National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Petroglyph National Monument

Natural Resource Report NPS/PETR/NRR—2022/2483

ON THE COVER
Black Volcano, Petroglyph National Monument.

Natural Resource Condition Assessment

Petroglyph National Monument

Natural Resource Report NPS/PETR/NRR—2022/2483

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Executive Summary

A subset of natural resources at Petroglyph National Monument (PETR or monument) was assessed for current condition. All available information, data, and expertise were utilized to determine resource condition and to evaluate whether the condition was stable, improving, or deteriorating (trend). A level of confidence was also provided for each assessment. Results of this assessment are presented in detail in Chapter 4 and discussed in Chapter 5.

In addition to overall assessments for the selected resources, a focused geomorphic assessment was conducted for arroyos—water courses in the monument that are seasonally dry but that can carry heavy sediment loads during storm events—to determine whether human land-use practices have led to increased erosion. Methodology, results, and references for this effort are presented in Appendices 1A–1D.

Petroglyph National Monument is directly adjacent to the rapidly growing city of Albuquerque, New Mexico, and human development and urban expansion are by far the greatest threats to monument natural resources. Habitat integrity (natural night skies and natural quiet) is most affected by urbanization and are in moderate to poor condition with generally downward trends. (Due to the near absence of perennial freshwater sources in the monument, water quality was not assessed.) Significant downstream modifications related to development have negatively affected the natural hydrology within the monument, though the cessation of land uses upstream that increase erosion (particularly grazing) have allowed vegetation recovery that reduces sediment transport.

Volcanic resources are well-documented and in generally good condition. Continued monitoring will assure that accidental and intentional human damage and/or erosion do not degrade these features in the future.

Climate change impacts in the region are expected to relate mostly to changes in precipitation patterns. Whether annual precipitation will decrease overall or remain at past levels but not within historic seasonal patterns (e.g., more intense summer storms coupled with reduced snowfall) is not clear.

Biological resources (vegetation and small to medium size vertebrates) are largely assumed to be in good condition, though data are mostly lacking or not current enough to have high confidence in this assessment. If climate change impacts include long-term drought, all biological resources will likely be affected. The potential impacts to biological communities from seasonal changes in precipitation are less clear.

Chapter 1. NRCA Background Information

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

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

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

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

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

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

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

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

Important NRCA Success Factors

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

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

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

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

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

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

[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. Park Resource Setting/Resource Stewardship Context

2.1. Introduction

Petroglyph National Monument (PETR or Monument) is located directly west of the City of Albuquerque in the north-central area of New Mexico (Fig. 2.1-1). The monument was primarily established to protect over 20,000 petroglyphs (images that have been carved into rocks), most of which date from 1,300 to 1,600 AD up to recent times (NPS 1997). Most of the petroglyphs are thought to have been created by ancestors of the present-day Pueblo Indians of central New Mexico. The placement of the pictures was not random but was integrally linked to the landscape, lending the volcanic and geologic features of the monument's particular cultural significance (Evans et al. 1993). Because so much development has occurred in the area, the monument also protects much of the remaining open space in Albuquerque's western region, including important natural resources unique to the Rio Grande Valley (Parmenter and Lightfoot 1996, Hester 2006).

2.1.1. Enabling Legislation and Administration

Beginning in the 1960s, local citizens began organizing to protect the petroglyphs in what is now the Piedras Marcadas Canyon area. The combined efforts of citizens and the City of Albuquerque resulted in the establishment of Indian Petroglyph State Park (now known as Boca Negra Canyon) in 1973, and eventually PETR in 1990 (described below). As written in the enabling legislation, PETR was established to:

- preserve the integrity of the cultural and natural resources in a human context;
- provide opportunities for diverse groups to understand, appreciate, and experience the monument in ways that are compatible with the monument's significance;
- cooperate with American Indians and Atrisco land grant heirs in perpetuating their heritage;
- function as a focal point for the collection, analysis, and dissemination of information relating to Rio Grande style and other forms of petroglyphs and pictographs (NPS 1997).

The significant elements of PETR (described in multiple documents referenced below) include one of the largest concentrations of petroglyphs in North America, unique research opportunities provided by the petroglyphs, the relevance of the petroglyphs and surrounding landscape to present-day American Indians and Atrisco land grant heirs, the Piedras Marcadas Pueblo, and the monument's landscape which defines Albuquerque's western horizon and provides a contrast to the adjacent expanding urban environment (NPS 2018).

The monument comprises approximately 7,200 acres (2,914 hectares) of land. Lands within the boundary of PETR are owned by the National Park Service (NPS), the State of New Mexico ("State"), the City of Albuquerque ("City"), and private landowners. Lands within the monument are jointly managed by the NPS and the City under a Cooperative Management Agreement (CMA)

This multi-agency management arrangement was specified in the enabling legislation but results in a challenging management and planning environment. Activities that span multiple units, particularly law enforcement efforts and long-term planning, can consequently require the participation of several entities that may have differing missions and/or expertise (M. Medrano pers. comm. 2011). In 2018, the monument received concurrent legislative jurisdiction which exists when both the state and federal governments have authority over a specific area. Under concurrent legislative jurisdictional authority, NPS Law Enforcement Park Rangers enforce the requirements of the United States Code, 36 CFR, assimilated state regulations, and the Superintendent's Compendium within the legislative boundaries of the monument.

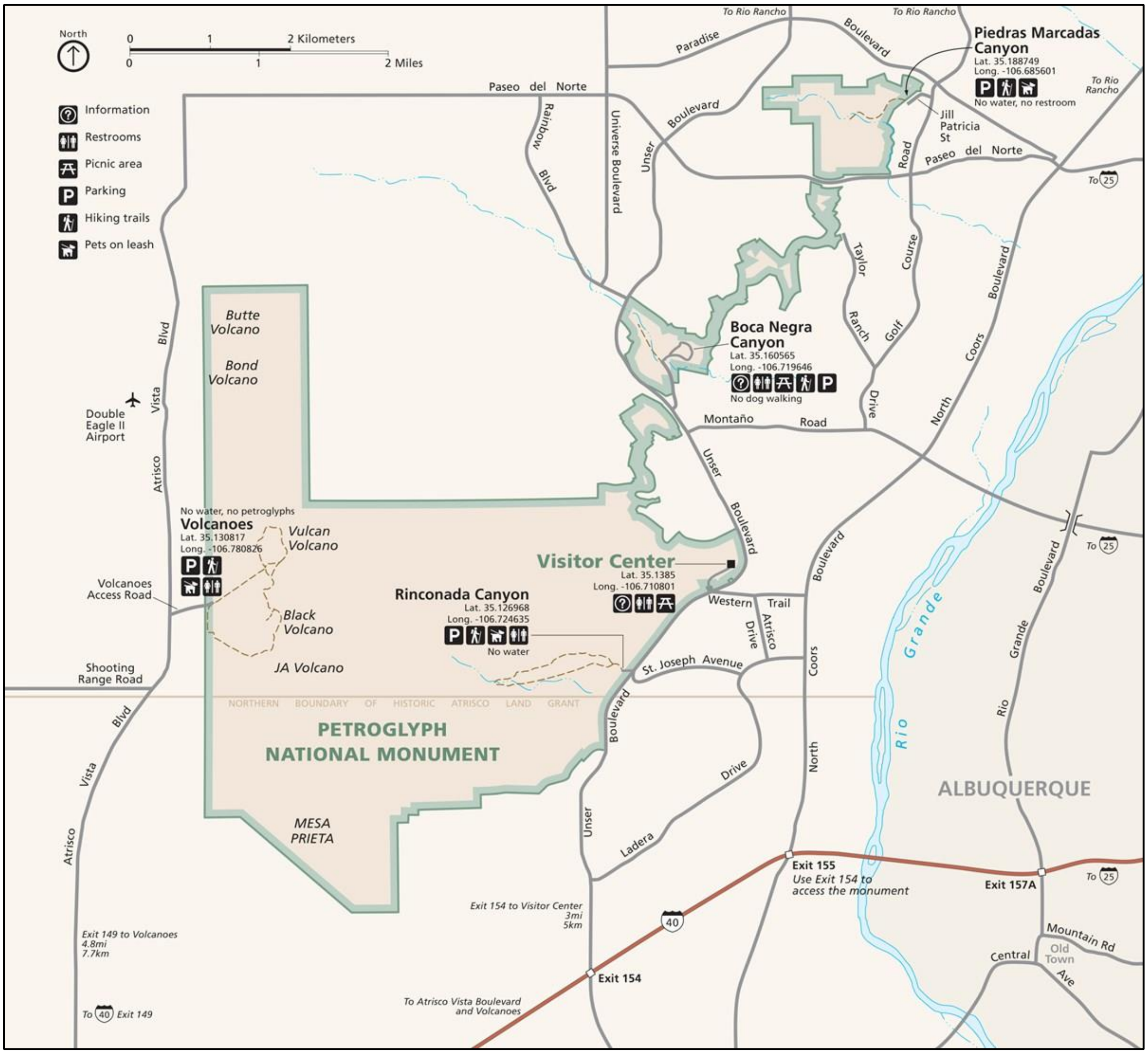

Figure 2.1-1. Location of Petroglyph National Monument, New Mexico. Photo: NPS.

2.1.2. Geographic Location and Physical Setting

Petroglyph National Monument lies in the southern portion of the Basin and Range physiogeographic province of North America and regionally within the Middle Rio Grande River Basin of the Rio Grande River (Figure 2.1-1; Finch and Tainter 1995, Griffith et al. 2006, Muldavin et al. 2012). The

Rio Grande Rift, which created the river basin, is a thin portion of the Earth's crust that runs from central Colorado through New Mexico to Mexico. Beginning approximately 32 million years ago (mya) the Colorado Plateau region separated from the middle portion of the continent along this seam, causing water to flow into this area of low elevation, a process that ultimately resulted in the formation of the Rio Grande River (Bachman and Mehnert 1978, Aldrich et al. 1986).

Locally, PETR is situated on a plateau known as the West Mesa, a prominent feature of the Albuquerque landscape to the west of and above the Rio Grande River (Hawley et al. 1995). Topographically the monument slopes downward from west to east until the mesa drops off at the volcanically formed escarpment (described below). Views from the mesa reach across the Rio Grande Valley and the City of Albuquerque to the distant Sandia Mountains to the east.

Surrounding Lands/Adjacent Ownership

The monument is surrounded by open space managed by the City of Albuquerque and private land, both developed and undeveloped (though zoned for future development). Because the City (population over 560,000) has seen such expansive and relatively dispersed development in the last 40 years (the greater Metropolitan Statistical Area [MSA] had a population of approximately 910,000 in the 2010 census; Hester 2006), residential neighborhoods now directly abut the monument on the north and additional residential, school, and sports facilities are located on the south boundary. A regional airport lies just to the west of the monument and plans have been approved to double the capacity of this airport. Recent efforts to preserve more open space near the monument and mitigate development impacts have seen some success (M. Medrano pers. comm. 2011). Impacts of development and adjacent land-use are discussed in detail throughout this document and specifically in Section 4.7.

2.1.3. Cultural Significance

Archaeological evidence indicates that humans have occupied the West Mesa for more than 10,000 years, with the earliest Paleoindians living a nomadic lifestyle that followed herds of large mammals (Holliday et al. 2006). By around 500 B.C. a drying climate led people from across the southwest to adapt to a lifestyle more focused on agriculture and hence reliant on permanent water sources (Campbell and Ellis 1952). Groups adopting an agricultural lifestyle eventually became well established in the Albuquerque area, and it is estimated that 90% of the monument's petroglyphs were created by early Puebloan people (Pueblo IV) who inhabited the area from about 1300 A.D. through the late 1680s (NPS 2018).

The Puebloan period ended with the arrival of the first Spanish explorers (Wendorf 1954). Specifically, in 1692, Don Fernando Duran y Chaves II, a native New Mexican, was awarded 82,000 acres of land on the west side of the Rio Grande River, the site now known as the Atrisco Land Grant. The land was used primarily for ranching but is now owned by a consortium of heirs, many of whom (though not all) have sold their properties for development (Sanchez 2014).

The West Mesa landscape is extremely significant to many Native American and Hispanic people. The location of the mesa allowed people to observe the entire region from one point and is connected in cultural lore with the much higher Sandia mountain range to the east. The volcanic features, particularly the "sisters" (the volcanic cones), were and are still considered by many to be a sacred site (Evans et al. 1993). A thorough treatment of the cultural significance and history of the West Mesa is beyond the scope of this report, however, the ties between the living, the physical, and the spiritual world that PETR represents for many people are recognized in relevant sections where they relate to natural resources. Treatments of this topic can be found in Evans et al. (1993) and Anschuetz et al. (2002).

2.1.4. Visitation

The number of people visiting PETR on an annual basis has increased from 68,065 in 1992 (two years after the monument was created) to 293,957 in 2019 https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Annual%20Park%20Recreation%20Visitation%20Graph%20%281904%20-%20Last%20Calendar%20Year%29?Park=PETR (These visitation statistics include all areas of the monument under co-management by the NPS and the City.) The substantial increase in visitation over the last several decades is due to day visits from the ever-increasing population of the greater Albuquerque area as well as an influx of visitors into the Albuquerque area for other events. For example, the greatest number of visitors to the monument is often in October (concurrent with the International Balloon Fiesta), and March (the height of the spring break season). Improved procedures for counting visitors along with newly designated trail systems are expected to result in a higher number of visitors recorded in coming years (D. Kissner pers. comm. 2017).

There is an acknowledged need for additional resources for visitor management by all participating agencies (M. Medrano pers. comm. 2011). For example, though regulations currently require visitors to stay on trails they often do not, resulting in the creation of social trails in many locations (N. Hendricks pers. comm. 2021). Dogs are allowed in some areas of the monument, but off-leash and dog waste pick-up violations are common in the monument (D. Kissner pers. comm. 2017). Monument managers have been challenged with maintaining adequate funding for interpretation and law enforcement needs as visitation continues to increase. The Visitor Use Management Plan (VUMP) completed in 2019, when implemented, will result in the establishment of formal trails and access points in areas that can best accommodate high visitor use, directing visitors away from sensitive sites. (NPS 2019).

2.2. Physical Resources and Processes

2.2.1. Climate

Weather patterns in PETR are typical of the semi-arid southwest, with wide variations in seasonal precipitation and temperature (WRCC, Sheppard et al. 2002, USACE 2013). Precipitation varies from 6 to 14 inches (15–36 cm) per year (average 8.5 in/22 cm), and occurs primarily in two seasons, winter and mid-to-late summer. Winter precipitation occurs generally between November and March, often in the form of snow, though the water content of the snow is generally low. Most precipitation falls as rain in the spring and especially during the summer monsoon season in July and August. Monsoon storms can be intense, often resulting in heavy rainfall and flooding. Summer days can be hot, with an average high temperature from June–August of about 90°F (32°C). Detailed climate information and climate change are addressed in Section 4.2.

2.2.2. Geology

The landscape of PETR is defined primarily by volcanic features formed by a series of eruptions, lava flows, and periods of deposition that occurred beginning approximately 130,000 years ago (Crumpler 1999, Zimmerer and McIntosh 2012). Most prominent are the three large and two smaller volcanic cones, and the "escarpment" which was created when lava flowed downslope toward the Rio Grande River over the existing softer soils which have subsequently eroded away, leaving the heavier, basaltic rocks without support (NPS 2006). As a result broken rocks have accumulated at the base of the escarpment, and these are the location of most of the petroglyphs found in the monument.

The escarpment ranges in height from approximately 30 ft (9 m) near the north end to 300 ft (91 m) at the south. Discontinuous deposits of Late Pleistocene and Holocene alluvial and aeolian sand are common on the uplands of the escarpment while late Oligocene to middle Pleistocene Santa Fe Group alluvial sands and gravels underlies the basalts (Connell 2007). Extensive Holocene colluvium and aeolian deposits also exist at the base of the escarpment in many places. In some places small playas formed where there were depressions in the basalt flows. The playas held small volumes of water and are associated with Paleoindian occupation of the area (Holliday et. al. 2006).

The cluster of volcanoes and associated basalt flows in the monument are known as the Albuquerque Volcanic Field (AVF), a significant geologic feature of the region. Additional volcanic features such as kipukas and cinder deposits are found throughout the monument. The entire volcanic field is approximately 7 mi (11 km) long and 5 mi (8 km) wide, with the three prominent peaks as the focal point. The last eruption occurred approximately 150,000 years ago, and the area is considered an active volcanic system by geologists. A good description of the AVF can be found on the website of the New Mexico Museum of Natural History and Science (http://www.nmnaturalhistory.org/volcanoes/albuquerque-basin-volcanic-field). An assessment of the volcanic features and additional descriptions are provided in Section 4.4.

2.2.3. Soils

Soil development in volcanic landscapes of the Southwestern US is usually correlated with the age of the underlying flow, determined largely by rates of basalt weathering and aeolian deposition (Peate et al. 1996). Most of the soils within PETR are either of aeolian origin or are eroded from volcanic-derived rocks. Because of their high sand and low clay composition, most of the soils in the monument are highly susceptible to transport by wind and water (NPS 2009, Muldavin et al. 2012), and disturbance by human activities (NPS 2018).

Wind deposition has led to more highly developed soils on both the windward side of the volcanoes and to the immediate lee side of the cones and younger lava flows, while much of the flow basalt on the east side of the monument has little or no soil development (Muldavin et al. 2012). Atop the lava flows are mostly well-drained soils that vary from very shallow to moderately deep, including sandy loams and fine sandy loams. Sandy soils are dominant at the base of the escarpment, and in some areas are relatively deep and support diverse plant communities (Muldavin et al. 2012).

2.2.4. Hydrology

The monument lies within the Rio Grande-Albuquerque subregion (HUC13020203) of the Rio Grande watershed. There are no permanent natural water sources in the monument, though ephemeral pools can form in basalt rocks, often serving as an important resource for amphibians and other wildlife (M. Medrano, pers. comm. 2011).

Impacts from localized and temporally defined processes, such as monsoon-driven summer rainstorms, structure much of the landscape (Gellis 1995). Drainages (arroyos) are dry for much of the year and carry water only during and after storms. The largest arroyo in the monument, North Boca Negra, is approximately 10 mi (16 km) long but less than 2 mi (3 km) of the arroyo is within PETR boundaries. During storm events multiple arroyos can combine to create several kilometers of temporary streams.

Water from the Albuquerque Mesa flows in an east/southeast direction toward the Rio Grande River. In several locations, downstream flows from PETR are either partially or completely channeled through developed areas, increasing flow velocity and affecting resources upstream (S. Monroe pers. comm. 2011). Ongoing concerns regarding the effects of development on hydrologic processes in the monument are discussed in detail in Section 4.3.

2.2.5. Fire

Little information regarding the historic natural role of fire in the region is available. Fire has been functionally absent from the system since the 1880s when livestock were introduced and fires routinely suppressed. Prior to that period it is thought that frequent (7–10 years), low intensity grassland fires were ecologically important (McPherson 1997, NPS 2005, Muldavin et al. 2012), and rainfall patterns following wildfires may have had strong effects on grassland response to fire (Drewa et al. 2006, Drewa and Haystad 2001).

2.3. Natural Resources

2.3.1. Vegetation Communities

Central New Mexico lies at the northern extent of the Chihuahuan desert but also exhibits ecological characteristics of the Great Plains and the Great Basin ecoregions (Finch and Tainter 1995, Ford et al. 2004). The majority of PETR (approximately 65%) is Southwestern grassland, and grasses dominate here both in number of species and percent cover (DeCoster and Swan 2009). Forbs are a major component of most communities, and there is a small extent of ephemeral riparian habitat (Muldavin et al. 2012).

The escarpment and other rocky volcanic areas are lightly vegetated (<10% plant cover) but support several unique species not found elsewhere (Muldavin et al. 2012). All vegetation communities in the monument are recovering from significant historic land uses including grazing, military activity, road construction and trash dumping (Muldavin et al. 2012). Muldavin et al. (2012) provide a comprehensive description of the monument’s vegetation resources, and grasslands are addressed specifically in Section 4.5.

2.3.2. Special Status Species

Various federal and state listed species may occur in Bernalillo County. Information accessed from the US Fish and Wildlife Service (USFWS) Information for Planning and Consultation (IPaC) website indicates that there are five federally threatened and endangered species listed in Bernalillo County, in which the monument is located. These include: the Rio Grande silvery minnow (*Hybognathus amarus*), New Mexico meadow jumping mouse (*Zapus hudsonius luteus*), yellow-billed cuckoo (*Coccyzus americanus*), southwestern willow flycatcher (*Empidonax traillii extimus*), and Mexican spotted owl (*Strix occidentalis lucida*). While there was a random occurrence of a Mexican spotted owl in the monument, in which it stayed for 1–2 days in March 2017, there are no other known federally listed species in the monument. The Rio Grande silvery minnow requires perennial water, which is not present in the monument. The New Mexico meadow jumping mouse is found in two riparian community types: persistent emergent herbaceous wetlands and scrub-shrub wetlands—neither which occurs in the monument. Both the yellow-billed cuckoo and southwestern willow flycatcher depend on dense riparian vegetation habitat, which the monument lacks.

Loggerhead Shrike (*Lanius ludovicianus*)

Loggerhead shrikes are a predatory grassland bird species that has declined throughout New Mexico and most of its range. Shrikes are resident in PETR, and though they were not detected during bird surveys in 2001–2003 (Johnson et al. 2007) they do nest in the monument and are often seen near the volcanoes (M. Medrano, pers. comm. 2011). Shrikes prefer grassland and low shrub habitats, vegetation communities that have largely been lost to development but are protected within PETR. Recent studies suggest changing climate conditions may also affect shrike populations (Borgman and Wolf 2015).

2.3.3. Species and Communities of Concern

Outcrop Plant Communities

Plant communities found on the rocky volcanic outcrops and the escarpment support several species absent from other areas of the monument (Muldavin et al. 2012). The dark volcanic rocks retain heat, but because of the disrupted surface, the sites also retain more moisture than the sandy and loamy soils of the mesa and flatlands. These sites are at risk from erosion, human impacts, and drier conditions resulting from climate change (Section 4.2).

Landbird Communities

PETR is an important site for breeding and migrating landbirds, but adjacent development has resulted in the introduction of several new resident species which may be competing with native bird populations (Johnson et al. 2007). Introduced and often aggressive species include rock doves, European starlings, and house sparrows. Several native species are found only in undeveloped sites, suggesting that they are particularly sensitive to development impacts (Parmenter and Lightfoot 1996).

Vertebrate Communities

The lands now within PETR would historically have supported a grassland fauna that included large ungulates (pronghorn antelope, mule deer, elk; Section 4.5) and a diverse community of small and medium-sized mammals (prairie dogs, black-footed ferrets, coyotes; Section 4.6). There are also several ephemeral pools that form in basalt rock locations that are important to amphibians and other wildlife species. Numerous impacts including hunting, pest control, and the introduction of non-native predators and competitors have reduced mammal diversity in these communities (Parmenter and Lightfoot 1996). Loss of habitat connectivity between PETR and adjacent remaining open space, an increase in domestic predators, and climate change are the greatest threats to mammal community diversity (Section 4.5).

2.3.4. Non-biologic Resources of Concern

Volcanic Resources

While volcanic resources are not likely vulnerable in the short term, there is concern that longer-term processes (erosion) could damage sites such as the escarpment and the geologic windows. There is also concern that the importance of the features within the context of the greater landscape is being rapidly degraded by ongoing development, adversely affecting the cultural significance of the features (M. Medrano pers. comm. 2011, Section 4.4).

Hydrologic Processes

Roads, housing developments, and other alterations to the mesa surface upstream from the monument have increased the volume of runoff that flows through monument drainages (S. Monroe pers. comm. 2011). Increased and unnatural levels of water flow can bring additional surface-based contaminants into the monument, accelerate erosion, and promote gullying that might damage or destroy petroglyphs (Gellis 1995). Downstream impacts, particularly road construction, have increased elevation differences between the monument and downstream sites thereby potentially increasing flow velocity and erosion above pre-development conditions (S. Monroe pers. comm. 2011; Section 4.3, Appendices 1A–1D).

