

Geoindicators Scoping Report for Big Bend National Park

Strategic Planning Goal Ib4

January 15-17, 2002
Panther Junction, Texas

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Geoindicator Scoping Summary

Introduction

A joint Geologic Resources Inventory workshop and geoindicator's scoping meeting for Big Bend National Park was held in Panther Junction, Texas on January 15-17, 2002. Participants included staff from Big Bend National Park, U.S. Geologic Survey (USGS), the National Park Service's Geologic Resources Division (GRD), Guadalupe Mountains National Park, Natural Resource Conservation Service, and academic institutions (Sol Ross State University, Texas Tech, and University of Texas PB). The Geologic Resource Inventory meeting is summarized in a separate report and available from the Geologic Resources Division. This report summarizes the group's geoindicators discussions and provides recommendations for physical studies to support resource management decisions, inventory and monitoring studies and research.

Purpose of meeting

The purpose of the meeting was threefold: (1) to identify significant geological processes and features that affect or influence the park's ecosystem, (2) to evaluate human influences on those processes, and (3) to provide recommendations for studies to support resource management decisions, geologic inventory and monitoring projects, and research to fill data gaps. The scoping meeting was designed to use the participants' expertise and institutional knowledge of the park.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of natural resource parks, information gathered at Big Bend National Park may be used to represent other parks with similar resources or patterns of use, especially when findings are evaluated for Service-wide implications.

Geoindicator background Information

An international Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a means to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for

assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators are used as a framework to guide the discussion and field observations during scoping meetings (Appendix C) and are considered a proxy for geologic processes. The geoindicators scoping process for National Parks was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

The health and stability of an ecosystem is evaluated during the geoindicators scoping process. The geologic resources of a park—soils, caves, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; impact water and soil chemistries; influence soil fertility and characteristics, hillslope stability, and the quality and quantity surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts (Appendix D).

Park selection

Big Bend National Park was selected as a participant for geoindicators scoping because of its unique geologic resources and varied human uses (Appendix E and F). This park was also chosen because it represents a semi-arid park with desert, montane and riverine environments typical in the northern Chihuahuan Desert.

Summary of Results

During the scoping meeting, geoindicators relevant to Big Bend National Park, were identified and evaluated. Eighteen geoindicators were recognized as on-going processes in the park (table 1). Two additional geologic indicators (table 2), not part of the original geoindicators list, was also included; geothermal springs and swelling clays. To simplify the discussions in this report, indicators listed in Table 1 and 2 will all be referred to as geoindicators.

Participants rated each geoindicator with respect to the importance of the geologic process on ecological health and the influence of human activity on the geoindicator. Park staff rated the significance of the geoindicator for park management. A rating of high, medium, and low was used.

Table 1: Geoindicators Table for Big Bend National Park

Geoindicators	Importance to park ecosystem	Human influence on geology	Significance for management
AEOLIAN			
Desert surface crusts and pavement	H	H	H
Dune formation and reactivation	L	L	L
Dust storm magnitude, duration, and frequency	M?	H	M
Wind erosion	H	H	H
GROUNDWATER			
Groundwater quality	H	L	H
Groundwater level and springs	H	H (local issue)	H
Karst activity	M	L?	M
SURFACE WATER			
Surface water quality	H	H	H
Stream channel morphology	H	H	H
Streamflow	H	H	H
Stream sediment storage and load	H	H	H
Wetlands extent, structure, and hydrology	H	H	H
SOIL			
Soil quality	H	H	H
Soil and sediment erosion	H	H	H
TECTONICS AND GRAVITY			
Slope failure	L	L	L
Seismicity	L	N/A	L
Surface displacement	L	L	L
OTHER			
Sediment sequence and composition*	U	U	U
N/A – Not Applicable H – HIGHLY influenced by, or with important utility for M – MODERATELY influenced by, or have some utility for L – LOW or no substantial influence on, or utility for U – Unknown	* Sediment sequences and composition is a tool with great significance for enhancing the information base of the park's ecosystem, identifying human influences on the ecosystem, and providing data for management decisions and planning.		

Table 2: Other Geologic Issues at Big Bend National Park

ADDITIONAL GEOLOGIC ISSUES	Importance to park ecosystem	Human influence on geology	Significance for management
Geothermal springs	H	H (local issue)	H
Swelling Clays	L	H (local issue)	H
H – HIGHLY influenced by, or with important utility for M – MODERATELY influenced by, or have some utility for L – LOW or no substantial influence on, or utility for			

Geoindicators with importance to park ecosystems

Big Bend National Park preserves a portion of the Chihuahuan Desert ecosystem in the United States. The topographic extremes and diversity of habitat supports a rich and diverse flora and fauna. The southern boundary of the park is the Rio Grande River. The river has cut deep, nearly vertical canyons through three mountain ranges and creates a band of riverine and riparian environments not commonly found in desert environments. More than 40 species of plants and animals in the park are federally listed as rare, threatened, or endangered.

Of the twenty geoindicators identified in the park, twelve were considered to be highly significant to park ecosystems. Water is an extremely critical resource in Big Bend National Park to support natural ecosystems in this arid environment, for visitor use and recreation, and provide domestic water supplies for local communities. Eight of the geoindicators with importance to park ecosystems were associated with groundwater and surface water and were: groundwater quality, groundwater level, geothermal springs, surface water quality, stream channel morphology, streamflow, stream sediment storage and load, and wetlands. Four geoindicators related to soil and aeolian geoindicators also rated high and include: soil quality, soil and sediment erosion, desert surface crusts and pavements, and wind erosion.

Geoindicators with significant human influence

Geologic processes can be influenced by human activities through extraction of natural resources, alteration of natural processes, visitor use impacts, park management practices and developments, land use adjacent to parks, and even global issues (e.g. industrial dust from China). Human induced changes can fall into two groups. There are changes that are irreversible, such as slope failures caused by trail and road construction, and those that are reversible, such as compacted soil. In order to manage ecosystems and natural resources, it is essential to have a fundamental understanding of how human activities impact or alter geologic processes.

Human influence on geologic processes was rated high for thirteen geoindicators. All the surface water and soil geoindicators that rated high for significance to ecosystems also rated high for human influence. Human influence on groundwater level and springs, geothermal springs, and swelling clay are significant issues at specific locations in the park. Dust storm magnitude, duration, and frequency and wind erosion also rated high for human influence on geology.

Geoindicators with high management significance

Geologic processes may have a high management significance due to safety concerns, administrative use of resources, or protection of fragile resources from detrimental human activities. It is important for park managers to be aware of what geologic processes are active in the park and how to adapt park management to address these processes. This

knowledge can greatly assist managers in making decisions to protect human safety and natural resources.

Human activities have significantly altered surface water processes and consequently changed the natural stream processes occurring in the park. Park management is concerned with mitigating and rectifying these human influences. Management significance was rated high for thirteen geoindicators and all the geoindicators that rated high for importance to park ecosystems also rated high for management significance.

In addition, swelling clays also rated high for management significance. The addition or removal of water affects the behavior of swelling clays and alteration of water flow by human activities can impact park infrastructure and roads where swelling clays occur.

Significant geoindicators

Particular attention is paid to those geoindicators with a high rating across all three categories; significance to the park's ecosystem, human influence or management significance. Ten geoindicators rated high for all three categories and almost all were associated with surface water and stream processes or groundwater.

Desert surface crusts and pavements

Physical and microbiotic crusts are present in the park. The extent of biological crusts in the park is unknown. Surface crusts are unique and fragile resources easily impacted by human activities.

Wind Erosion

Over-grazing of livestock caused loss of vegetative cover and removed desert pavements. Loss of vegetation has increased wind erosion and contributed to the loss of soils in Tornillo Flats area and in areas of along the Rio Grande. The park has also noted that there are signs that wind erosion is depositing sediments on microbiotic crusts and smothering them.

