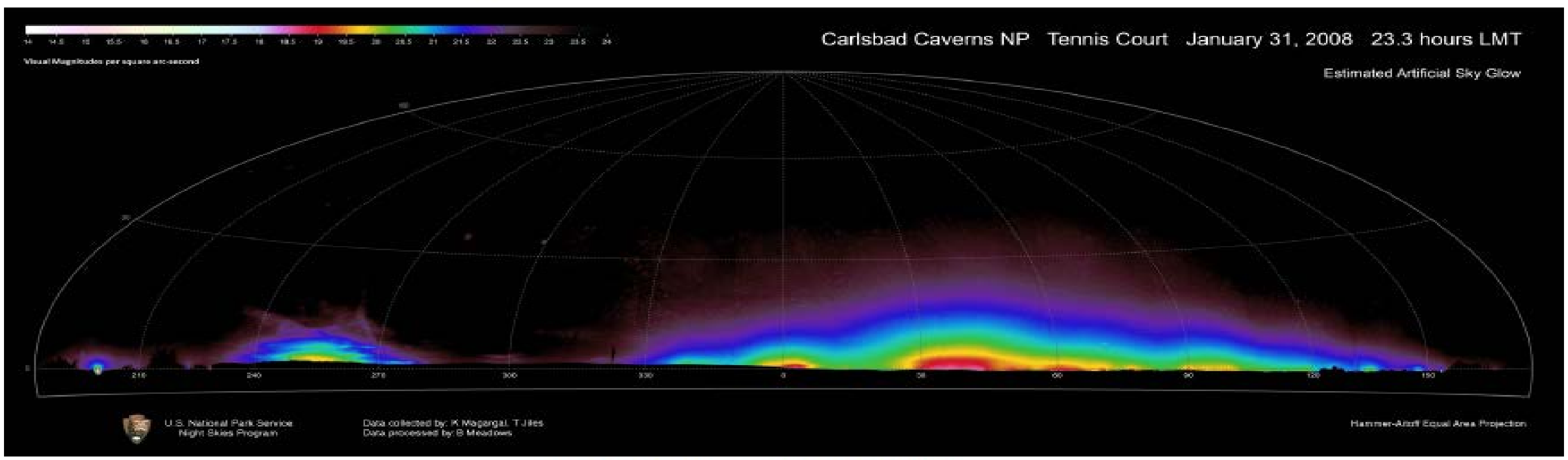
Place	Population (2010)	Distance (km)	Azimuth	Walker’s	Apparent Half-Width (degrees)
Carlsbad city	26,138	31.3	36	0.477	8.9
El Paso city	649,121	190.8	259	0.129	4.3
Artesia city	11,301	74.3	1	0.024	2.2
Roswell city	48,366	133.0	356	0.024	2.1
Loving village	1,413	34.4	70	0.020	1.6
Albuquerque city	545,852	384.0	328	0.019	1.9
Odessa city	99,940	200.2	99	0.018	1.7
Lubbock city	229,573	283.8	56	0.017	2.0
Hobbes city	34,122	134.7	63	0.016	1.9
La Huerta CDP	1,246	36.3	34	0.016	1.8
Midland city	111,147	219.9	94	0.015	2.0
Las Cruces city	97,618	221.4	275	0.013	2.1
Livingston Wheeler CDP	609	32.4	43	0.010	2.0
Happy Valley CDP	519	31.1	27	0.010	2.5
Alamogordo city	30,403	162.8	299	0.009	1.5
Whites City CDP	7	6.2	92	0.007	5.7
Socorro city	32,013	182.0	251	0.007	1.3
Amarillo city	190,695	413.3	35	0.005	1.3
Lovington city	11,009	132.9	50	0.005	0.9
Pecos city	8,780	123.2	134	0.005	1.1

CAVE080201 Date (LMT) 31-Jan-08 Time (LMT): 23.32



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest luminance (mag arcsec-²)	Brightest lumininance	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
21.30	329	21.76	215	15.29	83,309	21.64	-7.30	0.800	0.746

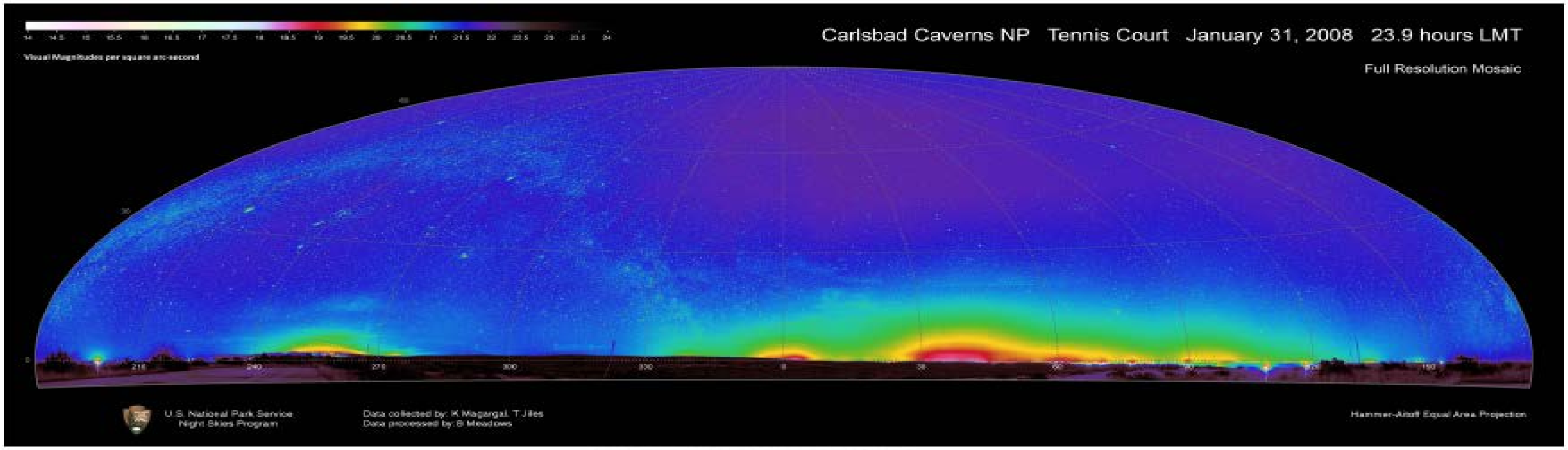


PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
89.2	83	27.0	14.1	3	19,023	0.34	-5.77	0.072	0.361