Viewshed

The locations of the petroglyphs in this region are non-random and were placed in a manner that was integrally linked to the landscape (Anschuetz et al. 2002). The volcanic peaks of PETR and the West Mesa are also significant points of location for all the Native peoples of the region. Preserving whatever connectivity remains in the natural viewshed is a priority for the monument even though the historic viewshed has been permanently altered (M. Medrano pers. comm. 2011).

Soundscape

The preservation of quiet places in the monument has been identified as an important goal, however, maintaining quiet places has proved increasingly difficult as regional development intensifies (NPS 2018). One of the greatest threats to preserving natural quiet in the monument is the presence of the adjacent regional airport (Double Eagle II), which will be expanded in the future. Aircraft currently flying out of this airport include military, law enforcement and news helicopters, experimental aircraft, paragliders and other small planes. The continued increase in residential and commercial development on monument boundaries brings associated traffic noise, sometimes at high levels, particularly during periods of construction. The natural quiet resource of the monument is addressed in Section 4.7.

2.4. Relevant Regional and Landscape-scale Information

Perhaps in no other NPS unit in the southwest is the proximity and intensity of human encroachment as pronounced in relation to monument resources as it is at PETR. Very little open space buffer was maintained between monument lands and development footprints, and in many locations houses and roads, as well as a dump site and additional planned developments, are directly adjacent to monument boundaries (Dickinson 2012). The construction of a 4-lane highway through the monument, after the land needed for road construction was removed from PETR by congressional action, has become an unfortunate example of the intense debate between economic interests, natural and cultural resource protection, and the rights of native cultures that is occurring across the southwest (US 1998, Cole 2002, Ruscavage-Barz 2007).

At present the greatest threat to natural resources from direct and indirect impacts of development are the degradation of the soundscape and the viewshed, alterations to natural hydrologic function that are leading to erosion and possibly damage to cultural resources and impacts to the ecology of the monument resulting from habitat fragmentation, edge effects, and non-native species introductions (Section 4.7).

2.5. Primary Threats to Natural Resources

2.5.1. Erosion

The wind- (aeolian) and water- (fluvial) driven movements of sand and soil within the monument are natural processes. However, human activities have altered these processes in identified but often unquantified ways (Gellis 1995, NPS 2018). Changes to natural erosional processes can potentially harm petroglyphs by accelerating natural scouring of the rocks, and can fill arroyos and stream channels, increasing the potential for additional streambank erosion and loss of vegetation. Monument managers do not have a sufficient understanding of these processes to mitigate any effects of erosion that may be greater than they were historically or that may be further influenced by climate change (M. Medrano pers. comm. 2011). A specific study attempting to measure arroyo change over time was included as part of this project and is described in detail in Appendix 1.

2.5.2. Non-native plants

Invasive plants are less of a threat in PETR than in many areas of the Southwest, primarily because the naturally harsh environmental conditions of heat and wind limit expansion of most species (M. Medrano pers. comm. 2011, Muldavin et al. 2012). The greatest abundance of weedy species is found near areas of high human use and where there is intermittent water. For example, along Boca Negra arroyo (north of the monument), overflow of a well and water tank have created artificial intermittent streams where exotic species have established. In 2015 Russian thistle (“tumbleweed”; *Salsola tragus*) was found to be pervasive across the monument; there are currently no means of effective control (M. Medrano pers. comm. 2011).

2.5.3. Non-native vertebrates

Housing developments along the periphery of the monument have facilitated an increase in the abundance of domestic animals that enter the monument. Cats are especially problematic and can have significant impacts on native prey species such as small mammals and songbirds (Kays and DeWan 2004). Dogs, both on- and off-leash, have numerous physical and ecological impacts in natural areas (Lenth et al. 2008, Vanak and Gompper 2009, NPS 2018). Coyotes, though not a domestic species, are highly adaptable to human presence and are likely increasing in number in the areas around the monument. Though coyotes compete with other native predators (fox, bobcat) the increase in coyotes over the last 20 years may also be controlling the numbers of feral cats and dogs (Parmenter and Lightfoot 1996, M. Medrano pers. comm. 2011, Section 4.6).

2.6. Natural Resource Stewardship

2.6.1. Management Directives and Planning Guidance

Wildfire Emergency Response Procedure (WERP), 2021

The NPS developed the WERP document for use by park units with limited or no fuels programs and generally rare fire events. NPS RM 18, chapter 4, describes the WERP, and includes potential fuels treatments as mechanical and/or prescribed fire projects to decrease risk of wildfire. All wildfires will be suppressed utilizing tactics to keep fires small while providing for protection of life and developed areas and infrastructure, and minimizing damage to resources from fire or suppression operations.

Visitor Use Management Plan (VUMP), 2018

To protect natural resources, the VUMP, as it is implemented, will create a managed trail and access system that will direct visitors to use the formal trail system, and prohibits off-trail use. Dogs off-leash are more stringently controlled, and bicycle use is now prohibited for much of the monument. These management actions will protect natural resources by reducing erosion, protecting native plants, and reducing the impacts of dogs on native species (NPS 2018).

Foundation Document, 2017

PETR's Foundation Document provides basic guidance for planning and management decisions. It identified PETR's fundamental resources and values (FRVs), which are the: petroglyphs, geologic resources, cultural and ethnographic landscape, and archaeological sites. It also identified other important resources and values for PETR, including flora and fauna, and recreational opportunities. For each FRV and other important resources and values, it includes a discussion on the current trends and conditions, threats and opportunities, data and/or GIS needs, and planning needs.

Resource Management Plan (RMP), 1999

The natural resource objectives in the RMP were generated largely from the goals of the GMP and include:

- preservation of the resources of the monument through scientifically-based management actions;
- establishment of a resource information base to monitor changes and support scientific and educational objectives;
- maintaining and reclaiming natural conditions and ecological processes as much as is practical given past resource abuses and encroaching urban development;
- maintaining natural quiet of the landscape by minimizing noise intrusion.

Final General Management Plan (GMP), 1997

The GMP addresses general topics of park management, including the cooperative agreement between the NPS and the City of Albuquerque and future plans for visitor management. Regarding natural resources, the main objectives outlined in the GMP are:

- preserve and protect natural (and cultural) resources through science-based management;
- support research of natural resources;
- maintain a resource information base (database) to support research and management;
- maintain natural conditions and ecological processes as much as possible;
- focus on issues of natural quiet, water quality and erosion.

2.6.2. NPS Inventory and Monitoring Program / Supporting Science

The inventory and monitoring program for PETR is managed through the NPS Southern Colorado Plateau Network (SCPN). Current monitoring at the monument includes vegetation, riparian ecosystems, and climate. Inventories have been completed for amphibians and reptiles, mammals and birds, and a vegetation study and map completed. The SCPN PETR website provides links to all published inventories, monitoring protocols and reports (https://www.nps.gov/im/scpn/petr.htm). Research and I&M efforts related to the focal resources assessed in this report will be referenced throughout Chapter 4.

2.6.3. Sources of Expertise

- Dale Kissner, Former Chief Ranger, PETR
- Mike Medrano, Former Chief of Resources, PETR

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Chapter 3. Study Approach

The PETR NRCA project was coordinated by the Southern Colorado Plateau Network (SCPN). In collaboration with the Northern Colorado Plateau Network (NCPN), SCPN hired an ecologist to focus on NRCAs in both networks. The ecologist was later funded through a cooperative agreement but continued to perform similar functions throughout the project. The PETR staff, in particular Mike Medrano, provided substantial input to the project including project definition and direction, data summaries and analysis, writing, and review.

3.1. Preliminary Scoping

The preliminary scoping process was organized by the SCPN coordinator and the NRCA ecologist. The first meeting between SCPN and the PETR staff and interested cooperators occurred in July 2010 at PETR Headquarters in Albuquerque, NM. The meeting was held for one day and began with an introduction by SCPN on goals and methods for the NRCA project.

Attendees then worked to develop a preliminary list of focal resource topics; PETR is a relatively small park and the list of resources was not difficult to identify nor did it take long to assign project priority levels to each topic (Table 3.1-1). However, the monument is managed by multiple agencies, and one of the challenges identified were the potential difficulties in obtaining data from some sources. A second challenge was defining a high priority topic that might be addressed using additional targeted funds (described below). After discussing the resource issues and data availability for each, the group prioritized the list in relation to both monument management priority and how well each topic would fit within the NRCA guidelines. By the end of the day the team had completed a first draft list of resource topics (Table 3.1-2).

Table 3.1-1. Priority Issues to be addressed within the PETR NRCA.

Resource	Issues/Concerns	Data/Indicators
Vertebrate Communities	Small and medium-sized vertebrates with ranges that include the monument are affected by human encroachment and habitat fragmentation. Social trails and off-leash dogs have direct impacts on wildlife. The monument likely provides some of the last remaining habitat for small and medium sized vertebrates and/or important linkages between their habitats.	A small mammal inventory was conducted by SCPN in 2001 and a biodiversity study in 1996. Monument staff may be collecting small mammal data in the future for other projects. Reference conditions for vertebrate communities would come from similar but less impacted habitats in the region.
Habitat Connectivity	Adjacent development has increased habitat fragmentation reducing migration and dispersal opportunities for wildlife. This situation reduces genetic exchange within populations and increases the likelihood of local extinctions, increases the abundance of invasive plant propagules, and facilitates negative interactions between wildlife and domestic animals.	The mammal inventory conducted by SCPN provides a complete but dated species list. Assessing habitat connectivity and functionality will be difficult. Reference conditions will likely come from similar systems unaffected by development impacts.
Volcanic Resources	Some features are threatened by human activities that increase erosion or cause direct damage. Many of the volcanic geologic resources have not been mapped at scales that identify individual features. A thorough survey of these resources would support management and planning, and monument staff considers this an important information gap.	In 2017, the NPS Geologic Resources Division (GRD) completed a geologic resources inventory report for the monument including a geologic map. In 2006 the NPS GRD completed a geologic resources evaluation, including a geologic map at 1:24,000. In 1996 the National Speleological Society assisted with an initial inventory of the monument's caves. Archaeological surveys have identified the locations of most known caves in the area. However, assessing the location and condition of these resources may be problematic within this NRCA.

Table 3.1-2. Selected resource elements organized within the NPS Ecological Monitoring Framework (EMF), relative priority scoring, and data availability and estimated workload.

EMF Level 1 Category	PETR Element/Resource	Mgmt. Priority	Project Priority	Data Availability	PETR Workload (1=1pp; 2=>1pp) [a]
Geology and Soils	Geomorphic processes/soil movement	High	High	historic contour information; soil survey; stream gauges [b]; LiDAR; SCPN photo points	2
	Volcanic resources (geothermic activity)	High	High	existing geologic maps at 1:24,000; vegetation map; local knowledge; archaeological surveys	1
Water	Groundwater quality	Low	Low	–	–
Biological Integrity	Vertebrate community condition	High	High	SCPN inventory; other sampling data	1
	Native grasslands	Medium	Medium	SCPN integrated upland monitoring; Muldavin et al. (2012);	1
	Invasive plants	Medium	Medium	plot data collected for vegetation map; unknown numbers of invasive plant populations at present	1
Landscapes (Ecosystem Pattern and Processes)	Fire Dynamics	Low	Low	–	–
	Connectivity/fragmentation	High	High	aerial photos; species lists	1
	Viewsheds	Low	Medium	GIS can be utilized to create a viewshed; existing and historic ground photos?	1
	Soundscape	Medium	Low	–	–

[a] 1: estimated workload less than one pay period of time for PETR staff; 2: estimated more than one pay period

[b] A USGS stream gage exists in the Mesa Prieta area of the monument but is not in use (#USGS 08329938 LADERA ARROYO AT ALBUQUERQUE, NM). Monument staff have discussed possible removal of the gage with USGS (C. Walter pers. comm. 2/21).3.1.1. Targeted Investigation Topic – Arroyo Geomorphology

SCPN included funding in each park's NRCA budget for an outside investigator to address one topic at a higher level of analysis than was possible without this funding. Because this opportunity was available, it was important for participants to identify resource topics that were not only amenable to such an approach but that were also of high importance to the park.

Monument staff at PETR determined that given the importance of erosion as both a natural process and a potential threat to the petroglyphs, understanding the current level of human input into erosional processes, i.e. in what ways and to what extent has development and other human activities altered erosion, was the highest priority. However, because NRCAs generally do not include funds for new data collection, determining what methods could be used to assess the condition of natural erosional processes was somewhat problematic, and this topic ultimately became the most challenging aspect of this NRCA (Appendix 1).

3.2. Study Design

3.2.1. Indicator Framework, Study Resources and Indicators

The group incorporated the NPS Ecological Monitoring Framework (Fancy et al. 2009) to identify and synthesize natural resource topics, indicators, and measures that would be emphasized in the study. This framework was selected due the tight integration of the framework with the NPS Inventory and Monitoring (I & M) program from which much of the data used in the NRCA would originate. Further, if large data gaps were identified for a particular resource or topic, this information could potentially be incorporated more easily into future I & M program reviews. Also included in the scoping discussions were general determinations of available data and the amount of time it would take PETR or other personnel to collate or synthesize necessary information.

Reference conditions were developed separately for each topic. Generally, the process utilized to develop relevant reference conditions was to conduct an initial literature search to determine what types of measures had been or were being used to evaluate similar resources. Discussions were then conducted with local knowledge experts and existing NRCAs from other NPS units were examined to compare reference conditions applied to similar resources.

In some cases, determining reference conditions was straightforward, however, in many cases there currently are no quantified reference conditions available. The process for determining reference conditions (or reasons why they are unavailable or unquantified) is included within each topic section in Chapter 4.

As the project developed, the group determined that the use of reporting areas would not enhance the project. The three primary influences acting on monument resources and processes at present—urbanization, erosion, and climate change—are acting across all natural systems and management areas.

3.2.2. General Approach and Methods

Once condition indicators for each resource were identified, determining resource condition was approached primarily by examining existing data from the I & M program and/or published sources and communicating with various resource experts. A thorough literature search was conducted first for the specific resources in PETR then for similar resources or processes studied in other locations.

3.2.3. Components Included in Each Analysis

Per the NPS NRCA guidelines, each individual resource assessment includes the following elements:

Background

This section describes the resource and generally why it was selected for inclusion in the project. This section includes threatened or endangered status if appropriate, biological and ecological descriptions and contexts, relevance to the NPS mission, and relationship to specific park planning and management efforts. If known, threats to the resource or process are included in this section.

Reference Conditions

The measures used to evaluate the condition of the resource are defined here. If no clear science-based measures appear to exist and alternate evaluation methods were utilized, those are also described here. The absence of any valid reference is noted here as well.

Data and Methods

This section can include references to both existing data and methodologies evaluated as well as specific assessment methods incorporated for this NRCA.

Resource Condition and Trend

This section summarizes what is known about the resource in relation to the described reference conditions.

Level of Confidence

In some cases, little is known about the status of the resource, the conditions that should be used to make the assessment, or both. This section evaluates the level of confidence the team had in making the assessment.

Data gaps/Research needs

This section varies in length and scope. In some cases, there are clear recommendations for further research or data that would be needed to have a high confidence in making an assessment. If the team had specific management recommendations to improve the state of the resource those may be included here as well.

Sources of Expertise

Subject matter experts not identified elsewhere are listed here.

References

Each section is followed by a complete reference list. In addition, as part of the final product a database of all references included in the full document was delivered to the NPS.

3.2.4. Project Challenges

In the fall of 2011, the project was suspended due to funding lapses. The funding for the NRCA project in FY 2012 was uncertain, and SCPN did not have the resources to incorporate the NRCA workload. In the summer of 2012 funding for the ecologist position was restored through a cooperative agreement. Also, the cooperator selected to address the geomorphology question was unable to complete the project, so the final analysis was completed by SCPN staff.

3.3. References

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161–174.

Chapter 4. Natural Resource Conditions

4.1. Climate

4.1.1. Background

Climate change is affecting natural resources and processes in national parks across the country at an increasing rate, particularly in the Southwest (Gonzalez 2011, Hansen et al. 2014). Data show that changes in temperature and precipitation are accelerating, and all models predict future increases in the rates of change if CO_2 emissions are not significantly and rapidly reduced (Weaver et al. 2007, Ashfaq et al. 2013, IPCC 2014). National Parks in the southwest may be particularly affected by warming and drying trends (Bingham et al. 2010, Gonzalez et al. 2018), and NPS recognizes that climate change presents an immense challenge for protecting resources (Saunders et al. 2007, NPS 2010, Whittington et al. 2013).

Climate change is a strong force that requires species, populations, and physical processes to respond rapidly to environmental conditions to which they are largely unadapted (Corlett and Westcott 2013), and to protect and preserve resources within this scenario will require immense effort (e.g. van Riper et al. 2014). This report identifies observed and predicted impacts to resource groups from climate change at PETR in general terms only.

Regional Climate – Temperature and Precipitation

The climate of the non-mountainous areas of central New Mexico is affected strongly by the North American monsoon in summer months (July–Sept), and by larger-scale phenomena originating mostly in the Pacific during the remainder of the year (Sheppard et al. 2002, Garfin et al. 2013). In the winter, occasional snowfalls in the Albuquerque area alternate with warmer, drier periods. Conditions in the spring (March–June) are mostly warm and dry with periodic windy periods, and falls are relatively mild and windy.

While storms cause temperatures to decrease temporarily, between storms temperatures in the summer months are generally high (Western Regional Climate Center [WRCC]). Average high temperatures range from over 90°F/32°C in July to less than 50°F/10°C in December and January, while minimum winter temperatures average below freezing (32° F/0°C).The average annual temperature in the Albuquerque region is approximately 51–55°F/10.5–13°C (USACE 2013).

Annual precipitation in Albuquerque is minimal (approx. 8.5 in/22 cm per year), and comes primarily during the monsoon (USACE 2013, Fig 4.1-1). General summaries of Albuquerque weather and climate can be found at www.weather.gov/climate/index.php?wfo=abq and www.usclimatedata.com/climate.php?location=USNM0005.

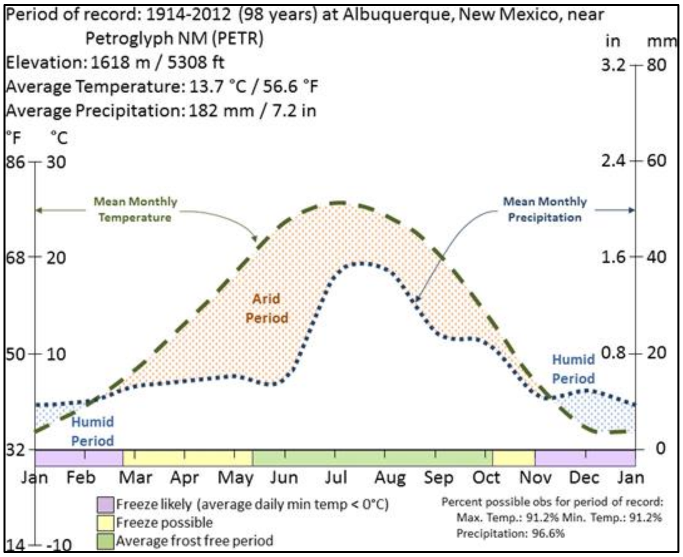

Figure 4.1-1. Average temperatures and precipitation amounts for Albuquerque, adjacent to PETR (from https://www.nps.gov/im/scpn/climate.htm).

4.1.2. Reference Conditions

Given the realities of climate change it is not possible to determine a reference condition for climate at PETR. Climate effects are global, and outside of promoting sustainable park operations NPS resource managers can do little to alter present or future climate effects. Monahan and Fisichelli (2014) compared the extent of change in numerous National Parks to historic conditions, the results of which for PETR are discussed below.

4.1.3. Data and Methods

Climate and weather monitoring for central New Mexico are conducted at multiple spatial scales by many entities. There is a non-automated weather station at PETR (Davey et al. 2006), but more consistent and long-term weather records for the region are available from stations outside the monument, most notably the Albuquerque International Airport (approx. 12 mi/20 km southeast of PETR) where weather data have been collected since the late 1890s (Davey et al. 2006; SCPN: https://www.nps.gov/im/scpn/weather-stations.htm).

A recent and very thorough climate data compilation was produced by the U.S. Army Corps of Engineers for a water needs assessment (USACE 2013). Most recently the BLM completed an analysis with the Department of Transportation (Simmons et al. 2015) that focused on the impacts of climate change on BLM transportation infrastructure but also included a synthesis of the most recent climate change predictions for the central New Mexico region. Long-term climate change predictions have been developed by numerous researchers. An evaluation of climate models and how they are being applied is beyond the scope of this assessment, and details of global (GCM) and regional (RCM) climate models used are available in referenced materials.

4.1.4. Resource Condition and Trend

Temperature

All recent studies indicate that average temperatures in the southwestern U.S. have increased since the onset of the industrial revolution (Hoerling et al. 2013). For central New Mexico, USACE (2013) reported that temperatures in the Upper Rio Grande Valley increased by approximately 0.4°F/0.3°C per decade from 1971 through 2012, and Gonzalez (2015) found that average annual temperatures in PETR have increased by 1.1°F/0.6°C since 1950.

Monahan and Fisichelli (2014) found that for PETR, three temperature variables were “extreme warm” (annual mean temperature, minimum temperature of the coldest month, mean temperature of the warmest quarter) in recent decades in comparison to the period from 1895–2012 and that no temperature variables were “extreme cold.” Summer temperature increases have been statistically significant (FWS 2013, Garfin et al. 2013) while winter and spring increases are apparent but not always significant (FWS 2013, Garfin et al. 2013, Gonzalez 2015).

Nearly all climate models predict that temperatures in the region will continue to increase over the next several decades, particularly during the summer and fall months (Karl et al. 2009, Gutzler and Robbins 2011, IPCC 2014, Simmons et al. 2015, UCS 2016). For PETR, future increases may range from 1.5°F/0.8°C to 5.8°F/3.2°C by 2014–2060 (Fisichelli et al. 2015).

Precipitation

Assessments of precipitation patterns at local scales are much less clear than they are for temperature (USACE 2013, Simmons et al. 2015). For PETR and central New Mexico, Monahan and Fisichelli (2014) found no precipitation variables have in recent decades been either “extreme wet” or “extreme dry” with respect to the period from 1895–2012. Across the entire southwest the period from 2000–2010 was extremely dry in comparison to the prior century (Hoerling et al. 2013), however, this period of drought and reduced precipitation may be the result of naturally-occurring Pacific sea-surface temperature changes rather than anthropogenically-driven atmospheric changes (Hoerling et al. 2013).

Models predict that overall precipitation across the southwestern U.S. will decline over the next several decades from between 3% and 13% under a high emissions scenario (RCP 8.5; IPCC 2014, Simmons et al. 2015). Some models suggest that there may be little change in total annual precipitation but altered seasonal patterns, for example more rain and less snow (Gutzler and Robbins 2011, Garfin et al. 2013, USACE 2013, IPCC 2014). Multi-year droughts as well as periodic high-intensity storm events are both expected to become more frequent and more severe (Karl et al. 2009, Garfin et al. 2013, FWS 2014).

For central New Mexico, storm intensity will likely increase most noticeably during the monsoon period (July–Sept; USACE 2013). Given these conditions and predictions for future climate impacts on their city, in 2019 the City of Albuquerque declared a Climate Emergency in response to climate change (https://www.krwg.org/post/albuquerque-city-council-declares-climate-emergency).

Effects on Natural Resources

All research indicates that there will be changes, sometimes profound, in vegetation community composition and structure resulting from climate change in National Parks (Notaro et al. 2012, King et al. 2013, Whittington et al. 2013). Overall, vegetation cover and species richness are expected to decline (Notaro et al. 2012), though some community types may increase in extent, for example sagebrush communities may benefit under changing climate scenarios (Finch 2012), and most investigators predict that rising temperatures will have variable impacts on vegetation if precipitation patterns change as well (Weiss et al. 2004).

In the Southwest, where water is naturally scarce, declining precipitation as well as changes in seasonal rainfall patterns will likely reduce grassland abundance (Williams and Albertson 2006). Though freshwater resources and associated species in PETR are rare, periodic storms do support some ephemeral stream-associated plant species (Muldavin et al. 2012). For these sites a reduction in average annual rainfall, and disturbed seasonal patterns, will likely result in fewer riparian species (NPS 2010, Garfin et al. 2013, FWS 2013, Friggens et al 2013). Higher temperatures have resulted in an increase in the average growing season (Hoerling et al. 2013) which can translate to disruptions to phenological relationships, for example between pollinators and resources (Friggens et al. 2013, Wright et al. 2015).