Groundwater level and springs

In Big Bend National Park, groundwater is an important resource to support natural ecosystems and provides the only reliable water supply for the park. While natural fluctuations in groundwater levels can occur, most changes are caused by human extraction. Groundwater is replenished from precipitation, but if the rate of withdrawal exceeds the rate of natural recharge then the groundwater resources will become depleted. In the desert environment of the park, natural springs and seeps provide critical water resources and are areas of biological diversity.

Geothermal springs

There are a limited number of geothermal springs in the park (about 12) and all are located along the banks of the Rio Grande. Geothermal springs provide a unique habitat necessary for the survival of the federally endangered Big Bend Gambusia. Human

activities have altered outflow areas for hot spring baths and the village of Rio Grande pumps water for human consumption.

Surface water quality

Surface water is limited in arid regions. Upstream of the park, agricultural runoff contributes pollutants such as pesticides to the Rio Grande. Water diversions and dams have caused lower streamflow and concentrates pollutants in the river during certain times of the year. Unsatisfactory water quality is evident in the park. High concentrations of nitrates and sulfates and increasing salinity are a concern for the park, and during certain times of the year fecal coliform bacterial levels may pose a human health threat. Population growth and industrial development have also occurred in recent years on both sides of the Rio Grande and may further degrade water quality.

Stream channel morphology, Streamflow, and Stream sediment storage and load

The Rio Grande is the second longest river in the United States. Dams and diversions throughout its length have significantly changed the hydrology, morphology and sediment transport of the Rio Grande. As a result of changes in streamflow and sediment transport, aquatic ecosystems along the stream corridor have been significantly impacted and altered.

Wetlands extent, structure and hydrology

Wetlands associated with springs and streams create isolated oasis throughout the desert and provide critical habitat for maintaining wildlife and produce concentrated areas of biodiversity. Wetlands are a critical component in the desert ecosystem and maintaining these features is critical.

Soils quality

Soil controls the distribution of vegetation in the park. Erosion of soils is a significant problem in areas of the park and restoration of vegetation in impacted areas of the park is problematic because of soil loss.

Soil and sediment erosion

Prior to establishment of the park, overgrazing combined with associated stock ponds and water diversions removed grass cover and altered natural hydrology. These activities resulted in extensive gully erosion and soil loss. Extension of gully systems continues to erode soils and decrease the extent of native grasslands. The park is investigating restoration alternatives to address these issues. Fossils are a valuable park resource. The park's paleontological resources in badlands type terrain can also be impacted by soil and sediment erosion. Exposed fossils will degrade when exposed by erosion.

Summary of Recommendations

The following summary of recommendations lists ideas discussed during the January 15-17, 2002 scoping meeting held in Big Bend National Park. The summary includes recommendations for inventory, monitoring and research studies, as well as,

recommendations for specific management issues, public education and planning. Recommendations are not listed in any order of priority.

Recommendations for Inventory

Inventory of caves in the park

Conduct a baseline survey of caves and associated features in Big Bend National Park. Contact grotto from New Mexico, dedicated to surveying caves and local grottos, for support in this inventory.

National Speleological Society, Grottos of New Mexico:
<http://www.caves.org/io/iolookup.php?state=NM>

Inventory soil geochemistry for heavy metal contamination

Conduct soil geochemistry sampling to determine if heavy metal contamination exists in park soils. Map soil horizons and determine the mobility of different heavy metals constituents in soils. (see Recommendation for Research; Heavy metal contaminants and park ecosystems)

Contact:

Lynn Loomis, Soil Scientist, Natural Resource Conservation Service
(915) 729-3217; e-mail: lynn.loomis@tx.usda.gov

Recommendations for Monitoring

Monitor dry deposition in the park and test for heavy metals

Dry deposition of heavy metals, nitrates, and other contaminants can affect park biota, soils, and can affect groundwater chemistry. Work with NPS Air Quality Division to develop a monitoring program for dry deposition in the park. Test for dry deposition of mercury, arsenic, and selenium in particulate matter. Also monitor for fly ash from coal powered plants and other pollutants. (see Recommendation for Research; Heavy metal contaminants and park ecosystems)

Monitor seasonal wind patterns in the park

Incorporate wind monitoring into air quality monitoring in the park. Establish wind monitoring at Terlingua and in the Tornillo Creek drainage. Develop a wind rose by season for these areas of the park.

Monitor springs in the park

Develop a systematic sampling strategy and monitoring protocols for springs in the park. Quantify water quality, seasonal changes in flow, and chemistry (alkalinity, pH, conductivity, dissolved oxygen). Evaluate variations in spring discharge between precipitation on a monthly, seasonal, and annual scale. Determine if there are geologic controls on the location of springs and with water quality. Also determine if springs are impacted by livestock and/or humans (i.e. trampling of vegetation and water quality). Potentially integrate monitoring of springs with wildlife use and vegetation surveys.

Refer to the Water Resource Management Plan-Big Bend National Park, Water Resource Project Statement BIB-N-554-001: Monitor water sources, springs-seeps. This project statement is to develop a systematic monitoring program that will yield a valuable database on park springs. This information coupled with climatic data will enable park resource managers to reliably estimate spring flows.

Evaluate ground water quality and levels

Continue monitoring water quality and levels at wells used for human consumption in the developed areas of the park. Measure groundwater flow rates at wells used for domestic use. Determine the carrying capacity of the groundwater and spring resources in the park and use data to evaluate future park developments. Refer also to the Water Resources Management Plan-Big Bend National Park, Water Resources Project Statement BIBE-N-554.001: Monitor water sources, springs – seeps.

Evaluate water quality and level of geothermal springs

Inventory geothermal springs in the park. Monitor water quality, temperature, chemistry, and flow rates of geothermal springs. Document resource damage or impacts at springs from human activities or other sources. Compare water quality of geothermal springs currently used for domestic water supply against drinking water standards.

Acquire water quality monitoring results for the Rio Grande

Establish an agreement between the park and other agencies monitoring water quality in the Rio Grande in which the results of all water quality and stream monitoring by the International Boundary and Water Commission, Texas Natural Resources Conservation Commission and the USGS will provide the results of monitoring efforts in a timely manner to the park. Refer also to the Water Resource Management Plan-Big Bend National Park: water resource project statement: BIBE-N-550.001 - Monitor water quality degradation, Rio Grande

Implement water quality assessment plan for the Rio Grande

Acquire funding to implement long-term water quality assessments to detect changes in water quality in the Rio Grande. Focus monitoring efforts on determining the status of aquatic life, trends in salinity and pollutants, changes in streamflow, and occurrences of water borne pathogens.

Reference:

Moring, Bruce, 2001, Identification of issues, monitoring objectives, and approach for development of a water-quality assessment plan for the Rio Grande in Big Bend National Park, Texas, U.S. Geological Survey Administrative Report, 11p.

Monitor gully erosion in the Tornillo Flats and Tuff Canyon

Establish photo-points, longitudinal profiles and cross sections for gully systems in Tornillo flats area and Tuff Canyon. Measure gully plots annually and determine erosion rates. Also estimate the long-term erosion rates for areas not subjected to heavy ranching and to compare with the Tornillo flats area.

Investigate the use of ILRIS for monitoring soil and sediment erosion in the park. ILRIS is a 3-dimensional laser imaging system. It is a tripod mounted surveying system with centimeter scale accuracy. Texas Bureau of Economic Geology has an ILRIS instrument and could develop cooperative monitoring studies with the park for Tuff Canyon and other soil erosion studies.

Contact:

For developing a study plan and determining project costs contact -
Jay Raney, Geologist, Texas Bureau of Economic Geology
(512) 471-1534; e-mail: jay.raney@beg.utexas.edu

Establish better park-wide coverage of weather and climatic meteorological stations

Very little data exists on micro-climates in the park. Work with NPS Air Resources Division to monitor microclimates in the park and tie to existing park studies and objectives.

