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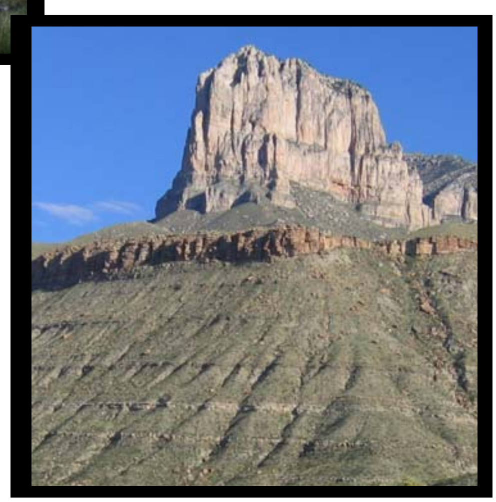
Natural Resource Program Center

Physical Resources Stewardship Report
Guadalupe Mountains National Park

Natural Resource Technical Report NPS/NRPC/NRTR—2008/121



ON THE COVER

Photographs: Guadalupe Mountains National Park taken by Don Weeks

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Natural Resource Technical Report NPS/NRPC/NRTR—2008/121

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Executive Summary

Physical resources at Guadalupe Mountains National Park (GUMO) play a vital role in the natural and cultural landscape, and should be managed to achieve the park's purpose and maintain its significance. GUMO is responsible for maintaining natural processes within the park boundaries, which is supported by several laws and policies outside the park's enabling legislation such as the National Park Service Organic Act (1916) and National Park Service Management Policies (2006).

With the recent completion of GUMO's draft General Management Plan (GMP), the park is building from the GMP's *desired conditions* identified for the priority natural and cultural resources and defining approaches (management strategies) in the GUMO Resources Stewardship Strategy (RSS) that move the resources toward the *desired conditions*.

This *Physical Resources Stewardship Report* assists GUMO with the RSS process, building from the GMP desired conditions for fundamental and important geologic, water and air resources. This report 1) evaluates natural resource health, 2) identifies stressors negatively impacting the priority natural resources, and 3) identifies strategies that begin to move these resources towards their respective *desired condition*.

Park Purpose and Significance

The *purpose statements* of a NPS unit communicate the reason(s) for which it was set aside and preserved by Congress. The purpose statements for GUMO's physical resources are listed below (National Park Service, GUMO draft General Management Plan 2008).

- to preserve an area possessing outstanding, globally unique geological features together with scenic, natural, and cultural values of great significance.
- to manage a designated wilderness area where the earth and its community of life are untrammeled, and where humans are visitors who do not remain.
- to provide opportunities for visitors to understand, enjoy, appreciate, and experience the unique nature of the park.
- to provide educational and research opportunities that enhance stewardship and wider understanding of resources.

Significance statements define what is most important about the national park's resources and values and are based on the *purpose* of why the national park was created. The GUMO *significance statements* that apply to geologic, water, and air resources are (National Park Service, GUMO draft General Management Plan 2008):

- GUMO is situated at the western terminus of the world's most extensive and well-exposed fossil reef, including related shelf and basinal rocks, which have achieved international designation as the world's best example of Middle Permian geology.
- GUMO is an island within an arid sea where an interface of Chihuahuan Desert, Rocky Mountains, and Great Plains flora and fauna was isolated by environmental changes. It

contains relict and endemic montane, canyon, and aquatic species in a delicate balance created by elements of physical geography, latitude, climate, and hydrology.

- Rugged and windswept, the Guadalupe Mountains provide wilderness opportunities to experience the unaltered dynamic of life in a remote landscape resplendent in its isolated beauty and inspirational solitude.

Fundamental and Other Important Physical Resources

It is important for NPS units to identify the priority resources and values critical to achieving the park's *purpose* and maintaining its *significance*. The following resources listed below were identified as *fundamental* or *important* during the development of the GUMO General Management Plan (National Park Service, GUMO draft General Management Plan 2008).

Fundamental Physical Resources

Geologic Resources	Water Resources	Air Resources
Capitan Reef and Related Deposits	Natural hydrologic processes (ground water, perennial streams, springs and seeps)	Views of the Western Escarpment
Western Escarpment	McKittrick Canyon riparian corridor	Views of canyons throughout the park
Salt Basin	Wilderness Character	Wilderness Character
El Capitan		
Guadalupe Peak		
McKittrick Canyon		
Gypsum Dunes		
Montane/Sky Island		
Wilderness Character		

Other Important Physical Resources

Geologic Resources:	Caves and Karst

Physical Resources and Desired Conditions

Desired conditions are qualitative descriptions of the integrity and character for a set of priority resources and values that park management has committed to achieve and monitor. The *desired conditions* developed in the GUMO *General Management Plan* for the park's priority physical resources (geologic, water, and air resources) are listed below:

Geologic Resources

The park's geologic resources are preserved and protected as integral components of the park's natural systems. Paleontological resources, including both organic and mineralized remains in body or trace form, are protected, preserved, and managed for public education, interpretation, and scientific research. Natural soil resources and processes function in as natural a condition as possible, except where special considerations are allowable under policy. Caves and karst are managed in accordance with approved management plans to perpetuate the natural systems associated with the caves and karst.

Water Resources

Surface water and ground water are protected and water quality meets or exceeds all applicable water quality standards. Watersheds are managed as complete hydrologic systems. Natural fluvial processes that create habitat features are protected. Natural floodplain values are preserved or restored. The natural and beneficial values of wetlands are preserved and enhanced.

Air Resources

Air quality in the park meets national ambient air quality standards for criteria pollutants and protects air quality-sensitive resources. Natural visibility conditions exist in the park and scenic views of the landscape are not impaired by human activities.

Indicators and Target Values

Indicators were selected to provide a barometer of health for GUMO's *fundamental* and *important* geologic, water and air resources. Target values were established for the respective indicator parameters to distinguish between acceptable and unacceptable function of natural systems.

Geologic Resources

<u>Specimen Abundance at Paleo Localities</u>

Indicators for the park's paleontological resources are based on inventories with set objectives. The principle objectives of a paleontological resource inventory include:

- Gather baseline paleontological resource data.

- Inventory known paleontological localities and specimens.
- Document field localities including mapping, GPS data acquisition, and photo monitoring.

A summary of the geologic resource vital signs and monitoring methods are listed in the following table.

Geologic resource vital signs and monitoring methods.

Vital Signs and Methods	Expertise	Special	Cost Equipment*	Personnel	Labor Intensity+
Erosion (Geologic Factors)					
Repeat Photography	Volunteer	No	$	Individual	Low
Erosion Stakes	Volunteer	No	$	Individual	Low
Technology-Enhanced	Scientist	Yes	$$$	Group	High
Erosion (Climatic Factors)					
Climatic Records	Volunteer	No	$	Individual	Low
Repeat Photography	Volunteer	No	$	Individual	Low
Technology-Enhanced	Scientist	Yes	$$$	Group	High
Catastrophic Geohazards					
Geologic Assessment	Volunteer	No	$	Individual	Low
Digital Mapping	Scientist	Yes	$$	Group	Medium
Technology-Enhanced	Scientist	Yes	$$$	Group	High
Hydrology / Bathymetry					
Repeat Photography	Volunteer	No	$	Individual	Low
Digital Mapping	Scientist	Yes	$$	Group	Medium
Technology-Enhanced	Scientist	Yes	$$$	Group	High
Human Access / Public Use					
Repeat Photography	Volunteer	No	$	Individual	Low
Digital Mapping	Scientist	Yes	$$	Group	Medium
Technology-Enhanced	Scientist	Yes	$$$	Group	High

*Cost: $ = <$1,000; $$ = $1,000 to $10,000; $$$ = >$10,000
+Labor Intensity: Low = <few hours; Medium = <full day; High = >full day

The change in specimen abundance at paleo localities (a.k.a the "Actual Loss" score) is measured by the Paleontological Locality Condition Assessment Form criteria. The frequency of monitoring is determined by the rates at which natural processes and/or human-related activities potentially impact each paleontological locality. Cyclic monitoring will be conducted at regular intervals, approximately every 1 - 10 years. The target values will be based upon acceptable limits as defined to minimize the loss of scientifically significant specimens or information due to natural processes or human factors.

GUMO Actual Loss Target Value = 20

Dunes, Dune Fields, and Sand Sheets

Wind speed and direction, along with moisture and sediment availability formed the dunes. Additionally, dune formation, stability and reactivation are influenced by climatic change and/or human disturbances. Sand movement is inhibited by moisture and vegetation cover. Monitoring of formation and movement along the margins of the dunes can also be used as an indicator of near-surface moisture conditions. Changes in dune morphology can indicate drought, variations in wind velocity and direction, or human disturbances.