Species in the southwest that are already at the southern extent of their distribution will likely experience further range contraction (Friggens et al. 2013, Leach et al. 2015). Overall, specialist taxa are expected to undergo much more substantial range contractions and population declines than are generalist species (Thomas et al. 2006, Schloss et al. 2012). Species whose ranges include areas where temperatures are already near the edge of their thermal tolerance are also expected to be particularly affected by climate change (Quintero and Wiens 2013). Several plant and animal species in PETR, in particular several unique millipede taxa, may persist here largely due to the relatively cool microclimate conditions provided by the basaltic field and could be at risk of extirpation with persistent drier conditions (Medrano 2015).

4.1.5. Level of Confidence

Moderate to High

4.1.6. Data gaps/Research needs/Management recommendations

Extreme weather events driven by climate change will likely have important effects on PETR natural resources. Periods of drought are expected to limit recruitment and/or increase mortality of plant species, potentially leading to less vegetation cover in the monument in coming decades. A decrease in total vegetative cover could facilitate greater runoff during flood events, so a monitoring program with adaptive management recommendations for reducing erosion during extreme weather events should be included in park planning (M. Medrano pers. comm. 2011).

4.1.7. Sources of Expertise

- M. Medrano, Former Chief of Resources, PETR

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4.2. Arroyos

4.2.1. Description

Geologic setting

A primary resource concern at PETR is the impact of accelerated erosion on the landscape overall and the petroglyphs specifically. As described briefly in Chapter 2, PETR is situated within the Rio Grande Rift, a geologic structural feature which has produced extensive volcanic activity over the last 500,000 years. Within the park, a feature known as the escarpment—the eastern edge of an historic lava flow—trends generally north-south and in many places is 20–30 meters high (Kelly 2014), forming what is regionally known as the West Mesa. As the escarpment eroded it broke into large boulders on which many of the petroglyphs were carved, but continuing erosion is now threatening many of these same sites.

Erosional processes and arroyos

Erosion is the result of physical processes typically driven by water (fluvial) or wind (eolian). Erosion rates vary widely dependent on factors such as sediment type, the relative strength of water (fluvial) and wind (eolian) forces, the amount of vegetation present, and downslope topography. Gully formation is an extreme form of stream channel erosion where channels are incised in valley deposits. In semi-arid regions such as the American southwest, gullies are commonly referred to as arroyos (Elliott et al. 1999), and numerous researchers have confirmed past episodes of arroyo incision in the PETR region (Cooke and Reeves 1976; Webb and Hereford 2001). Generally, arroyos change through time from a narrow, V-shaped gully to a wide, U-shaped gully with a higher width-to-depth ratio (Gellis 1992). Arroyo widening decreases stream power which leads to sediment deposition and plant establishment (Hereford 1984, Elliott et al. 1999).

Natural and human influences on erosion in PETR

Climate

The climate of PETR is described in detail in Section 4.2, and is characterized by cool to cold, relatively dry winters, and hot, wet (monsoonal) summers, and it is during the monsoon season that most erosion occurs. Intense summer rainstorms frequently occur as moist air is carried aloft by air currents rising from sun-heated slopes, thus doubling or tripling the average annual precipitation received in the adjacent valley. The summer rains can generate high magnitude runoff events in arroyos flowing to the Rio Grande. One precipitation event in 1991, estimated to have a 50-year recurrence interval, produced 3 inches of rain in 45 minutes. Rainfall during the month of September 2013 was the second greatest recorded since 1895, resulting in extensive gullying at PETR and in the adjacent neighborhood of Santa Fe Village. Increased storm-water flows can move large amounts of debris and degrade water quality.

Land use and urban development

The eastern boundary of the monument has experienced extensive urban development during the past 30 years (Section 4.6). Currently, the monument is bounded to the north and east, and portions of the west and south by housing, commercial businesses and school and sport facilities, while the area north of Piedras Marcadas, Boca Negra Canyon, and Volcano Cliffs is developed and urbanization is advancing westward and southward on top of the escarpment. Numerous paved and unpaved roads exist on the West Mesa, as well as many social and/or undesignated recreational trails (K. Kissner pers. comm. 2017, NPS 2018).

To support the expanding housing developments, highly engineered storm drainage infrastructure was created on the east side of PETR, downstream from all the primary PETR arroyos, to direct floodwaters to the Rio Grande River. In 2013 Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) constructed the Boca Negra Dam on the West Mesa (Albuquerque Metropolitan Arroyo Flood Control Authority 2015). The dam drains into the Boca Negra Arroyo below the escarpment, flowing through PETR. Storm water runoff from the southeast exposure of the peninsula escarpment between Rinconada Canyon to the north and Ladera Arroyo to the south is captured in a retention basin near the south boundary of PETR known as Lava Bluff Pond.

These landscape modifications affect natural flows in and from PETR, increasing flowspeed during storms and interrupting existing flow patterns (S. Monroe pers. comm. 2011). A significant monsoon-driven storm event in 2013 resulted in rainfall amounts of between 4 and 5 inches (approx. 10–12 cm) over a several day period (NWS 2013). The existing storm drain system was insufficient and inadequately maintained to contain the water flowing from the escarpment and other higher elevation areas of the monument, resulting in substantial flooding and damage to homes and adjacent neighborhoods (Bilderback 2013).

4.2.2. Reference Conditions

Erosion is a natural process that has shaped the West Mesa landforms for thousands of years, and the highly erodible sediments are subject to rapid transport during intense rainfall events. However, human activities can significantly exacerbate the rates and severity of erosional processes. It is difficult, therefore, to determine what natural rates of erosion should be in the absence of human interference. As described below, for this assessment historical aerial photos were used to attempt to measure changes in arroyo geomorphology over time and to relate these changes to both natural and human-accelerated erosion processes.

Arroyo Systems in PETR

Several primary arroyo systems drain eastward from the Albuquerque volcanic field across the West Mesa escarpment. These arroyos carry flow across the top of the escarpment then incise through the eastern edge to eventually widen at the base and then flow to the Rio Grande River (Figure 4.2-1). In north to south order these arroyos are:

- **Piedras Marcadas Arroyo**, the furthest north arroyo system in the monument that flows through Piedras Marcadas Canyon.
- Three arroyos drain the top of the escarpment then join to form **La Boca Negra Arroyo**, which flows off the escarpment down through Boca Negra Canyon.
- Three branches of **San Antonio Arroyo** flow separately on top of the escarpment and join below its base in the area north of Marsh Peninsula.
- **Rinconada Arroyo** drains the top of the escarpment, flowing through Rinconada Canyon.

- **Ladera Arroyo** is the southernmost large arroyo system associated with the monument, draining the south end of the escarpment. The **Ladera Training Dike** at the south end of the escarpment "trains" the water to head north and eventually to the Mirehaven Diversion Canal/Ladera Dam sediment basins.
- **Mirehaven Arroyo** is the southernmost arroyo in the monument.

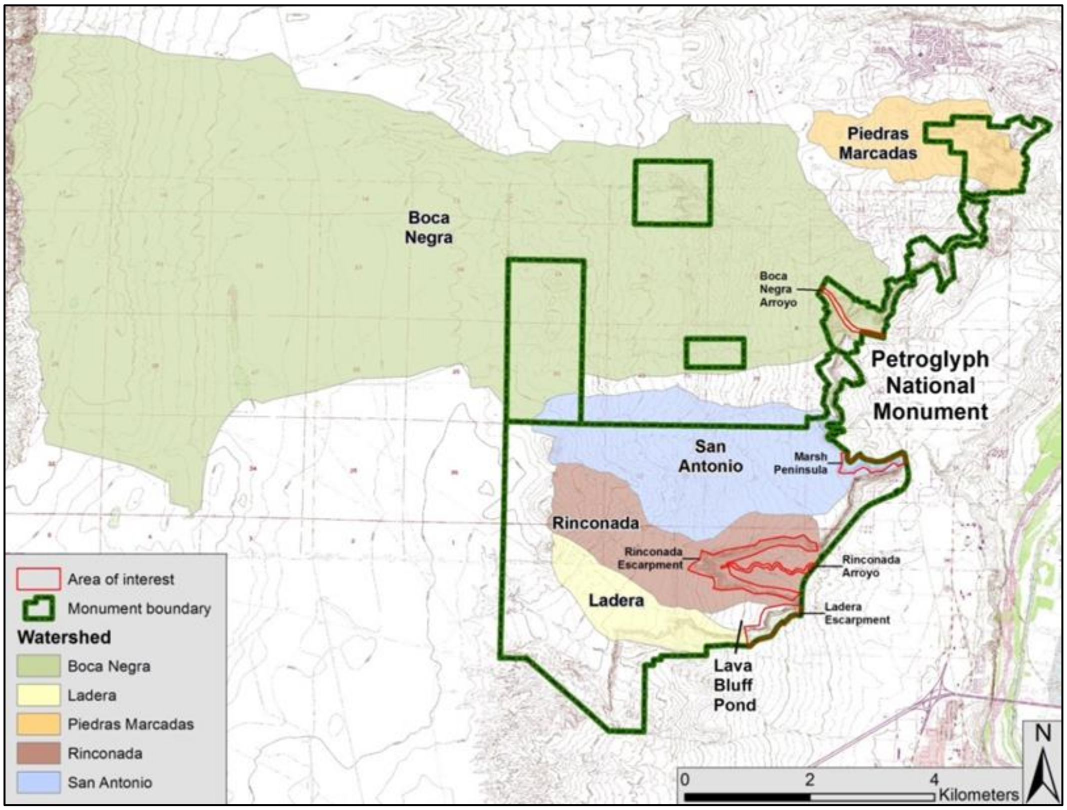

Figure 4.2-1. Main arroyos systems at Petroglyph National Monument, New Mexico. Photo: NPS.

4.2.3. Data and Methods

In 2011 as part of this NRCA, a Cooperative Ecosystems Study Unit (CESU) task agreement was initiated with the Museum of Northern Arizona (MNA) to evaluate the use of historical and recent aerial imagery in assessing temporal arroyo change in the monument. MNA did not complete a final report for the project, however, enough of the work was completed to determine that GIS analysis of the aerial imagery could not provide sufficient precision and consistency to detect change (see Appendix 1 for a detailed project summary). This result was due in part to low pixel resolution of some of the earlier images and to obscuration of features due to sun angle and shadowing effects.

Visual examination of the aerial images, however, did provide a clear pattern of re-vegetation through time at some arroyos and tributaries in PETR in response to the elimination of grazing. Consequently, a second effort associated with this NRCA undertook a quantitative evaluation of arroyo evolution by digitizing portions of un-vegetated channel area on aerial imagery spanning the period 1935 through 2014. Unvegetated arroyo polygons were digitized for a 0.75 mi (1.2 km) section of Rinconada Arroyo and a 0.2 mi (350 m) reach of Ladera Arroyo using 1935, 1959, 2010 and 2014 aerial imagery. The reaches chosen are representative of the low-slope arroyos within the target study area, below the escarpment. The reaches studied were further restricted to those in which the channel is visible in the 1935, 1959, and 2010 photos and which have not been altered by construction (channelized or rerouted). For each reach and time period, the unvegetated channel area was digitized, and the average channel width and area were calculated.

Historic Studies Evaluated

As Albuquerque experienced rapid growth in the early 1990s, several studies were undertaken to examine potential increased erosion and gullying in and near PETR, and all of these were reviewed for this assessment:

- The *San Antonio Corridor Plan – Draft* (Resource Technology Inc. 1988) was prepared for the City of Albuquerque providing a description of existing conditions in the San Antonio watershed including geology, soils, and plants.
- Gellis (1995) identified and qualitatively ranked fifty gullies at PETR based on evidence of geomorphic characteristics (primarily depth, incision and bank erosion). Most of the arroyos included in the study were in the Piedras Marcadas and La Boca Negra Arroyo systems and exhibit a range of erosional characteristics. The concentration of arroyos increased northward in the monument, as did the intensity of erosion. The report suggests that a high density of roads and trails in the northern portion of the monument results in unnaturally high erosion rates in some years.
- Brouillard (2011) and Skrupskis (2000) focused on arroyo development in the Piedras Marcadas watershed. Instrumentation was used to collect climate data, sedimentation rates, and flow data for the area. Aerial photographs were used to evaluate land use changes during the period 1936 to 1996. Similar to Gellis (1995), these reports concluded that increased urbanization and roads have caused increased extent and rates of erosion.

4.2.4. Condition and Trend

Arroyos at PETR appear to be trending generally from a highly eroded state towards a more stable condition, though the pattern is offset by periodic and localized increases in soil loss. Preliminary analysis of historic aerial imagery from the period 1935 through 2010 showed an overall decrease in channel area and increase in vegetation on former channel surfaces in reaches of Rinconada and Ladera arroyos.

The 1935 aerial imagery shows broad unvegetated channels at both Rinconada and Ladera arroyos, however, due to poor resolution it is not possible to determine whether the broad channels are the result of channel incision or deposition of fine sediments. Subsequent aerial imagery shows progressive channel narrowing and vegetation establishment following the model of arroyo evolution defined in Gellis (1992).

Periodic intense precipitation events combined with altered landscapes in some locations oppose this trend. Significant precipitation during September 2013 produced widespread flooding in the Albuquerque region, including extensive erosion and mobilization of fine sediments in the arroyos at

PETR. Aerial imagery obtained in 2014 shows an unvegetated channel pattern at Piedras Marcadas, North Boca Negra, San Antonio, and Rinconada arroyos in PETR similar to that seen in the 1935 aerial imagery. The 2014 aerial imagery does not show this pattern for Ladera Arroyo.

Preliminary analyses indicate aoelian deposition followed by events of fluvial disturbance and erosion are part of the natural cycle. There are locations, however where factors outside of the monument boundary are affecting erosion within the monument, and locations where unsustainable social trail networks are contributing to erosion events (M. Medrano pers. comm. 2011, NPS 2018).

4.2.5. Level of Confidence

Moderate

4.2.6. Data Gaps/Research Needs/Management Recommendations

Systematic methods similar to those adopted by Gellis (1995) should be implemented for qualitative and quantitative monitoring of arroyos at PETR. Monitoring methods should include a standardized protocol that clearly defines arroyo geomorphology and a classification system that includes measurements of channel width, channel depth, degree of channel braiding, sinuosity, channel incision, channel bank erosion, angle of channel bank, vegetation cover, and sediment grain size.

The selection of appropriate monitoring methods depends on project objectives and available resources; a reasonable scale for monitoring all arroyo change should be established at 0.5 meters. Specific research and monitoring needs at various scales include the following:

- Landscape scale (park-wide):
  - Aerial Photogrammetry
  - LiDAR (Laser Imaging, Detection, and Ranging)
- Local scale (< 0.25 mi/0.5 km)
  - Ground-based photogrammetry
  - Photopoints
- Transect scale (arroyo-specific):
  - GPS survey data
  - Total Station survey data

4.2.7. Sources of Expertise

- Mike Medrano, Chief of Resources, PETR (now at Guadalupe Mountains NP)
- John Wood, Geologist, NPS
- Steve Monroe, Hydrologist, Southern Colorado Plateau Network (now retired)

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4.3. Volcanic Features

4.3.1. Description

The distinctive landscape of PETR was created largely by a series of volcanic episodes occurring between approximately 195,000 (± 15,000 yrs) and 131,000 (± 11,000 yrs) ago (Chan et al. 2016, KellerLynn 2017). During this period two major volcanic events created the escarpment, cones, and other features collectively known as the Albuquerque Volcanic Field (AVF; Crumpler 1999, NMBGMR 2006). The geology of the area has been well-studied and described (for example see Baldridge 1979, Olsen et al. 1987, Crumpler 1999, NPS 2006, Lozinsky 2006, and a good general description on the website of the New Mexico Natural History Museum [Geoscience | New Mexico Museum of Natural History & Science (nmnaturalhistory.org)]). Presented below is a brief summary of the processes that created the extant AVF features at PETR (Figure 4.3-1).

Features

The "escarpment" is a large, cliff-like "wall" of basalt, (rock formed by the rapid cooling of lava), and other geologic debris located along the eastern edge of the monument. The escarpment formed after lava flowed downslope toward the Rio Grande River (west to east). Over time the underlying softer materials eroded away, causing the igneous rocks layered above to fall to the base of the terminus of the flow (the wall). Most of the petroglyphs in the monument are found on these varnish-coated basaltic rocks (O'Meara 2007).

The three most prominent volcanic cones (south to north) are JA, Black, and Vulcan, known as the Three Sisters. During the events that led to the creation of the cones, lava was extruded slowly from fissure vents resulting in the cone shapes seen today. There were also explosive events, and extant rocks and formations, particularly at JA cone, which reveal these multiple volcanic processes. Two smaller cones, Bond and Butte, are located north of Vulcan (Kelley 2010).

In addition to the cones and the escarpment, numerous smaller remnants of volcanic and tectonic activity exist in the monument. Deposits of wind-blown materials (ash) are present in many locations, and features are abundant that reflect the interactions of lava with underlying surfaces (lava tubes), gaseous elements and lava (fossilized vesicles) and rocks deposited during eruption events ("bombs"; Crumpler 1999). Geologic "windows" were formed by processes similar to those that formed the escarpment when lava flowed over areas of softer sediment which later eroded away. In addition to their geologic significance, many of the volcanic sites also provide important habitat for several unique plant species and small vertebrate communities (Parmenter and Lightfoot 1996, Bogan et al. 2007).

Status/Threats

Though the cultural relevance and human safety concerns related to the volcanic field are important concerns of park managers (Judge 1973, NPS 2006), this assessment focuses on the current condition of volcanic features as physical natural resources that may be at risk (M. Medrano pers. comm. July 2010).

The majority of volcanic features in PETR are accessible to visitors, and there is a risk to features not only from hiking and other authorized activities, but also from vandalism that can result in damaged and stolen features and rocks (NPS 2006, M. Medrano pers. comm. 2011, NPS 2018). Erosion of volcanic-derived material is a slow process that is occurring, for example rocks on the escarpment can be washed out of the soil or surface layers during heavy precipitation events (M. Medrano pers. comm. 2011). Perhaps of most concern to managers is the lack of a full inventory, including GPS locations, of all features within the monument and the risks to features from the absence of information (M. Medrano pers. comm. 2011).

4.3.2. Reference Conditions

Human-caused damage to any of these sites should be absent. Natural erosional processes should be identified, and monitoring of sites conducted to assure that future physical changes to features are not anthropogenic in origin. Many of the sites also provide habitat, and in particular native plant diversity in these locations should be maintained and human impacts on vegetation prevented.

4.3.3. Data and Methods

Studies of multiple aspects of the Albuquerque Volcanic Field and the Rio Grande Rift have been conducted, including Kudo (1982), Olsen et al. (1987), Peate et al. (1996), Wilson et al. (2005), and Lozinsky (2006). An ongoing dating process for the volcanic materials is further refining existing location information (M. Medrano pers. comm. 2011, Thompson et al. 2020). A geologic resources study was completed in 2017 (KellerLynn 2017, Figure 4.3-1), and a new USGS geologic map of PETR published in 2020 (Thompson et al. 2020; Figure 4.3-2).

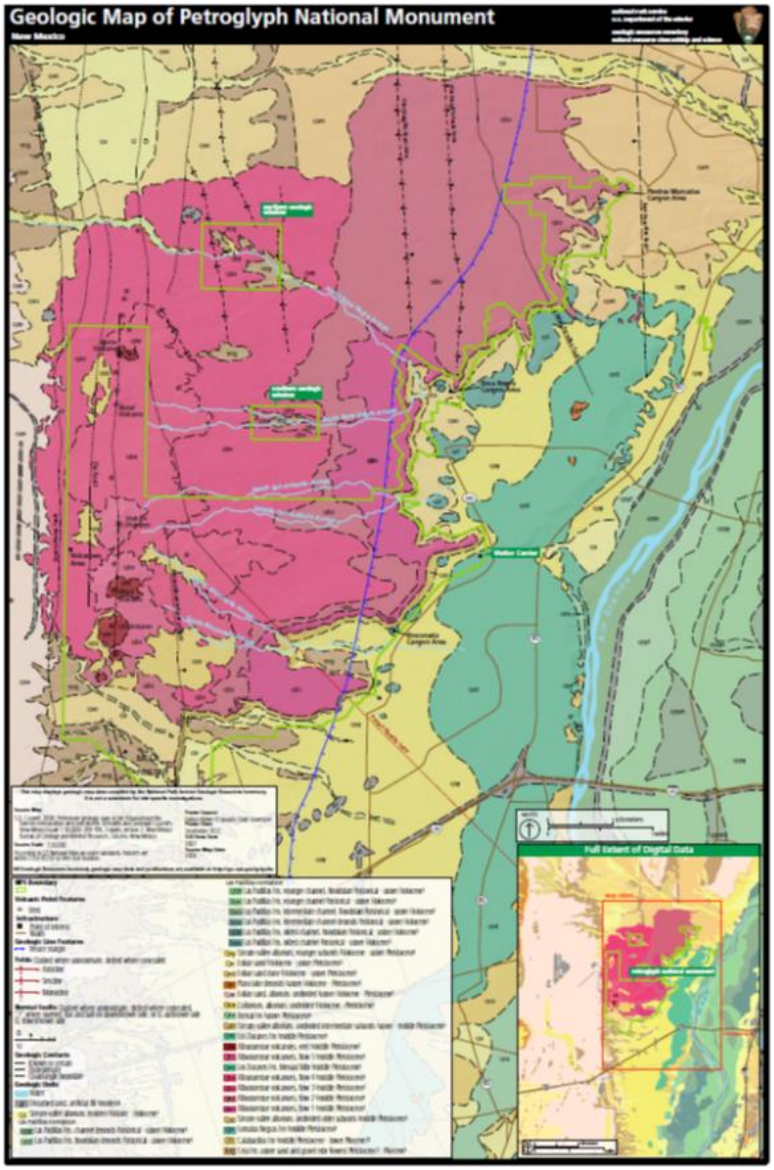

Figure 4.3-1. Geologic map from KellerLynn 2017.

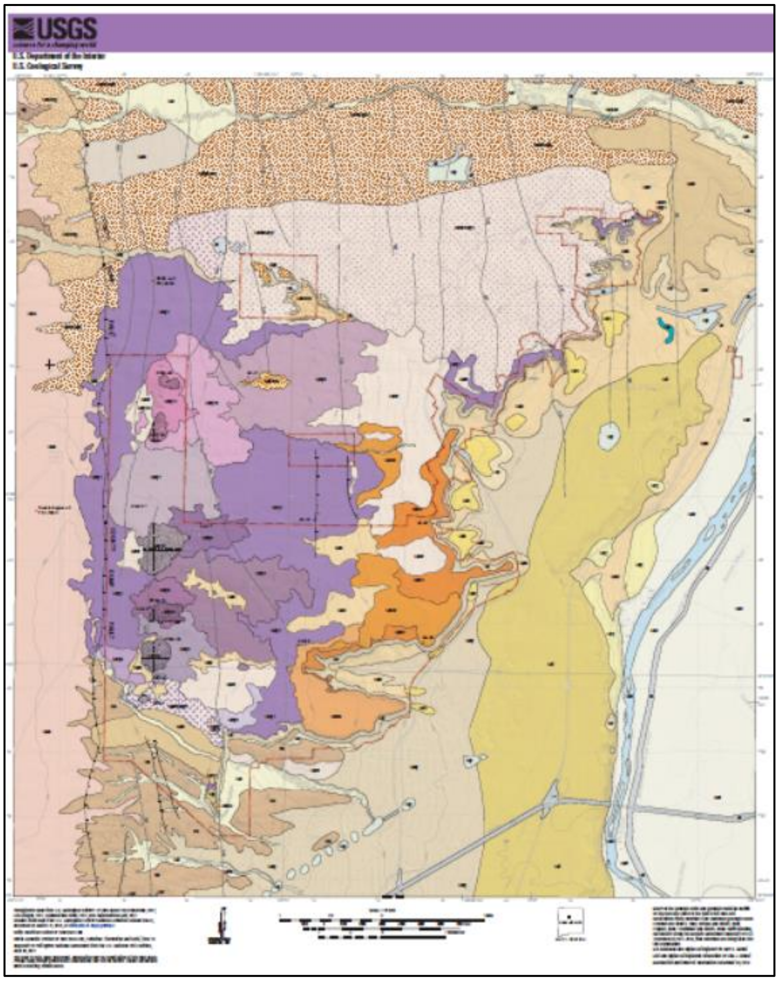

Figure 4.3-2. Geologic map from Thompson et al. 2020.