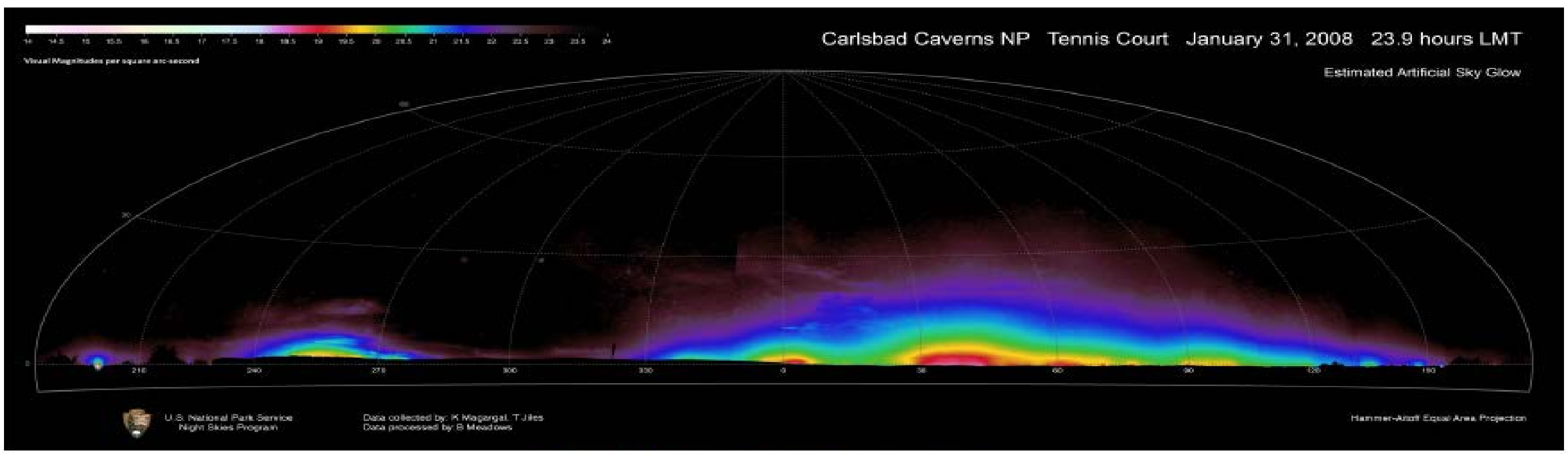
False color mosaic images of the CAVE night sky on the night of 31 January 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

CAVE080201 Date (LMT) 31-Jan-08 Time (LMT): 23.87



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest luminance (mag arcsec-²)	Brightest lumininance	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
21.29	331	21.78	210	15.29	83,207	21.67	-7.30	0.798	0.758

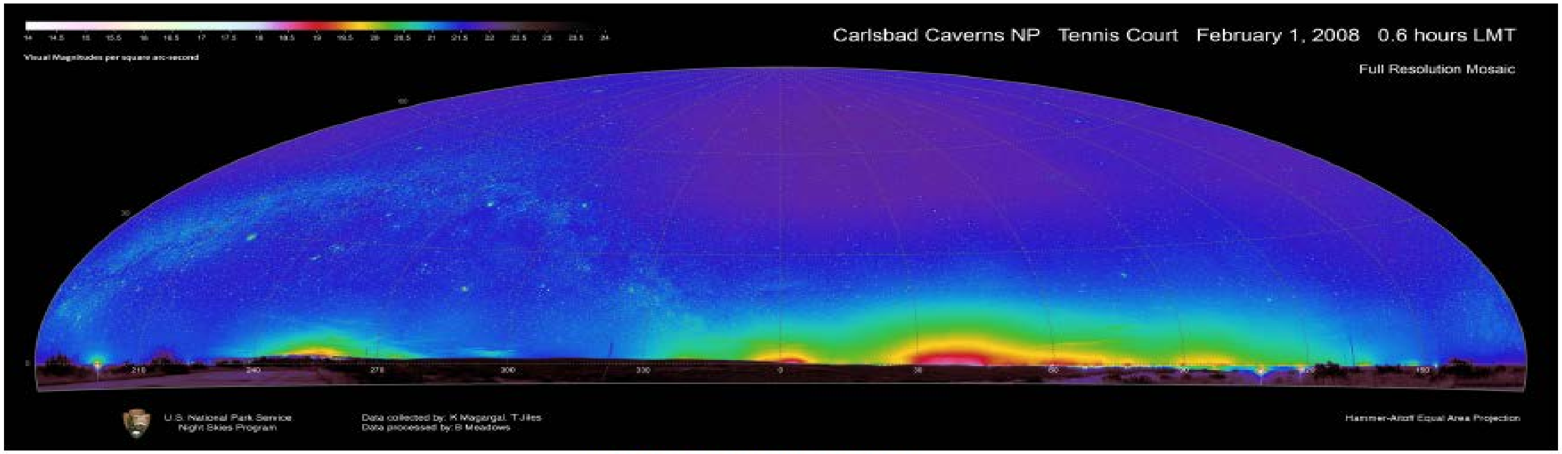


PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
88.7	85	28.4	13.9	1	25,555	0.34	-5.80	0.072	0.373

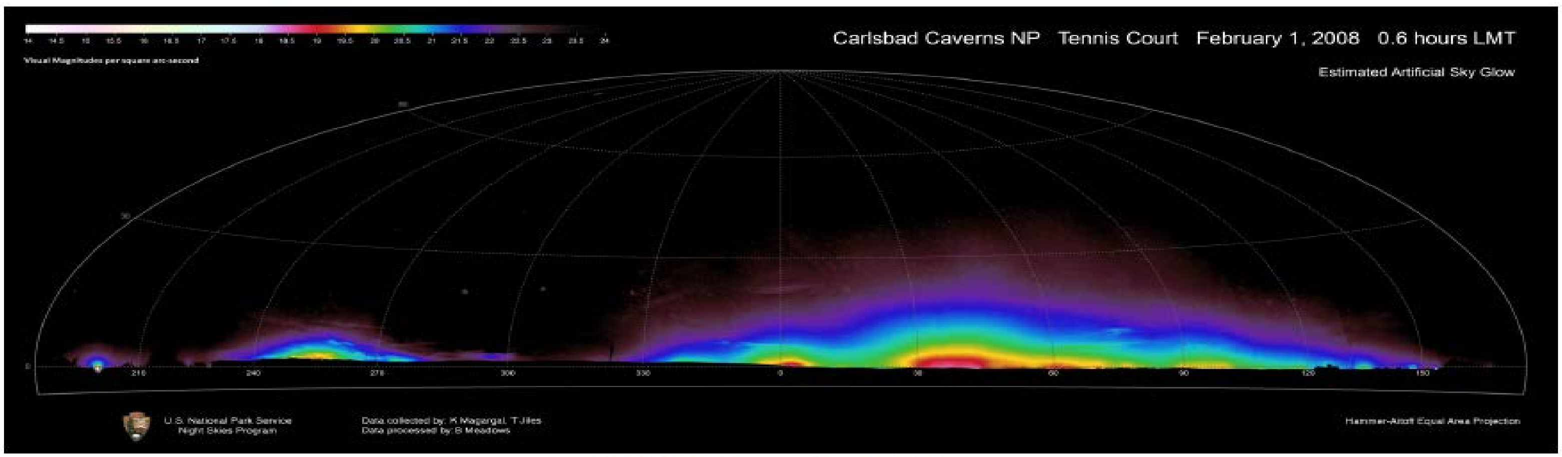
False color mosaic images of the CAVE night sky on the night of 31 January 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

CAVE080201 Date (LMT) 1-Feb-08 Time (LMT): 0.57



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (μcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (μcd/m²)	Brightest luminance (mag arcsec-²)	Brightest lumininance	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
21.30	329	21.81	204	15.29	83,082	21.71	-7.30	0.788	0.748



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (μcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
89.5	79	23.8	11.6	2	29,976	0.32	-5.71	0.063	0.354

False color mosaic images of the CAVE night sky on the night of February 1, 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

Appendix I. Night sky quality monitoring report data collected at the tennis court near the CAVE Visitors Center for night of 1 February 2008.