Investigate application of Advanced National Seismic System (ANSS) in the park

Seismic monitoring in the park could be tied into a newer USGS seismograph initiative. Contact the regional coordinator for the Mid-America region of ANSS.

References:

ANSS - Advanced National Seismic System Fact Sheet 075-00
<http://geopubs.wr.usgs.gov/fact-sheet/fs075-00/fs075-00.pdf>

Background for ANSS Program

<http://www.anss.org//ANSScurrent.html>

Planning, information and management of ANSS- Mid America Region

<http://www.anss-ma.org/>

Recommendations for Research

Investigate how heavy metal contaminants enters the park ecosystem

Evaluate how mercury and other heavy metals enter the park ecosystems. Dispersion of toxic substances in the surface and groundwater, soils, stream sediments, geothermal waters, and windblown dust needs to be studied. The USGS proposes four geologic mapping investigations in Big Bend National Park. Two tasks in the overall study plan relate directly to mercury and heavy metal issues in the park.

Proposed USGS Studies:

Geochemistry of altered rock, mineral deposits, and surface and ground water resources.
http://minerals.cr.usgs.gov/projects/big_bend/task3.html

Contact: Pat Shanks, Geologist, USGS
(303) 236-2497; e-mail: pshanks@usgs.gov

Mercury contaminant studies of abandoned mercury mines at Terlingua and Mariscal Mountain, Texas

http://minerals.cr.usgs.gov/projects/big_bend/task1.html

Contact: John Gray, Geologist, USGS

(303) 236-2446; e-mail: jgray@usgs.gov

Evaluate evidence of ground breaking earthquakes in the park

Estimate the magnitude, recurrence and frequency of ground breaking earthquakes.

Contact:

Harold Gurrola, Seismologist, Texas Tech University

(806) 742-3299; e-mail: gurrola@gesc.ttu.edu

Describe and determine the areal extent, distribution, and age of microbiotic soils

Quantify and describe microbiotic soils in the park. Determine how they form and how quickly they colonize. Map the extent and distribution of microbiotic soils and develop baseline data. Evaluate if the underlying geology influences microbiotic soils.

Contact:

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(915) 729-3217; e-mail: lynn.loomis@tx.usda.gov

Jayne Belnap, Soil Ecologist, USGS

(435) 719-2333 ;e-mail: jayne_belnap@usgs.gov

Reference:

Biological Soil Crusts

<http://www.soilcrust.org/crust101.htm>

Introduction to Microbiotic Crusts

<http://soils.usda.gov/sqi/files/MicrobCr.pdf>

Cryptobiotic Soils: Holding the Place in Place

<http://geochange.er.usgs.gov/sw/impacts/biology/crypto/>

Determine the effects of atmospheric deposition on components of the park ecosystem

Evaluate the influence of atmospheric deposition of pollutants and particulate matter on water and soil quality. Determine if long-term change or alteration in vegetation and aquatic life is occurring.

Determine rockfall frequency

Determine rockfall frequency for slopes by monitoring weathering rates of exposed landslide surfaces and determine age of the surfaces through cosmogenic dating. Use historic aerial photography to also look at rockfall frequency and size. The landslide at

Dog Canyon can provide a test case for monitoring the conditions of the rock face weathering and revegetation following a rockfall.

Recommendations for Geologic Studies to Support Park Management Issues

Inventory of photographic coverage for park

Aerial photography can provide a historic overview of long-term changes of geologic processes and other natural resources in the park. Imagery can be used to support geologic inventory, monitoring, and research studies. It also can provide invaluable information for remote areas of the park. Identify and inventory existing aerial photography for parklands. Compile a database containing date of photography, photo scale, identify whether color or black and white images, type of imagery (oblique, stereo, satellite, infra-red, orthophotography coverage), area covered, and location of photos and air photo flight lines.

Potential photography:

Photography by Ross Maxwell that accompanied geologic mapping in the park.

Contacts

Midland Energy Library; Gay Rulla, Library Manager, (915) 683-8057

Petroleum Museum; e-mail: info@petroleummuseum.org, (915) 683-4403

Texas Bureau of Economic Geology; Jay Raney, e-mail: jay.raney@beg.utexas.edu, (512) 471-1534

Quantify erosion impacts on paleontological resources

Quantify erosion rates in badlands-type terrain in the park that contain paleontological resources. Determine how rapidly new fossils are exposed and destroyed (i.e. number of specimens eroded in a given time). Exposed fossils begin to degrade when exposed by erosion. Document if livestock grazing is accelerating erosion and impacting paleontological resources.

Develop management interpretations for the updated soil survey

Work with the NRCS and the GRD to develop derivative products (maps and descriptions) that highlight the management significance of soils and demonstrates how to use soil survey information in cultural and resource management and for use by maintenance staff in the park. In developing useful interpretive materials, refer to the list of soil resource issues in Big Bend National Park developed by park staff.

Contact:

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(303) 987-6948; e-mail: pete_biggam@nps.gov

Lynn Loomis, Soil Scientist, Natural Resource Conservation Service
(915) 729-3217; e-mail: lynn.loomis@tx.usda.gov

Evaluate impacts of channel changes and streamflow on park infrastructure

Use historic air photos to track rates of migration of the meander loop near the Cottonwood Campground and other areas of concern. Utilize dendrochronology to help map and date channel migration.

Develop products to persuade Mexico to experiment with flows on the Rio Conchos.

Streamflow on the Rio Conchos is the primary source of free flowing water for the Rio Grande. Conduct scientific studies similar to the Grand Canyon/Glen Canyon Dam to determine the best way to mimic natural flows and determine timing and flow regimes necessary to maintain the Rio Grande.

Document livestock trail erosion and impacts to park resources

Cattle and horse trails in the park concentrate runoff and can cause erosion. Establish and quantify erosion from livestock trails in the park and determine impacts on the park's natural resources.

Recommendations for Public Education**Develop interpretive products from geologic studies**

Need to bridge the gap between scientists and the public. Develop accurate and timely interpretive geologic products for park visitors that provide for an understanding, appreciation, and protection of physical resources of the park.

References

National Park Service, 1996, Water Resources Management Plan - Big Bend National Park, Department of Hydrology and Water Resources, University of Arizona, Tucson, Big Bend National Park, Big Bend National Park, Texas, and Nation Park Service – Water Resources Division, Fort Collins, Colorado. 163 pp.

Meeting Participants

Big Bend National Park

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United States Geological Survey

Bob Scott, Denver, CO
Pat Shanks, Denver, CO
Ralph Shroba, Denver, CO

Other Participants:

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Lynn Loomis, Natural Resource Conservation Service, Marfa, TX
Jay Raney, Texas Bureau of Economic Geology, Austin, TX
Kevin Urbanczyk, Sul Ross State University, Alpine, TX

Appendices

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- B. Human Influences
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- E. Park Setting
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- G. Compilation of Notes Taken During Geoindicator's Scoping Discussion
- H. Geothermal Springs Geoindicator Description

Appendix A. Descriptions of 27 Geoindicators

Appendix B. Human Influences

Appendix C. Introducing Geoindicators

Appendix D. Species Don't Stand Alone—Geology's Role and Importance in Ecosystems

Appendix E. Park Setting and Resources

Big Bend National Park encompasses more than 800,000 acres in southwest Texas. For more than 1,000 miles, the Rio Grande forms the international boundary between Mexico and the United States; Big Bend National Park administers approximately one-quarter of that boundary. Within the 118 twisting miles that also define the park's southern boundary, the river's southeasterly flow changes abruptly to the northeast and forms the "big bend" of the Rio Grande.

Because the Rio Grande serves as an international boundary, the park faces unusual constraints when administering and enforcing park rules, regulations, and policies. The park has jurisdiction only to the center of the deepest river channel; the rest of the river lies within the Republic of Mexico.