Monitoring includes changes in size, shape and position of individual dunes and dune fields utilizing repeated ground, aerial, or satellite surveys (i.e. LIDAR). The frequency of monitoring is every 5 - 10 years. Testing the use of LIDAR in understanding and documenting dune dynamics is currently occurring at White Sands National Monument through the Chihuahuan Desert Network (CHDN) Inventory and Monitoring Program. Knowledge gained from this project will be applied to the dune fields at GUMO in future monitoring efforts. Past and future dune activity can be constructed by correlating temperature, precipitation records and utilizing paleorecords for remnant Quaternary dunes in North America. Target values are based on acceptable limits for active dune areas on park lands, as well as on associated ground water levels.

GUMO Percent Change in Spatial Extent of Dunes, Dune Fields and Sand Sheets Target Value ≤ natural variability as determined by changes in size, shape and position of the dunes utilizing LIDAR survey analysis.

GUMO Shallow Ground Water Target Elevation at Dunes, Dune Fields and Sand Sheets = no change from natural seasonal ground water elevations.

Cave and Karst Photo-Monitoring and Inventory/Survey

Caves determined to be environmentally sensitive and/or containing significant paleontological resources should have baseline data gathered. Photo-monitoring of the caves, documentation of cave features and resources (both natural and cultural) will consist of photo points that are recoverable and linked to cartographic survey points. The frequency of monitoring is every 5 - 10 years. Additionally, the monitoring plan (with protocols) that Carlsbad Caverns National Park has drafted will also assist monitoring of this physical resource at GUMO.

In addition to photo-monitoring, a companion inventory will be performed. An inventory/survey will include a cave's features, biota, cultural and paleontological resources. The survey will determine the number and identification of cave species which use the twilight or dark zones in the cavern. Cultural resources surveys will be conducted at the entrances and in the twilight zone areas as well as into the dark zone of the caves to define and describe historic use of the cavern. Paleontological resources should be surveyed using indicator and monitoring protocols developed for the park's paleontological inventories. Target values are based on acceptable limits or no change to the current condition as a baseline is developed after the inventory phase.

GUMO Cave and Karst Photo-Monitoring = no change from established baseline condition from cave.

GUMO Cave and Karst Inventory/Survey = no change from established baseline condition from cave.

Water Resources

Nutrients

Since many states, including Texas, do not have nutrient-specific criteria, the U.S. Environmental Protection Agency developed guidance (assessment tools and control measures) for specific waterbodies and ecological regions across the country, using reference conditions (conditions that reflect pristine or minimally impacted waters) as a basis for developing nutrient criteria. Since GUMO has very minimal nutrient data, these ecoregion nutrient criteria were selected as "interim" nutrient target values for GUMO.

EPA established reference conditions for the respective regions by choosing the upper 25th percentile (75th percentile) of a reference population of streams. The 75th percentile represents minimally impacted conditions. GUMO is located in Nutrient Ecoregion II (Western Forested Mountains) and III (Xeric West), as defined by the EPA. Interim nutrient target values were selected for total phosphorus and total nitrogen for rivers and streams in these two regions using the procedures described by U.S. Environmental Protection Agency (2000b; 2000c).

GUMO "Interim" Nutrient Target Values: Total Nitrogen: $\leq$ 1.0 mg/L and Total Phosphorus $\leq$ 18 µg/L

Turbidity

Similar to nutrients, the same EPA preferred method for establishing reference conditions for Ecoregions II and III was used to select an interim turbidity target value since adequate park data does not exist. Choosing the upper 25th percentile (75th percentile) of a reference population of streams and interim target value was selected for turbidity (U.S. Environmental Protection Agency, 2000b; 2000c).

GUMO "Interim" Turbidity Target Value: $\leq$ 4.0 Formazin Turbidity Unit (FTU)

Spring Discharge

Since GUMO does not have a baseline for seasonal ground water elevations, flow direction and flow velocity for the aquifer(s) that support natural resources and park operations, spring discharge was selected as an "indicator" for ground water health. With limited spring discharge data recorded from the past four or five decades, these values will be used as "interim target values" until park-specific hydrogeology can be better defined through installation and monitoring of ground water wells and existing wells screened at the appropriate aquifer depth(s).

The following four springs and McKittrick and Choza creeks in GUMO were selected to evaluate aquifer trends in water quantity.

Smith Spring “Interim” Discharge Target Value ≥ 8 gallons per minute (gpm)

Guadalupe Spring “Interim” Discharge Target Value ≥ 5 gpm

Frijole Spring “Interim” Discharge Target Value ≥ 2 gpm

Bone Spring “Interim” Discharge Target Value ≥ 2 gpm

South McKittrick Creek Discharge Target Value: no change from natural seasonal baseline data

Choza Creek Discharge Target Value: no change from natural seasonal baseline data

Benthic Macroinvetebrates

The Texas Commission of Environmental Quality uses rapid bioassessment protocols as cost-effective screening tools for evaluating the biotic integrity of benthic macroinvertebrate assemblages. This method is referred to as the Benthic Index of Biotic Integrity (BIBI). The Texas Surface Water Quality Monitoring Procedures (>http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-416/index html >) provide a detailed description of sampling and analysis protocols for the BIBI.

Harrison (2008) recently modified the BIBI that was developed for Texas streams to better account for inherent stream conditions that exist in the Southern Deserts and Southern Texas Plains ecoregions of West Texas. This modified BIBI is used to select a target value range for GUMO.

GUMO Benthic Index of Biological Integrity Target Value ≥ 21 (High Aquatic Life Use)

Stream Habitat

Physical stream habitat is the physical template upon which the biological structure of stream communities is built; without adequate habitat the biological potential of streams is limited. The following table describes the Habitat Quality Index (Surface Water Quality Monitoring Procedures: http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-416/index.html) as currently used by the Texas Commission of Environmental Quality. This index is comprised of nine habitat measurements with each measurement being scored into four scoring categories.

GUMO Habitat Quality Index Target Value ≥ 20

Air Resources

Atmospheric Deposition of Nitrogen and Sulfur Compounds

The target values for nitrogen (N) and sulfur (S) wet deposition are based on several factors, including natural background deposition estimates and deposition effects on ecosystems. Estimates of natural background deposition for total (wet and dry) deposition are approximately 0.25 kilograms per hectare per year (kg/ha/yr) in the West and 0.50 kg/ha/yr in the East for either N or S. For wet deposition only, this is roughly equivalent to 0.13 kg/ha/yr in the West and 0.25 kg/ha/yr in the East. The proportion of wet to dry deposition varies by location but, in general, wet deposition is approximately one-half of total deposition. Ecosystem responses have been documented at very low levels of deposition (e.g., 3 kg/ha/yr total deposition, or about 1.5 kg/ha/yr wet deposition) (Fenn *et al*., 2003; Krupa, 2002). Evidence is not currently available that indicates that wet deposition amounts less than 1 kg/ha/yr cause ecosystem harm. Therefore, for parks lacking quantitative deposition-response information, including GUMO, an "interim" target value of 1 kg/ha/yr wet deposition of either N or S is recommended. In the "2006 Annual Performance & Progress Report: Air Quality in National Parks," parks with wet N and S deposition less than 1 kg/ha/yr were considered to have "good" air quality in terms of deposition (National Park Service, 2006b).

GUMO Wet Deposition of Nitrogen or Sulfur "Interim" Target Value ≤ 1 kg/ha/yr

Visibility

Scenic values include visibility, that is, not only how far you can see but how well you can see. GUMO is a Class I area and the NPS has been working with the State of Texas to define natural conditions for visibility at the park as part of the State's plan to make progress towards natural visibility conditions. The Environmental Protection Agency requires States to track visibility using an index for haze called deciview, so for GUMO the RSS goal for "unobstructed views" will also be tracked using the deciview index.

The deciview index is scaled so that a reading of zero deciviews would represent an atmosphere free of particles. For the purposes of tracking the goal of "unobstructed views" the deciview index is computed for the 20 percent most and 20 percent least impaired days on a yearly basis. The State of Texas, with concurrence from NPS, has determined that the 20 percent most impaired days for any given year at GUMO should not exceed 12 deciviews. The 20 percent least impaired days should not exceed 2 deciviews. This range of 2 to 12 deciviews represents the estimated range of impairment that would result from natural biological and geological events such as periodic forest fires and sandstorms. Having measured visibility meet these values would be consistent with the goal of having unobstructed views.

GUMO Deciview Index Target Value for the 20% most impaired days ≤ 12 deciviews

GUMO Deciview Index Target Value for the 20% least impaired days ≤ 2 deciviews

Natural Resource Condition Summary Table

With indicator parameters and target values established, the condition of GUMO's priority physical resources can now be evaluated for resources with sufficient indicator data. Comparing the current condition of the priority resource with the established target or interim target value(s) will determine the "health" of that specific resource. As new data is made available, these condition assessments can be further refined. By identifying which indicators and sampling locations achieve or do not achieve the selected target value, park management can then begin to correlate influences (stressors) for the impacted physical resources.