4.3.4. Condition and Trend

Overall, the condition of the volcanic landscape and integrity of individual features is fair- to good. PETR experienced extreme weather events in July and September 2013 and in July and September 2014, during which the volcanic features on top of the mesa were largely unaffected (M. Medrano pers. comm. 2011). However, significant erosion was observed along the escarpment as a result and questions regarding the degree to which natural erosional processes have been accelerated by human activities has yet to be determined (M. Medrano pers. comm. 2011). Reports of vandalism and unintentional human-caused damage are primarily anecdotal (M. Medrano pers. comm. 2011), but these impacts should decline with the implementation of the preferred alternative presented in the Visitor Use Management Plan (NPS 2018).

4.3.5. Level of Confidence

Nearly all volcanic features in the monument have been surveyed, and in many cases physical condition of the features documented by imagery within the last decade (M. Medrano pers. comm. 2011). However, overall confidence in the current condition of most features is moderate.

4.3.6. Data Gaps/Research Needs/Management Recommendations
Additional surveys of geologic features should be conducted at finer scales than has been done previously to obtain current conditions of individual features. Various maps and sources of information regarding the volcanic landscape are available, but need to be gathered, analyzed and annotated for use by park management. Future climate change impacts may affect features in ways that could be detected with additional data (M. Medrano, pers. comm. 2011). Monument planning should include visitor use management approaches that protect features (i.e., trail locations; NPS 2018).

4.3.7. Sources of Expertise
- Mike Medrano, Former Chief of Resources, PETR
- Tim Connors, Geologist, NPS Geological Resources Division

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4.4. Native Grasslands

4.4.1. Description

Temperate grasslands of the southwest United States range from the warm-temperate semi-desert grasslands of the Chihuahuan Desert to the south, with hot summer and mild winters, extending northward into the more cold-temperate grasslands of the Southern Great Plains and Colorado Plateau/Great Basin with milder summers and cold winters (Brown et al. 1982). As a whole they are characterized by moderate amounts of rainfall (250–400 mm) with strong differences in seasonal temperatures, and long dry seasons. Historically, these grassland have been grazed by large ungulates and burrowing mammals such as prairie dogs (*Cynomys* sp.) and kangaroo rats (*Dipodomys* sp.; Ford et al. 2004). On the whole these grasslands, when in good condition, support a high diversity of vertebrate species including grassland birds, rodents, rabbits, and carnivores (Askins et al. 2007, Macías-Duarte and Panjabi 2013, Steidl et al. 2013, Seamster et al. 2014), many of which are imperiled from land use and type conversion (Comer et al. 2018).

Since PETR lies at the juncture of the three major biogeographic regions—the Colorado Plateau/Great Basin, Southern Great Plains, and Chihuahuan Desert—the grasslands reflect a complex mosaic of plant associations representative of each of the regions (Frey and Yates 1996, Robbie 2004, Griffith et al. 2006, Muldavin et al. 2012). There are three major grassland types within PETR identified at the macrogroup level of the U.S. National Vegetation Classification (FGDC 2008; Table 4.4-1 and described below). For more detailed descriptions see Weiss et al. (2004), Robbie (2004) and Muldavin et al. (2012). In addition, full descriptions of macrogroups can be found at USNVC.org. The distribution of the grassland types in PETR as mapped by Muldavin et al. (2012) are shown in Figure 4.4-1.

Table 4.4-1. Grassland vegetation macrogroups and groups in PETR with association map units from Muldavin et al. 2012.

Grassland Type	Macrogroup and Group	Cumulative Area in PETR (ha/ ac)
Chihuahuan Semi-Desert Grassland (Map units: 8A, 8B, 8C, 8D, 8E, 8F)	Chihuahuan Sandy Plains Semi-Desert Grassland Chihuahuan Semi-Desert Foothill Grassland Chihuahuan Semi-Desert Grassland	759.5/ 1876.8
Great Basin & Intermountain Dry Shrubland & Grassland (Map units: 7A, 7B, 7C)	Intermountain Semi-Desert Grassland	911/ 2251.1
Great Plains Shortgrass Prairie & Shrubland (Map units: 6A, 6B, 6C)	Great Plains Shortgrass Prairie	550.8/ 1360.9

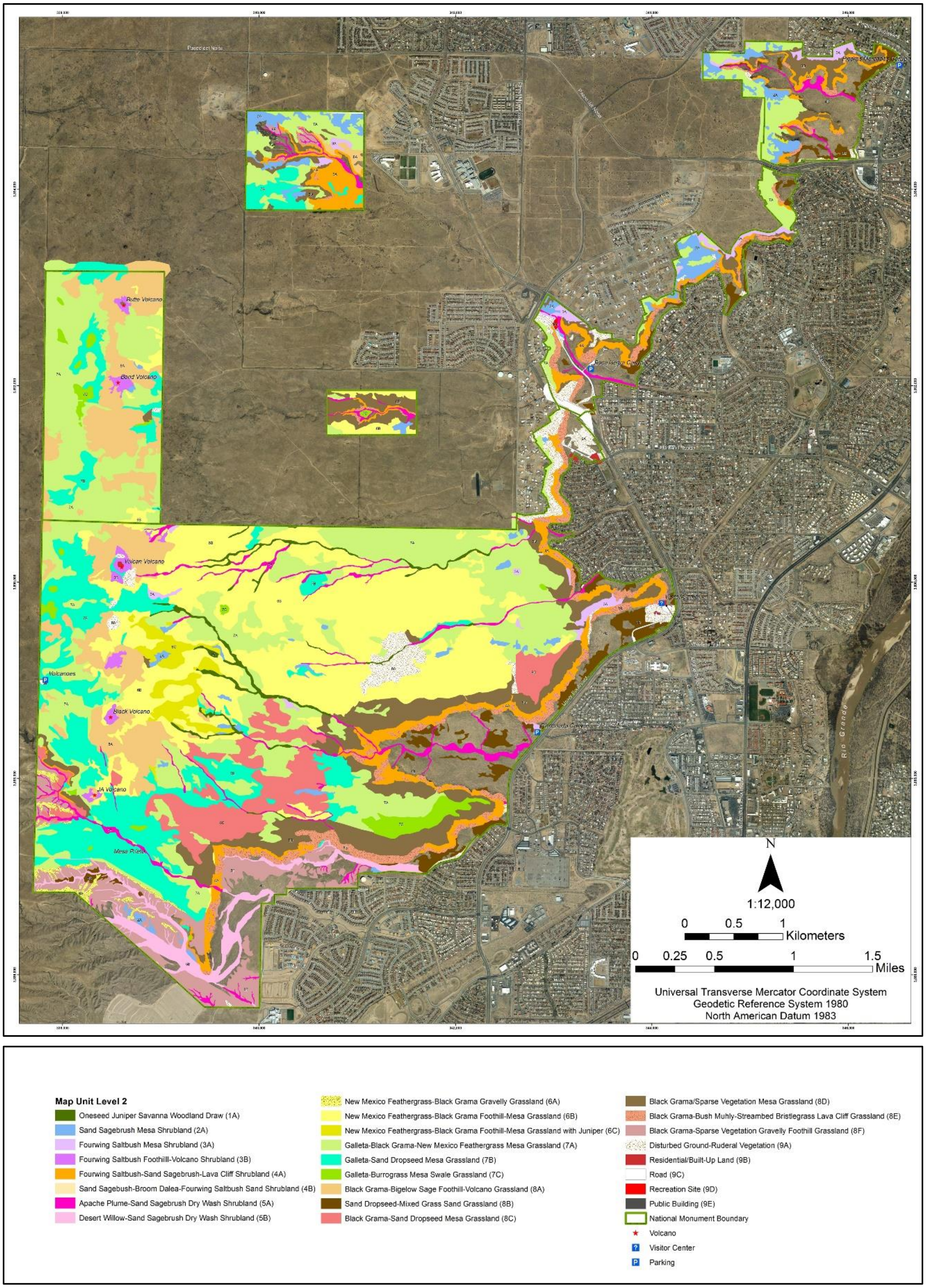

Figure 4.4-1. PETR Level II vegetation map showing the distribution of the major vegetation types in the park (from Muldavin et al. 2012).

Chihuahuan Semi-desert Grasslands

This group includes seven associations dominated by black grama (*Bouteloua eriopoda*), bush muhly (*Muhlenbergia porteri*), dropseed (*Sporobolus cryptandrus),* and *S. flexuosus*. Most of these grassland types are in the open rolling plains of the central-southern area of PETR but they can extend up onto the slopes of volcanic cinder cones to the west and down the basalt boulder strewn escarpment slopes to the east (Figure 4.4-2). As with most semi-desert grasslands, shrubs and subshrubs are common and integral elements of these communities (e.g., Mormon teas (*Ephedra torreyana*), yuccas (*Yucca baileyi*), and snakeweed (*Gutierrezia sarothrae*)). Collectively, these grasslands represent an important occurrence of the type at the northern edge of their range (Muldavin et al. 2012).

Figure 4.4-2. Chihuahuan Semi-desert grasslands dominated by black grama on the lava plains of PETR. Photo: E Muldavin.

Great Basin and Intermountain Dry Shrublands and Grasslands

Great Basin/Intermountain grasslands are found across the Colorado Plateau and Four Corners region, from southwestern and south-central Colorado to southern Utah and into Arizona and New Mexico (Brown et al. 1982, Weiss et al. 2004). In PETR, there are five associations in this macrogroup, all dominated by James' galleta (*Pleuraphis jamesii*), often in association with the cool season (C3) New Mexico needlegrass (*Hesperostipa neomexicana*) and various warm-season (C4) grasses. Shrubs are common and can include four-wing saltbush (*Atriplex canescens*), sandsage (*Artemisia filifolia*), broom snakeweed (*Gutierrezia sarothrae*), and prickly pears *(Opuntia* *phaeacantha*). These communities are distributed primarily on gently sloping terrains of lava flows 2, 3, and 4 along the western front of the volcanoes, on lava flows overlain with alluvium, colluvium, or a fine veneer sands in the southern mesa area, and along the low rim of the mesa to the north (Muldavin et al. 2012; Figure 4.4-3).

Figure 4.4-3. Great Basin and Intermountain grasslands are common in in PETR and dominated by James's galleta. Photo: E. Muldavin.

Great Plains Shortgrass Prairie

Great Plains grasslands cover much of the central U.S. and northern Mexico including northwestern Texas and southern Colorado through southwestern New Mexico (Weiss et al. 2004). In PETR, two associations are found, with mostly rocky to gravelly soils on the eastern slopes of the volcanoes, and extend eastward and downslope to the mid-mesa area. The sites are mostly dominated by New Mexico feathergrass but have transitional elements to desert grasslands with dropseeds (Muldavin et al. 2012; Figure 4.4-4).

Figure 4.4-4. Great Plains Shortgrass Prairie grasslands in PETR are extensive and are primarily a mix New Mexico needlegrass and dropseeds. Photo: E. Muldavin.

<u>Ecology</u>

Many studies in arid lands have demonstrated the strong relationship between climate and herbaceous species productivity, and specifically the critical roles of pulsed rainfall and favorable temperatures in promoting plant growth (Williams and Albertson 2006, Collins et al. 2010, Hamerlynck et al. 2012, Throop et al. 2012, Baez et al. 2013, Moran et al. 2014). Seasonal monsoon precipitation (June–September) in the American southwest is positively correlated with grassland productivity not only in the same year but in following years (Weiss et al. 2004, Muldavin et al. 2008; Reichmann et al. 2013). Higher levels of soil organic matter (though naturally low in arid systems) are also correlated with higher soil moisture and greater vegetative cover in southwest grasslands (Finch and Tainter 1995, Gremer et al. 2015).

Research has also examined the role of herbivores, specifically seed-eaters, in regulating desert plant communities (Davidson and Lightfoot 2006). The results have been equivocal; some work has shown little regulation by rodents and much greater response by plants to precipitation (Baez et al. 2006) while other research indicates that rodent communities have a strong impact on arid land vegetation (Brown and Heske 1990). Prairie dogs have important roles as structural engineers in many grasslands (Ryerson and Parmenter 2001, Davidson and Lightfoot 2006, Ceballos et al. 2010), though it is unclear whether prairie dogs ever were abundant in the PETR area; they are currently absent as far as is known. Invertebrates also have sometimes critical roles in grasslands at multiple trophic levels (e.g. as prey, seed dispersers, and consumers; Whitford et al. 1995, Collinge 2000). And there are almost no sites in the southwestern US where the current distribution and composition of grasslands is detached from past and/or current grazing practices (Van Auken 2000, Yanoff and Muldavin 2008).

While fire was likely important, the historic role of fire in New Mexican grasslands is not entirely clear; fire return intervals prior to grazing may have been on the order of 5–30 years (McPherson 1997, NPS 2005, Muldavin et al. 2012), and rainfall patterns following wildfires may have had strong effects on grassland response to fire (Drewa et al. 2006, Drewa and Haystad 2001).

Regional Conservation Value

Petroglyph National Monument is the northern node of an unofficial network of southwestern grassland reserves, extending through Sevilleta National Wildlife Refuge, White Sands Missile Range, Fort Bliss, Guadalupe Mountains National Park and Big Bend National Park (Muldavin et al. 2012). Despite the long history of the intensive livestock grazing of the 19th century and ongoing grazing until park establishment in 1990, the grasslands are in exceptional condition with respect to canopy cover and diversity, and shrub encroachment has been limited (Muldavin et al. 2012). Grasslands dominated by cool-season grasses such as New Mexico feathergrass (*Hesperostipa neomexicana*) that occur in the northern portion of PETR are considered vulnerable at a global scale, meaning they are at moderate risk of extinction due to small population and/or limited range factors, and grazing pressure as the first species to green up in the spring (NatureServe). While these grasslands occur sporadically to the south in the reserves listed above, the largest protected stands likely occur in PETR, and there are no known protected populations in the Great Plains region.

Similarly, black gramma (*Bouteloua eriopoda*)-dominated grasslands are considered vulnerable in the Southwest and Mexico due to intensive grazing pressure over the last 400 years (Muldavin et al. 2012; Comer et al. 2018). Though grazing was likely common and intensive prior to PETR establishment, the large stands of black gramma grasslands in the southern portion of PETR represent a major occurrence at the northern extent of these Chihuahuan Semi-Desert Grasslands that is presently protected from grazing and recovering (Muldavin et al. 2012).

Threats

Desert grasslands across the Southwest are threatened by multiple factors including drought, grazing, invasive plant species, and climate change (Finch and Tainter 1995, Muldavin et al. 2012; Comer et al. 2018). At present the greatest threats to PETR grasslands appear to be erosion, climate change, fragmentation, and declining native vertebrate diversity (Merola-Zwartjes 2004, M. Medrano pers. comm. 2011). High and often uncontrolled visitor use is having multiple impacts on vegetation, including off-trail activity across monument grasslands (NPS 2018). Shrub encroachment is minimal and invasive plants are not common and do not appear to compete with native species, though Russian thistle (*Salsola tragus*) can be abundant in certain years in the monument (M. Medrano pers. comm. 2015).

Reduced rainfall, as is predicted by nearly all climate change models (Section 4.2) will likely have profound impacts on desert grasslands (Williams and Albertson 2006). Reduced precipitation and lower soil moisture are predicted to accelerate encroachment by woody species (Throop et al. 2012, Baez et al. 2013). Nitrogen deposition may increase abundance of some species over others, particularly favoring blue grama (*Bouteloua gracilis*) in Chihuahuan desert grasslands (Baez et al. 2007). Grazing impacts in many desert landscapes have converted native grasslands to shrublands via soil disturbance and removal of native herbivores (Frey and Yates 1996), though this is not currently a direct threat in PETR.

4.4.2. Reference Conditions

It is difficult to determine natural (pre-settlement) conditions for southwestern grasslands given the long period of impacts and change (Fletcher and Robbie 2004). Determining conditions for an area like PETR where several grassland types occur in relatively small and patchy locations is particularly difficult. Minimally, plant species diversity and community structure should be preserved, while dominant native species should persist. Invasive plant species should be absent.

Soil characteristics such as moisture, nutrient levels and organic matter should (ideally) be within parameters that stabilize soils and promote plant establishment and growth. Functioning grasslands should be ecologically supportive of a range of native animal species including birds, rodents, insects, and grazers.

4.4.3. Data and Methods

Very few data are available from grassland studies or monitoring at PETR. SCPN has established upland monitoring plots (DeCoster and Swan 2009), but monitoring began only recently and changes in plant diversity, if any are occurring, are as yet undetermined. As far as is known there is no current monitoring of vertebrates or invertebrates in the grassland areas of the monument, nor is there soil monitoring.

4.4.4. Condition and Trend

Though data are scarce, in general PETR grasslands appear to be in "exceptional condition with respect to canopy cover and diversity" (Muldavin et al. 2012). Shrub encroachment is minimal, and invasive species for the most part have not established (DeCoster and Swan 2009, M. Medrano pers. comm. 2011), though there are reports of scattered Russian thistle (*Salsola* spp.) and cheatgrass (*Bromus tectorum*) extant within the monument (C. Walter pers. comm. 2/2021). Muldavin et al. (2012) found grass cover averaged 30% but in some areas was as high as 60%. Plant species richness is high, and there is little evidence of lasting effects of past grazing (Muldavin et al. 2012). Little else is known regarding current ecological condition of the grasslands, particularly with regard to the absence of fires in present-day systems (see Chapter 2).

Future change resulting from climate shifts in desert grasslands is largely dependent on changes in soil moisture conditions, a somewhat complicated dynamic responsive to both annual and seasonal variability (Gremer et al. 2015, Munson and Long 2017). Long-term drought will certainly reduce productivity in grasslands (Williams and Albertson 2006, Peters et al. 2012, Gremer et al. 2015), but impacts may be patchy across the region if local seasonal storm events increase in frequency and/or intensity (Bodner and Robles 2017). Fragmentation of grasslands in the southwest will likely continue to increase, and PETR may provide an important protected area for grassland ecosystems in the region (Muldavin et al. 2012).

4.4.5. Level of Confidence

Moderate

4.4.6. Data Gaps/Research Needs

Monitoring of grasslands, including faunal components as well as soil properties, should be continued and expanded, including the addition of new plot locations that are planned within the SCPN vegetation monitoring program for PETR.

Implementation of the preferred alternative in the proposed Visitor Use Management Plan (NPS 2018) would improve protection of monument grasslands.

4.4.7. Sources of Expertise

- Jim DeCoster, Former Botanist, NPS Southern Colorado Plateau Network

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4.5. Non-avian Vertebrates

4.5.1. Description

Desert environments of the southwestern U.S. support a high diversity of native vertebrate species (Parmenter et al. 1995). However, urban encroachment, climate change, the loss of native carnivores and other impacts are likely reducing available habitat for many native vertebrates in the urban environs of greater Albuquerque (Parmenter and Lightfoot 1996, McDonald et al. 2018; Section 4.7). This assessment addresses resident species (home ranges entirely or largely within PETR) and those for which PETR provides only a portion of required resources (transients). There are no known federally endangered or threatened non-avian vertebrate species in PETR, and only one that is State listed (spotted bat; *Euderma maculatum*).

<u>Amphibians and Reptiles</u>

Reptiles are uniquely adapted to desert conditions (Cloudsley-Thompson 1991), and the diversity of reptiles in PETR is high (Table 4.5-1). Several toads have been documented from PETR, mostly from ephemeral pools (Figure 4.5-1). Predicted drought conditions in coming years will likely reduce the availability of these habitats for amphibians (Friggens et al. 2013).

Figure 4.5-1. Mexican spadefoot toad, *Spea multiplicata*. (https://www.nps.gov/media/photo/view.htm%3Fid%3D8AB62F0E-155D-451F-67F9268283D29CC3).

Table 4.5-1. Amphibians and reptiles present or potentially present in PETR. X = confirmed; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Nowak and Persons 2008, and Griffith 2020.

Category	Species	Common Name	Parmenter & Lightfoot (1996)	Persons & Nowak (2008)	NPSpecies	Notes
Amphibians	*Spea multiplicata*	Mexican spadefoot toad	–	X	X	–
	Bufo woodhousii	Woodhouse's toad	X	–	PP	–
	Scaphiopus multiplicatus	Southern spadefoot toad	X	–	–	–
	S. couchii	Couch's spadefoot	X	–	PP	–
	Spea bombifrons	Plains spadefoot	X	–	PP	–
	Bufo cognatus	Great Plains toad	X	–	U	–
	B. punctatus	Red-spotted toad	U	–	U	–
	Ambystoma tigrinum	Tiger salamander	X	–	U	–
Reptiles (Snakes)	*Arizona elegans* [a]	Glossy snake	X	X	X	–
	Diadophis punctatus [a]	Ring-necked snake	–	X	X	1st record from PETR by Persons and Nowak (2008)
	Heterodon nasicus [a]	Western hog-nosed snake	X	X	X	probably common throughout the monument
	Hypsiglena torquata	Nightsnake	–	–	X	museum voucher only but probably common
	H. jani texana [a]	Texas nightsnake	–	–	–	–
	Masticophis flagellum [a]	Coachwhip	X	X	X	common
	M. taeniatus [a]	Striped whipsnake	X	X	X	probably common
	Pituophis catenifer [a]	Bullsnake (gopher snake)	X	X	X	–
	Rhinocheilus lecontei [a]	Long-nosed snake	X	X	X	–
	Salvadora grahamiae [a]	Mountain patch-nosed snake	–	–	–	–
	Tantilla nigriceps	Plains black-headed snake	X	X	X	–
	Crotalus atrox [a]	Western diamondback	X	X	X	frequently observed outside of grasslands

[a] Griffith 2020 (Sandia Laboratories 2019).

Table 4.5-1 (continued). Amphibians and reptiles present or potentially present in PETR. X = confirmed; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Nowak and Persons 2008, and Griffith 2020.

Category	Species	Common Name	Parmenter & Lightfoot (1996)	Persons & Nowak (2008)	NPSpecies	Notes
Reptiles (Snakes) (continued)	*C. viridis* [a]	Prairie/western rattlesnake	X	X	X	–
	Sistrurus catenatus [a]	Massasauga	X	X	X	–
	Gyalopion canum [a]	Chihauhuan hook-nosed snake	U	–	PP	probably occurs
	Lampropeltis getula	Common kingsnake	–	–	PP	probably occurs
	Coluber constrictor	Racer	X	–	U	–
	Lampropeltis triangulum	Milksnake	–	–	U	possibly occurs
	Thamnophis spp.	Garter snakes (black-necked, western, checkered, common)	X	–	U	–
Reptiles (Lizards)	*Crotaphytus collaris* [a]	Collared lizard	X	X	X	–
	Gambelia wislizenii	Long-nosed leopard lizard	X	X	X	common in Rinconada Cyn
	Leptotyphlops dulcis	Texas slender blind snake	–	–	X	dead specimen collected by M. Medrano
	Holbrookia maculate [a]	Common (lesser) earless lizard	X	X	X	uncommon; volcanoes area only
	Phrynosoma hernandesi [a]	Greater short-horned lizard	X	X	X	–
	P. modestum [a]	Round-tailed horned lizard	X	X	X	–
	Sceloporus undulatus [a]	Fence lizard	X	X	X	common
	Uta stansburiana [a]	Side-blotched lizard	X	X	X	most abundant lizard found (Nowak and Person 2008)
	Eumeces obsoletus [a]	Great Plains skink	X	X	X	–
	Cnemidophorus [Aspidoscelis] inornatus [a]	Little striped whiptail	–	X	X	grasslands

[a] Griffith 2020 (Sandia Laboratories 2019).