South of the border, people call the Rio Grande by its Spanish name, Rio Bravo del Norte. South of the river lie the Mexican states of Chihuahua and Coahuila and the new protected areas for flora and fauna, which are comprised of regions known as the Maderas del Carmen and the Cañon de Santa Elena.

Big Bend National Park has national significance as the largest protected area of Chihuahuan Desert topography and ecology in the United States. Few areas exceed the park's value for the protection and study of geologic and paleontologic resources. Cretaceous and Tertiary fossil organisms exist in variety and abundance. Archeologists have discovered artifacts estimated to be 9,000 years old, and historic buildings and landscapes offer graphic illustration of life along the international border at the turn of the century.

The park exhibits dramatic contrasts; its climate may be characterized as one of extremes. Dry, hot late spring and early summer days often exceed 100 degrees in the lower elevations. Winters are normally mild throughout the park, but sub-freezing temperatures occasionally occur. Because of the range in altitude from approximately 1,800 feet along the river to 7,800 feet in the Chisos Mountains, a wide variation in available moisture and in temperature exists throughout the park. These variations contribute to an exceptional diversity in plant and animal habitats.

The 118 river miles that form the southern park boundary include the spectacular canyons of Santa Elena, Mariscal, and Boquillas. The Rio Grande, meandering through this portion of the Chihuahuan Desert, has cut deep canyons with nearly vertical walls through three uplifts comprised primarily of limestone. Throughout the open desert areas, the highly productive Rio Grande riparian zone includes various plant and animal species and significant cultural resources. The vegetative belt extends into the desert along creeks and arroyos.

Appendix F. Park Geologic Setting

This section to be completed by BIBE park geologist.

Arid and Semi-Arid Geoindicators

Desert Surface Crusts and Pavements

Desert pavements and crusts occur over most of the landscape in the park. Two types of desert crusts occur in the park; physical and biological crusts. Desert surface crusts and pavements are very important to the ecosystem in the park. Raindrop impact and flowing water can create physical surface crusts. Surface crusts are generally temporary conditions. Physical crusts decrease infiltration of water into the soil, increase runoff, and can inhibit emergence of seedlings. In contrast to physical crusts, biological or microbiotic crusts contain microbial organisms that create a soil crust bound together by organic materials and form in the upper centimeters of the soil surface. Microbial communities can consist of fungi, cyanobacteria and lichens. Growth of these organisms contribute organic matter to the soil which aids in water retention and paves the way for other plants to grow.

Desert pavement develops when wind scours smaller particles of sand and dust leaving only a layer of pebbles and rocks armoring the ground surface. Pavements cover the flat plains in the park. However, the area and extent of microbiotic crusts is unknown. Need to also determine how old, how quickly biological crusts colonize and how long it takes to form.

Need to look at the chemical aspect of microbiotic soils. These soils can be affected by fly ash from coal-powered plants, aerosols, dust from abandoned mercury mines, etc.

Human activities, primarily grazing practices, have created physical crusts on a large scale. Biological crusts are locally disturbed by camping activities, airborne deposition of pollutants.

Wind Erosion

Wind erosion is a natural process, but decades of over-grazing caused the removal of vegetation and destroyed desert pavements in areas of the park. Wind erosion in the park has increased due to loss of vegetative cover in the Tornillo Flats area and is a significant factor impacting some of the soils, such as tornillo loam and pajarito soil. The park is investigating potential options for restoring and converting Tornillo Flats back to historic grasslands.

Accelerated wind erosion within the Rio Grande corridor is also a concern. There are also signs of wind erosion depositing sediment on top of microbiotic crusts and smothering them.

Wind erosion is rated as high for importance to the parks ecosystem, human influence and significance for management.

Dune Formation and Reactivation

Dunes are limited in extent in the park. Dunes occur at Bone Spring draw. A large dune field exists south of the Rio Grande at the village of Boquillos Del Carmen provides a source of sand. Boquillos village is known as a wind tunnel. Across the river, at the mouth of Boquillos Canyon is a sand slide. The primary human influence is foot traffic, but there are no observable changes from human activities.

Due to the limited extent of dunes in the park, this geoinicator was rated low for human influence on the geologic process, and for management significance.

Dust storm magnitude, duration, and frequency

Dust storms are a mechanism to transport sediment. Human disturbances such as overgrazing, farming, or removal of vegetation can increase the magnitude and frequency of dust storms. Dust storms can remove large quantities of surface sediments and topsoil.

Dust storms in the park may originate from agricultural lands to the north. Since the mid-1980's when grassland restoration activities were initiated, there has been a marked reduction in dust storms. Within the park, dust storms occur in the Tornillo Creek drainage because of past grazing impacts and the loss of vegetative cover.

In the spring, the park experiences strong winds. Summer winds are from the southeast while winter winds are from the north and west. Wind blowing from the northern edge of the park can bring mercury into the park. Terlingua is on the north western side of the park is known for its mercury mines. In the Study Butte area near Terlingua, mercury was found in peregrine falcons.

Mercury is not tested for in air quality monitoring. Concentrations of mercury have been found in peregrine falcons in the Study Butte Region. Wind blowing from northern edge of park can bring mercury into the park. Need to monitor heavy metal concentrations (mercury, arsenic, and selenium) in particulate matter. Two air quality samplers will be installed at the K-Bar Research Area. The instruments will be used to analyze and quantify minute airborne particles present in Big Bend and the monitoring is effort is part of a larger network throughout Texas and the United States. The instruments will determine the total amount of particulates present and quantify the amounts of 35 elements along with sulfates, nitrates and organic compounds.

No data exists on microclimates in the park. Meteorological data collected at Rio Grande Village are different from a study site about ½ mile away. Need to establish better park-wide coverage to monitor microclimate and weather data.

Importance of this geoinicator to the park ecosystem was rated unknown but considered moderate. This geoinicator was rated high for human influence. Significance for management was rated moderate. The rating may change if new information shows impacts to park ecosystems.

Groundwater Geoindicators

Groundwater Quality

Groundwater quality in the park is strongly influenced by the high degree of mineralization in areas associated with igneous rocks. High levels of fluoride are found throughout aquifers in the park. High total dissolved solids (sulfates) occur in groundwater, but are not over the acceptable limits for public consumption. The park wants to reduce the total dissolved solid levels in park water supplies.

Wells in the floodplain are hydrologically connected to the Rio Grande River. Therefore contaminants (bacteria, pesticides and industrial chemicals) existing in the river will be present in groundwater used for domestic water supply. Degraded water quality at Castolon is a potential health and safety hazard in the park. The water supply at Castolon is high in dissolved solids due to high sulfate quantities, but levels do not exceed thresholds for public health. The park wants to reduce total dissolved solids and is working to improve the water treatment systems for Castolon.

K-Bar spring supplies domestic water for Panther Junction and Oak Springs supplies water to the Basin. Maintenance monitors groundwater quality for public health issues. However, groundwater quantity not measured. Need to determine capacity of existing groundwater wells and springs in the park to help determine capacity of existing groundwater resources to support future park developments.

At Oak Springs, monitoring by Kevin Urbanczyk of Sul Ross State University, found that the nitrates were below EPA values but higher than other groundwater sources in the park. Only the nitrates were high and not sulfates. This maybe due to sewage lagoons.

John Alcott has studied the landfill and groundwater quality at Grapevine Hills Road. After heavy rains, the fissures form on the surface of the landfill. The park has submitted for funding to move the landfill out of the park and restore the area. This project remains unfunded at this point.

Airborne deposition of nitrates is occurring in the park. The park is concerned with the affect of dry deposition on soil pH and affects on groundwater chemistry. The park has submitted a funding proposal to study the airborne deposition of contaminates and the affects on biota and soils. Need to gather dry deposition data in the park.