The current conditions and stressors for GUMO's priority physical resources are summarized in the following Natural Resource Condition Summary Table.

Guadalupe Mountains Natural Resources Condition Summary Table: Geologic Resources, Water Resources, and Air Resources								
Fundamental or Other Important Resources and Values	**Desired Conditions**	**Attributes**	**Beneficial Influences**	**Detrimental Influences**	**Indicators**	**Management Target**	**Current Condition**	**Target Met?**
GEOLOGIC RESOURCES								
Capitan Reef and Related Deposits, Wilderness Character	The park's geologic resources are preserved and protected as integral components of the park's natural systems. Paleontological resources, including both organic and mineralized remains in body or trace form, are protected, preserved, and managed for public education, interpretation, and scientific research. Natural soil resources and processes function in as natural a condition as possible, except where special considerations are allowable under policy.	• Fossil reef exposures/paleo specimens • Hillslope features and processes • Geologic formations • Depositional features • Geomorphic processes • Weathering • Wilderness character	• Remote location	• Accelerated erosion processes • Roads and trails • External minerals development • Fossil collection • Climate change • Plant collection • Visitor impacts • Research sampling • Air quality • Vegetation • Fire	1. Change in specimen abundance at paleo localities ("Actual Loss" score) as measured by the Paleontological Locality Condition Assessment Form criteria	1. Actual Loss score = 20 for each locality	1. 48 of 50 localities actual loss score = 20 (30 additional localities evaluated using a different form without any point scoring)	1. No
Western Escarpment, El Capitan, Guadalupe Peak, McKittrick Canyon, Montane/Sky Island, Wilderness Character	The park's geologic resources are preserved and protected as integral components of the park's natural systems. Paleontological resources, including both organic and mineralized remains in body or trace form, are protected, preserved, and managed for public education, interpretation, and scientific research. Natural soil resources and processes function in as natural a condition as possible, except where special considerations are allowable under policy.	• Fossil reef exposures/paleo specimens • Hillslope features and processes • Geologic formations • Depositional features • Geomorphic processes • Weathering • Hydrological processes • Wilderness character	• Remote location	• Accelerated erosion processes • Roads and trails • External minerals development • Fossil collection • Climate change • Plant collection • Visitor impacts • Research sampling • Air quality • Vegetation • Fire	1. Change in specimen abundance at paleo localities ("Actual Loss" score) as measured by the Paleontological Locality Condition Assessment Form criteria	1. Actual Loss score = 20 for each locality	1. 48 of 50 localities actual loss score = 20 (30 additional localities evaluated using a different form without any point scoring)	1. No
Salt Basin, Gypsum Dunes, Wilderness Character	The park's geologic resources are preserved and protected as integral components of the park's natural systems. Paleontological resources, including both	• Gypsipherous soils • Landforms and geomorphic features (coppice	• Remote location	• Accelerated erosion processes • Roads and trails • External minerals development	1. % change in spatial extent of dunes, dune fields and sand sheets as measured by LIDAR mapping	1. % change no greater than natural variability as determined by changes in size, shape and position	1. Unknown	1. Unknown

Guadalupe Mountains Natural Resources Condition Summary Table: Geologic Resources, Water Resources, and Air Resources								
Fundamental or Other Important Resources and Values	**Desired Conditions**	**Attributes**	**Beneficial Influences**	**Detrimental Influences**	**Indicators**	**Management Target**	**Current Condition**	**Target Met?**
	organic and mineralized remains in body or trace form, are protected, preserved, and managed for public education, interpretation, and scientific research.	dunes, shoreline terraces and ridges, salt lake deposits, gypsum sand dunes); • Windblown features and processes (dune formation and stability) • Wilderness character		• Climate change • Plant collection • Visitor impacts • Research sampling • Air quality • Vegetation • Fire • Local/regional ground water development • Waste brine disposal (desalinization plant) • Ranching • Illegal ORV use • Irrigation	2.Change in seasonal shallow groundwater elevations	of the dunes 2. No change from natural seasonal ground water elevations.	2. Unknown	2. Unknown
Caves and Karst, Wilderness Character	Caves and karst are managed in accordance with approved cave management plans to perpetuate the natural systems associated with the caves and karst.	• Caves • Karst landscapes / systems • Sedimentation processes • Water chemistry • Drip and rimstone pools • Cave formations • Unique cave biota • Paleo resources • Archeological resources • Wilderness character	• Remote location	• Accelerated erosion processes • Roads and trails • External minerals development • Fossil collection • Climate change • Visitor impacts • Research sampling • Air quality • Local/regional ground water development • Alteration of surface drainage • Waste disposal	1. Cave and karst photo-monitoring. 2. Cave and karst inventory/survey	1. No change from established baseline. 2. No change from established baseline.	1. Unknown 2. Unknown	1. Unknown 2. Unknown

Guadalupe Mountains Natural Resources Condition Summary Table: Geologic Resources, Water Resources, and Air Resources								
Fundamental or Other Important Resources and Values	**Desired Conditions**	**Attributes**	**Beneficial Influences**	**Detrimental Influences**	**Indicators**	**Management Target**	**Current Condition**	**Target Met?**
AIR RESOURCES								
Views of the Western Escarpment and Canyons throughout the park, Wilderness Character	Air quality in the park meets national ambient air quality standards for criteria pollutants and protects air quality-sensitive resources. Natural visibility conditions exist in the park and scenic views of the landscape are not impaired by human activities.	• Air quality (visibility and particulate matter) • Clarity of distant landforms/measurement of scattered light • Viewshed/scenic vistas • Wilderness character	• Class 1 airshed • Remote location • Sub-rural, wilderness character • Topography (elevational gains) • Lack of roads (within park) challenging iconic vistas	• Fires, wind, climatic factors • Pollution/fugitive dust from roads, drill pads, agriculture • Traffic/road use • Highway and other unpaved roads • Power generation • Land use (encroaching urbanization) • Vegetative cover • Contrails	1. Deciview index	1a. Deciview index ≤ 2 on the 20% least impaired days 1b. Deciview index ≤ 12 on the 20% most impaired days	1a. Deciview index average of 6 on the 20% least impaired days 1b. Deciiview index average of 17 on the 20% most impaired days	1a. No 1b. No
					2. Wet deposition of nitrogen or sulfur	2. *Interim Value*: ≤ 1 kg/ha/yr	2a. Wet deposition of nitrogen approx. 1.9 kg/ha/yr 2b. Wet deposition of sulfur approx. 1.6 kg/ha/yr	2a. No 2b. No

Guadalupe Mountains Natural Resources Condition Summary Table: Geologic Resources, Water Resources, and Air Resources								
Fundamental or Other Important Resources and Values	**Desired Conditions**	**Attributes**	**Beneficial Influences**	**Detrimental Influences**	**Indicators**	**Management Target**	**Current Condition**	**Target Met?**
WATER RESOURCES								
Natural Hydrologic Processes (ground water, perennial streams, springs, seeps), McKittrick Canyon riparian corridor, Wilderness Character	Surface water and groundwater are protected and water quality meets or exceeds all applicable water quality standards. Watersheds are managed as complete hydrologic systems. Natural fluvial processes are allowed to proceed unimpeded, and stream processes that create habitat features are protected. Natural floodplain values are preserved or restored. The natural and beneficial values of wetlands are preserved and enhanced.	• Wilderness character • Watershed integrity • Physical stream habitat • Geomorphic processes • Aquifer integrity • Aquatic biological integrity • Water quality	• Remote location • Top of the watershed	• Local/regional development of groundwater resources • Poor design of hiking trails • Atmospheric deposition • Park waste management systems (septic, etc.) • Visitor use impacts • Parking lot and horse corral runoff • Drought • Climate Change • Building in floodplains	1.Discharge 2.Total nitrogen 3.Total phosphorus 4.Turbidity 5.Benthic Index of Biological Integrity (IBI) score 6. Habitat Quality Index (HQI) score	1. *Interim values*: Smith Spring ≥ 8 gpm, Guadalupe Spring ≥ 5 gpm, Frijole Spring ≥ 2 gpm, Bone Spring ≥ 2 gpm, South McKittrick Creek = natural seasonal range, Choza Creek = natural seasonal range 2. *Interim value*: ≤ 1 mg/L 3. *Interim value*: ≤ 18 µg/L 4. *Interim value*: ≤ 4 FTU 5. ≥ 21 (High Aquatic Life Use) 6. ≥ 20 (High quality habitat)	1. Smith Spring 8-48 gpm, Guadalupe Spring 5-7 gpm, Frijole Spring 2-4 gpm, Bone Spring 2-3 gpm, South McKittrick Creek = unknown, Choza Creek = unknown 2.Unknown 3.Unknown 4.Unknown 5.Unknown 6. Unknown	1.Yes (South McKittrick Creek and Choza Creek unknown) 2.Unknown 3.Unknown 4.Unknown 5.Unknown 6. Unknown

Strategies

The following strategies work towards improving natural resource data collection and begin to address the known stressors, moving GUMO's priority geologic, water, and air resources towards their respective *desired conditions*.