NPS NIGHT SKIES PROGRAM DATA NIGHT REPORT

CAVE080202 Carlsbad Caverns NP **Tennis Court** **2-Feb-08**

Data Night Attributes

Longitude:	-104.43975	Camera:	IMG 2	Air temp. (C):	10.6	ZLM:	6.50	OBS_1:	K Magargal
Latitude:	32.17881	# of sets:	5	R. H. (%):	19.0	BORTLE:	4	OBS_2:	T Jiles
Elevation (m):	1344	Exposure (secs):	10	Wind Speed (mph):	8	SQM:	21.44	OBS_3:	

NARRATIVE: Windy and unsteady. Conditions improved after winds died down during third data set. The zodiacal light was prominent early in the evening. Airglow was moderate (downgrading Bortle class), but zenith was dark. SQM 21.44 and LZM 6.5 (Kate) in Gemini.

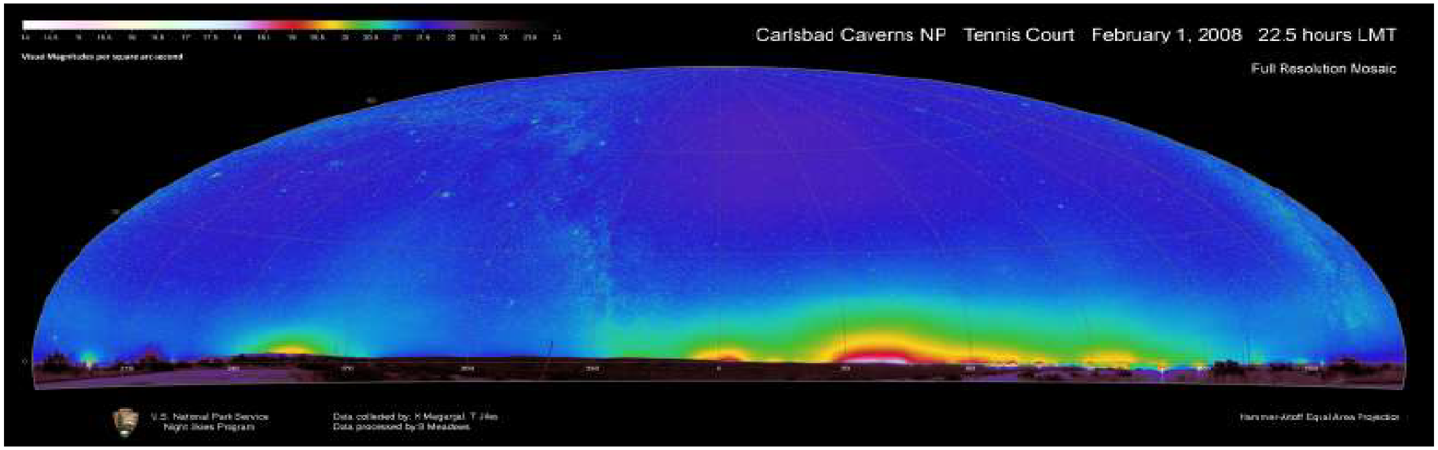
Data Set Attributes

	Quality Flags				Natural Sky Model			Extinction				Collection Properties			
Data Set	Use-able	Col-lection	Pro-cessing	Atmo-sphere	Zenith airglow (μcd/m²)	Fit quality	Natural sky model fit notes	Ext. coeff. (mag/airmass)	Std err Y	# stars used	# stars reject	% Clouds	Ave. Point Error	Max Point Error	total bias drift
1	Y	5	5	5	83	4	Slightly stronger airglow than previous night	0.129	0.04	91	1	1	0.41	0.71	4.9
2	Y	5	5	5	73	4	Slightly stronger airglow than previous night	0.131	0.04	104	1	1	0.38	0.68	5.8
3	Y	5	5	5	76	4	Slightly stronger airglow than previous night	0.139	0.05	92	7	1	0.34	0.65	2.7
4	Y	5	5	5	76	4	Slightly stronger airglow than previous night	0.134	0.05	98	4	1	0.30	0.62	6.6
5	Y	5	5	5	83	4	Slightly stronger airglow than previous night	0.129	0.04	94	5	1	0.27	0.59	4.9

Populated Places

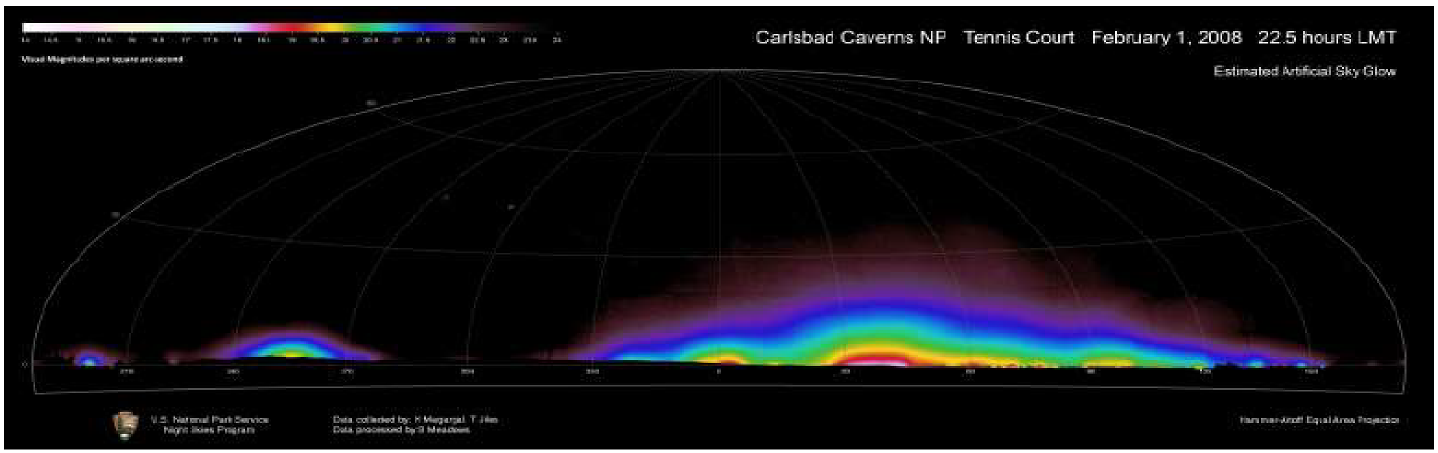
Place	Population (2010)	Distance (km)	Azimuth	Walker's	Apparent Half-Width (degrees)
Carlsbad city	26,138	31.3	36	0.477	8.9
El Paso city	649,121	190.8	259	0.129	4.3
Artesia city	11,301	74.3	1	0.024	2.2
Roswell city	48,366	133.0	356	0.024	2.1
Loving village	1,413	34.4	70	0.020	1.6
Albuquerque city	545,852	384.0	328	0.019	1.9
Odessa city	99,940	200.2	99	0.018	1.7
Lubbock city	229,573	283.8	56	0.017	2.0
Hobbes city	34,122	134.7	63	0.016	1.9
La Huerta CDP	1,246	36.3	34	0.016	1.8
Midland city	111,147	219.9	94	0.015	2.0
Las Cruces city	97,618	221.4	275	0.013	2.1
Livingston Wheeler CDP	609	32.4	43	0.010	2.0
Happy Valley CDP	519	31.1	27	0.010	2.5
Alamogordo city	30,403	162.8	299	0.009	1.5
Whites City CDP	7	6.2	92	0.007	5.7
Socorro city	32,013	182.0	251	0.007	1.3
Amarillo city	190,695	413.3	35	0.005	1.3
Lovington city	11,009	132.9	50	0.005	0.9
Pecos city	8,780	123.2	134	0.005	1.1