Table 4.5-1 (continued). Amphibians and reptiles present or potentially present in PETR. X = confirmed; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Nowak and Persons 2008, and Griffith 2020.

Category	Species	Common Name	Parmenter & Lightfoot (1996)	Persons & Nowak (2008)	NPSpecies	Notes
Reptiles (Lizards) (continued)	*C. neomexicanus* [a]	New Mexican whiptail	X	X	X	grasslands
	C. exsanguis [a]	Chihuahuan spotted whiptail	U	–	U	–
	C. uniparens	Desert grassland whiptail	U	–	–	–
	C. inornatus	Little striped whiptail	U	–	–	–
	C. velox	Plateau striped whiptail	U	–	–	–
	C. tesselatus	Checkered whiptail	U	–	–	–
	C. tigris	Western whiptail	U	–	–	–
	C. exsanguis	Chihuahuan spotted whiptail	U	–	–	–
	Terrapene ornata	Western box turtle	X	–	X	several records
	Urosaurus ornatus	Tree lizard	–	–	U	probably absent

[a] Griffith 2020 (Sandia Laboratories 2019).

<u>Mammals</u>

Lagomorphs (Rabbits and Hares)

Rabbits are generally smaller than hares, practice an escape strategy of hiding rather than running, and live mostly in burrows while hares use vegetation as protection. The name “jackrabbit” is a misnomer, and a typical hopping animal with strong back legs and big ears seen in PETR would almost certainly be a hare. Both groups are in the genus *Lepus*.

Rabbits and hares (“rabbits”) are voracious herbivores, and though cliche most species can breed nearly continuously in warm weather when resources are sufficient. This strategy allows rapid recovery from disturbance for the rabbits and a sustained and important prey resource for predators (Delibes-Mateos et al. 2007, Hernandez et al. 2011). When predators are absent from a system, rabbit populations may increase dramatically, though the importance of predators in limiting rabbits appears dependent on other environmental inputs (Newsome et al. 1989, Figure 4.5-2).

Two species of lagomorphs are common in the monument and one additional species may be present but has not been confirmed (Table 4.5-2). One species of hare in New Mexico, the white-tailed jackrabbit (*Lepus townsendii*), is State listed as threatened but does not occur in PETR. Other than this species lagomorphs have no legal protection in New Mexico and can be hunted and controlled by landowners without limits.

Figure 4.5-2. Jackrabbits can become extremely abundant, particularly in the absence of predators when preferred vegetation is abundant (https://www.nps.gov/bibe/learn/nature/what-animal.htm).

Table 4.5-2. Mammals present or potentially present in PETR. X = present; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Bogan et al. 2007, and Griffith 2020.

Category	Species	Common Name	Parmenter & Lightfoot (1996) [a]	Bogan et al. (2007)	NPSpecies	Notes
Insectivores	*Notiosorex crawfordi*	Desert shrew	U	PP	PP	locally rare but wide distribution;
	Sorex merriami	Merriam's shrew	–	U	–	–
	Sorex nanus	Dwarf shrew	–	U	–	–
Bats	*Myotis ciliolabrum*	Western small-footed bat	–	X (present)	X	–
	Lasionycteris noctivagans	Silver-haired bat	X	X	X	–
	Eptesicus fuscus	Big brown bat	–	X	X	–
	Tadarida brasiliensis	Brazilian free-tailed bat	–	X	X	–
	Nyctinomops macrotis	Big free-tailed bat	–	X	X	–
	Lasionycteris noctivagans	Silver-haired	–	–	X	–
	Myotis californicus	California myotis	–	PP	PP	–
	M. evotis	Long-eared myotis	–	–	PP	–
	M. lucifugus	Little brown bat	–	PP	PP	–
	M. thysanodes	Fringed myotis	–	PP	PP	–
	M. Volans	Long-legged	–	–	PP	–
	M. yumanensis	Yuma myotis	–	PP	PP	–
	M. ciliolabrum	Small-footed myotis	–	–	X	–
	M. velifer	Cave myotis	X	–	–	–
	Pipistrellus hesperus	Western pipistrelle	–	PP	PP	–
	Lasiurus cinereus	Hoary bat	–	PP	PP	–
	Euderma maculatum	Spotted bat	–	PP	PP	New Mexico Threatened
	Corynorhinus townsendii	Townsend's big-eared bat	–	PP	PP	–

[a] Parmenter and Lightfoot (1996) did not conduct mistnetting or acoustical surveys for bats.

Table 4.5-2 (continued). Mammals present or potentially present in PETR. X = present; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Bogan et al. 2007, and Griffith 2020.

Category	**Species**	**Common Name**	**Parmenter & Lightfoot (1996) [a]**	**Bogan et al. (2007)**	**NPSpecies**	**Notes**
Bats (continued)	*Antrozous pallidus*	Pallid bat	–	PP	PP	–
Rodents	*Ammospermophilus leucurus*	White-tailed antelope squirrel	–	X	X	common
	Chaetodipus hispidus	Hispid pocket mouse	–	U	–	–
	C. intermedius	Rock pocket mouse	–	X	X	–
	Dipodomys ordi	Ord's kangaroo rat	X	X	X	common, scrubland
	D. merriami	Merriam's k-rat	–	X	PP	scrubland
	D. spectabilis	Banner-tailed k-rat	X	X	X	scrubland
	Erithizon dorsatum	Porcupine	–	X	X	–
	Mus musculus	House mouse	X	X	X	–
	Neotoma albigula	White-throated woodrat	X	X	X	common
	N. micropus	Southern plains woodrat	X	X	X	grassland
	Onychomys leucogaster	Northern grasshopper mouse	X	X	X	scrubland
	Perognathus flavus	Silky pocket mouse	X	X	X	common, scrubland
	P. flavescens	Plains pocket mouse	X	X	X	scrubland
	Peromyscus eremicus	Cactus mouse	X	X	X	very common
	P. leucopus	White-footed mouse	X	X	X	–
	P. maniculatus	Deer mouse	X	X	X	common
	P. nasutus	Rock mouse	X (*P. difficilis*)	PP	PP	–
	P. truei	Pinon mouse	X	X	X	–

[a] Parmenter and Lightfoot (1996) did not conduct mistnetting or acoustical surveys for bats.

Table 4.5-2 (continued). Mammals present or potentially present in PETR. X = present; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Bogan et al. 2007, and Griffith 2020.

Category	Species	Common Name	Parmenter & Lightfoot (1996) [a]	Bogan et al. (2007)	NPSpecies	Notes
Rodents (continued)	*P. boylii*	Brush mouse	X	U	–	–
	Reithrodontomys megalotis	Western harvest mouse	X	X	X	–
	R. montanus	Plains harvest mouse	X	X	X	grassland
	Spermophilus spilosoma	Spotted ground squirrel	X	X	X	–
	Spermophilus [Osteospermopholus] variagatus	Rock squirrel	X	X	X	–
	Thomomys bottae	Botta's pocket gopher	X	X	X	Grassland, scrubland
	Cynomys gunnisoni	Gunnison's prairie dog	–	U	–	unlikely
	C. ludovicianus	Black-tailed prairie dog	–	U	–	greatly reduced across N.A.; proposed for FWS listing but determined not warranted; grassland;
	Neotamias dorsalis	Cliff chipmunk	–	U	–	–
	Onychomys torridus	Southern grasshopper mouse	–	U	–	–
	O. leucogaster	Northern grasshopper mouse	–	–	X	–
Rabbits and Hares	*Sylvilagus auduboni*	Desert cottontail	X	X	X	scrubland
	Lepus californicus	Black-tailed jackrabbit	X	X	X	–
	Sylvilagus floridanus	Eastern cottontail	–	PP	PP	–

[a] Parmenter and Lightfoot (1996) did not conduct mistnetting or acoustical surveys for bats.

Table 4.5-2 (continued). Mammals present or potentially present in PETR. X = present; PP = probably present; U = unconfirmed but possibly present. Compiled from multiple sources including Parmenter and Lightfoot 1996, Bogan et al. 2007, and Griffith 2020.

Category	Species	Common Name	Parmenter & Lightfoot (1996) [a]	Bogan et al. (2007)	NPSpecies	Notes
Carnivores	*Taxidea taxus*	Badger	X	X	X	–
	Urocyon cinereoargenteus	Gray fox	–	X	X	–
	Canis latrans	Coyote	X	X	X	–
	Ursus americanus	Black bear	–	X	–	transient
	Lynx rufus	Bobcat	–	X	X	transient
	Spilogale gracilis	Western spotted skunk	–	PP	X	scrubland
	Mephitis	Striped skunk	X	–	X	–
	Procyon lotor	Raccoon	–	U	–	–
	Vulpes macrotis	Kit fox	–	U	–	–
	Vulpes	Red fox	–	U	–	–
	Puma concolor	Mountain lion	–	U	–	transient; record from around 2000.

[a] Parmenter and Lightfoot (1996) did not conduct mistnetting or acoustical surveys for bats.

Rodents

Rodents are one of the most diverse groups of mammals, especially in xeric environments (Kotler and Brown 1988). Rodents have critical functional roles as seed predators and dispersers in shrub and grassland environments and serve as prey for numerous terrestrial and aerial predators (Crawley 2000). Rodent species diversity if often high in desert systems, and rodents are particularly adapted in many cases to harsh desert conditions (Price and Brown 1983; Figure 4.5-3).

Results from Parmenter and Lightfoot (1996) and Bogan et al. (2007) indicate that there are likely 20–25 rodent species present in PETR. Shrews are difficult to survey and generally found in more mesic habitats (Frey and Yates 1996). No shrews have been documented from PETR, though desert shrews may be present (Table 4.5-2). Prairie dog populations occasionally colonize areas just outside the monument boundary but have not been documented within the monument, and it is not known whether prairie dogs were historically present in what is now PETR (M. Medrano pers. comm. 2011). If prairie dogs were historically included in the PETR ecosystem, their absence, given the importance of the species in structuring grassland environments, has likely resulted in a system altered from historic conditions (Rickel 2005).

Figure 4.5-3. Ord’s kangaroo rat, *Dipodomys ordi* (www.nps.gov/whsa/learn/nature/kangaroo-rats.htm).

Bats

Bats in the southwestern US are primarily insect feeders, so the near-absence of standing water in PETR likely reduces food resources for bats here (Johnson et al. 2008). However, bats may be utilizing monument habitats for roosting while foraging in nearby urban areas (where flying insect abundance is greater due to human water sources and anthropogenic light (Duchamp et al. 2004), and along the Rio Grande River (Lintott et al. 2015, Tye and Geluso 2019). For example, bats are often observed foraging under streetlamps just outside of the boundary of the monument, and there are abundant sources of water in the residences along the monument boundary (M. Medrano pers. comm. 2011).

Carnivores

Carnivores in PETR are primarily mid-size, transient species (Table 4.5-2). The presence of free-ranging domestic cats and dogs in the monument, some of which are likely feral, is a serious threat to native small carnivore populations such as foxes and raccoons (Vanak and Gompper 2010) as well as native prey populations (Doherty et al. 2015). Coyotes are common, and may in fact be more abundant, though not as healthy, than they would otherwise be due to the abundance of available urban resources (Murray et al. 2015). Coyotes may also be limiting numbers of dogs and cats (M. Medrano). If climate change impacts in the region include reduced rainfall and continued drought, indirect impacts on carnivores may be transmitted through declining vegetation resources for prey (Windberg et al. 1997).

4.5.2. Reference Conditions

Because several thorough vertebrate surveys have been conducted at PETR (e.g. Parmenter and Lightfoot 1996 and Bogan et al. 2007), the current list of native species is likely complete; Tables 4.5-1 and 4.5-2 include all documented and potential vertebrate species present in the monument (Bogan et al. 2007; M. Medrano pers. comm. 2011). The reference conditions for diversity, then, is that all previously documented native species remain extant within the monument and that non-native species be absent.

Almost nothing is known regarding the demographics of any species or trends in population numbers and no references can be established for population condition.

4.5.3. Data and Methods

In 1994–1995, Parmenter et al. (1996) conducted a survey of the biological resources of PETR that included mammals and herptiles (amphibians and reptiles) but not bats; the methods utilized are described in that report. Parmenter and Lightfoot (1996) compiled a total species list of 26 non-volant (non-flying) mammals including domestic dogs and cats (identified in Table 4.5-2). In 2001 Nowak and Persons (2008) surveyed PETR for herptiles as part of the SCPN amphibian and reptile inventory. Their methods are described in their report, and they accumulated a total of 25 species (identified in Table 4.5-1). From 2001–2003 Bogan et al. (2007) incorporated random as well as targeted field searches and trapping to survey for mammals and recorded ten species (identified in Table 4.5-2), but had little success documenting the presence of bats. As far as is known there have been no subsequent surveys, monitoring efforts, or research for non-bird vertebrates at PETR since the early 2000s (M. Medrano pers. comm. 2011).

The only known recent vertebrate surveys in the region are conducted by the Department of Energy at Sandia Laboratories located just to the southeast of Albuquerque as part of their annual environmental site reports, most recently in 2019 (Griffith 2020). The entire Sandia complex is much larger than PETR (51,559 acres) and includes a greater diversity of ecotypes, however, their results may provide some information regarding vertebrate diversity in grassland and shrub areas similar to PETR habitats. For example, two sites sampled for reptiles in 2019 (they found no amphibians) are described as “grassland with sparse dwarf shrub” and “large shrub grassland” (Griffith 2020; vegetation descriptions and sampling methods are provided therein). Medium and large-sized mammals are sampled using camera traps, most of which are in vegetation types not found in PETR (Griffith 2020).

4.5.4. Resource Condition

Overall vertebrate diversity in PETR appears high, though as far as is known there have been no surveys or vertebrate studies within the monument for almost two decades. Continued urbanization around the monument is almost certainly resulting in direct and indirect impacts to wildlife from habitat loss, domestic animals, and human behaviors such as the use of rodenticides (Serieys et al. 2015, Elliott et al. 2016).

Amphibians and Reptiles

Predicted drought conditions resulting from climate change in coming years will likely reduce the availability of aquatic habitats for amphibians (Friggens et al. 2013), and amphibians in general will respond more negatively to climate shifts in desert environments than will reptiles (Griffis-Kyle et al. 2018, Mims et al. 2020). As far as is known, reptile diversity is high and there are at present no identified threats to this group overall.

Mammals

Native species diversity for rodents was found to be high in previous studies, but there are no recent data that indicate whether this condition has changed. Nothing is known regarding current population status of any native rodent species. Non-native house mice (*Mus musculus*) have been present in the visitor center building in the monument for at least ten years, and non-native Norway rats (*Rattus norvegicus*) were observed in the visitor center in January 2017 but only for a two-week period. Aggressive trapping in the building and exterior exclusion work resulted in the removal of the rats, and mice are currently kept under control by monument maintenance staff (D. Kissner pers. comm. 2017). Lagomorph mortality increased in 2020 due to rabbit hemorrhagic disease (C. Walter pers. comm. 2/2021); population-level impacts from disease-related mortality on rabbit species within the monument from this outbreak are unknown.

The proximity of natural open space, human development (Duchamp et al. 2004), and the Rio Grande River likely facilitates high species diversity for bats in the Albuquerque region. Roosting and foraging sites for bats are often quite distant, thus many species may utilize PETR resources as well as areas outside the monument on a daily basis. The presence of white-nose syndrome (WNS), a fatal disease in bats cause by fungal presence, is a concern for bat species across the country but has not yet been detected in central New Mexico. Almost nothing is known regarding habitat use, species diversity, or population trends for bats in PETR.

The ecological status of carnivores in the region has been highly altered by human land use for over a century. The largest species are absent, and mid-size species, particularly coyotes, are on one hand increasing in response to human resources in some areas and hunted severely in others. Very little is known regarding mid-size mammal use of PETR; increased management of visitors with dogs should decrease impacts from dog behavior and feces on native species (M. Medrano pers. comm. 2011).

4.5.5. Level of Confidence

Moderate to high for diversity, Low for population information for any species.

4.5.6. Data Gaps/Research Needs

Additional information on vertebrates in PETR is needed (M. Medrano pers. comm. 2011). Surveying and monitoring for vertebrates is time-consuming but should be attempted, for example Bogan et al. (2007) suggested that parks prioritize monitoring of vertebrate species and groups, perhaps for rare species or in threatened habitats. In PETR shrews and bats have historically been under-sampled (Frey and Yates 1996, Bogan et al. 2007). Alternatives to trapping (the most time-consuming though effective survey method), include camera trapping, which has proven successful even for small species such as rodents (Perkins-Taylor and Frey 2020).

Research addressing the potential and/or present impacts of climate change and urbanization on native vertebrate species should be encouraged.

4.5.7. Sources of Expertise

- M. Medrano, Former Chief of Resources, PETR

4.5.8. Literature Cited

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4.6. Ecosystem Integrity (Habitat Connectivity, Dark Night Skies, and Natural Quiet)

4.6.1. Description

The ways in which lands surrounding national parks are utilized can have substantial impacts on natural resources and ecological processes (Fahrig and Merriam 1994, Hansen and DeFries 2007, Wade and Theobald 2010, Rudnick et al. 2012, Hansen et al. 2014). PETR has experienced intense land development in surrounding areas since it was established, perhaps as much or more than almost any other NPS site (Dickinson 2012).

Multiple aspects of human presence—noise, light, roads, air and water pollution—individually and collectively degrade the ability of ecosystems to function naturally. Though NPS generally has relatively little control over land use activities outside monument boundaries, identifying potential impacts can assist with resource management goals and support NPS positions and interactions with adjacent communities and partners (Rudnick et al. 2012).

Habitat Connectivity

The presence of roads and land conversion in and near natural areas are the primary contributors to habitat fragmentation (Spencer and Port 1988, Andrews 1990, Trombulak and Frissell 2000, Rudnick et al. 2012, Dietz et al. 2013, Riley et al. 2014, Adhikari and Hansen 2018). The loss of natural landscapes to housing presents perhaps the greatest threat to existing protected natural areas (Radeloff et al. 2010). Impacts to diversity and ecosystems are not limited to direct habitat loss but also include indirect impacts such as disruptions of hydrologic processes as discussed in Section 4.3 (Bar-Massada et al. 2014).

Roads and associated vehicle traffic affect ecosystem integrity through direct impacts (animal mortality), and indirectly via increased noise, the introduction of toxic materials and non-native plants, reductions in genetic diversity (Delaney et al. 2010), and multiple impacts from human disturbance on animal behavior (Mader 1984, Tyser and Worley 1992, Benitez-Lopez et al. 2010, Dietz et al. 2013, Kitzes and Merenlender 2014). Though much work has demonstrated the effects of roads on wide-ranging large mammals, populations of small vertebrates (e.g. rodents and lizards) and birds can also be strongly affected by the presence of roads and urbanized landscapes (Brehme et al. 2013, Munguia-Vega et al. 2013, Unfried et al. 2013).

Dark Night Skies

The importance of maintaining dark night skies has become a priority issue in national parks, and increasing attention is being paid by NPS and others to measuring as well as minimizing the impacts of anthropomorphic sources of light (Henderson et al. 1985, Schelz and Richman 2003, NPS 2006, Duriscoe et al. 2007). Anthropogenically-derived light comes directly from all sources powered by electricity and batteries as well as indirectly from human-sourced light reflected back from the atmosphere (polarized light; Horvath et al. 2009). “Light pollution” is fundamentally a cultural concept and refers to the over-abundance of artificial light in human landscapes (“lightscape”; Rogers and Sovick 2001, Sovick 2001, Moore et al. 2013) and is often measured and discussed within the NPS as part of the visitor experience (Moore 2001, Longcore and Rich 2004, Smith and Hallo 2013).

Less often addressed are the ecological impacts of artificial light (ecological light pollution) during diurnal dark periods. Artificial light at night can have considerably different impacts on wildlife and ecological processes than it does on humans (Longcore and Rich 2004, Rich and Longcore 2005, Horvath et al. 2009). Evolutionarily the moon provided the only source of light at night, and organisms adapted their biology and behaviors to the light patterns of lunar cycles (Duriscoe et al. 2007). Consequently, the dark night sky is considered the natural condition to which biotic components of ecosystems have evolved.

Research has examined the impacts of artificial night light on many groups of organisms, including plant populations (Lewanzik and Voight 2014); insects (Geffen et al. 2014, Perkin et al. 2014); birds (songbirds, owls, shorebirds, seabirds (Kempenaers et al. 2010, Rodriguez et al. 2012); amphibians (Perry et al. 2008); rodents, bats (Stone et al. 2009); snakes, marine organisms, and primates (Le Tallec et al. 2013; see Gaston et al. 2013 and Davies et al. 2014 for reviews). For example, the presence of artificial light at night can result in increased predation, reduced productivity, direct mortality, and reduced time for nocturnal foraging (Longcore and Rich 2004, Duriscoe et al. 2007). Cumulatively these impacts can affect population dynamics, successional processes and biodiversity (Kyba and Hölker 2013, Gaston et al. 2013, Lewanzik and Voigt 2014).

Natural Quiet

Soundscapes are often defined as the total amount of ambient noise in an area measured in terms of frequency and amplitude (decibels; Ambrose and Burson 2004). Because national parks are often (perhaps wistfully) considered “islands” of quiet (Lynch et al. 2011, Miller 2008), the NPS has been working for several decades to establish baseline conditions and develop measuring and monitoring methods for soundscapes in national parks (Miller et al. 2008). Similar to the topic of light pollution, however, soundscapes have primarily been addressed as a cultural resource in relation to visitor experiences (Rogers and Sovick 2001, Sovick 2001, Miller 2008, Lynch et al. 2011) with relatively less attention being given to ecological and landscape-scale impacts (Barber et al. 2011).

Soundscape ecology is an emerging field that attempts to connect ecological processes with human and natural sounds at landscape scales (Dumyahn and Pijanowski 2011, Pijanowski et al. 2011, Traux and Barrett 2011). When evaluated ecologically, the impacts of anthropogenic sounds are usually considered in terms of effects on wildlife. For example studies have demonstrated the negative impacts of noise on songbirds (Slabbekoorn and Ripmeester 2008, Francis et al. 2011), bats (Schaub et al. 2008), rodents (Shier et al. 2012), frogs (Barber et al. 2010, Bee and Swanson 2007), and invertebrates (Morley et al. 2014). Prey species are particularly sensitive to human noise because it both mimics predator sounds and masks it (Landon et al. 2003, Chan et al. 2010, Brown et al. 2012).

Road noise appears to have measurable negative impacts on wildlife, altering animal behavior, movement patterns, ability to find prey (Siemers and Schaub 2011) and breeding processes (Reijnen and Foppen 2006, Bee and Swanson 2007, Barber et al. 2011). Some species are able to adapt to long-term additions of noise in their environment but others are not (Barber et al. 2010), and impacts at individual and population scales can further translate up to ecosystem and process levels (Slabbekoorn and Halfwerk 2009).

4.6.2. Reference Conditions

Habitat Connectivity and Quality

This assessment focuses on habitat connectivity and quality for non-avian vertebrates and bats; assessment of habitat quality for birds is beyond the scope of this effort.

Because measures of ecosystem and habitat integrity are species and process specific, there are no common reference conditions for all resources of interest in PETR (Piekielek and Hansen 2012, Rudnick et al. 2012). Ideally there would be no negative impacts (direct or indirect) on natural resources from outside land uses. The diversity of all small and medium-sized mammals would persist, indicating the absence of habitat fragmentation impacts at this scale. Population dynamics of species that move in and out of the monument would be maintained, indicating the absence of barriers to travel and genetic exchange. However, there is a nearly overwhelming absence of studies and data available to define these parameters for PETR species.

Dark Night Skies

Levels of artificial light should have no measurable impacts on animal behavior or physiology. NPS directives have recommended a ratio of average anthropogenic sky luminance to natural conditions (ALR) be the primary measure for evaluating night sky conditions, though they stress that other metrics such as vertical and horizontal illuminance and impacts to species of concern should be considered for specific purposes (Moore et al. 2013).

Natural Quiet

The NPS measures noise conditions in relation to human health (NPS 2013). For example, 35 decibels (dBA) or less is recommended for sleeping, while 60 dBA would interrupt normal conversation (described in NPS 2013). Clearly these values may or may not have relevance to wildlife behavior and biology (Barber et al. 2011).