Geologic Resources

Paleontological Resource Inventory and Monitoring

Use of the Paleontological Locality Condition Assessment form to evaluate current known localities must suffice until a comprehensive inventory strategy is developed. The assessment form's ratings can be used as interim target values. The following list of needs can be undertaken individually until staffing and/or funds become available:

- Continue to explore areas for undocumented paleo resources.
- Map new localities.
- Protect specific stratotype and fossil locations.
- Catalog collected and salvaged fossils of significance.
- Incorporate protection of paleontological resources into planning efforts such as a trail management plans and develop a geological resources management plan.
- Develop photomonitoring protocols (SOPs) for *in situ* and museum paleo collections.
- Partnership opportunities on research – develop a park needs list for research and market it to researchers
- Document other specimens and localities from other institutions.
- Database management and GIS inventory upkeep for paleo resources.

Cave Inventory and Monitoring

Undertake a new inventory and develop a subsequent monitoring protocol for cave resources. The lack of personnel and fiscal resources prevents the park from planning, organizing, and implementing a comprehensive cave inventory. In the interim, implement the 1991 Cave Management Plan. In addition, the following list of needs can be undertaken individually until staffing and/or funds become available:

- Perform new cave inventory
- Explore/search for new cave localities and map.
- Revise the Cave Management Plan.
- Monitor and permit cave research and exploration in the park.
- Maintain park cave permitting system.

Salt Basin Dunes Monitoring

Develop a monitoring protocol for the Salt Basin. GUMO and CHDN should coordinate the respective mapping and monitoring efforts within the network. The data generated could be used for regional trend analyses, maximize monitoring efficiencies and reduce mapping and monitoring costs. The lack of personnel and fiscal resources prevents the park from implementing a comprehensive monitoring program for the Salt Basin. The following list of needs can be pursued individually until staffing and/or funds become available:

- Acquire high-resolution mapping of the dunes and surrounding source areas to evaluate dune dynamics.
- Utilize the ongoing soils mapping effort to determine extent of gypsipherous soils and dependent vegetation communities.
- Develop a ground water monitoring program through the use of shallow piezometers.
- Determine natural range of variability of dune movement and determine dune mobility index.

Soil Stability Monitoring

Perform qualitative assessments, in association with monitoring and inventory information, to provide early warnings on soil impacts. GUMO and CHDN should coordinate their respective monitoring efforts within the network, as one of the seven CHDN monitoring protocols is *Soils and Vegetation*. This protocol will heavily rely on the *Interpreting Indicators for Rangeland Health* (Herrick *et al*., 2005). It is an established protocol that provides a preliminary evaluation of soil/site stability, hydrologic function, and biotic integrity (at the ecological site level). This will provide early warnings of potential problems and opportunities by identifying areas that are potentially at risk of degradation or where resource problems currently exist. The lack of personnel and fiscal resources prevents the park from implementing a comprehensive program to implement the *Interpreting Indicators for Rangeland Health* protocol, though the CHDN monitoring program may meet some of the park's needs regarding monitoring of soil stability. The following list of needs can be pursued individually until staffing and/or funds become available:

- Utilize the ongoing soils mapping effort to determine baseline soils data and dependent vegetation communities.
- GUMO should evaluate current trail designs, closing unwanted access and redesigning trails, as needed, to minimize soil erosion and sedimentation into surface waters at GUMO.

Water Resources

Water Quality Monitoring Program

GUMO and Chihuahuan Desert Network (I&M) staff should coordinate sampling efforts (water quality parameters, sample methodologies, and sample locations) between their respective water quality programs at the park to assess both surface and ground water at GUMO, concentrating on four springs (Smith Spring, Guadalupe Spring, Frijole Spring, and Bone Spring) and South McKittrick and Choza creeks. As additional resources are made available, expansion of sampling locations (Manzanita Spring, etc.) and water quality parameters (dissolved oxygen, water temperature, bacteria, pH, etc.) should be assessed and implemented where feasible. For potable water supplies, GUMO should use the U.S. EPA drinking water standards (U.S. Environmental Protection Agency, 2007) as target values.

- Turbidity samples should be collected to establish baseline and further refine the current "interim" turbidity target value of ≤ 4.0 FTU. Until this is completed, interim target values are provided based on regional EPA data.

- Since there are no State criteria for nutrients, it is recommended that nutrient samples (total phosphorus and total nitrogen) be concurrently collected with biological and stream habitat assessments recommended in this report to examine the statistical relationship between nutrient concentrations and the assessment endpoints, such as the benthic indices of biotic integrity and habitat quality index. Once clear nutrient relationships can be correlated with water resource health, park-specific numerical criteria can be determined that support the desired conditions for GUMO's water resources. Until this has been completed, interim nutrient target values are provided based on regional EPA data.

Benthic Macroinvetebrates

- Green (1993) provides the best scientific information for determining reference condition for McKittrick Creek. Ostensibly, one could use Green's data to calculate the BIBI for McKittrick Creek. This would represent baseline, reference condition (circa 1993) for the creek. A present day determination of the BIBI would then be compared to the 1993 reference condition. If it is determined that Green's data are not amenable for use in calculating the BIBI, then a present day determination of the BIBI would serve as the baseline, reference condition.

Stream Habitat

- Habitat data collected in conjunction with benthic macroinvertebrate community surveys provides a holistic evaluation of the health of biological assemblages. GUMO is encouraged to seek assistance in using the Habitat Quality Index currently used by the Texas Commission of Environmental Quality (Surface Water Quality Monitoring Procedures: http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-416/index.html), which was described earlier in the report ("Indicators and Target Values"). This index is comprised of nine habitat measurements with each measurement being scored into four scoring catergories.

Riparian System Assessment

- A riparian assessment tool, Assessing Proper Functioning Condition (Bureau of Land Management, 1995) can be used to evaluate riparian systems. This technique employs an interdisciplinary team to assess riparian area "functionality" according to 17 hydrological, vegetational, and stream geomorphological factors. It provides an initial screening tool that can separate areas that are functioning well from those in need of more intensive evaluation or management actions. In this way, money and effort can be targeted toward higher priority issues. The assessment of the park's riparian systems is seen as an infrequent (e.g., every 5 years), long-term effort to address the riparian functionality in the face of: 1) increased or inappropriate resource use; and 2) the effects of climate change (e.g., invasion of exotic or terrestrially-based vegetation into the riparian areas due to increase in temperatures and/or decreases in surface/ground water quantity).

Spring/Seep Systems

A standardized sampling protocol is needed that will allow a more thorough understanding of the effects of disturbance on spring biota and moderate the effects of anthropogenic uses to prevent additional loss and restore spring habitat quality.

- A sampling protocol developed by Sada *et al.* (2003) for the NPS Mojave Inventory and Monitoring Network is recommended. This protocol offers a three-tiered approach based on the nature of the NPS planning process: 1) assessment of resource condition; 2) if resource conditions do not meet desired conditions, then conduct surveys that address management challenges; 3) a third level of more quantitative information may be needed to address individual resource issues, which require long-term monitoring. Level 1 surveys are designed to identify and characterize spring resources, delineate the distribution of important species and salient aspects of their habitat, and to determine unique resource challenges. Level II surveys qualitatively sample riparian and aquatic communities to determine community structure, and quantitatively sample salient physicochemical elements to identify aquifer affinities. Finally, Level III surveys quantitatively sample additional physicochemical elements to determine aquifer dynamics. In addition, they quantitatively sample riparian and aquatic communities and habitats to determine spatial and temporal variation in environmental and biotic (e.g., abundance and community structure) characteristics, and to quantitatively determine biotic and abiotic interactions. Sada *et al.* (2003) provide a description of the Level I protocol; protocols for Levels II and III will be forthcoming.

Aquifer Characterization

- Elevation of the local ground water table(s) (potentiometric surface) in the immediate area of GUMO should be established to document ground water flow directions, seasonal fluctuations and overall trends in ground water levels. Building from the recent ground water work (well inventory) completed by the Edwards Aquifer Research and Data Center in San Marcos, Texas, GUMO should use existing ground water wells with appropriate screened intervals and add to that network of wells (installation of piezometers), as needed. It will be important to know the “screened’ intervals of the wells in order to correlate the measurement to the appropriate aquifer (shallow versus deep aquifer). From the water level data, ground water flow directions can be determined for the respective aquifers. Aquifer tests (pumping tests or slug tests) can be performed on select wells to define local hydraulic conductivity and flow velocities of aquifers.

  Installation and monitoring of shallow piezometers are encouraged within the gypsum sand dunes to evaluate seasonal fluctuations in the shallow water table.