Groundwater Level and Springs

Groundwater is used for domestic water supply in developed areas of the park. It is essential to determine the present recharge rates around developed areas in the park and determine sustainable extraction levels for human consumption that doesn't degrade or mine this critical resource. Studies indicate that there is a close correlation between rainfall and recharge. Need to evaluate the park's aquifers and determine pump rates and monitor water levels.

At the Rio Grande Village, geothermal springs are extracted for the domestic water supply (see geothermal spring discussion). These geothermal springs provide critical habitat for an endemic fish species that is federally listed as endangered.

Park-wide springs are affected by drought. The Reynold's well was dry for the second time in five years. Some wells that are dry as a result of the drought have not been in this condition for decades.

At the town of Lajitas, millions of gallons/day is anticipated to be used for urban use and golf courses. Some of the wells are adjacent to the park. Use of groundwater is covered by the Texas "right to capture."

In the desert environment of Big Bend National Park, natural springs, seeps and tinajas (surface depressions in rocks of low permeability that collect rain and are ephemeral features) are critical resources. In 1966-68, the USGS conducted an investigation of water resources in the park and determined the occurrence of springs. Spring discharge was estimated and some water samples were collected for chemical analyses. The park conducted more recent and comprehensive inventories of springs in the Big Bend area in 1984-87 and 1990. These studies reported discharges for over 300 water sources that ranged from 0.001 to 90 gallons per minute. The intent was to monitor springs on a 5-year cycle but there is no available funding to conduct long-term monitoring of these resources.

Need to develop a systematic sampling strategy and protocols for monitoring springs in the park. Quantify water quality, seasonal changes in flow, and water chemistry. Evaluate variations in discharge between precipitation on a monthly, seasonal, and annual scale. Determine relationship between geology and location of springs and water quality. Identify if livestock and/or humans (i.e. trampling of vegetation, water quality) are impacting springs.

Geothermal Springs

(see Appendix G for a detailed Geothermal Spring Geoindicator description)

Geothermal springs are limited in extent (estimated about 12 in the park), but are an extremely important resource in Big Bend National Park for federally endangered Big Bend Gambusia which are endemic to warm spring habitats near Boquillas Crossing and Rio Grande Village in park. Geothermal springs along the Rio Grande create a unique habitat used by gambusia. The gambusia is extremely vulnerable to fluctuations in water quality, quantity, and temperature. The population at Boquillas Spring disappeared when the spring stopped flowing in 1954. The gambusia population near Rio Grande Village drastically declined in the mid-1950's, after the area was altered to provide a fishing pool. By 1960, the Big Bend Gambusia could no longer be found at the Rio Grande Village location. At one point, the population was reduced to one female and two males. The present population of fish are descendents from these three fish. To ensure the species' future, the artificial refugium was modified to receive piped-in warm water. The only wild population exists in a protected pond located in Big Bend National Park

Geothermal extraction does not occur in the park. Upstream water diversions on the Rio Grande River has significantly altered flow regimes and caused lower summer baseflows. Groundwater will provide a relatively higher contribution baseflows. Chemistry of geothermal waters may affect aquatic ecosystems.

Human impacts to geothermal springs in the park occur locally along the Rio Grande. Humans do not affect geothermal processes. However, when geothermal water reaches the ground surface, human activities alter the hot spring outflow to create hot pools/baths. For example, at the Bath House areas around hot springs have been modified to create pools and have impacted the use of thermal springs by federally listed fish. The park has considered restoration of these areas. The Rio Grand Village also extracts geothermal spring water for consumption. Human impact to geothermal springs is considered high locally along the Rio Grande River.

Inventory geothermal springs in the park. Monitor water quality, chemistry, and flow rates. Document resource impairment at springs.

Mercury deposits represent fossil geothermal depositional environments. Studies of how mercury deposits form in the park's geothermal springs may provide a present day analog. An understanding of heavy metal sources and transport in past hydrothermal systems related to volcanism and/or ore-forming processes would be useful.

Establish monitoring of geothermal springs along the Rio Grande. Currently, there is no consistent collection of geothermal data. Changes in the temperature of geothermal springs could affect endangered fish species and is a park management issue. Use temperature data loggers (Onset tidbits) to continuously monitor temperature of geothermal spring.

Karst

Karst and fracture caves provide important habitat to most species of bats in the park and karst caves also provide habitat for unique biota.

Spelunkers started to inventory caves in the Mariscal Mountains and found 8-10 caves. One cave was found in the Santa Elena limestone on the mesa and there was a solute collapse along the monocline. Work with local grottos to map and inventory cave features in the park.

Human activities do not influence the karst processes that form caves in the park, but human vandalism significantly impacts cave resources and features.

Surface Water Geoindicators

Surface Water Quality

Surface water is critical in maintaining both the aquatic and riparian habitats of Big Bend National Park. It also provides water supply for park visitors and residents and provides

water for recreation. Surface water resources in the park occur at springs, seeps, streams, and rivers. Water diversion on the Rio Grande has caused serious and long-term impacts to the stream and riparian corridor and affected surface water quality.

Unsatisfactory water quality is evident within the park. High concentrations of nitrates and sulfates are a concern. Fecal coliform bacteria levels are high during certain times of the year and pose a human health risk for rafters and swimmers. One segment of the Rio Grande below the Presidio had elevated fecal coliform bacteria levels that exceed the swimmable standards. Occasional algae blooms also cause fish kills in the river.

Salinity has increased in the Rio Grande. In places, salinity concentrations increase by a factor of three from spring to summer. Increases in salinity may be attributed to increased return flows from agriculture and wastewater discharge. High concentrations of pollutants from industrial plants, agricultural runoff (pesticides), and septic systems occur in the Rio Grande. From 1994-97, high concentrations of pollutants occurred in the river. During that time period, drought conditions also contributed to increased concentration of pollutants. There is concern that recent population increases and developments along the border, and newly developed industrial plants will increase pollution loading and could further deteriorate the existing water quality in the park.

River rangers monitor pH. There are two USGS National Stream Quality Accounting Network (NASQUAN) water quality stations located upstream and downstream of the park- Rio Grande below Rio Conchos and Rio Grande at Foster Ranch near Langtry.

Stream Channel Morphology

Stream channel dimensions, channel pattern, and sinuosity can be affected by changes in streamflow and sediment discharge. Significant and rapid changes in stream dimensions, discharge and pattern may reflect human activities such as water diversion and increased sediment loads resulting from land clearance, road construction, farming, or timber harvesting.

The Rio Grande is the second longest river in the United States (2,000 miles in length) with headwaters in the southern Rocky Mountains of Colorado. The river is no longer free flowing and dams and diversions throughout its length have significantly impacted the hydrology, morphology and sediment transport. The Rio Grande serves as an international boundary between the U.S. and Mexico (1,000 miles). The park administers about one-quarter of the international boundary and the park's jurisdiction extends only to the middle of the deepest channel.

Extensive water diversions and dams upstream of the park have resulted in significantly smaller peak flows on the Rio Grande and the river cannot transport the annual stream sediment. This has resulted in alteration of channel morphology, floodplains and riparian areas. Need to quantify long term trends.

Tributaries of the Rio Grande carry large amounts of sediment to the river during flash floods. Historically, this sediment would later be carried away by large flows on the Rio

Grande, and the river channel and floodplain would be large enough to handle the average high flows. Dams have decreased the average peak spring runoff to a third or less of the historical peak flows. The river cannot clean out the sediment deposited from the tributary streams under these smaller flow regimes.

Channel morphology issues include:

- Migration of a meander loop of the Rio Grande is impacting the Cottonwood Campground.
- Lack of high flows on the Rio Grande has caused encroachment of vegetation on gravel bars and changes in channel morphology.
- Baker Lodge is a historic building threatened by bank erosion and channel changes.
- Exotic tamarisk and salt cedar are colonizing the streambed and banks and altering stream morphology, changing vegetation and water quality.