4.6.3. Data and Methods

A targeted noise assessment study was conducted at PETR in 2010 (NPS 2013, Rapoza and MacDonald 2014). The methods are described in detail therein, and results showed that at two sites, human sounds were heard over 50% of the time and aircraft noise was common. However, as mentioned these measures are in relation to human hearing, and there are no published studies or monitoring efforts relating to wildlife impacts from human noise. As far as is known no night sky or habitat connectivity assessments have been completed for PETR.

4.6.4. Condition and Trend

Petroglyph National Monument is located within the City of Albuquerque and the urban area is rapidly expanding around the monument. . In the mid-2000s, petroglyph rocks were moved for construction of Paseo del Norte, a road built through original monument lands. An airport, Double Eagle II, is on the west side of the monument. Ongoing development of neighborhoods to the north, south, and east sides of PETR is occurring. Monument staff report that there are few to any places or times in the monument when helicopters or low-flying aircraft are not present and audible (M. Medrano pers. comm. 2011, Rapoza and MacDonald 2014), and airport operations are authorized for expansion in the future so noise impacts are likely to increase (http://documents.cabq.gov/planning/;

accessed 11/2020). Development to the southeast of the monument, including a new Amazon distribution facility near I-40 and Atrisco Vista Boulevard, will likely increase traffic on Atrisco Vista Boulevard and contribute to noise and potential impacts to wildlife. On unincorporated Bernalillo County land to the southeast of the monument, the Upper Petroglyphs Sector Development Plan (approved in 2019), would allow for a mixed-use community with residential, neighborhood commercial centers, roadways, trails, and open space opportunities.

The night sky is strongly impacted by the City of Albuquerque; however, there are opportunities to experience dark night sky events at the volcanoes and other sites (M. Medrano pers. comm. 2011). Vegetation communities inside the monument are generally in good condition (Section 4.5), but in most cases are disconnected, at least for larger species, at many points surrounding the monument. Nothing is known regarding the effects of night sky illumination, anthropogenic noise, or habitat connectivity on wildlife habitat in PETR.

Overall, the condition of PETR in terms of habitat integrity and connectivity is low. Many areas of the monument support in-tact though small ecosystems that support relatively high plant diversity, and communities of small mammals are likely representative of unimpacted communities in similar environments, but medium and large animal species are almost certainly affected by habitat loss and impacts from reduced connectivity. Several monument sites are in various stages of ecological recovery, while others are impacted to variable degrees by human impacts, particularly off-trail use (M. Medrano pers. comm. 2011, NPS 2018). Unfortunately, at least one study predicts that if the City of Albuquerque continues to allow the patterns of growth seen to date, PETR will be nearly surrounded by urbanized land use within a few decades (Hester 2006).

4.6.5. Level of Confidence
Moderate for dark night skies and natural quiet; moderate for habitat quality for small mammals and reptiles; low for habitat connectivity and quality for medium and large mammals.

4.6.6. Data Gaps/Research Needs
A robust ecological monitoring program will be implemented with the completion of the Visitor Use Management Plan (2019; M. Medrano pers. comm. 2011, NPS 2018).

Existing development proposals for the region include habitat corridors and such efforts should be encouraged. Also, the City of Albuquerque has added open space adjacent to portions of PETR that serve as a buffer to the monument. Boundary expansion would be beneficial in these areas to support additional and long-term protection of the area’s natural resources.

The need for soundscape monitoring was identified in the Visitor Use Management Plan and should be implemented when possible (C. Walter pers. comm. 2/2021).

4.6.7. Sources of Expertise
- Mike Medrano, Former Chief of Resources, PETR

4.6.8. Literature Cited

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Chapter 5. Discussion

5.1. Summary

Petroglyph National Monument was designated to preserve the West Mesa Escarpment and Las Imagines Archaeological District (where the majority of the over 20,000 petroglyphs are located) along with other significant cultural and natural resources. As identified in the monument's Foundation Document (NPS 2017), the purpose of PETR is to protect and promote the understanding of petroglyphs in context with the cultural and natural features of Albuquerque's West Mesa (Escarpment) and perpetuate the heritage of traditional communities connected to these landscapes. The monument includes a rich biological resource as well as unique geologic features. The monument's geologic formations (e.g., volcanoes, escarpment) are significant to the ethnographic landscape, along with traditionally significant plants and animals, caves, and naturally occurring expansive viewsheds—all contributing to the sacredness of this place.

As discussed in Chapter 3, PETR natural resources and processes of concern were selected with reference to and then organized within the ecological framework described by Fancy et al. (2009; Table 5.1). One of the purposes of utilizing an ecological organizing framework is to determine the breadth of ecosystem components across which targeted resources occur. For example if all of the assessed resources fall within the scope of Biological Integrity, such an assessment would be neglecting several components of the target ecosystem (Noss 1999).

Table 5.1 indicates that at least two resource topics were included in each ecosystem component category except water, which is appropriate for a small park with limited standing or perennial flowing water present (For this discussion we included the assessment of arroyos within the geologic and soils component.). The following discussion includes a general summary of data used and data gaps, an assessment of overall condition, and future concerns for each of the resource topics.

Table 5.1. PETR topics addressed in the NRCA organized within the ecological monitoring framework.

Element	Topics Addressed in the NRCA
Geology and Soils	Geomorphic Processes/Soil Movement/Arroyo Dynamics Volcanic Resources
Water	–
Biological Integrity	Vertebrate Communities Native Grasslands
Ecosystem Pattern and Process	Habitat Connectivity Dark Night Skies Natural Quiet

5.2. Geology and Soils

Though external development has altered the natural hydrologic conditions and resulted in periodic extreme erosional events (Section 4.3), at present erosion in arroyos subject to flash flooding appears to be closer to natural conditions as vegetation communities recover from grazing and increase soil retention. There is a fair amount of information on erosion of the arroyos, largely as a result of the efforts described in this report, though it should be noted that this work was completed prior to the 2013 flood event. Because high-intensity storms may become more frequent in response to climate change (Section 4.2), soil loss will continue to be of concern, and continued monitoring of arroyos and erosional processes within PETR using techniques similar to those described in Appendix 1 is needed. Volcanic resources are generally not at risk, though damage to specific sites from vandalism or accident is possible. Volcanic and geologic resources in PETR are fairly well surveyed but ongoing monitoring is needed.

5.3. Ecologic Integrity

Biological resources are rich but increasingly detached from and affected by surrounding landscapes and urbanization. Native grasslands are generally of high quality, though effects of climate change may impact diversity and favor more xeric and possibly exotic species. Vegetation monitoring provides good information on grassland integrity in terms of plant diversity and distribution though additional sampling would be beneficial.

There is a near absence of information on most other biological resources including vertebrates and invertebrates. Vertebrate diversity appears high, though almost nothing is known about changes that may be occurring to any vertebrate groups (e.g. rodents, reptiles, meso-carnivores). Bird diversity appears high but is being affected by human-associated species. And though anecdotal, some observers suggest that native species diversity may be declining (M. Medrano pers. comm 2011). Virtually nothing is known regarding population dynamics of any vertebrate species, and additional information on the faunal resources of the monument is needed. Threats to biological resources include climate change, indirect effects of visitation (dogs, off-trail activities), and continued development adjacent to monument lands.

Human pressures from outside the monument (urbanization and development) as well as inside (insufficient resources for visitor use management) are the greatest threats to monument resources. Information and empirical studies on direct and indirect impacts to monument resources from development adjacent to monument lands is generally lacking. Opportunities to experience natural quiet and dark night skies in the monument are declining.

5.4. Literature Cited

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161–174.

National Park Service (NPS). 2017. Foundation Document, Petroglyph National Monument, New Mexico.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355–364.

Appendix 1: Evaluating Remote Sensing Techniques for Detecting Arroyo Change and Erosion at Petroglyph National Monument

Section A. Project Description

Summary

As part of the Petroglyph National Monument NRCA, the National Park Service initiated a task agreement with the Museum of Northern Arizona (MNA) to evaluate the use of historical and modern aerial imagery for assessing geomorphological changes in monument arroyos over time. A draft report was submitted by MNA to the Southern Colorado Plateau Network (SCPN) in the spring of 2013, however a final report was never completed. The following summary is based on the draft MNA report, spatial data collected during the project, NPS review comments on the draft report, and additional GIS analysis undertaken by SCPN staff.

The goal of the project was to assess the suitability of a time series of aerial imagery for the creation of high-resolution (<1m/pixel) digital elevation models (DEMs) at six sites: North Boca Negra Arroyo, Marsh Peninsula, Rinconada Arroyo, the Rinconada Escarpment, a portion of the Ladera Escarpment including Lava Bluff Pond, and Ladera Arroyo (Fig. A-1). If this effort proved successful, the resulting DEMs would be utilized to quantify changes in arroyo geomorphology (In general, changes in width and/or depth of arroyos between images are assumed to result from erosional processes, i.e. widening due to soil transport; Antevs 1952.). Management of these areas to prevent further erosion and efforts to enhance vegetation sites would be supported by a better understanding of arroyo formation and recovery processes (Malde and Scott 1977, Lagasse et al. 1985).

However, after evaluation, MNA determined that it would not be possible to create high-resolution DEMs from the available imagery. A second effort to conduct a two-dimensional analysis using a combination of GPS and GIS methods to measure and analyze arroyo cross-sections at specific sites also proved problematic, so SCPN staff conducted a separate GIS analysis to calculate and compare unvegetated areas across photo intervals, as an increase in vegetation over time would indicate declining rates of soil transport. This approach was somewhat successful and provided coarse scale information regarding changes in arroyo geomorphology at sites where imagery was suitable, but was limited by the quality and resolution of the imagery and by where channels were visible and had not been altered by human activities in a period between photos.

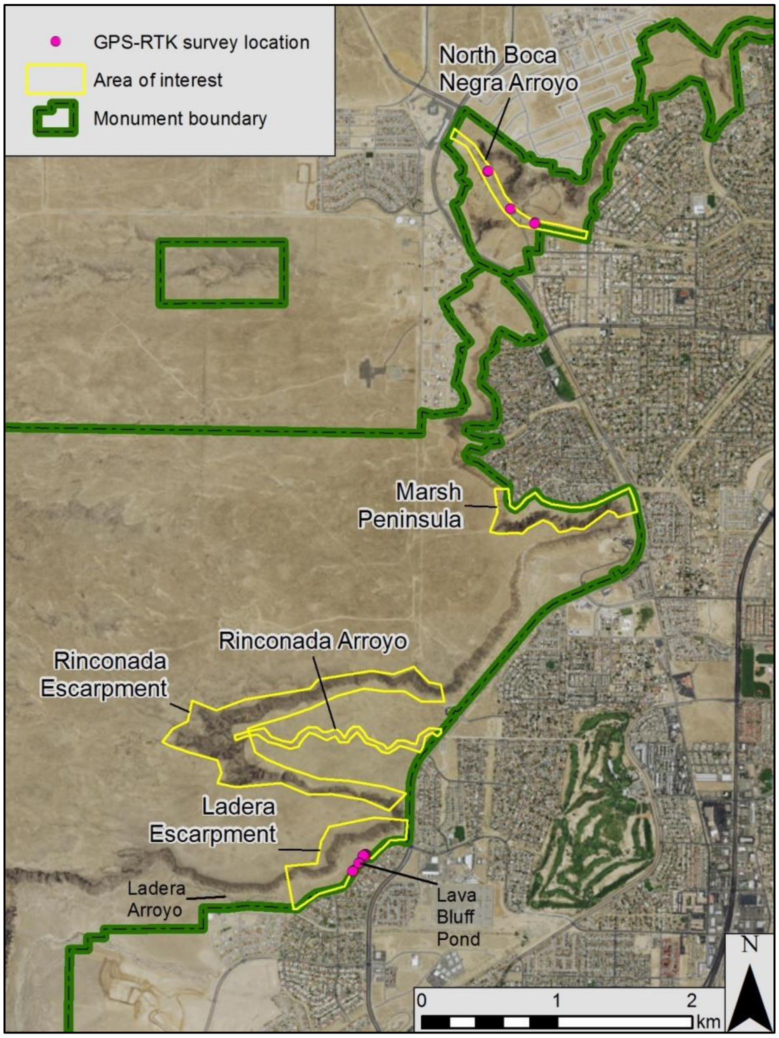


Figure A-1. Site location map produced by Museum of Northern Arizona.

Methods

Aerial Imagery Evaluation for DEM Creation

Twenty sets of georeferenced aerial imagery from 1935 to 2010 were evaluated to determine suitability for creating DEMs (Table A-1). The datasets were evaluated for image quality, pixel resolution, and arroyo visibility. The evaluation was conducted in ArcGIS 10.1 to verify georeferencing and pixel resolution.

Table A-1. Imagery datasets used for analysis.

Year	Cell size (ft)	Cell size (m)	Data Type	Format	Spatial Reference
1935	4.09	1.24	Black and white	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1945	12.44	3.78	Black and white	IMG	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1949	10.88	3.31	Black and white	BMP	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1951	3.55	1.08	Black and white	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1959	2.76	0.84	Black and white	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1963	5.84	1.78	Black and white	IMG	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1967	3.71	1.13	Black and white	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1973	3.12	0.95	Black and white	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1975	11.37	3.46	Black and white	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1982	17.36	5.28	Infrared	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1986	17.47	5.31	Infrared	IMG, TIFF	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1990	8.08	2.46	Black and white	IMG	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
1996	1.24	0.38	True color – DOQQ	BIP	Undefined (but assigned NAD_1983_UTM_Zone_13N (Meter) [a]
1999	1.00	0.30	True color	MrSID	NAD_1983_UTM_Zone_13N (Meter)
2004	1.00	0.30	True color	MrSID	NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet
2006	0.50	0.15	True color	ECW	NAD_1983_HARN_StatePlane_New_Mexico_Central_FIPS_3002_Feet
2008	0.50	0.15	True color	MrSID	NAD83(HARN) / New Mexico Central (ftUS)
2010	0.50	0.15	True color	MrSID	NAD83[HARN]/New Mexico Central [ftUS]
2012	0.50	0.15	True color	TIFF	NAD_1983_HARN_UTM_Zone_13N
2014	0.50	0.15	True Color	MrSID	NAD 1983 StatePlane New Mexico Central FIPS 3002 Feet

[a] The only dataset that was not georeferenced.

Field-based RTK-GPS data collection

A site visit to PETR was made in May of 2012 by MNA to collect ground reference data for existing arroyo cross-sections and to assess the feasibility of monitoring arroyo change remotely using orthoimagery. Arroyo location data were collected using real time kinematic (RTK) global positioning system (GPS) survey methods at North Boca Negra Arroyo and Lava Bluff Pond using a Topcon GR3 RTK-GPS system.

The RTK-GPS base station occupied a temporary ground control point (GCP) at each site for a minimum of two hours while the rover antenna collected the cross-section GPS data. Coordinate point data were collected at three cross-sections along the North Boca Negra Arroyo and at six cross-sections at Lava Bluff Pond. At North Boca Negra the top of a stake placed near the surveyed cross sections was used as the GCP, and at Lava Bluff Pond a nail in the road was used as the GCP. Topographic data were collected at points where there was a change in slope of the cross-section.

The RTK-GPS data were differentially corrected against the closest CORS stations by the National Geodetic Survey (NGS), and the rover GPS data positions corrected from the GCP data. Details showing the CORS stations used to differentially correct each GCP are shown in Table A-2.

Table A-2. RTK-GPS control point distance from CORS station and overall RMS error.

RTK Control Point Site	CORS Stations	Distance from CORS Station (km)	OVERALL RMS (m)
North Boca Negra Arroyo	ALBUQUERQUE 5 (ABQ5)	30.6	0.013
	SANDIA_ASLNM2004 (P034)	33.7	0.013
	SANTA FE (NMSF)	89.7	0.013
Lava Bluff Pond	SANDIA_ASLNM2004 (P034)	31.3	0.014
	CLINESCORNNM2007 (P120)	101.6	0.014
	SANTA FE (NMSF)	93.7	0.014

GIS-based Arroyo Analysis

Arroyo cross-sections were digitized from the 2010 orthoimagery datasets at six sites near Lava Bluff Pond and three sites along North Boca Negra Arroyo. In 2012 topographic position data were collected using the RTK-GPS system at the same sites. The sites were then visually located in the GIS by overlaying the RTK-GPS cross-section end points with the selected orthoimagery, and the arroyo width measured along a line segment perpendicular to the thalweg (lowest point of the arroyo) by digitizing a line segment as close as could be determined to the top edge of each bank.

Detecting Change in Vegetated Area of Arroyo Bottoms

To determine the pattern of re-vegetation over time, a process leading to greater bank stability, SCPN staff visually delineated unvegetated areas in portions of several arroyos in all available photos. Unvegetated polygons were created for sections of Rinconada Arroyo (total 1.2 km) and Ladera Arroyo (total 350 m) that were representative of low-slope arroyos within the target study area (Figure A-2) from the 1935, 1959, 2010, and 2014 imagery. Reaches were further restricted to those in which the channel is visible in the 1935, 1959, and 2010 photos and which have not been altered (channelized or rerouted). The lower portion of Rinconada Arroyo was excluded because by 2010 the vegetation present in the channel was indistinguishable from the surrounding vegetation. The lower portion of Ladera Arroyo was also excluded because of difficulties identifying vegetated portions of the channel. North Boca Negra Arroyo was excluded due to impacts from road and housing construction.

Figure A-2. Location of digitized reaches at Rinconada Arroyo (left) and Ladera Arroyo (right), 2014 orthoimagery.

The minimum vegetated polygon size was 248 ft^2 (23 m^2). The 2010 and 2014 orthoimagery was digitized at a scale of 1:300. Digitizing for the 1959 imagery was done at scales of 1:1000 and 1:800 for the Ladera and Rinconada arroyos, respectively; for 1935, digitizing was done at a scale of 1:800.

A channel centerline was created for each photo period by employing a centerline creation tool (in ArcGIS) to the outermost channel boundary. The average channel width for each period was then calculated by dividing the total unvegetated polygon area by the length of the respective centerline (area = length x width). Error was calculated by the visual estimation that the digitized channel boundary was usually identified to within 2 pixels of the actual channel boundary. Because the channel is defined by 2 banks, the total estimate of error for each time period is therefore ± 4 pixel size.

Results

<u>Aerial Imagery Dataset Evaluation for DEM Creation</u>

The pixel resolution of the 20 imagery datasets varies from 0.15–5.31 m (0.5–17.4 ft) per pixel (Figure A-3); eight datasets (1996 to 2014) have the highest resolution (0.2–0.4 m/ 0.5–1.2 ft), six datasets (1935 to 1973) have mid-range resolutions (0.8–1.8 m/ 2.7–5.8 ft), and six datasets (1945 to 1990) have relatively low resolution (2.5–5.3 m/ 8.1–17.4 ft).

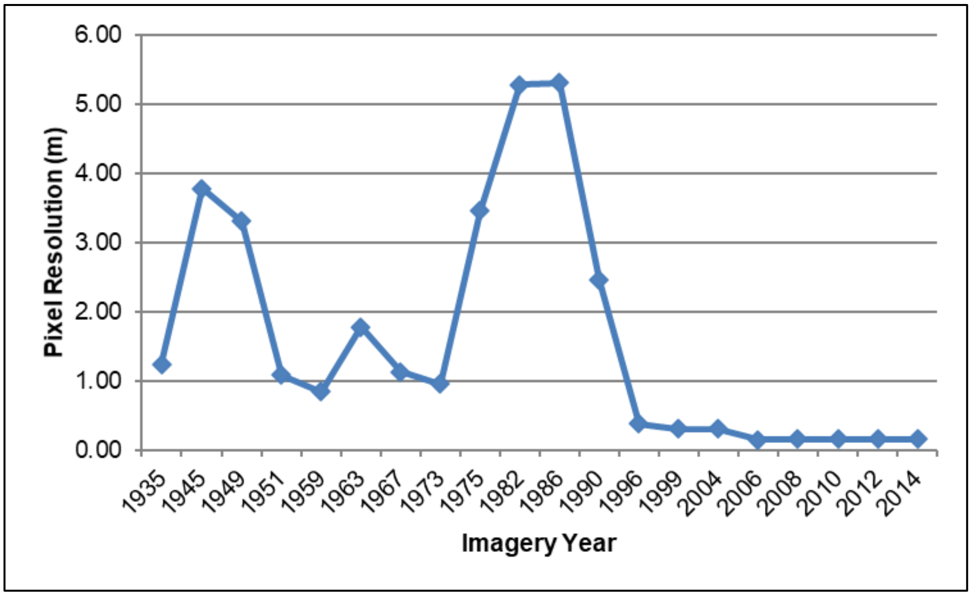


Figure A-3. Pixel resolution of 20 aerial imagery datasets from years 1935 to 2014.

Field-based RTK-GPS data collection

The length of each cross-section was calculated using the Pythagorean Theorem where (x1, y1) and (x2, y2) are Cartesian coordinates in a plane, and the distance between them is given by the equation:

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

RTK GPS-measured cross-section widths are presented in **Table A-3** for Lava Bluff Pond and Table A-4 for North Boca Negra Arroyo. Cross-sectional views of the arroyos are presented in Appendix 1B.

GIS-based Arroyo Analysis

The two sets of digitized arroyo widths described above were overlaid on the 2010 orthoimagery to evaluate the accuracy of the digitized GIS measurements (Appendix 1C). The difference in the RTK-GPS measured widths and digitized GIS widths for six cross-sections at Lava Bluff Pond, where the GPS cross-section data focused on the erosional features, ranged from −1.2 m to 3.1 m (Table A-3). At North Boca Negra Arroyo, the difference between GPS and digitized GIS channel widths for three cross-sections ranged from 1.4 m to 9.9 m (Table A-4). The root mean square error (RMSE), a measure of the difference between the RTK-GPS location and the GIS digitized location values using the square root of the mean of the squares of the deviations, provides a measure of accuracy. For Lava Bluff Pond the RMSE was 1.61m (Table A1-3) and at North Boca Negra Arroyo the RMSE was 6.10m (Table A-4).

There was a large difference in measured channel width values between the RTK-GPS data and the digitized GIS cross-sections at North Boca Negra Arroyo, again likely due to the difficulties in identifying arroyo edges in the images. For example, the difference between the RTK-GPS and the GIS digitized width measurement at cross section 2 was over 9 meters at North Boca Negra Arroyo (Table A-4).

Table A-3. Comparison at Lava Bluff Pond between arroyo cross-section widths measured with RTK-GPS in 2012 and two independent GIS digitized arroyo width measurements using the 0.15m resolution 2010 orthophoto.

Lava Bluff Cross-section Number	RTK-GPS Measured Width (m)	GIS Digitized Width (m): Trial 1	GIS Digitized Width (m): Trial 2	Mean Digitized Width (m)	Deviation: Trial 1	Deviation: Trial 2	Mean Deviation
3	5.04	2.27	4.27	3.27	2.78	0.78	1.78
5	5.79	4.49	2.73	3.61	1.30	3.06	2.18
6	3.36	3.38	4.53	3.96	−0.02	−1.17	−0.60
7	4.33	2.89	4.13	3.51	1.44	0.20	0.82
8	4.32	1.74	3.89	2.81	2.58	0.43	1.50
9	2.29	3.52	2.60	3.06	−1.23	−0.32	−0.77
RMSE Error	**–**	**–**	**–**	**–**	**1.61**	**1.61**	**1.40**
Pixel Error	**–**	**–**	**–**	**–**	**11**	**11**	**9**

Table A-4. Comparison at North Boca Negra Arroyo between arroyo cross-section widths measured with RTK-GPS in 2012 and two independent GIS digitized arroyo width measurements using the 0.15m resolution 2010 orthophotos.