Floodplain Management

- GUMO will preserve floodplain values and minimize potentially hazardous conditions associated with flooding. When it is not practicable to locate or relocate development to a site outside the floodplain, the NPS is instructed to prepare and approve a statement of findings in accordance with procedures described in Director's Order 77-2 (Floodplain Management). Requirements for development in floodplains are contained in Executive Order 11988 (National Park Service, 2006a).

Wetlands Inventory

- Wetlands within GUMO should be delineated by qualified staff or certified wetlands specialists using the Cowardin *et al.* (1979) system. GUMO should conform with NPS Management Policies concerning wetlands and wetland protective actions, and in NPS DO 77-1. The spatial extent of wetlands and wetland types should be captured in a geographic information system (GIS) database and updated as new information is made available.

Wastewater Treatment

- GUMO should determine compliance of existing septic system within the park and upgrade inadequate systems, as needed.

Parking Lot and Horse Corral Management

- GUMO should consider stormwater treatment for parking lot runoff using bioretention areas, filter strips, and other proven practices that can be integrated into the landscaped areas. Park operations should continue to include proper waste removal at horse corrals in the park and minimize sediment runoff in the devegetated areas.

Climate Change

- GUMO should evaluate what can and should be done to minimize the effects of climate change on their natural resources, and to maximize opportunities for wildlife, vegetation, and the processes that support them to survive in the face of climate change. Contacting and working with the NPS Climate Change Coordinator, Dr. Leigh Welling (970.225.3513) to identify state and local resources that can assist GUMO with an appropriate management direction should be the first step. Monitoring the outcomes from New Mexico's Climate Change Advisory Group (CCAG) would also be informative to park staff as they move forward with appropriate management actions towards climate change.

Water Rights

- In order to address the park's water rights needs, park administration must develop an understanding, on a case-by-case basis, of the park's water uses and water-dependent resources. This understanding should incorporate risks associated with water development adjacent to, or nearby, the park. With such an understanding, the park should then determine whether existing water rights, based either on state law or federal law, are sufficient to meet the park's mission. While preserving its legal remedies, the park should seek to protect its water rights and resources through state water administrators, and where appropriate, through negotiations with other competing water uses (Lord, pers. comm., 2008). GUMO should consult with the NPS Water Resources Division (Water Rights Branch) as they work through this water rights strategy for the park.

Participation in Local, State, and Regional Water Resource Management

- GUMO is strongly encouraged to participate in these regional water planning efforts (Far West Texas Water Plan) so they are able to understand and appropriately react to future development of water resources. Additional partnerships should be explored with the Texas Commission of Environmental Quality, Edwards Aquifer Research and Data Center (San Marcos, TX), and U.S. Geological Survey in expanding and sharing the collection of vital data for water resources.

Air Resources

Monitoring Atmospheric Deposition

- GUMO should continue monitoring wet deposition, which is done as part of the National Atmospheric Deposition Program (NADP). GUMO personnel operate and maintain a NADP sampler, which collects weekly precipitation samples for laboratory analysis. Precipitation is analyzed for nitrate, ammonium, sulfate, hydrogen ions, and other cations and anions. Data are reported as concentrations, in milligrams per liter (mg/L), or deposition, in kilograms per hectare (kg/ha). Because the GUMO sampler is part of an over 200-site network, data can be compared spatially and temporally to other sites.

Monitoring Visibility

- GUMO should continue to monitor and track visibility conditions, which are monitored as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. The IMPROVE network monitors atmospheric particles and aerosols on a one in three day schedule throughout the year at over 110 locations in the U.S, including a site near GUMO.

Given the periodic and short-term impairment events (e.g., duststorms) at GUMO, the IMPROVE network monitoring should be supplemented with a nephelometer. This instrument provides continuous measurements of aerosol extinction, a surrogate for visibility. A nephelometer would provide better time resolution of events captured on the IMPROVE filters and indicate the frequency and magnitude of visibility impairment events on days not currently monitored under the IMPROVE sampling protocol.

Participation in Local, State, and Regional Air Quality Management

- GUMO is strongly encouraged to continue to participate in local, state, and regional air quality management activities. GUMO, along with the NPS Air Resources Division, should continue to provide guidance to permit applicants regarding air quality and air quality related value (AQRV) analyses. This guidance is found in the Federal Land Managers AQRV Workgroup (FLAG) Report (National Park Service 2000). In addition, GUMO should continue to consult and advise the State of Texas on the State's plan to make progress towards natural visibility conditions.

Introduction

This *Physical Resources Stewardship Report* (PRSR) is designed to build from Guadalupe Mountains National Park's (GUMO's) *General Management Plan* (GMP) and support development of GUMO's *Resource Stewardship Strategy* (RSS). The RSS serves as a bridge between the qualitative statements of desired condition established in the GMP and the measurable goals and implementing actions that will be identified in the park *Strategic Plan* and *Implementation Plans*. The following section outlines the NPS planning framework and describes how this report fits into this planning process.

National Park Service Planning Framework

Changes in NPS general planning (2004 *Park Planning Program Standards*) and resources planning (draft *Director's Order 2.1: Resource Stewardship Planning*) required programmatic revision to the existing NPS Water Resources Planning Program to assure that its products support the new NPS planning framework within which planning and decision-making are now accomplished. The importance of supporting park planning is also recognized by the other NPS Natural Resources Program Center (NRPC) divisions. This report is the first product to expand into more than one natural resource discipline, with contributions from the Water Resources Division (WRD), Geological Resources Division (GRD), and Air Resources Division (ARD).

Within the new planning framework, the following six elements of planning are captured in six planning-related documents (Figure 1):

1. The *Foundation for Planning and Management* (Foundation Statement) defines the legal and policy requirements that mandate the park's basic management responsibilities, and identifies and analyzes the resources and values that are fundamental to achieving the park's purpose or otherwise important to park planning and management.
2. The *General Management Plan* (GMP) uses information from the Foundation Statement to define broad direction for resource preservation and visitor use in a park, and serves as the basic foundation for park decision-making, including identification of management zones and *desired conditions* for fundamental and important park resources and visitor experiences.
3. The *Program Management Plan* tiers off the GMP, identifying and recommending the best strategies for achieving the desired resource conditions and visitor experiences presented in the GMP. Program planning serves as a bridge to translate the qualitative statements of *desired condition* established in the GMP into measurable or objective indicators that can be monitored to assess the degree to which the *desired conditions* are being achieved. Based on information obtained through this analysis, strategies are listed that move the resource(s) and visitor experiences towards the *desired conditions*. The Program Management Plan component for natural and cultural resources is the *Resource Stewardship Strategy* (Figure 1).

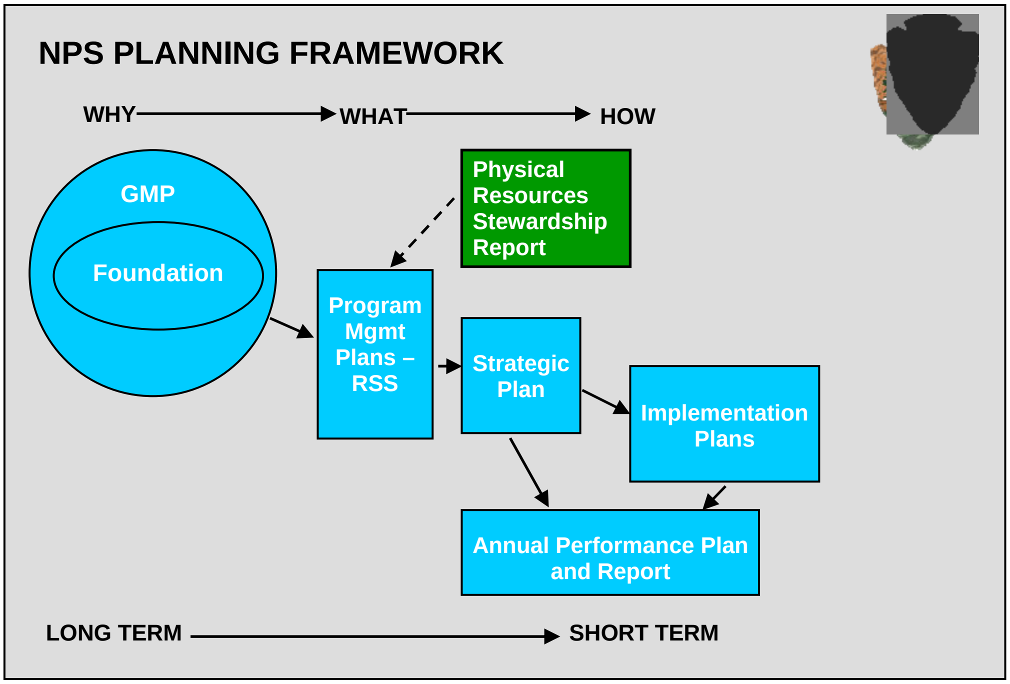

Figure 1. The NPS framework for planning and decision making (blue boxes). Green box represents WRD-GRD-ARD supporting planning product. RSS = Resource Stewardship Strategy.