Need to document channel migration. Use historic air photos. Establish photo points and stream cross section surveys. Also utilize dendrochronology to map channel migration and delineate areas of channel changes.

Everett studied the aggradation of the streambed upstream of the Presidio on the Rio Grande. Measured the rate of aggradation with channel cross sections. Studies the effects on the riparian zone and biota.

Bruce Moring, USGS, established baseline studies of river morphology and channel characteristics, and biology of the Rio Grande River. Established five benchmark monitoring stations between Colorado Canyon and Black Gap. Conducted comprehensive surveys of river morphology, mapped the streambed, measured streamflow and particle size distribution, mapped riparian zones and sampled fish and aquatic invertebrates.

Exotic nutria are invading rivers and stripping all emergent vegetation and changing stream and riparian habitat and available shading.

Streamflow

Streams respond rapidly to changes in sediment load, precipitation, and runoff. Stream systems also play a key role in the regulation and maintenance of biodiversity. Changes in streamflow can be indicators of changes occurring in watershed dynamics and land use. Streamflow can be strongly modified by human actions (dams, reservoirs, irrigation, and diversion for use outside the watershed).

The Rio Grande is no longer a natural flowing river. Extensive water diversions and dams upstream of the park have significantly decreased the streamflow in the Rio Grande affecting flow regimes, flow duration, and daily and peak flows. The average spring peak flows are a third or less of historic peak flows. Prior to water diversions, stream sediment in the Rio Grande was transported by large flows to the Gulf of Mexico. So much water is diverted from the Rio Grande that between El Paso and the Presidio, the streambed is often dry. As a result of upstream water extraction and dams, hydrographs from the Rio Grande now closely correspond to flow hydrographs from the Rio Conchos.

More than 70 percent of the streamflow on the Rio Grande downstream of the Presidio comes from the Rio Conchos which originates in Mexico.

Maintenance of streamflow in the Rio Grande is an international issue between the United States and Mexico. The International Boundary and Water Commission (IBWC) manages the water in the Rio Grande from Fort Quitman to the Gulf of Mexico. A 1944 treaty between the United States and Mexico allots all of the water entering the Rio Grande from major tributaries on the United States' side and at least one-third of the combined annual flow from the six Mexican tributaries to the United States. The Rio Conchos is the largest of the six Mexican tributaries.

Need to develop a product to help convince Mexico to experiment with flows similar to the Grand Canyon and Glen Canyon Dam studies. Streamflow on the Rio Conchos is the primary source of free flowing water for the Rio Grande. Conduct scientific studies similar to the Grand Canyon/Glen Canyon Dam to determine the best way to mimic natural flows and determine timing and flow regimes necessary to maintain the Rio Grande.

Stream sediment storage and load

Sediment load in part determines channel shape and pattern. Changes in sediment yield reflect changes in basin conditions. Stream sediment storage and load is strongly influenced by human actions, such as in the construction of dams and levees, timber harvesting, road building and farming in drainage basins. On the Rio Grande, dams have altered the natural stream hydrograph and changed the peak flows and the sediment load and storage. High flows are infrequent because of upstream dams and affect bedload transport.

Establishment of exotic plants, like tamarisk and salt cedar, along the river corridor are also causing changes in the stream sediment storage.

Stream deposits also represent huge potential sinks for, and sources of, contaminants. Heavy metal contaminants may be part of the fine silt component of the stream load in the Rio Grande.

Wetlands extent, structure and hydrology

Wetlands are areas of high biological productivity and diversity, and provide important sites for wildlife habitat. There are two distinct types of wetlands in the park. There are wetlands associated with springs. These are of critical importance in the park because they create isolated oasis throughout the desert and provide critical habitat to maintaining wildlife and concentrated areas of biodiversity.

Riparian wetlands are another type of wetland in the park. These types of wetlands are primarily located along the Rio Grande and are dependent on seasonal flooding. Significant changes in the flow regimes of the Rio Grande have affected riparian wetlands. Loss of flows in the Rio Grande has changed the species composition of riparian zones and extirpated some species of amphibians. Introduction of exotic species

has also affected wetlands. Invasion of tamarisk along the river corridor also deposition of sediment and water availability for riparian wetlands.

Need to characterize the loss of riparian function due to lower flow regimes in the Rio Grande. Identify different flow strategies to maintain the wetlands and articulate the benefits to riparian species.

Need to protect existing wetlands around geothermal springs in the Rio Grande Village for federally listed endangered fish species.

See also geoindicator discussions on groundwater level and springs and geothermal springs.

Soils

Soil Quality

As one of earth's most vital components of the ecosystems, soil is essential for the continued existence of life on the planet and has a major influence on terrestrial ecosystems. Human activities influence soil properties by causing increased compaction and acidification from inorganic fertilizers and acid rain.

Soil quality is good in areas of the park with higher precipitation. At lower elevations, soil quality is low. In the Tornillo flats area, soil quality is functioning poorly because of soil loss from past ranching activities.

The Natural Resource Conservation Service in cooperation with the Park Service will be updating the soil survey for Big Bend National Park. The soil survey will map soils of the park (1:24,000 scale), update descriptions to include more information that will help the park manage and protect its resources. A soil scoping session was held at BIBE in May 2001 to determine what products will be developed within the Soil Resource Inventory and discuss additional “focused” soils work performed to help address management needs. The soil survey is scheduled to be completed in 2004.

Deposition of airborne mercury and heavy metals may cause contamination of soil and stream sediments. Local mines extracted bentonite, humate (coal), mercury and lead zinc. Mercury and sulfate can also be found along fault systems and also on the edge of intrusions.

A study in Colorado cored trees and used a mass spectrometer to identify heavy metals. They were able to identify different periods of mining.

Conduct soil geochemistry sampling to determine if heavy metal contamination exists in park soils. It is important to describe soil horizons. Mobility of heavy metal constituents in soil is different. Mercury was found up to 2 miles downstream from its source in Terlingua Creek and can become a potential human health hazard.

Soil and Sediment Erosion (Water)

Removal of soil occurs primarily through fluvial processes (erosion by water) such as sheet, rill, and gully erosion. Soil erosion reduces the levels of the basic plant nutrients and decreases the diversity and abundance of soil organisms. Sediment eroded from a watershed and delivered to a stream can degrade aquatic habitat and water quality. Increased turbidity due to fine sediment loads (silt- and clay-sized material) may adversely affect aquatic organisms such as macroinvertebrates and fish. Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture, forestry, construction, surface mining and urbanization.

Prior to establishment of the park, extensive sheep and cattle grazing, and associated stock ponds and water diversions removed natural grass cover and vegetation and altered natural hydrology. The loss of vegetation cover from overgrazing caused a change in infiltration of water, increased overland flow and concentrated runoff. This resulted in development of extensive gully systems and loss of soils in the Tornillo Flats area. Extension of gully systems continues to erode soils and decrease native grassland areas. The park is investigating restoration alternatives to these issues.

Need to establish photo-points, longitudinal profiles and cross sections for gully systems. Measure gully plots annually and track erosion rates. Also, estimate the long-term erosion rates for areas not subjected to heavy ranching and compare erosion rates to areas with extensive grazing.

ILRIS is a 3-dimensional laser imaging system. It is a tripod mounted surveying system with centimeter scale accuracy. Investigate the use of ILRIS for monitoring soil and sediment erosion in the park. Texas Bureau of Economic Geology has an ILRIS instrument and could develop cooperative monitoring studies with the park for Tuff Canyon and other soil erosion studies. Contact Jay Raney for developing a study plan and determining project costs.

Livestock (cows, horses and burros) continue to cause impacts to park resources along the unfenced park boundary. Streamflow is much lower than historically due to dams and flows no longer create a natural barrier for livestock crossing the Rio Grande. As a result, more cattle are crossing into the park removing vegetation, creating trails, and causing erosion. Erosion from livestock trails can affect natural, archeological, and paleontological resources in the park. Need to establish and quantify erosion from livestock trails in the park and assess the impacts on the park's natural resources.