North Boca Negra Cross-section Number	RTK-GPS Measured Width (m)	GIS Digitized Width (m): Trial 1	GIS Digitized Width (m): Trial 2	Mean Digitized Width (m)	Deviation: Trial 1	Deviation: Trial 2	Mean Deviation
2	14.31	4.01	4.42	4.21	10.30	9.89	10.09
4	3.12	1.57	1.35	1.46	1.55	1.77	1.66
5	7.65	6.05	4.24	5.15	1.61	3.41	2.51
RMSE Error	**–**	**–**	**–**	**–**	**6.10**	**6.10**	**6.08**
Pixel Error	**–**	**–**	**–**	**–**	**41**	**41**	**41**

Due to relatively low sun angles when the photos were taken, in several cases it was difficult to identify a precise location for arroyo edges, particularly for the east-west oriented arroyos. This was especially apparent at the Lava Bluff Pond site, where the shadowing on the north-facing slope created enough contrast in the orthoimagery to see the general area of the arroyo but it was difficult to accurately identifying the bank edge, especially on the south-facing slope (Appendix 1, Section C). Delineating the arroyo edges and creating cross-sections at the North Boca Negra Arroyo site was easier for cross-sections 4 and 5, perhaps because the arroyos are relatively wider and more clearly defined by vegetation on the perimeter of the channel.

Detecting Arroyo Change through Changes in Vegetated Area

Changes in channel width interpreted from differences in vegetated land cover at Rinconada and Ladera arroyos between 1935 and 2014 is shown in Figures A-4 and A-5. At both sites vegetation cover apparently increased greatly between 1959 and 2014. Summarized in Table A-5.

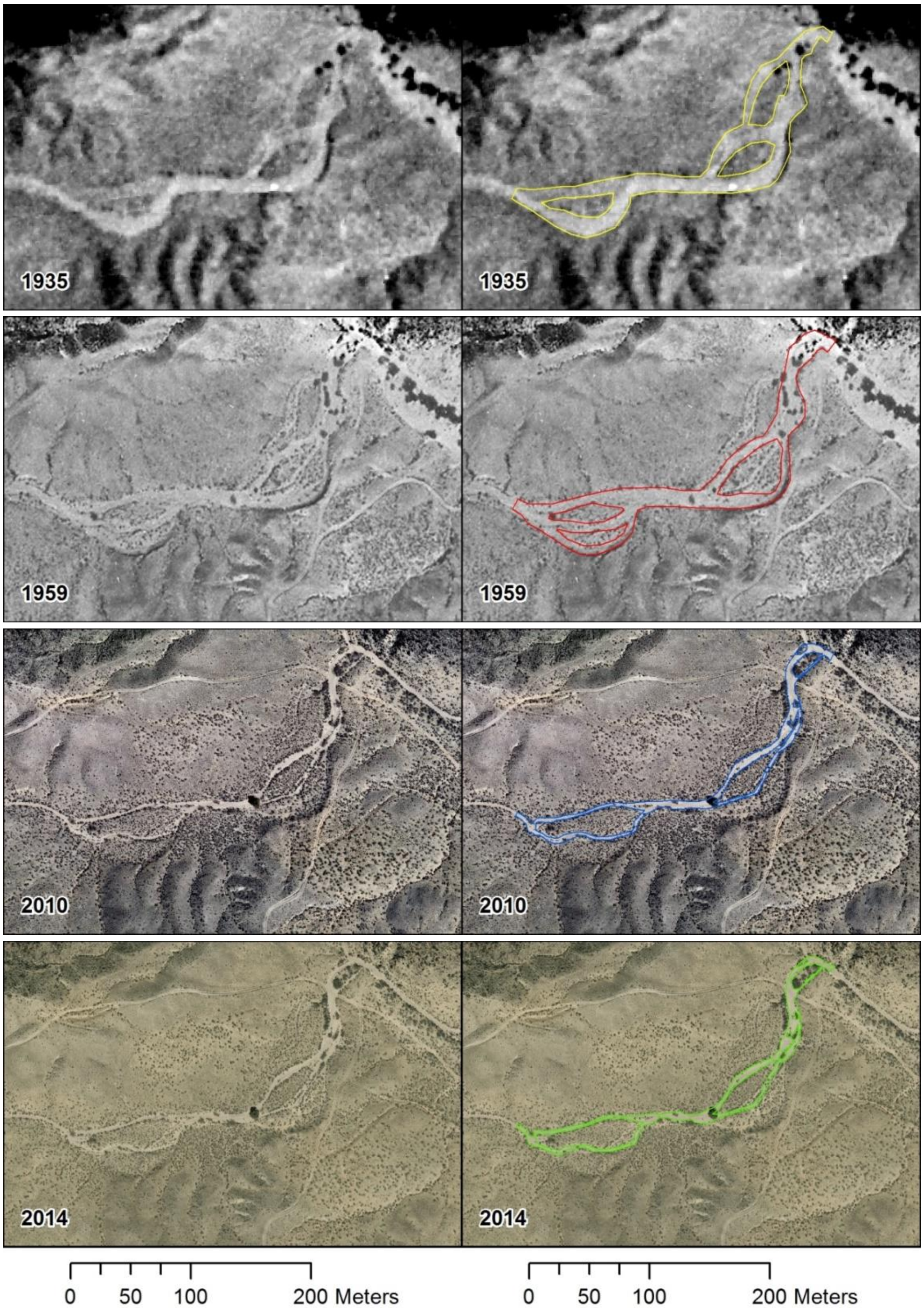


Figure A-4. Historical aerial photo sequence at Ladera Arroyo showing an increase in vegetation on former channel surfaces, resulting in a narrower unvegetated channel area by 2010 and 2014. Photographs obtained from Petroglyph National Monument Headquarters, Albuquerque, New Mexico.

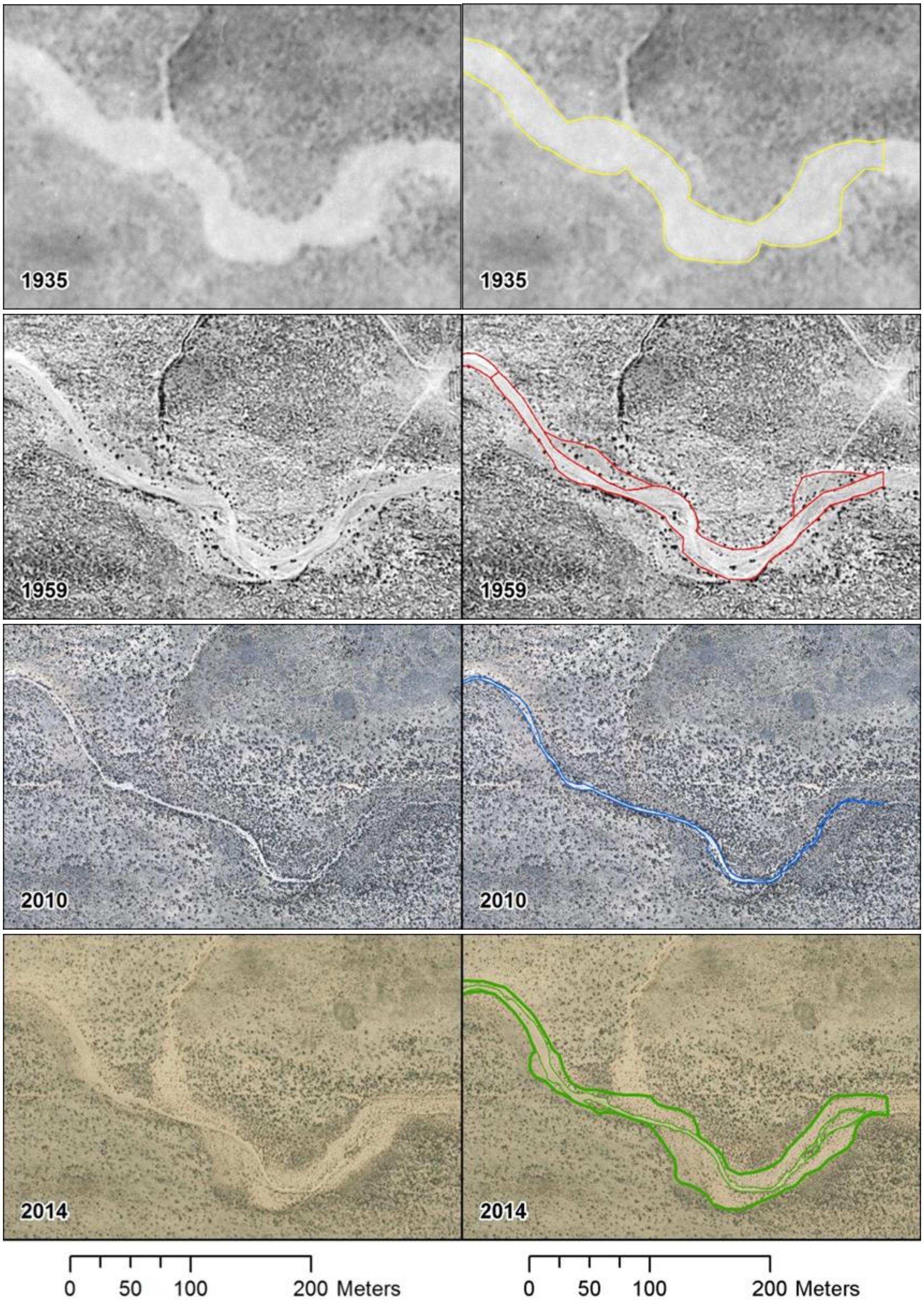


Figure A-5. Historical aerial photo sequence at Rinconada Arroyo showing an increase in vegetation on former channel surfaces, resulting in a narrower unvegetated channel area by 2010 and a wider de-vegetated channel by 2014. Photographs obtained from Petroglyph National Monument Headquarters, Albuquerque, New Mexico.

Table A-5. Changes in channel width at Rinconada and Ladera arroyos from 1935 to 2014 as calculated from digitized polygons. Values in parentheses show the range of channel width change including the estimated pixel error.

Site (Arroyo)	Year	Average Width (m)	Error (m) estimated as pixel size x 4	Area (m2)	Percent decrease from 1935 total [a]
Rinconada	1935	32.5	5.2	39,025	–
Rinconada	1959	11	3.3	13,252	66% (56–76%)
Rinconada	2010	3	0.6	3,547	91% (89–93%)
Rinconada	2014	13.6	0.6	16,326	58% (56–60%)
Ladera	1935	21.9	4.2	7692	–
Ladera	1959	19.3	2.7	6,744	12% (0–25%)
Ladera	2010	7.1	0.5	2,487	68% (65–70%)
Ladera	2014	6.5	0.5	2,288	70% (68–73%)

Discussion

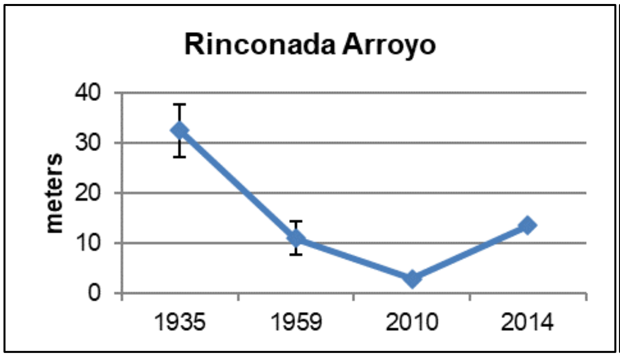
Aerial Imagery Dataset Evaluation for DEM Creation

After evaluating the resolution and quality of the available imagery, MNA determined that DEM creation at a sufficient resolution to detect changes in arroyo geomorphology over time was not possible. Arroyos in the study area vary in depth from approximately 15 cm to over a meter, and widths vary from less than one meter to 9 meters across. Thus, DEM creation at the finest resolution possible from the existing data (15 cm) would not provide information at a scale fine enough to quantify change in most cases.

Field-based RTK-GPS data collection and GIS arroyo delineation

The available cross-sectional data were collected prior to and independent of this project and the history of site selection for those locations is unknown. Whether GCP were identified at the time is unknown, and in most cases it was difficult to identify adequate GCP in the images at scales relevant to arroyo change measures. In addition, it appears that data collection methods between the two efforts varied, for example the description of a channel (width) was not always consistent, making it difficult to delineate points on either side of the channel where the cross-section was measured.

Some of the differences found between the GPS-RTK and the GIS digitized widths can be attributed to the limitations of the two methods used to identify and measure channel width. At North Boca Negra Arroyo cross-section 02, the top edges of the banks were identified in the GPS-RTK cross-section graph at the point where the ground surface becomes more horizontal and the measured cross-section distance is 14.307m (Figure A-5). The GIS digitized channel edges were identified by the presence of vegetation in the orthoimagery (Figure A-6) and the average GIS digitized channel width was 4.2m (Table A-4; Figure A-7). However, the presence of vegetation is not necessarily an indicator of geomorphic surface boundaries. GPS-RTK could be more effectively used to ground-truth orthoimagery if both vegetative and geomorphic attributes were recorded.



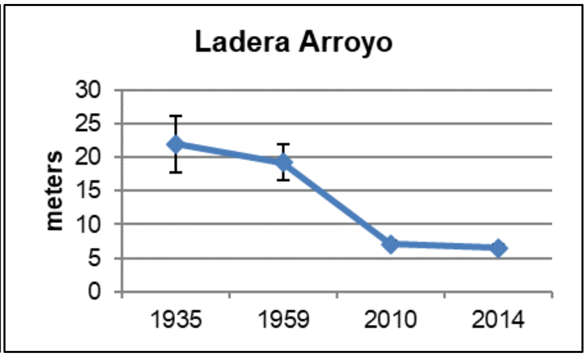


Figure A-6. Average channel width at Rinconada and Ladero arroyos. Average channel width at Rinconada Arroyo showing a decrease from 1935 to 2010 and an increase in 2014 (left). The average channel width at Ladera Arroyo decreased from 1935 to 2014 (right).

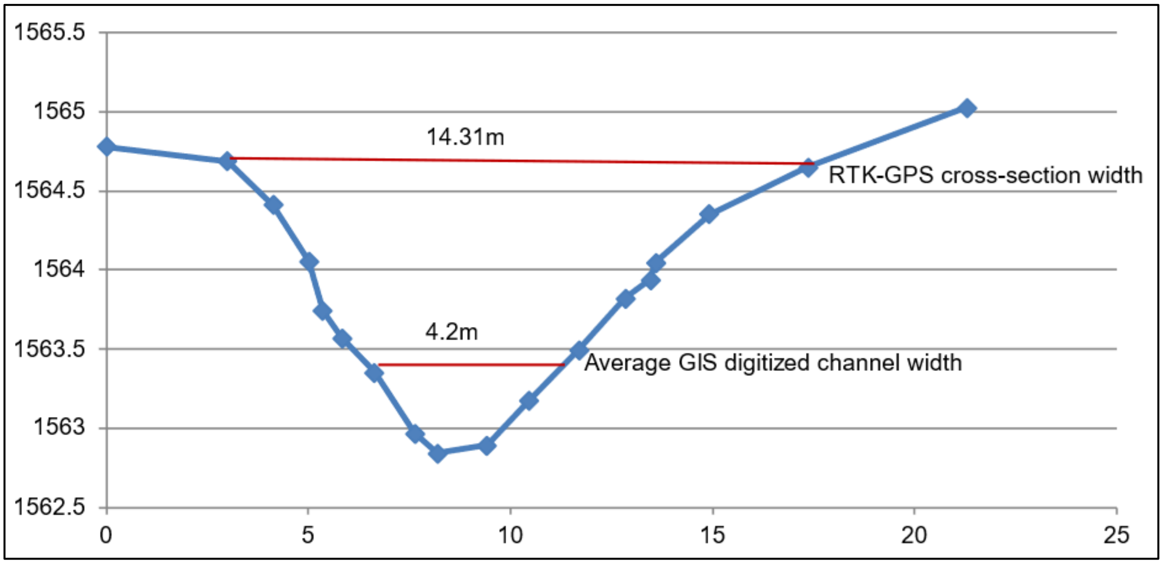


Figure A-7. View of GPS-RTK surveyed cross-section 02, North Boca Negra; Horizontal lines show the GPS-RTK measured cross-section distance and the mean GIS digitized channel width.

<u>Delineating Landcover Change</u>

Similar issues arose during the 2-D GIS analysis; bank edges were difficult to define in many images due to the lack of soil contrast and geomorphic evidence, and the presence of vegetation in more recent imagery sometimes obscured previously visible banks.

<u>Detecting Arroyo Change through Changes in Vegetated Area</u>

Preliminary analysis of historic orthoimagery from the period 1935 through 2010 showed an overall decrease in channel area and increase in vegetation on former channel surfaces in reaches of Rinconada and Ladera arroyos. The 1935 orthoimagery shows broad unvegetated channels at both Rinconada and Ladera arroyos. Due to poor resolution it is not possible to determine whether the broad channels are the result of channel incision or deposition of fine sediments. Subsequent orthoimagery shows progressive channel narrowing and vegetation establishment following the model of arroyo evolution defined in Gellis (1992).

Significant precipitation during September 2013 produced widespread flooding in the Albuquerque region, including extensive erosion and mobilization of fine sediments in the arroyos at PETR. Orthoimagery obtained in 2014 shows an unvegetated channel pattern at Piedras Marcadas, North Boca Negra Arroyo, San Antonio, and Rinconada arroyos in PETR similar to that seen in the 1935 orthoimagery. The 2014 orthoimagery does not show this pattern for the Ladera Arroyo.

Conclusions

Although MNA determined that the older imagery was too low in resolution (0.83–5.31 m/pixel; 2.7–17.4 ft) to meet original project objectives, it may be possible to use newer imagery (0.15 to 0.38 m/pixel; 0.49–1.25 ft) to detect arroyo change using the DEM method. Other photo interpretation issues could be addressed with field data collection.

The RTK-GPS data collection effort could be improved by collecting more topographic GPS data along the cross-section, including the edges of the unvegetated inner channel in conjunction with the edges of the wider vegetated channel.

Detecting Arroyo Change through Changes in Vegetated Area

Changes in channel width interpreted from differences in vegetated land cover at Rinconada and Ladera arroyos between 1935 and 2014 are quantified in Table A-5, and visually in Figures A-4 and A-5. At both sites, measurable increases in vegetation, and additional examination of images from the intervening time period would likely reveal more time-specific changes.

Section B. RTK-GPS Cross-section Data

Lava Bluff Pond

Figures B-1 through B-6 show cross-sections 3,5,6,7,8 and 9 at Lava Bluff Pond.

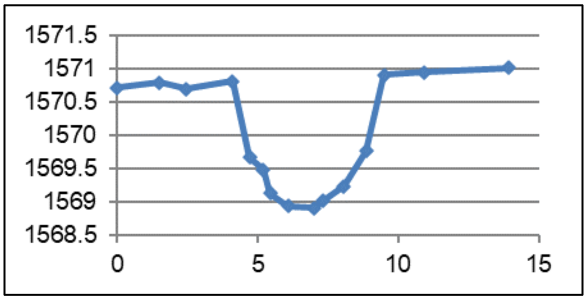


Figure B-1. Cross-section 3; Horizontal distance of 5.043m.

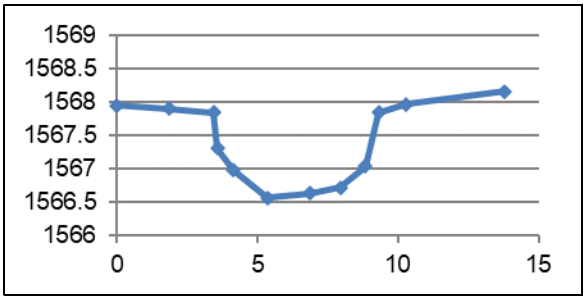


Figure B-2. Cross-section 5; Horizontal distance 5.791m.

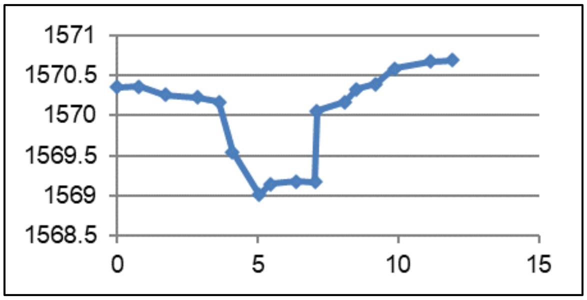


Figure B-3. Cross-section 6; Horizontal distance 3.361m.

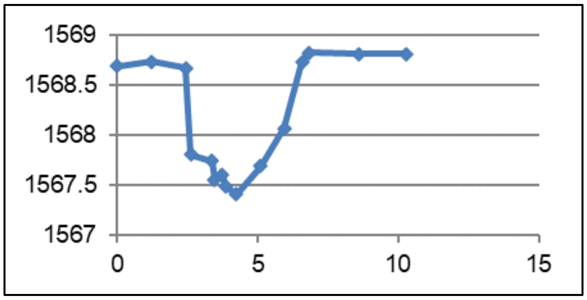


Figure B-4. Cross-section 7; Horizontal distance 4.331m.

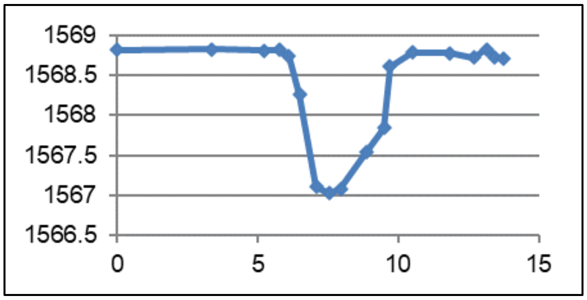


Figure B-5. Cross-section 8; Horizontal distance 4.319m.

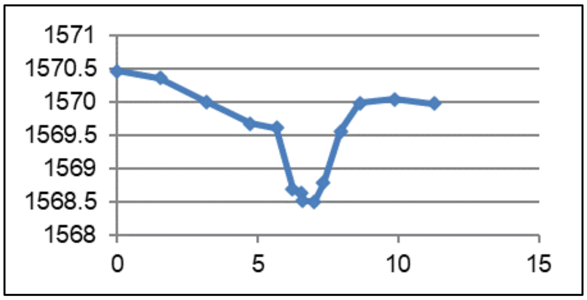


Figure B-6. Cross-section 9; Horizontal distance 2.288m.

North Boca Negra Arroyo

Figures B-7 through B-9 show cross-sections 2,4 and 5 at North Boca Negra Arroyo.

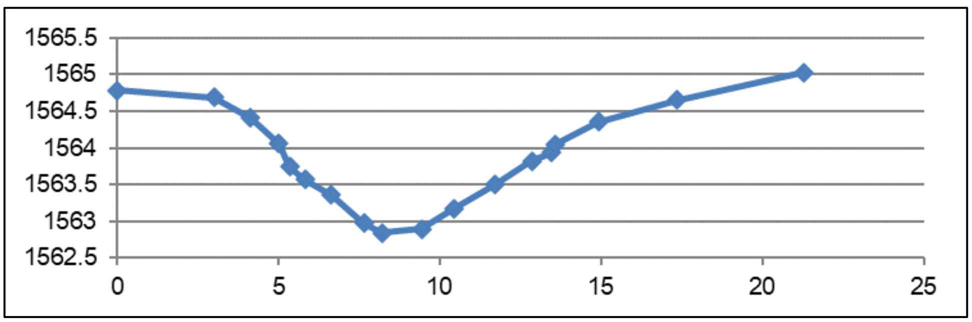


Figure B-7. Cross-section 2; Horizontal distance 14.307m.

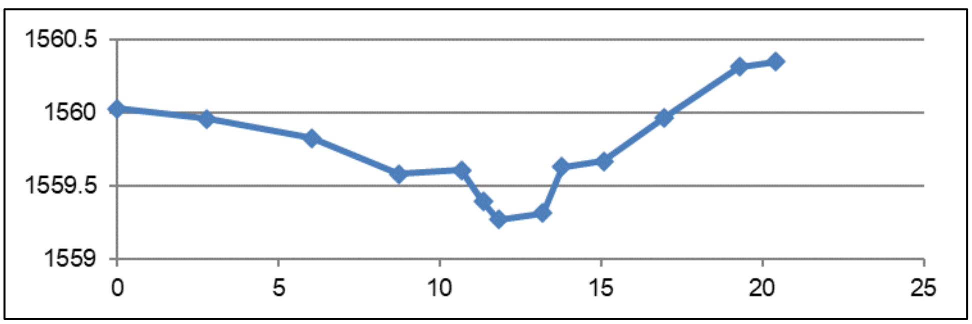


Figure B-8. Cross-section 4; Horizontal distance 3.118m.