CAVE080202 Date (LMT) 1-Feb-08 Time (LMT): 22.51



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (μcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (μcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest lumininance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
21.20	360	21.59	250	15.29	83,115	21.52	-7.39	0.897	0.802

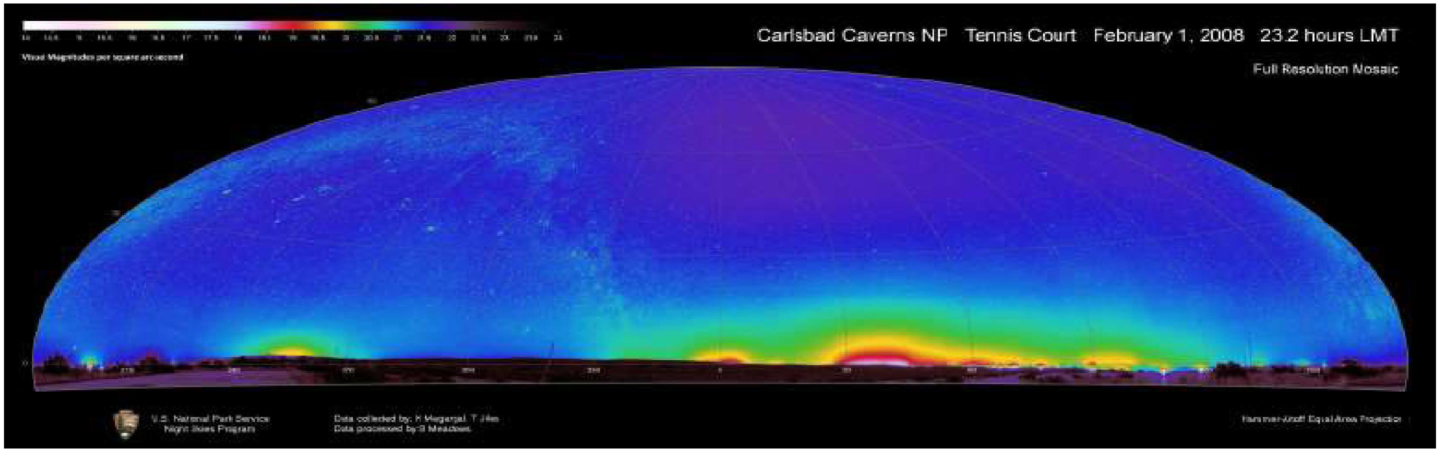


PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (μcd/m^2)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (μcd/m^2)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
90.8	71	18.3	7.8	4	17,530	0.29	-5.60	0.050	0.347

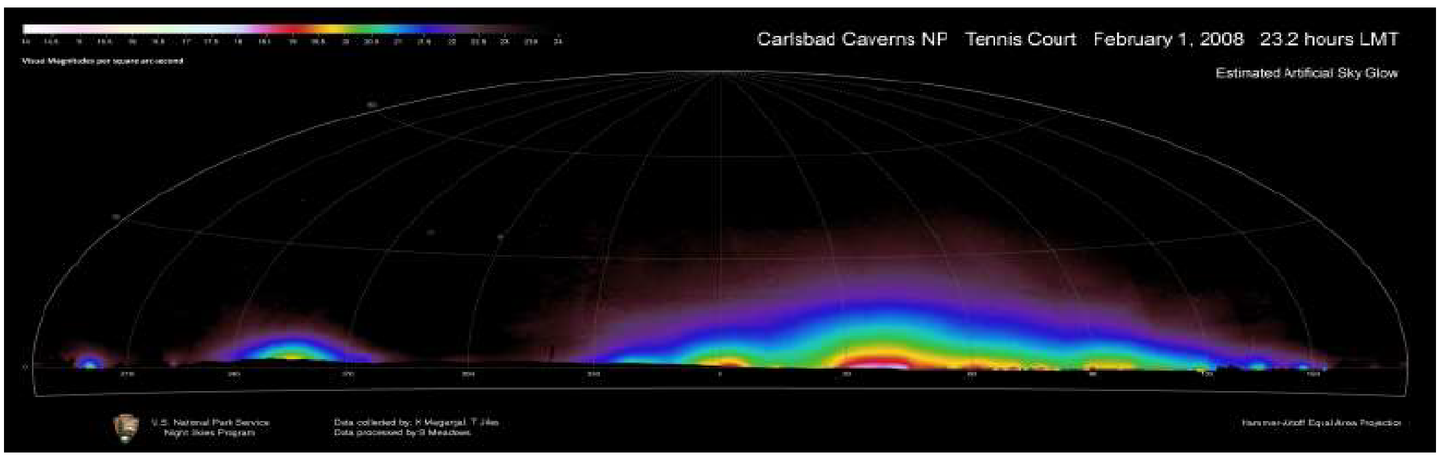
False color mosaic images of the CAVE night sky on the night of 1 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

CAVE080202 Date (LMT) 1-Feb-08 Time (LMT): 23.20



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (μcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (μcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest lumininance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
21.22	352	21.72	223	15.35	78,740	21.57	-7.37	0.866	0.790