Soil and sediment erosion can impact the park's paleontological resources. Need to quantify erosion rates in badlands-type terrain with paleontological resources. Determine how rapidly new fossils are exposed and destroyed (i.e. number of specimens eroded in a given time). Document if livestock grazing and trail networks are accelerating erosion and impacting paleontological resources. Use historic air photos to look at erosion over time. Investigate the use of ILRIS as a monitoring tool to determine erosion rates.

Seismic and Gravity

Slope Failures

In the park, slope failures are primarily rockfall and generally are not a pressing resource management issue. Slope failures can be locally important and occur in the park at the foot of Casa Grande, the park development in the Chisos Basin and Panther Junction, and a few backcountry trails.

Joel Wagner, NPS Water Resources Division, investigated flood hazard at Panther Junction and identified the hazard associated with large boulders falling into the Panther Junction development.

Landslide at Dog Canyon can provide a test case for monitoring the conditions of the rock face and vegetation following a rockfall. Can also, determine rockfall susceptibility for slopes by monitoring weathering rates of exposed surfaces and conduct cosmogenic dating to determine age of surfaces.

Seismicity

Earthquakes are predominantly natural events and occur infrequently in the region. The park has a seismograph in the visitor's center.

There is potential for monitoring and gathering seismic data as part of the USGS, seismic initiative (Advanced National Seismic System). Evaluate the frequency, magnitude, and recurrence interval of ground-breaking earthquakes. Determine when the last event occurred and the magnitude.

Surface Displacement

Potential for surface displacement in the park is low and as a result it ranked low as a natural process, human influence and management significance in the park.

Volcanic Unrest

The youngest age of volcanic rock in the park is 17 million year old. This geoinicator is not applicable to the park.

Other Geoinicators

Sediment Sequence and Composition

Sediment sequences and composition is a tool with great significance for enhancing the information base of the park's ecosystem. The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

Lakes, wetlands, streams, floodplains, and other bodies of marine or fresh water commonly accumulate deposits derived from bedrock, soils, and organic remains within the drainage basin, though fine particles can also be blown in by winds from distant natural, urban and industrial sources. Of particular value in determining long-term data on water chemistry are the remains of aquatic organisms that can be correlated with

various environmental parameters. In addition, fossil pollen, spores, and seeds reflect past terrestrial and aquatic vegetation. These aquatic deposits may preserve a record of past or on-going environmental processes and components, both natural and human-induced, including soil erosion, air-transported particulate, solute transport, and landsliding. Sediment deposits can, thus, provide an indication of the degree and nature of impact of past events on the system, and a baseline for comparison with contemporary environmental change.

Information to evaluate this geoinicator was lacking at the time of discussion and its value as a tool for Big Bend National Park is unknown at this time.

Swelling Clays

Volcanic ash alters to smectites (clay mineral). These types of clay minerals expand when they become wet with water, and when they dry out, the loss of water causes the clays to shrink or compact. Human activities can alter natural drainage patterns and runoff and in turn this may affect the duration, frequency and magnitude of the clay shrink/swell cycle. As a result, if water is concentrated on areas underlain by smectites, it may cause the clays to swell and for areas that are de-watered, it may cause the clays to shrink. Areas underlain by smectites can promote slope failures, and cause problems for pipelines, roads, structures, and developments. In the park, swelling clays cause maintenance issues where the units are exposed such as along roads.

A good example of how human activities alter geologic process such as swelling clay occurred in the Chisos Basin. In the Chisos Basin large expanses of parking lots and roads were paved without enough planning with regards to drainage. Water generated as runoff on the pavement flowed downslope, jumped a curve, and flowed under the new Visitor Center. The Visitor Center was built on top of a deposit of bentonite clay. Water directed at the foundation of the building caused the clay to swell/shrink which in turn heaved the building causing serious structural problems. This problem was solved by constructing a drop inlet to catch water at the low point of the parking lot in front of the Visitor Center. The water was diverted through a buried culvert. The improved drainage design has apparently worked and structural problems with the building have ceased.

In the early development of the Chisos Basin a road cut was made through a section of clay. The clay was then used as a fill material elsewhere and as road fill. This can create a host of problems if the clay is moved from an outcrop to a more exposed position.

Potential locations of swelling clays can be identified from a geologic map of the park. Volcanic ash is also high in uranium and a gamma ray spike can identify layers of concern. Texas Department of Transportation has investigated how to identify swelling clay minerals to avoid using it in road base.



GEOLOGIC RESOURCE MONITORING PARAMETERS

Geothermal Springs



Brief Description: Geothermal springs provide a means to conduct long-term monitoring programs of changes in the subsurface hydrologic and temperature environments. Although geothermal waters fall in the general description of ‘groundwater’, they reflect subsurface temperatures and chemistries found in deeper parts of the earth rather than from shallow surface or near surface environments. These waters circulate through rock strata sufficiently deep and hot to produce discharge temperatures of at least 8°C (15°F) above the mean annual temperature of the region. In most circumstances ground water circulation of only a few hundred meters is insufficient to produce hot spring temperatures. These elevated water temperatures require circulation downward from a few hundred to several thousand meters in depth. It is not uncommon for geothermal springs to develop along major fracture zones or faults that act as ready conduits for waters to reach the needed depths to acquire heat and reemerge at the surface.

Geothermal springs are influenced strictly by temperature variations deeper in the subsurface, below any temperature affects attributed to climatic changes. Three sources of heat for these subsurface thermal systems have been proposed. First, an area that has had geologically recent volcanic activity will tend to have an elevated local temperature. Surface water can circulate down to these shallow (less than 6 km), young (but not necessarily molten) magma chambers and become warmed from the localized heat of the chamber. Second, water may circulate very deep in the earth through local joints and faults where a normal geothermal gradient exists. This deep convection system allows heat to be transferred to the circulating water and be brought up to the earth’s surface. Third, there may exist an abnormally high local thermal gradient that has resulted from the blockage of normal heat flow by rock layers of low thermal conductivity. Surface waters circulating down into proximity of this elevated thermal gradient will encounter locally elevated temperatures and thus become heated above what might normally exist at this depth in other areas.

Geothermal springs are also classified according to how they produce their waters at the earth’s surface. A geothermal spring that does not discharge water forcefully into the air is considered to be a hot spring. Geothermal springs that throw water into the air fall under the classification of geyser. Additionally, the chemical composition of these two general classifications of geothermal springs is quite different. Springs that produce warm water is generally weakly mineralized. However, when hot or

boiling water is generated, such as in a geyser, heavily mineralized alkaline water high in chloride and silica is produced at the surface, often forming 'sinter' terraces composed of these mineral deposits.

The chemical classification of geothermal springs is a function of the type of subsurface host rock through which the water flows. Waters that circulate entirely through carbonate and clastic strata contain moderate total dissolved solids composed of Ca, Mg, HCO_3 , and SO_4 . Waters from zeolitized, silicic volcanic rocks contain low to moderate total dissolved solids composed primarily of Na and HCO_3 . Evaporite waters contain high total dissolved solids of Na, Cl, SO_4 , HCO_3 , and Li. Based upon their chemistry and geologic setting, evaporite waters have been in contact with evaporite rocks and limestone.

Significance: Geothermal springs can establish, support, or impact existing surface environments at the point of discharge and in the immediately adjacent area. The range of environmental impact is dependent upon both the temperature and chemical composition of the discharge water.