4. The *Strategic Plan* tiers off the Program Management Plan, identifying the highest-priority strategies, including measurable goals that work toward maintaining and/or restoring the park's *desired conditions* over the next 3 to 5 years.
5. *Implementation Plans* tier off the Strategic Plan, describing in detail (including methods, cost estimates, and schedules) the high-priority actions that will be taken over the next several years to help achieve the *desired conditions* for the park.
6. The *Annual Performance Plan and Report* measures the progress of projects from the Implementation Plan with objectives from the Strategic Plan.

The *Physical Resources Stewardship Report* supports this new planning framework (Figure 1) and is designed specifically to address the natural resource needs in a park's Resource Stewardship Strategy.

In 2008, GUMO completed their GMP to comply with the 1978 National Parks and Recreation Act requiring all NPS units to develop a GMP. The GMP was needed to address priority resources at the park and identify new information and understanding about the park's resources.

GUMO requested technical assistance from the NPS WRD and GRD in 2007 to develop this *Physical Resources Stewardship Report*, in support of the national park's next planning product, the *Resource Stewardship Strategy* (RSS). Once the technical assistance started, ARD joined the effort to better meet the natural resources information needs at GUMO.

Physical Resources Stewardship Report Objectives

The overarching goal of this *Physical Resources Stewardship Report* is the development of comprehensive strategies for “fundamental” and “other important” water, geologic, and air resources that work toward achieving or maintaining the GMP’s desired conditions, with measurable or objective indicators to assess the degree to which the desired conditions are being achieved. More specifically, this report will: 1) summarize existing information on water, geologic, and air resources, and if insufficient, develop strategies for its acquisition; 2) assess existing water, geologic, and air resource data in terms of measurable values in comparison with values defined for achievement of desired conditions – if information is incomplete or lacking quality, describe strategies for its acquisition; 3) describe trends in water, geologic, and air resource conditions based on available monitoring information – if information is insufficient, develop strategies for its acquisition and analysis; 4) identify and analyze water, geologic, and air resource management issues that are impediments to achievement and maintenance of desired conditions; and 5) develop resource strategies to achieve and maintain the desired resource conditions.

Physical Resources Stewardship Report and NEPA

The National Environmental Policy Act (NEPA) mandates that federal agencies prepare a study of the impacts of major federal actions having a significant effect on the human environment and alternatives to those actions. The adoption of formal plans may be considered a major federal action requiring NEPA analysis if such plans contain decisions affecting resource use, examine options, commit resources or preclude future choices. Lacking these elements, this *Physical Resources Stewardship Report* has no measurable impacts on the human environment and is categorically excluded from further NEPA analysis.

According to Director’s Order (DO) #12 Handbook, *Conservation Planning, EIS and Decision Making* (section 3.4), Physical Resources Stewardship Reports normally will be covered by one or more of the following Categorical Exclusions:

- 3.4.B (1) Changes or amendments to an approved plan when such changes have no potential for environmental impact.
- 3.4.B (4) Plans, including priorities, justifications, and strategies, for non-manipulative research, monitoring, inventorying, and information gathering.
- 3.4.B (7) Adoption or approval of academic or research surveys, studies, reports and similar documents that do not contain and will not result in NPS recommendations.
- 3.4.E (2) Restoration of non-controversial native species into suitable habitats within their historic range.
- 3.4.E (4) Removal of non-historic materials and structures in order to restore natural conditions when the removal has no potential for environmental impacts, including impacts to cultural landscapes or archeological resources.
- 3.4.E (6) Non-destructive data collection, inventory, study, research, and monitoring activities.

- 3.4.E (7) Designation of environmental study areas and research natural areas, including those closed temporarily or permanently to the public, unless the potential for environmental (including socioeconomic) impact exists.

These Categorical Exclusions require that formal records be completed (Section 3.2, DO-12 Handbook) and placed in park files. It is the responsibility of the national park to complete the documentation for the applicable Categorical Exclusion(s) when the *Physical Resources Stewardship Report* is approved and published.

Guadalupe Mountains National Park Location and Demography

Guadalupe Mountains National Park (GUMO) is located in west Texas (Hudspeth and Culberson counties) along the Texas-New Mexico boundary, approximately 110 miles east of El Paso, Texas and 55 miles southwest of Carlsbad, New Mexico (Figure 2).

GUMO was established in 1972, preserving the rugged spirit and remote wilderness of the American West (Figure 3). This is a region of diverse habitats and vegetation, varying from desert valleys and plateaus to wooded mountain slopes. Elevations in the region range from 1,850 ft (565 m) (msl) to 8,749 ft (2,667 m) (msl) at Guadalupe Peak (Texas Parks and Wildlife, 2007). GUMO preserves the heart and western terminus of the Capitan Reef, a limestone fossil reef that contains the world's best example of Middle Permian geological formations.

Agriculture, including both the beef industry and irrigated farming, is the most significant economic activity in the region, with an increase in minerals exploration. This area encompasses the most arid region in Texas where the region's economic health and quality of life are dependent on a sustainable water supply that is equitably managed (Far West Texas Water Planning Group, 2006). With an average annual rainfall around 12 inches, the raising of crops in this region requires irrigation.

The park has been designated a Class I air quality area under the Clean Air Act and, as such, receives the highest protection under the Act.

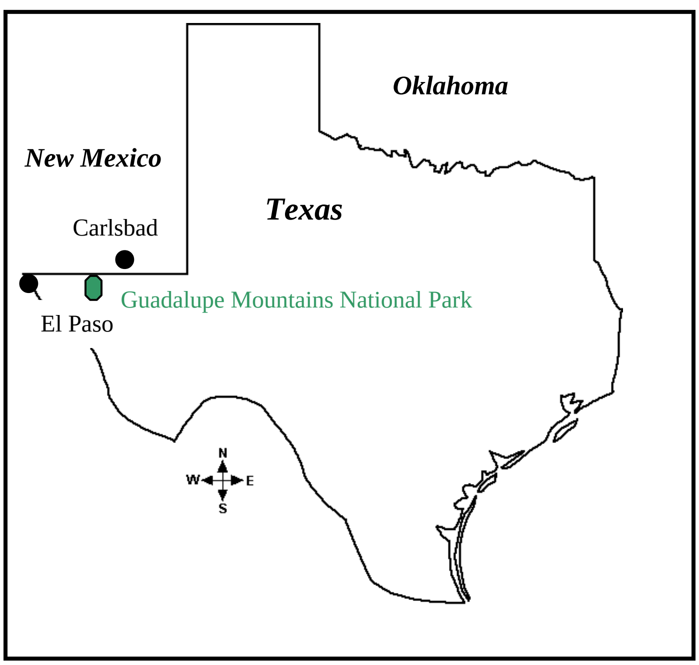

Figure 2. Regional Location Map.