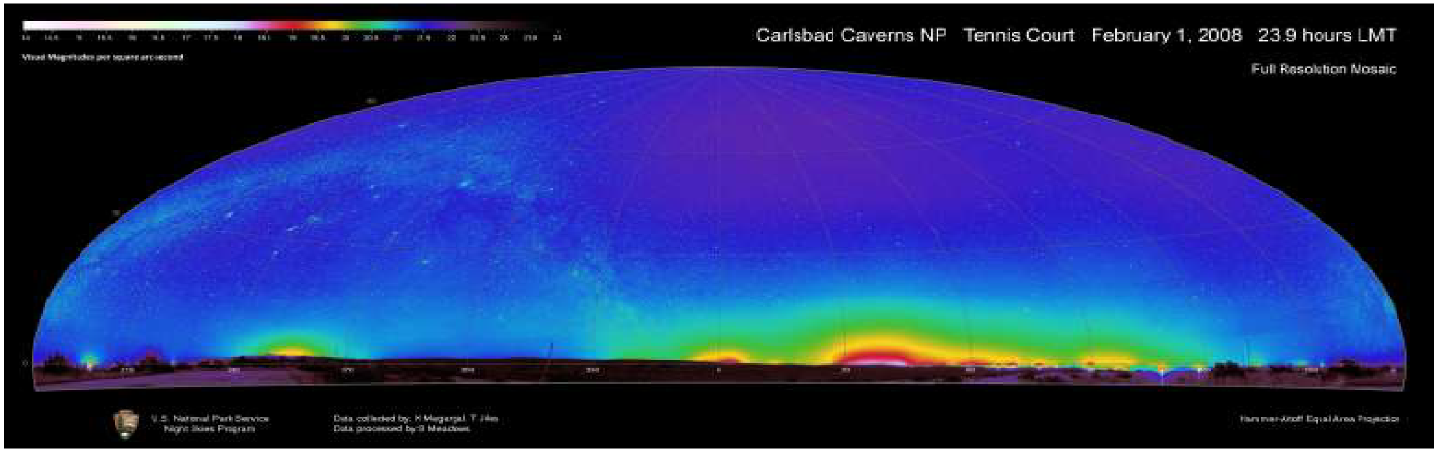


PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (μcd/m^2)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest luminance (μcd/m^2)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
89.3	82	28.6	15.1	-3	14,948	0.33	-5.76	0.072	0.368

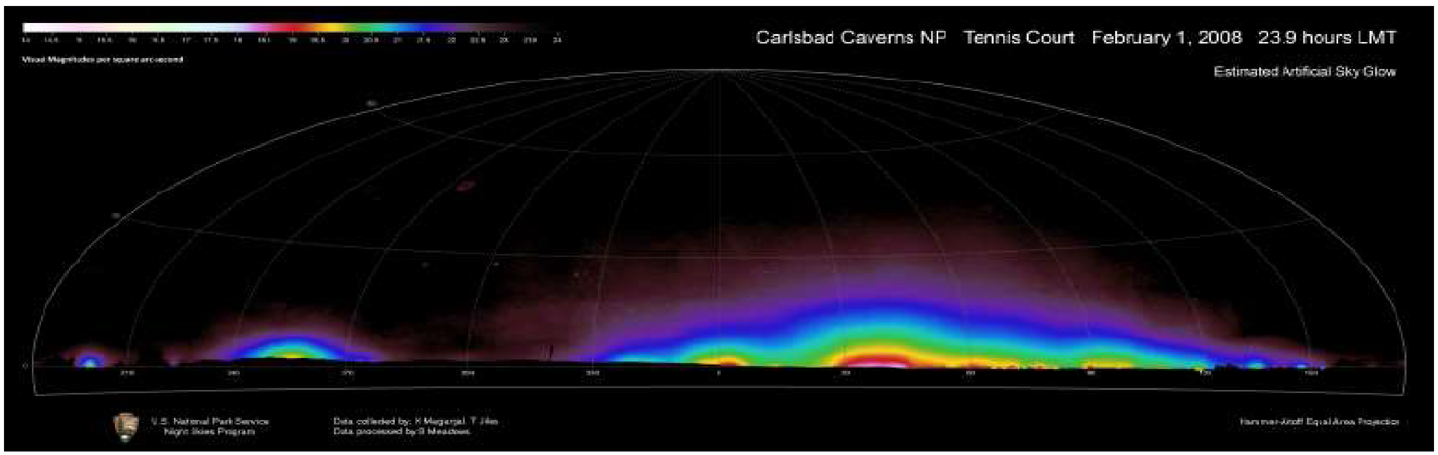
False color mosaic images of the CAVE night sky on the night of 1 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

CAVE080202 Date (LMT) 1-Feb-08 Time (LMT): 23.90



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (μcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (μcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest lumininance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
21.22	352	21.70	226	15.32	80,875	21.59	-7.37	0.864	0.787

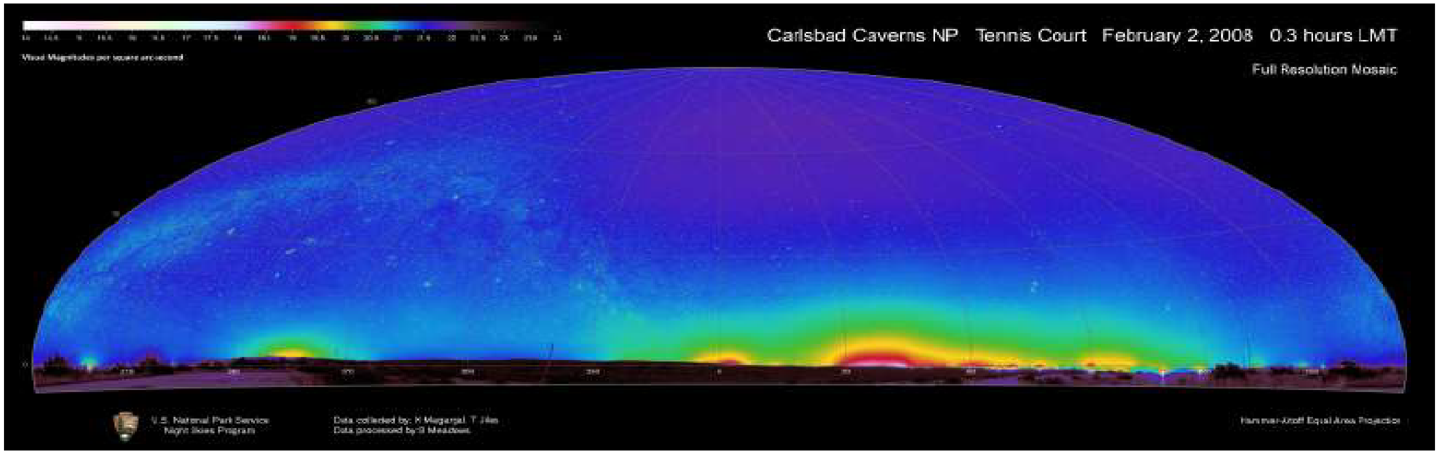


PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (μcd/m^2)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (μcd/m^2)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
88.8	82	28.6	14.5	5	15,439	0.33	-5.76	0.073	0.366