High temperature, high-mineralized discharge waters will establish site-specific mineral crusts and deposits of local beauty and fragility. These crusts can form various geometries and colors that are dependent upon both how the water is discharged and its chemical composition. In areas such as Yellowstone, these mineral formations, as well as the manner of water discharge, become an important tourist attraction. Geyser activity tends to build a cone of mineral deposits immediately surrounding the point of discharge, with additional mineral deposits being found on the ground surrounding the geyser. Water that is discharged above ground level and forms local water falls can form sheet deposits of mineralized dripstone.

Diverse life forms may also be found locally near these geothermal outpourings. For example, microorganisms, such as bacteria, viruses, fungi, and protozoa, can be present within the discharge water and associated with the mineral deposits that are endemic only to this specific environment, an environment generally hostile to most life forms. These life forms are important not only for acquiring a better understanding of how various toxic environments can support life, but also the potential use of these microorganisms for cleaning anthropogenically induced toxins from the environment.

Low temperature, low mineralized geothermal waters, while not necessarily displaying sinter crust formations, will still generally have higher temperature and higher dissolved solids than what would be found in non-geothermal springs. These types of springs are far more abundant than the high temperature, highly mineralized waters typically encountered within areas of geyser activity. Historically, many of these lower temperature geothermal springs have been developed and used as health resorts. In some areas where drilling for hydrocarbons has encountered artesian flows of low temperature geothermal waters, ranchers have made use of these waters for their stock and as a limited water resource for their families. These geothermal springs probably do impact the local ecological environment.

However, as so much research involving geothermal springs has focused on the high temperature environments, the actual impact of the lower temperature waters is unknown. Thus greater effort involving data collection and observation is needed in a variety of geothermal spring types to better understand the wide range of influence that these may have on the local environment.

Environment where Applicable: Geothermal springs have the potential of forming anywhere that subsurface water has encountered a source of heat sufficient to warm the emergent spring waters. The multiplicity of sources for heating subsurface water and the potential increase in dissolved chemical solids does not necessarily relegate these springs geographically to any one area of the country. However, there is a greater tendency to encounter geothermal springs in areas of existing or past volcanic activity. Thus the American west is a primary candidate for encountering geothermal spring activity and a principal target area for geothermal spring monitoring.

Types of Monitoring Sites: Natural springs that have been identified and defined as geothermal springs based upon the temperature of outflow water. Areas where drilling has encountered subsurface geothermal water and provided a conduit for these waters to begin a natural artesian flow at the ground surface.

Method of Measurement: The temperature and chemistry of geothermal spring waters must be determined to establish useful data. First order measurement of geothermal water can be conducted in similar manner to that conducted with the groundwater quality geoindicator description. Direct measurements of temperature, pH, and HCO₃ (bicarbonate) content can be conducted on geothermal spring waters on site at the point of outflow. Sufficient sample should also be taken upon initiation of a monitoring program to define baseline geochemistry of the geothermal waters using various appropriate laboratory-testing procedures. Such secondary testing will establish a profile of the water type and possible flow path through the various subsurface rock strata. This sampling will allow for laboratory geothermometry determinations that investigate specific chemical constituents that reflect subsurface temperature. Finally, water samples from geothermal springs should be taken for laboratory analysis of the microorganisms that might be endemic to the subsurface hydrologic system that generates the springs.

Frequency of Measurement: Measurement frequency will be defined after determining whether periodic variations in temperature, chemistry, or biota exist in produced geothermal waters. For initiating a monitoring program sampling frequency should not be less than 4 times a year, with a possible maximum of 6 times a year. Should this data display no variations then monitoring could be pared back

to no less than 2 times a year. Should the data display variations, it must first be determined whether the variations are seasonal or related to other subsurface changes to the deep hydrologic environment. The fact that geothermal water has had to circulate deeper into the earth to acquire its heat argues for a longer residence time for these waters in the subsurface, with a resulting low impact by local changes in climate or surface precipitation. However, there may occasionally be good flow through from surface waters deep into the subsurface that then reemerge locally as geothermal springs. In these instances seasonal variations may indeed be observed through a monitoring program. Sampling frequency would then need to be established to monitor the variations that are identified. Should sampling variations be found that relate to changes in subsurface fluid path through varying rock strata or to changes in the subsurface thermal regimes, appropriate sampling frequencies would need to be chosen or adjusted to monitor these subsurface changes.

Limitations of Data And Monitoring: Unless seasonal changes of water temperature or chemistry are found, variations in geothermal waters may occur over much longer periods of time. A long-term monitoring program must be established that periodically checks all chemical and microbiological parameters. First order measurements, once a routine interval is established, will be the easiest to maintain over time. As geothermal springs are most often affected by geological changes, commitment must be established for monitoring over decades in order to assess these kinds of subsurface variations.

Possible Thresholds: Establishment of good water collection techniques is required in order to compare data over many years that will normally be collected by different collecting agents. Minimizing collector bias at all geothermal springs can be lessened by establishing the use of standard equipment, and collection and measurement techniques through adoption of a specific protocol to be followed by all individuals involved regardless of geothermal spring location.

Key References:

- Ben-Ari, E.T., 2002, Microbiology and geology: Solid marriage made on Earth: ASM News, vol. 68, no. 1, p. 13-18.
- Henry, C.D., 1979, Geologic setting and geochemistry of thermal water and geothermal assessment, Trans-Pecos Texas: The University of Texas at Austin Bureau of Economic Geology Report of Investigation No. 96, 48 p.
- Waring, G.A., 1965, Thermal springs of the United States and other countries of the world – a summary: U.S. Geological Survey Professional Paper 492, 383 p.

Related Environmental and Geological Issues: Long-term geothermal spring monitoring provides the primary means for assessing variations in the deep subsurface hydrologic and geothermal environment. Evaluation of the natural variability in thermal fluid discharge at hot springs requires an accumulation of well-documented historic data. Changes in chemistry can indicate changes in source water or flow path of these waters through different rock strata. Temperature changes, if not related to an influx of water from alternative sources, can elucidate changes in the subsurface thermal regime brought on by heat flow changes related to renewed subsurface magmatic activity and crustal unrest. Both of these changes in water quality can result in changes in the natural biota either found within the thermal waters or supported by these waters at the discharge point. Such data will help to develop realistic conceptual models of geothermal systems and their operation.

Overall Assessment: Monitoring geothermal waters provide a direct means for assessing changes in temperature and flow path of water in the subsurface. Variations in temperature imply changes in the heat source, variations in the path of subsurface water flow, or unexpected additions of shallower surface water into the deeper hydrologic regime. Chemical variations may indicate the mixing of waters from different host rocks. Such changes can impact the endemic environment at the point of discharge and, if these changes are significant, affect the hydrologic and organic environment to some distance away from the geothermal springs.

Source: This summary of monitoring parameters has been adapted from the Geoindicator Checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Geoindicators include 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health. Geoindicators were developed as tools to assist in integrated assessments of natural environments and ecosystems, as well as for state-of-the-environment reporting. Some general references useful for many geoindicators are listed here:

Berger, AR. & W.J. Iams (eds.), 1996. *Geoindicators: assessing rapid environmental change in earth systems*. Rotterdam: Balkema. The scientific and policy background to geoindicators, including the first formal publication of the geoindicator checklist.

Goudie, A. 1990. *Geomorphological techniques*. Second Edition. London: Allen & Unwin. A comprehensive review of techniques that have been employed in studies of drainage basins, rivers, hillslopes, glaciers and other landforms.

Gregory, K.J. & D.E. Walling (eds) 1987. Human activity and environmental processes. New York: John Wiley. Precipitation; hydrological, coastal and ocean processes; lacustrine systems; slopes and weathering; river channels; permafrost; land subsidence; soil profiles, erosion and conservation; impacts on vegetation and animals; desertification.

Nuhfer, E.B., R.J. Proctor & P.H. Moser 1993. The citizens' guide to geologic hazards. American Institute for Professional Geologists (7828 Vance Drive, Ste 103, Arvada CO 80003, USA). A very useful summary of a wide range of natural hazards.