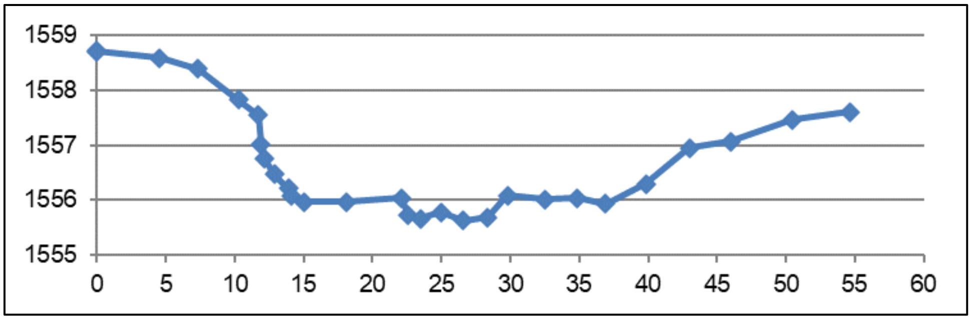


Figure B-9. Cross-section 5; Horizontal distance 7.654m.

Section C. Comparison of digitized GIS arroyo widths for the 2010 orthoimagery, Lava Bluff and North Boca Negra.

Figures C1 through C9 show arroyo widths for Lava Bluff Pond and North Boca Negra arroyos.

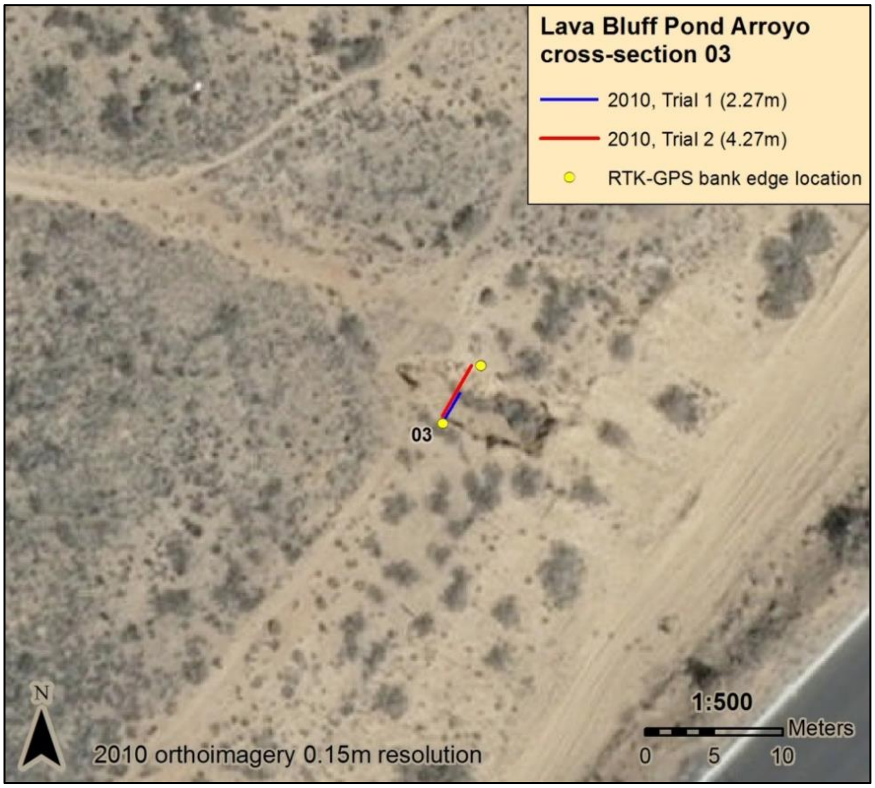


Figure C-1. Lava Bluff Pond cross-section 03.

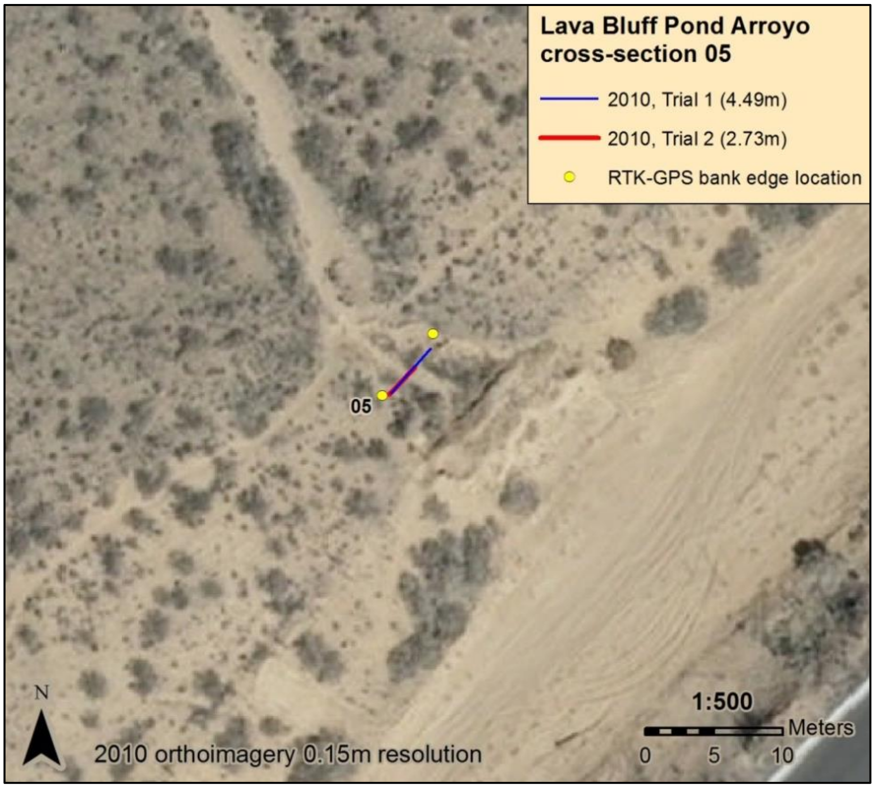


Figure C-2. Lava Bluff Pond cross-section 05.

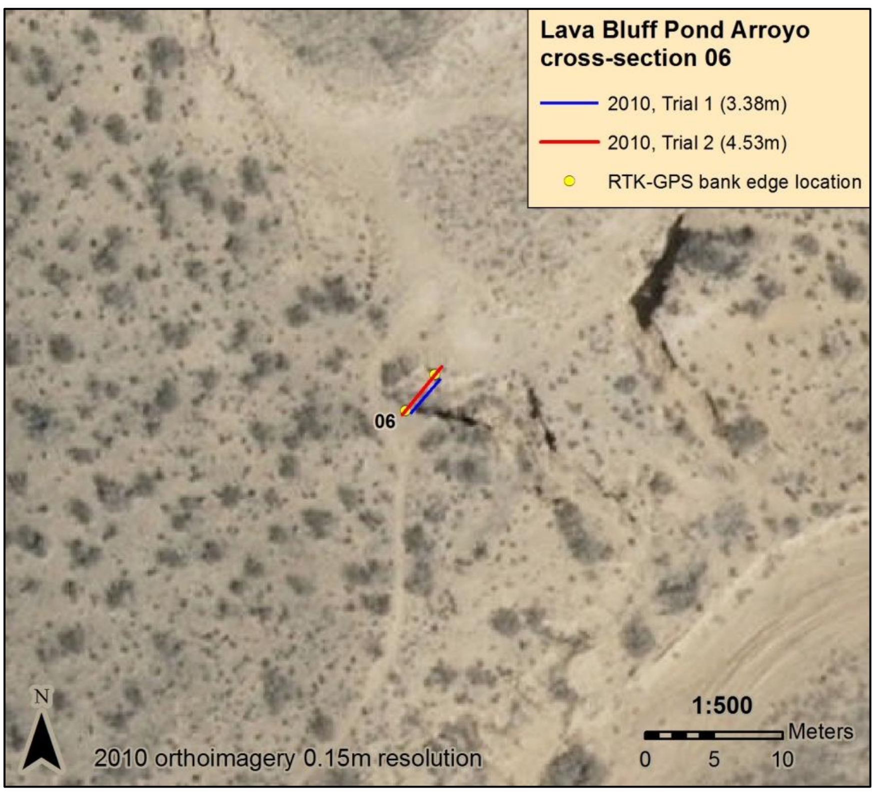


Figure C-3. Lava Bluff Pond cross-sections 06.

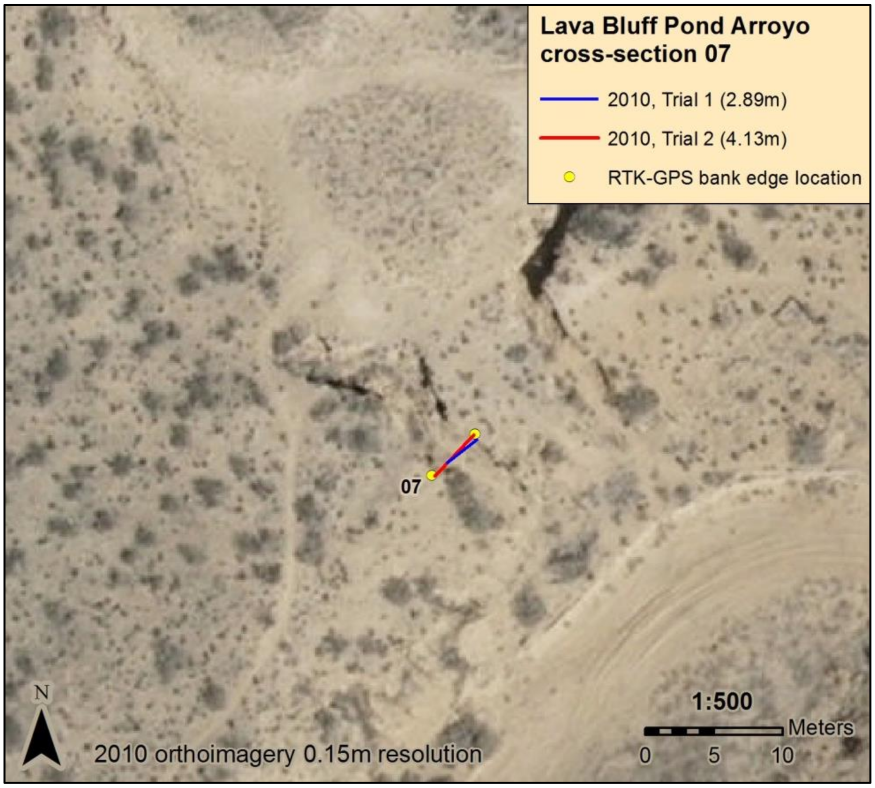


Figure C-4. Lava Bluff Pond cross-sections 07.

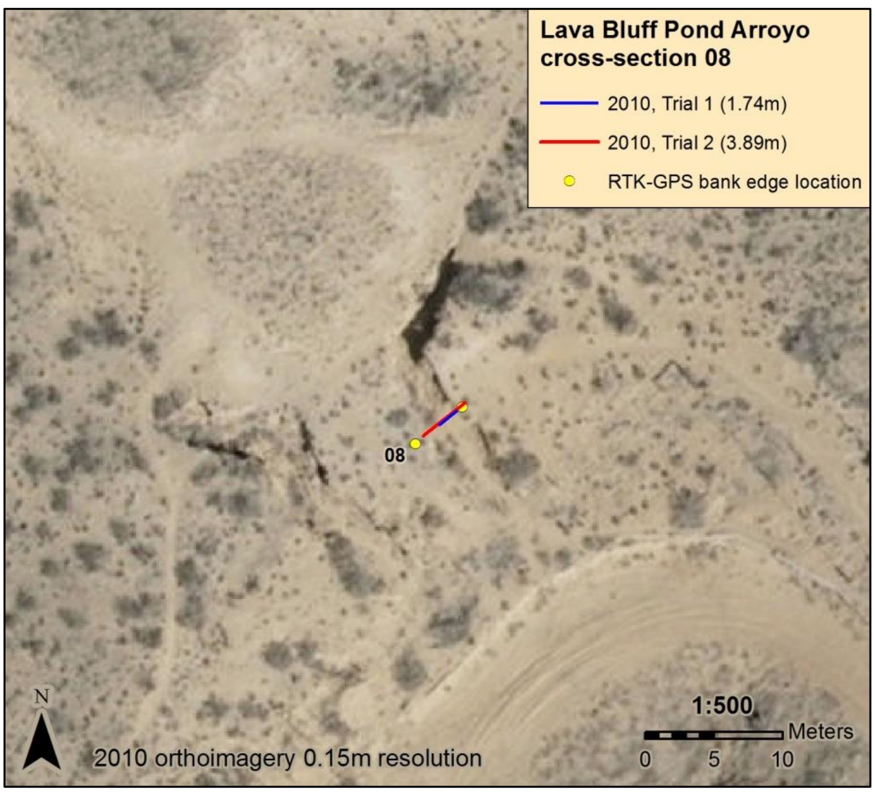


Figure C-5. Lava Bluff Pond cross-sections 08.

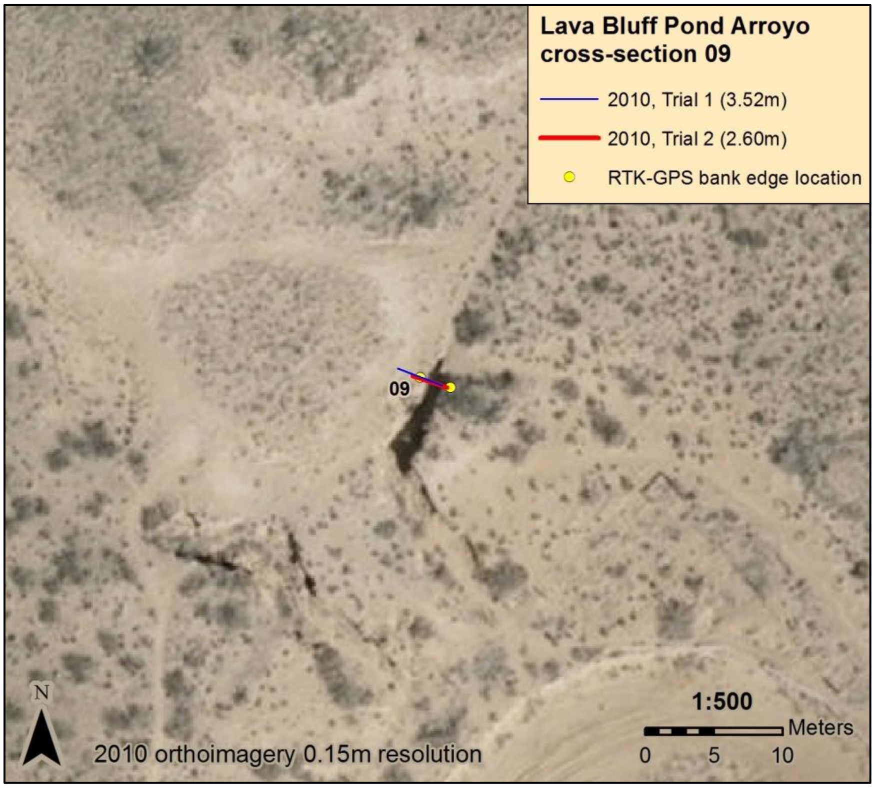


Figure C-6. Lava Bluff Pond cross-sections 09.

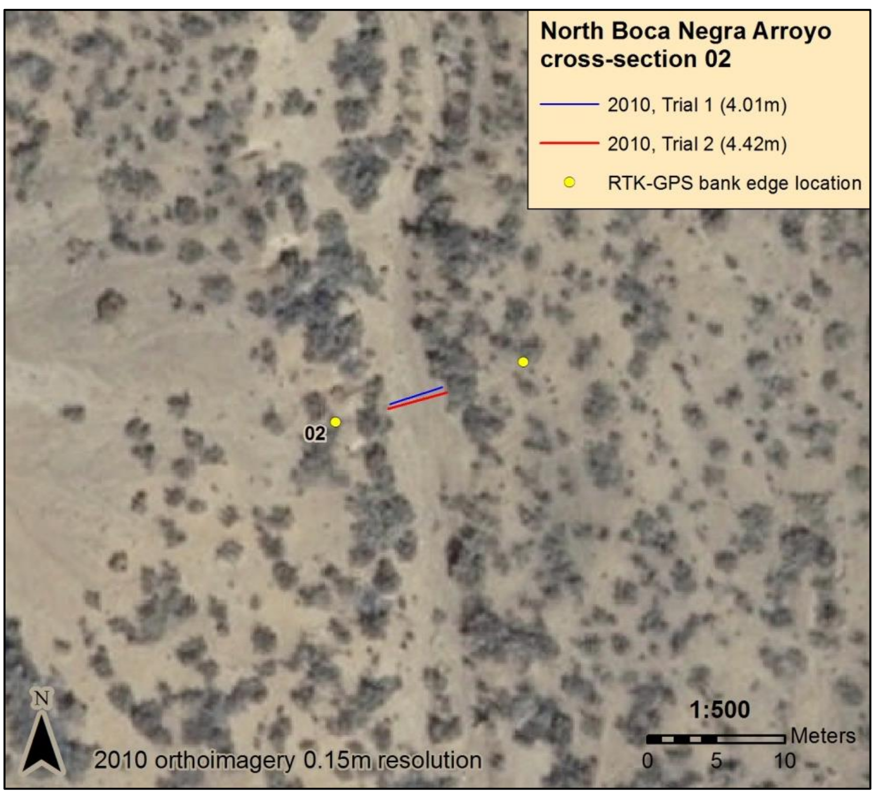


Figure C-7. North Boca Negra Arroyo cross-section 02.

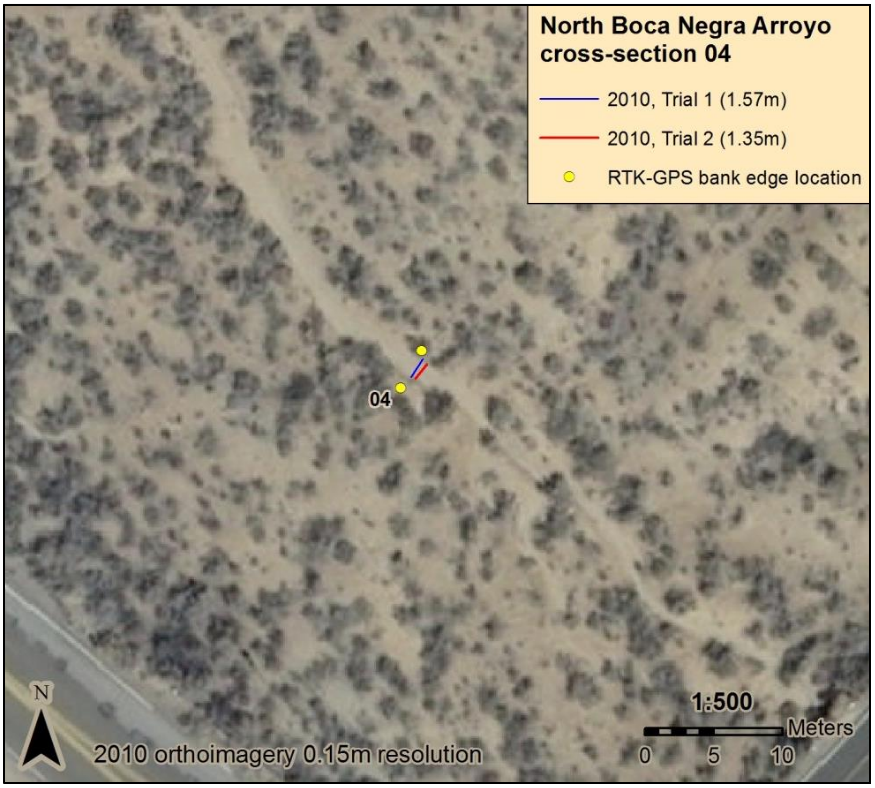


Figure C-8. North Boca Negra Arroyo cross-section 04.

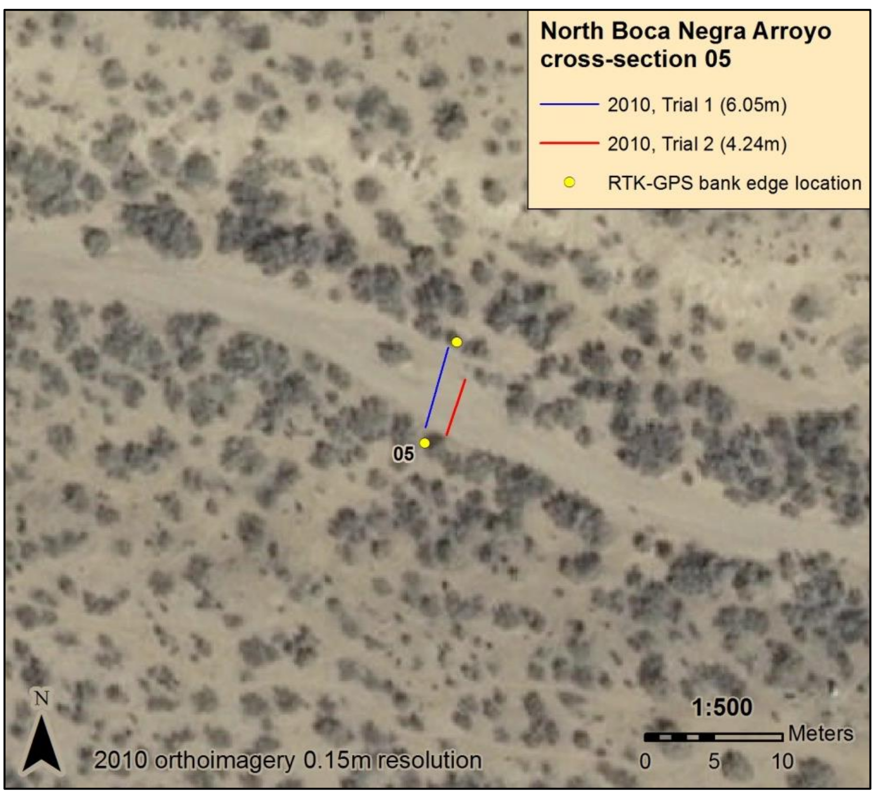


Figure C-9. North Boca Negra Arroyo cross-section 05.

Section D. Sources of Error

Subjective sources of error

- When examining aerial imagery, a stream channel is defined using the visual difference between the channel bed and adjacent upland using contrasts in color, vegetation and visual texture. In systems with vegetated banks, the visible boundary may be that of the active channel bottom. In channels with tall steep banks, the camera angle or sun angle may distort the true location of both the channel top and bottom boundaries.
- From the ground, a stream channel is defined using the visual features mentioned above as well as topographic breakpoints in the active channel banks. Channel measurements are usually to the top of the active channel bank and therefore may not be comparable to air photo measurements.
- The top-of-bank channel boundaries can be difficult to identify in imagery of channels with vegetated or shallow-sloped banks, resulting in problems when comparing to field measurements made at the top of the bank.
- Floods can create a wide, short-lived scour or fill surface in an arroyo that is not maintained in following years, and this may have been the case when the 2014 photos failed to reveal much of what occurred in 2013. Choosing the correct channel boundary in these cases is subjective and may depend on whether future years reinforce or dampen the new scour/fill boundary.
- Large gaps in the photographic record likely hide multiple shifts in channel size, thus the true variability in channel width through time may be underestimated.

Quantitative/Technical sources of error

- In the best case of digitizing an air photo with very well distinguished channels, the error associated with digitizing would be ± 2 pixels for each channel bank. In most cases the error will be larger and will depend on photo resolution, photo quality, and channel conditions.
- For air photos of channels with tall steep banks the camera viewing angle may distort the boundaries of both the channel base and the tops of the banks.
- For air photos, photo rectification errors are often ± 2–5 meters, therefore repeat measurements may be in slightly different locations with different resulting channel widths.
- For field measurements, apparent differences in channel widths can result from only slight shifts in measurement locations. For field and air photo measurements, the exact boundary placement can be subjective.

Literature Cited for Appendices A1–D1

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