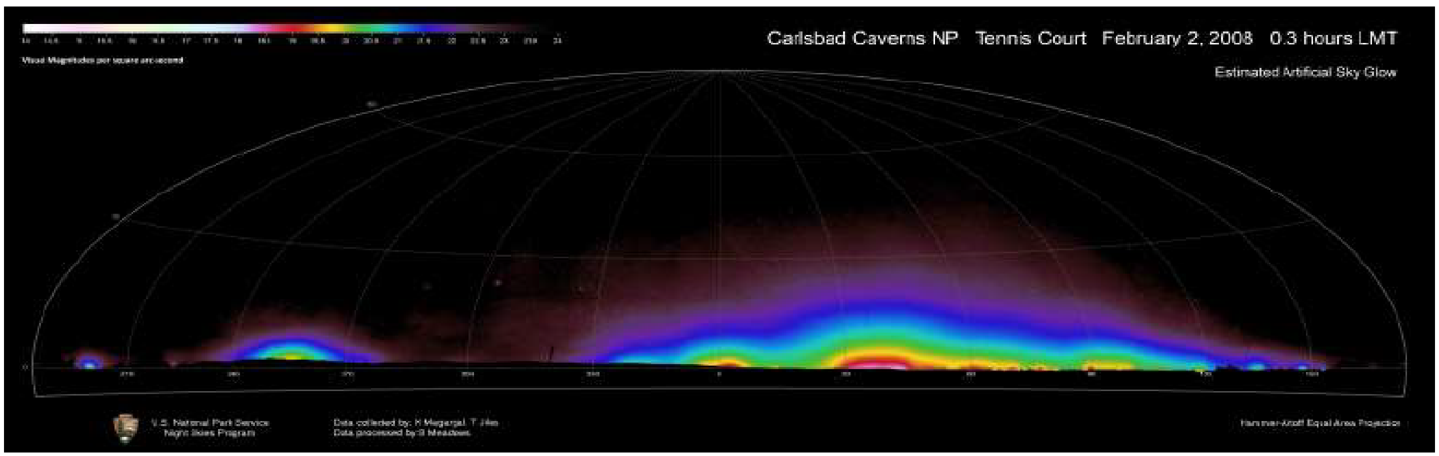
False color mosaic images of the CAVE night sky on the night of 1 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

CAVE080202 Date (LMT) 2-Feb-08 Time (LMT): 0.35



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (μcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (μcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest lumininance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
21.22	351	21.72	223	15.32	80,796	21.61	-7.36	0.861	0.788

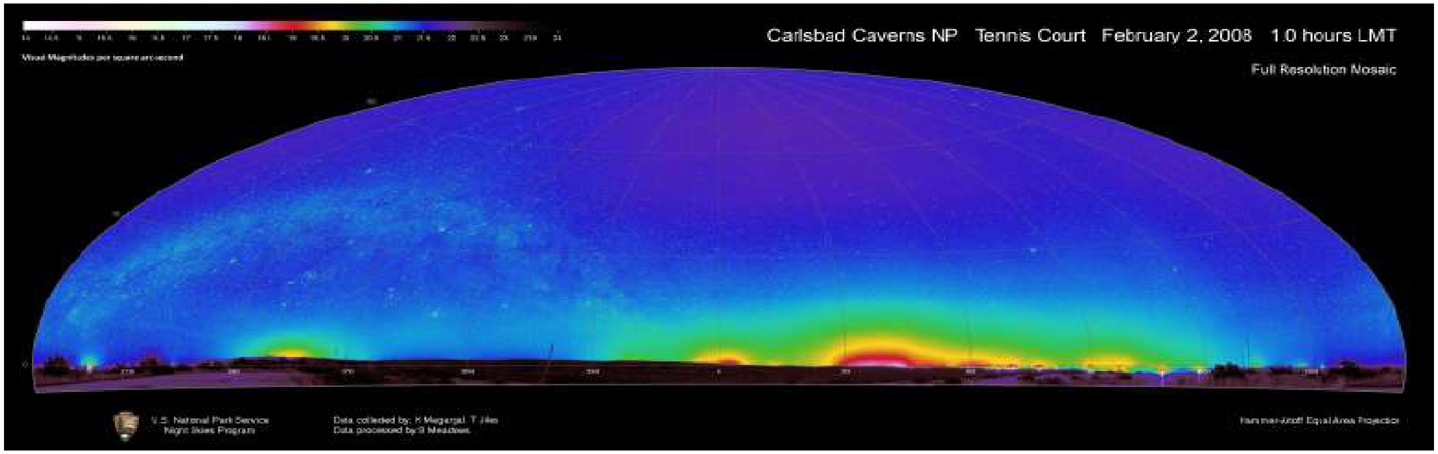


PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (μcd/m^2)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (μcd/m^2)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
88.8	80	27.9	15.1	6	13,719	0.32	-5.73	0.073	0.363

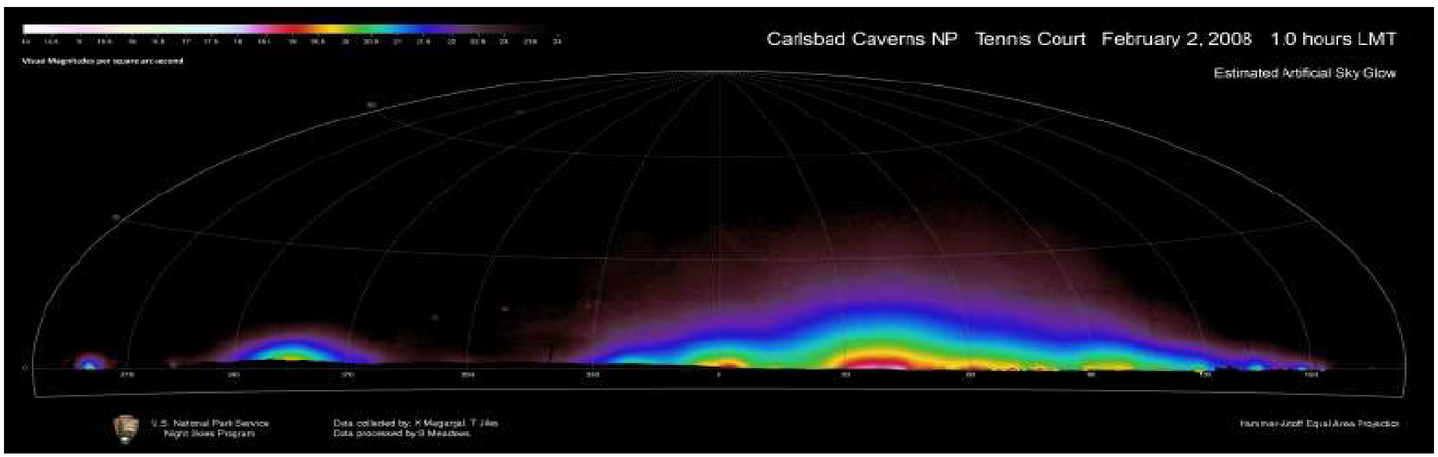
False color mosaic images of the CAVE night sky on the night of 2 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

CAVE080202 Date (LMT) 2-Feb-08 Time (LMT): 1.04



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec⁻²)	Average Sky Luminance (μcd/m²)	Zenith Luminance (mag arcsec⁻²)	Zenith Luminance (μcd/m²)	Brightest luminance (mag arcsec⁻²)	Brightest luminance	Synthetic SQM (mag arcsec⁻²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
21.21	355	21.73	220	15.34	79,359	21.62	-7.38	0.869	0.793



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (μcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest luminance (μcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
89.9	71	21.6	11.8	4	15,474	0.29	-5.60	0.060	0.346

False color mosaic images of the CAVE night sky on the night of 2 February 2008. View is from the old tennis courts near the Visitor Center (Images courtesy of NPS NSNSD).