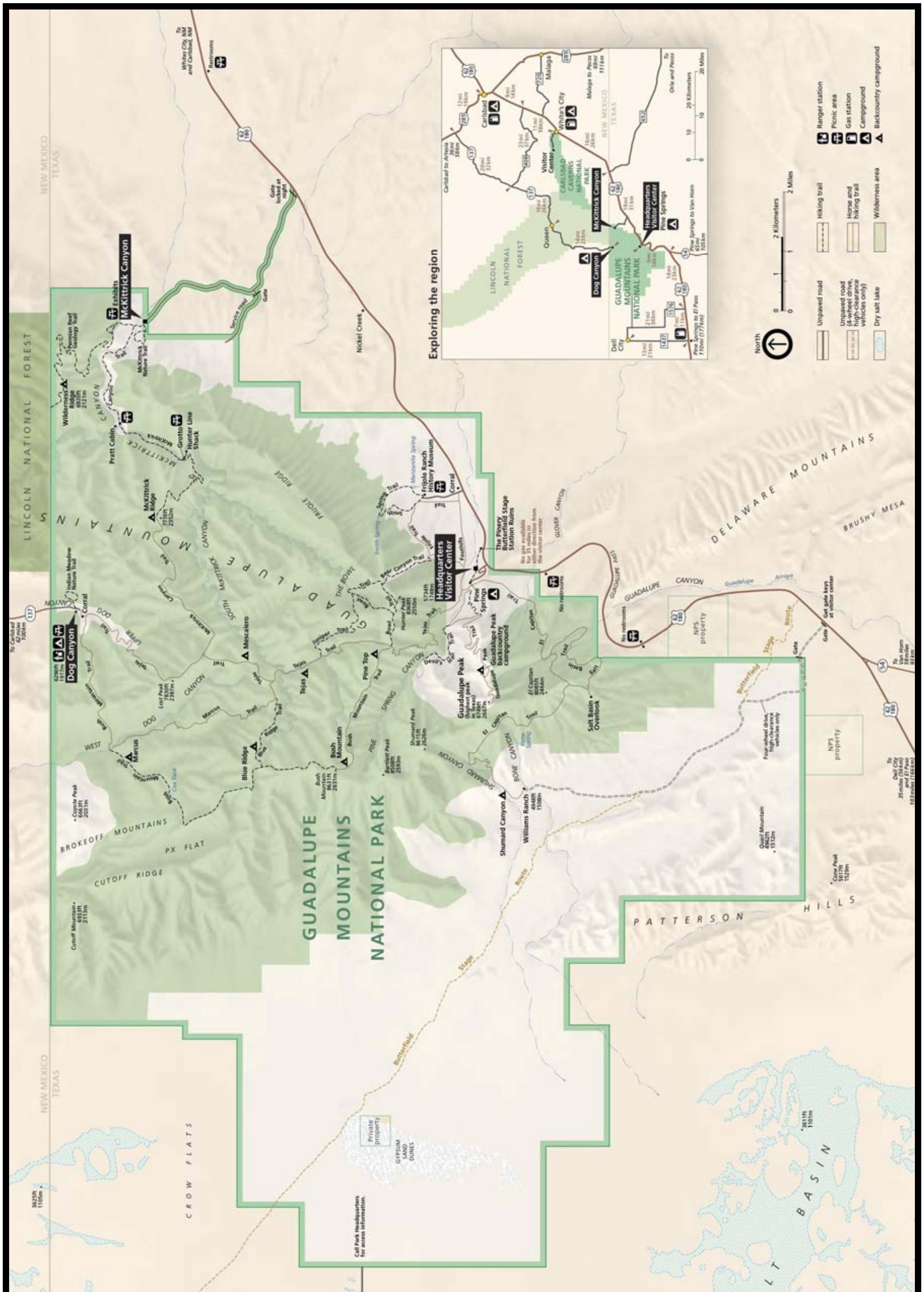

Figure 3. Guadalupe Mountains National Park (National Park Service, 2008).

Description of Natural Resources

Climate

GUMO is located in the northern part of the Chihuahuan Desert, a large arid zone that extends southward into Mexico. The higher altitudes of GUMO receive sufficient precipitation to be considered semiarid, rather than true desert. Most rainfall occurs between June and October. Rainfall during the spring and summer months is dominated by widely scattered thunderstorms. Because of the convective nature of thunderstorms, the amount of spring and summer precipitation in the region increases with elevation. Winter precipitation comes from frontal systems, which are generally soaking rains covering larger areas (Far West Texas Water Planning Group, 2006).

Over most of the area, average annual rainfall is less than 12 inches, but varies greatly from year to year and from lower to higher elevations. The average annual rainfall at Pine Springs (elevation 5597 ft msl), along GUMO's eastern boundary, was 18.3 inches between 1939 and 1995 (Figure 4) (World Climate, 2008). July and August are usually the higher rainfall months (Texas Parks and Wildlife, 2007).

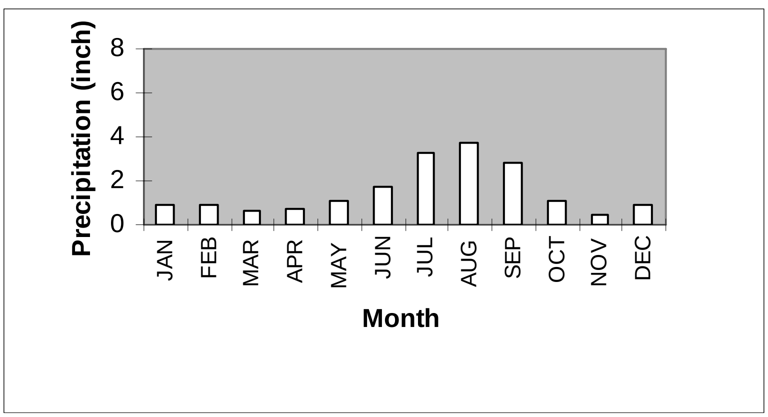

Figure 4. Monthly mean precipitation (1939-1995), Pine Springs, Texas (5597 ft msl) (World Climate, 2008).

South, central and west Texas have experienced recurrent periods of drought from the 1990s through 2006. The El Nino Southern Oscillation, a cyclical fluctuation of ocean surface temperature and air pressure in the tropical Pacific Ocean, affects pacific moisture patterns, and is responsible for long-term (decadal) changes in Texas' precipitation, leading to periods of moderate to severe drought. During a weak oscillation, precipitation will generally be below average and some degree of drought will occur. During a strong oscillation, Texas will usually experience above average precipitation.

Physiography

GUMO is located within the Basin and Range physiographic province, which covers much of the southwestern United States and northwestern Mexico. This physiographic province is typified by elongate north-south trending arid valleys bounded by mountain ranges. This physiographic province is characterized by higher elevations and greater local relief than is observed anywhere else in Texas (Far West Texas Water Planning Group, 2006). The Basin and Range province in Texas is divided into two sections, the Mexican Highland and the Sacramento section. The Sacramento section, which includes GUMO, has more extensive plateaus than the Mexican Highland, and contains the highest point in Texas, Guadalupe Peak, at 8,749 ft (2,667 m) above mean sea level (msl).

The basins are down-fallen blocks of crust and the ranges are relatively uplifted blocks, many of which tilt slightly eastward at their tops. The normal arrangement in the basin and range system is that each valley (i.e., basin) is bounded on each side by one or more normal faults that are oriented along or sub-parallel to the range front.

The local terrain around GUMO includes basins broken by numerous small mountain ranges including the Guadalupe Mountains. These create sky islands of cooler, wetter climates within the desert, and such elevated areas have both coniferous and broadleaf woodlands, and even forests along drainages and favored exposures.

Geology

During the Permian Period (roughly 260 million years ago), the Delaware Basin was a vast inland sea that covered over 10,000 square miles of what we now know as Texas and New Mexico. Near the shallow margins of this sea, calcium carbonate precipitated from the water and various invertebrate species such as fusulinids, bryozoans and calcareous sponges formed the Capitan Reef. GUMO sits at the point where the reef formed a wedge pointing southward (Figure 5).

The two most prominent points in the park, El Capitan and Guadalupe Peak mark the location of the seaward face of the Capitan Reef. The vast landscape to the south of Guadalupe Peak was once covered by the deep waters of the Delaware Sea and northward, the lagoon and coastal plain. Today, reef exposures are revealed in the canyons and caves found throughout the Guadalupe Mountains. The most extensive exposure is the 40 mile stretch of southeastern escarpment that extends northward through GUMO and Carlsbad Caverns National Park. Within GUMO, the entire 2000 foot extent of the Capitan Reef is displayed in McKittrick Canyon

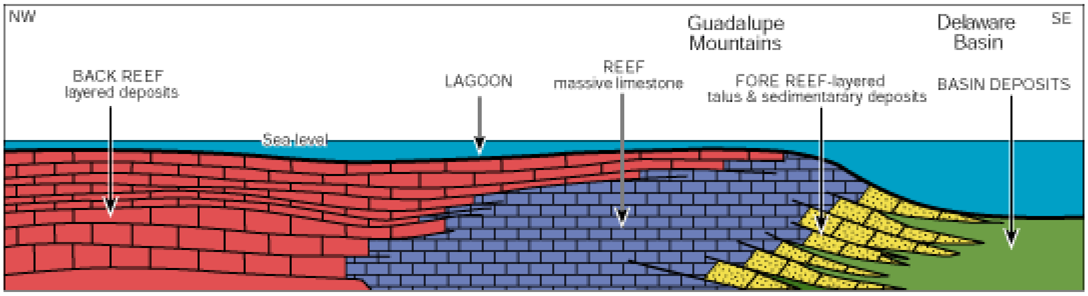

Figure 5. Cross-section of Capitan reef complex (Foster, 1983; Jagnow and Jagnow, 1992).

Regionally, the geologic units are divided into three groups based on their lithologic and hydrogeologic characteristics. These three groups are the Permian shelf, the Capitan Shelf Margin (which is the actual reef trend itself), and the Basin Fill in the interior of the basin (Uliana, no date) (Figure 6).

The Permian Shelf group, or facies, are the rocks that were deposited in the shallow water landward of the shoal island trend of the shelf crest (Figures 5 and 6). This group consists of lower permeability carbonate sediments and evaporites, like gypsum and rock salt. The natural permeability of these rocks is very low, so the overall permeability in the shelf facies is dependant upon fracture porosity – in other words, most of the water is flowing through fractures. Consequentially, the success of water wells drilled into the shelf facies is dependant upon hitting a productive fracture, and therefore, well yields in these rocks are highly variable.