Appendix J. Temperatures of pools found in Lechuguilla Cave from the EPA STORET database (EPA 2015) and two different studies conducted by (Levy [2007a, 2007b]).

Levy (2007a)	**Lake Chandalar**	**Lake of the Blue Giants**	**Lake Margaret**	**Lake of the White Roses**
EPA STORET °C (°F)	18.7 (65.7)	19.1 (66.4)	19.4 (66.9)	20.2 (68.4)
Levy Results °C (°F)	18.4 (65.1)	19.2 (66.6)	19.4 (66.9)	20.4 (68.7)
Levy (2007b)*	**Lake Lechuguilla**	**Lake Louise**	**Pearlsian Gulf water supply**	**Tower Place water supply**
EPA STORET °C (°F)	N/A	20 (68)	N/A	19 (66.2)
Levy Results °C (°F)	18.7 (65.7)	20.2 (68.4)	19.6 (67.3)	18.9 (66)

*Results averaged between two sample years (2005 and 2006); except for Tower Place water supply, which only had one sample year

Appendix K. pH values of pools found in Lechuguilla Cave from the EPA STORET database (EPA 2015) and two different studies conducted by (Levy [2007a, 2007b]).

Levy (2007a)	**Lake Chandalar**	**Lake of the Blue Giants**	**Lake Margaret**	**Lake of the White Roses**
EPA STORET	7.52*	8.3	8.07	7.6
Levy Results	7.98	7.94	7.86	7.34
Levy (2007b)*	**Lake Lechuguilla**	**Lake Louise**	**Pearlsian Gulf water supply**	**Tower Place water supply**
EPA STORET	8	7.9	7.79	7.9
Levy Results	8.05	7.64	7.63	7.62

*Results averaged between two sample years (2005 and 2006); except for Tower Place water supply, which only had one sample year

Appendix L. TDS values of pools found in Lechuguilla Cave from the EPA STORET database (EPA 2015) and two different studies conducted by (Levy [2007a, 2007b]).

Levy (2007a)	**Lake Chandalar**	**Lake of the Blue Giants**	**Lake Margaret**	**Lake of the White Roses**
EPA STORET mg/l	269.7*	335.4*	339	152.2*
Levy Results mg/l	276	348	315	406
Levy (2007b)*	**Lake Lechuguilla**	**Lake Louise**	**Pearlsian Gulf water supply**	**Tower Place water supply**
EPA STORET mg/l	310	289.3*	220	329
Levy Results mg/l	345	336.5	378.5	360

*Results averaged between two sample years (2005 and 2006); except for Tower Place water supply, which only had one sample year.

Appendix M. Temperature of pools found in Carlsbad Caverns from the study completed by Forbes (2000) and the EPA STORET database (EPA 2015). With Forbes (2000) being the study providing the most abundant data (to this date) on Carlsbad Cavern pools, results were similar between sources.

Note: NM = No Measure and "same" designates values found in the EPA STORET dataset that were taken from the Forbes (2000) study.

Forbes (2000)	**Balcony Pool[c]**	**Big Shelf Pool[c]**	**Calcite Raft Pool[d]**	**Devil's Spring[d]**	**Green Lake[d]**	**Guadalupe Room[b]**	**Horsehead Pool[d]**
Forbes °C (°F)	18.5 (65.3)	14.6 (58.9)[a]	18.2 (64.8)[a]	11.2 (52.2)[a]	13.4 (56.1)[a]	NM	15.8 (60.4)[a]
EPA STORET °C (°F)	same	same	N/A	same	same	N/A	same

Forbes (2000)	**Iron Pool[c]**	**Lake of the Clouds[d]**	**Longfellows Bathtub[d]**	**Mirror Lake[d]**	**Rookery Pool[d]**	**Sword of Damocles Pool[c]**
Forbes °C (°F)	15.7 (60.3)[a]	18.9 (66.02)[a]	14.2 (57.6)[a]	14.9 (58.8)[a]	13.6 (56.5)[a]	13.8 (56.8)[a]
EPA STORET °C (°F)	15.6 (60.1)	19.2 (66.6)	same	same	same	14 (57.2)

a. Results averaged between multiple samples from two sample years (1994 and 1995).

b. Samples from 1994.

c. Samples from 1995.

d. Samples from both 1994 and 1995.

Appendix N. pH values of pools found in Carlsbad Caverns from the study completed by Forbes (2000) and the EPA STORET database (EPA 2015). With Forbes (2000) being the study providing the most abundant data (to this date) on Carlsbad Cavern pools, results were similar between sources.

Note: NM = No Measure and "same" designates values found in the EPA STORET dataset that were taken from the Forbes study.

Forbes (2000)	**Balcony Pool**[c]	**Big Shelf Pool**	**Calcite Raft Pool**[c]	**Devil's Spring**[b]	**Green Lake**[d]	**Guadalupe Room**[c]	**Horsehead Pool**[c]
Forbes	8.19	NM	8.08[a]	8.21[a]	8.39[a]	NM	8.27[a]
EPA STORET	8.08[a]	N/A	N/A	same	same	N/A	8.0[a]

Forbes (2000)	**Iron Pool**[d]	**Lake of the Clouds**[d]	**Longfellows Bathtub**[d]	**Mirror Lake**[d]	**Rookery Pool**[d]	**Sword of Damocles Pool**
Forbes	8.60[a]	8.29[a]	7.65[a]	8.01[a]	8.36[a]	NM
EPA STORET	8.58[a]	8.32[a]	same	same	same	N/A

a. Results averaged between multiple samples from two sample years (1994 and 1995).

b. Samples from 1994.

c. Samples from 1995.

d. Samples from both 1994 and 1995.

Appendix O. TDS values of pools found in Carlsbad Cavern pools from the study completed by Forbes (2000) and the EPA STORET database (EPA 2015). With Forbes (2000) being the study with the most abundant data (to this date) on Carlsbad Cavern pools, results were similar between sources.

Note: NM = No Measure and “same” designated values found in the EPA STORET dataset that were taken from the Forbes study.

Forbes (2000)	**Balcony Pool[c]**	**Big Shelf Pool**	**Calcite Raft Pool**	**Devil's Spring[b]**	**Green Lake[d]**	**Guadalupe Room[b]**	**Horsehead Pool[d]**
Forbes mg/l	NM	NM	NM	915.5[a]	657[a]	439	595.5[a]
EPA STORET mg/l	348	N/A	N/A	1,393.33[a]	954[a]	same	3,006.67[a]

Forbes (2000)	**Iron Pool[c]**	**Lake of the Clouds[d]**	**Longfellows Bathtub[d]**	**Mirror Lake[d]**	**Rookery Pool[d]**	**Sword of Damocles Pool**
Forbes mg/l	8166[a]	479.5[a]	3809.5[a]	298	612.5[a]	NM
EPA STORET mg/l	24,050.4[a]	727.67[a]	5,763.67[a]	418.5[a]	861[a]	N/A

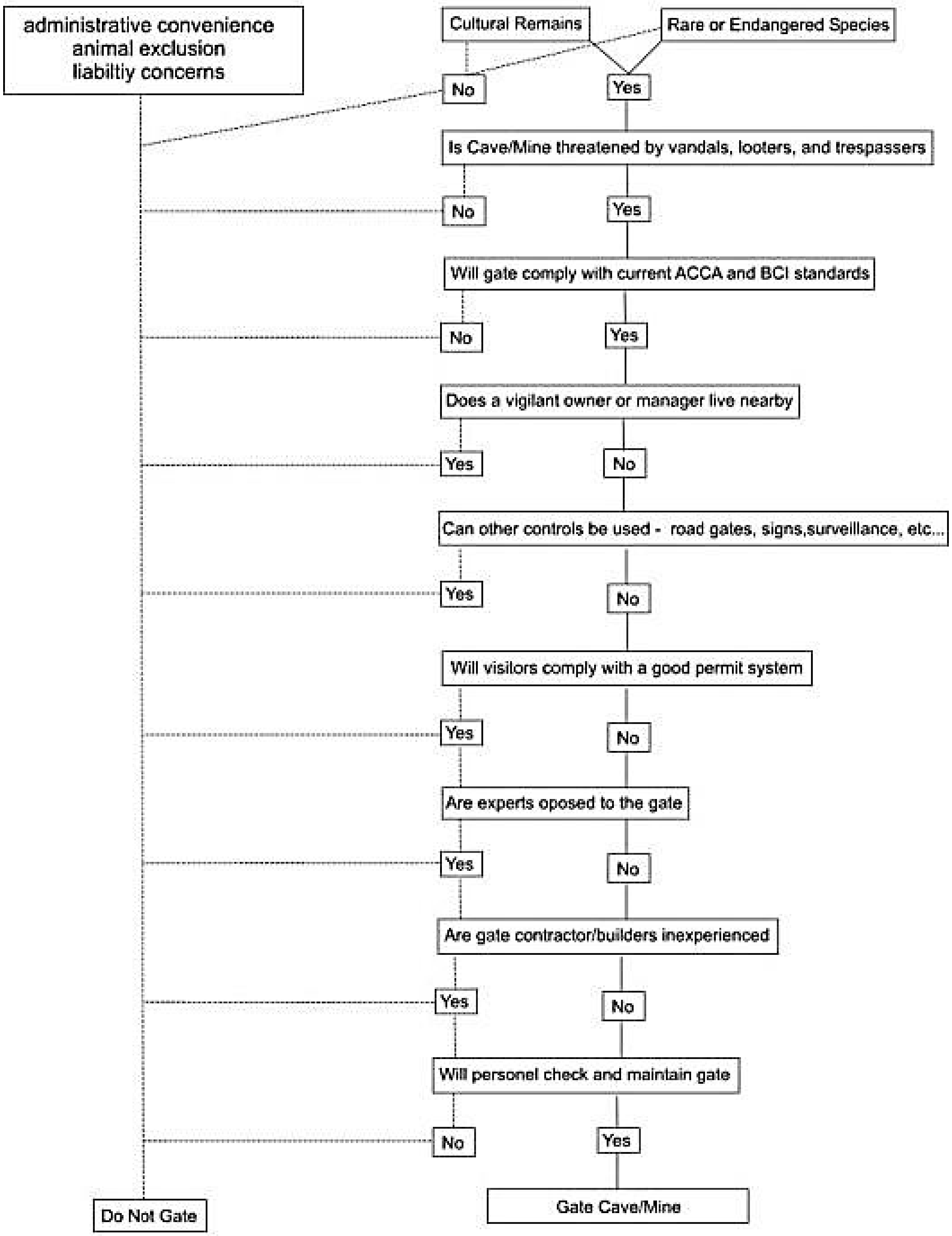
a. Results averaged between multiple samples from two sample years (1994 and 1995).

b. Samples from 1994.

c. Samples from 1995.

d. Samples from both 1994 and 1995.

Appendix P. A simplified flowchart used to help make a decision on whether or not to install a cave gate (Fant et al. 2009).



Appendix Q. Potential sources of groundwater contamination for Carlsbad Caverns. Table displays where contamination can come from, where it could end up, and the level of vulnerability to the cave (van der Heijde et al. 1997).

Source	Recipient cave area	Vulnerability
RV/bus parking lot west of visitor's center	Quintessential Right	High
	Crystal Springs Dome area of Big Room	Moderate
Car parking lot east of visitor's center	Quintessential Right	High
	Unmapped cavern area between Big Room and Quintessential Right	Moderate
Visitor's Center	Quintessential Right	Moderate
	Unmapped cavern area between Big Room and Quintessential Right	Low
Underground lunchroom	Lower Cave	Low
Park offices	Main Corridor between Devil's Spring and Iceberg Rock	High
Employee housing	Main Corridor between Devil's Spring and Iceberg Rock	Low
	Guadalupe Room, Left Hand Tunnel, and New Section	Low
Maintenance yard	Left Hand Tunnel and New Section	High
	Quintessential Right	High
	Left Hand Tunnel and New Section	High

Source	Recipient cavern area	Vulnerability
Pumphouse	Main Corridor between Devil's Spring and Iceberg Rock	Extreme
	Left Hand Tunnel and New Section	Low
	Quintessential Right	Low
Main road between service road to maintenance yard and road to lower parking lot	Chocolate High and Scenic Rooms area	Moderate
	Main Corridor between Devil's Spring and Iceberg Rock	Low
	Left Hand Tunnel and New Section	Low
Main road between road and to lower parking lot and visitor's center parking lot	Scenic Rooms, Boneyard, and Hall of Giants park of the Big Room	Moderate
Road between main road and lower parking lot	New Mexico Room and Scenic Rooms	High
Service road near offices	Main Corridor between Devil's Spring and Iceberg Rock	High
Main road north of maintenance yard and service road to maintenance yard	Seeps along seep line in Walnut Canyon	Low
Sewer line from housing, offices, and maintenance yard to pump house	Main Corridor between Devil's Spring and Iceberg Rock	High
Sewer line from pump house and visitor's center to turn south for crossing ridge top	Left Hand Tunnel	High
	Quintessential Right	High

Source	**Recipient cave area**	**Vulnerability**	**Source**	**Recipient cavern area**	**Vulnerability**
	Natural Entrance	Moderate	Sewer line from Bat Cave Draw to Delaware Basin	Quintessential Right	Moderate
Bat Cave Draw (lower) parking lot	Left Hand Tunnel and New Section	Moderate		Lake of the Clouds Area	Moderate
	Quintessential Right	Moderate			
	Main Corridor between Devil's Spring and Iceberg Rock	Extreme			

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National Park Service
U.S. Department of the Interior

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