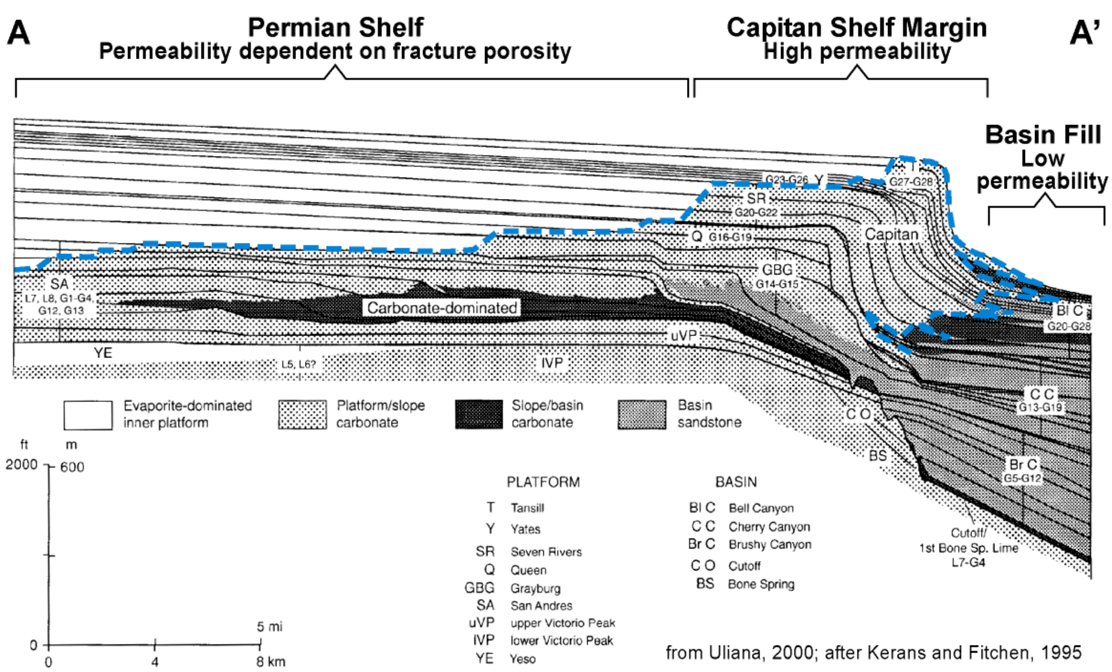

Figure 6. Permian Basin Geology (Uliana, no date).

The Capitan Shelf Margin facies is the reef itself along with a band of outer shelf rock characterized by coarse grain size and high porosity (Figures 5 and 6). The reef rocks have a relatively high porosity and permeability, even without fracturing, due to the primary porosity present when the reef was formed. The high primary porosity in these rocks is further increased by karstification, or dissolution of the bedrock by flowing ground water. An excellent example of karstification is Carlsbad Caverns, an extensive cave network formed in the Capitan Shelf Margin limestone.

The Delaware Basin facies is the remains of the mud and silt that washed into the middle of the basin and settled out on the sea floor (Figures 5 and 6). Unlike the carbonate and evaporite rocks of the other two facies, these rocks consist mainly of low permeability siliciclastic sediments (like fine sand, silt, and clay). The permeability of the basin fill is generally very low, and well yields are usually not very good. However, a number of thin carbonate tongues emanate from the base of the forereef slope and intercalate between thick siliciclastic wedges. These tongues are the primary conduits of ground water that flows from a number of springs at the base of the southeast escarpment.

Salt Basin

Landforms within the Salt Basin, located along GUMO's western boundary (Figure 3), record the existence of a large isolated lake that gradually dried and became a playa lake basin during the last 10,000 years of the Quaternary Epoch. Progressive shrinking of the lake left behind classic geomorphic features such as coppice dunes, salt lake deposits, shoreline terraces, shoreline dune ridges, and the second largest gypsum sand dune field in North America.

Caves and Karst

The carbonates that make up much of the geology at GUMO have actively eroded, producing karst features, such as caves, in the landscape. The caves found within the park are not large in volume and relatively short in surveyed linear distance; contain significant speleothem deposition; and, are relatively dry (due to the semi-arid terrestrial environment and cool winter air that enters the caves). A majority of these caves are joint controlled and formed in the massive Capitan Reef formation and its contacts with adjacent forereef and backreef rocks. Though activity is currently limited, there is the potential for education and recreational opportunities to a broad spectrum of park visitors, from the casually curious to the avid caver, while also providing opportunities for scientific study of cave resources.

Paleontology

In 1855, a geologist and member of a party exploring for a feasible railroad route to California along the newly established U.S. and Mexico border recorded strata of the southern tip of the Guadalupe Mountains and collected fossils from the Capitan Limestone in the vicinity of Guadalupe Pass and El Capitan. The collection was used to identify the Guadalupe Mountains as the first known marine Permian outcrops in North America. Almost a half century later in

1901, a U.S. Geological Survey (USGS) geologist, extensively collected invertebrate fauna from the strata of the southern Guadalupe Mountains, mostly of the Capitan Limestone on the southern slopes of Guadalupe Peak. In 1908, the USGS published a monograph based on these collections (Girty, 1908). Since the 1950s, the majority of paleontological studies of GUMO have focused on depositional environments, in particular, understanding of the sedimentological origin of the Capitan Reef and equivalent backreef and basinal depositional patterns.

Investigators have found more than 500 Permian fossil species in the Guadalupe Mountains. Organisms such as calcareous sponges, encrusting calcareous algae, and bryozoans formed the framework of the reef. The common group of shelled creatures known as brachiopods are found in abundance in the Permian Basin. Also abundant during reef building were fusulinids, which date back 250 to 350 million years. These unicellular creatures became extinct at the end of the Permian Period. Fusulinids are members of a major group of fossils called foraminifera that possess lime-rich shells, which helped build the Capitan Reef. A third abundant group of fossils in the Permian reef is the echinoderms, such as crinoids (sea lilies) and echinoids (sea urchins). Various mollusks are also part of the reef complex, for example, gastropods (snails), scaphopods (tusk shells), cephalopods with chambered shells (modern cephalopod species include octopi and squid), and pelecypods (clams) (DuChene, 2000), as well as corals, trilobites, and conodonts.

Since the 1930s, investigators have recognized the Guadalupe Mountains for their significant Pleistocene/Holocene cave fossils, including herptefauna; avian remains (i.e., bones and feathers); small mammals; and extinct sloth remains (i.e., dung and hide with hair). Four of the 10 known localities in the world for fossil sloth dung occur in GUMO: Lower Sloth Cave, Upper Sloth Cave, Dust Cave, and Williams Cave. Based on plant macrofossils and pollen collected from caves in GUMO, investigators have established a 13,000-year-long chronological sequence of late Pleistocene and Holocene plant communities in the Guadalupe Mountains. The plant communities in the Guadalupe Mountains have gradually changed from relatively mesic (moist) woodland and forest associations during pluvioglacial climates in the Late Wisconsin glacial epoch to the present xeric (dry) Chihuahuan desert scrub.

Soils

The soils of GUMO are influenced strongly by elevation and aspect. They tend to be calcareous and very thin to absent. Rock cover holds most of the shallow soils in place, which protects them against erosion and traps moisture. Exposure and disturbance of the soils of GUMO make them highly susceptible to wind and water erosion. The numerous arroyos reflect the significance of floods with deposition and bank cutting a normal occurrence. The thicker soils in the Salt Basin are of two types; sand and gypsiferous. The latter support only a few, highly adapted plants and unusual cryptobiotic organisms.

Hydrology

Watersheds

According to the NPS Management Policies, the NPS will manage watersheds as complete hydrologic systems, and will minimize human disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams (National Park Service, 2006a).

Watersheds are delineated by the U.S. Geological Survey using a nationwide system based on surface hydrologic features. This system divides the country into 21 regions, 222 subregions, 352 accounting units, and 2,262 cataloguing units (U.S. Geological Survey, 2008). A hierarchical hydrologic unit code (HUC) consisting of 2 digits for each level in the hydrologic unit system is used to identify any hydrologic area. The 6-digit accounting units are generally referred to as basins. HUC is defined as the Federal Information Processing Standard (FIPS) and generally serves as the backbone for the country's hydrologic delineation.

GUMO is located at the intersection of three Basins; 1) Rio Grande Closed Basins' (USGS cataloging unit: 130500), 2) Upper Pecos (USGS cataloging unit: 130600), and 3) Lower Pecos (USGS cataloging unit: 130700) (U.S. Geological Survey, 2008).

Streams

West Texas streams are part of a very fragile ecosystem, dependent upon a scarce water supply, often fed by springs. As in other parts of the state, these streams provide a variety of habitats, from shallow, swift-flowing areas to deep, slow-moving pools supporting a variety of fish, reptiles, amphibians, insects and mammals. The associated riparian areas provide critical habitat to local wildlife (Texas Parks and Wildlife, 2007).

The Guadalupe Mountains contain boreal environments which serve as a refuge from the desert for many plant and animal species. Springs and perennial streams, found in these mountainous areas, provide a permanent habitat for many species. South McKittrick Creek arises from a spring-fed source in South McKittrick Canyon. This stream flows discontinuously, but perennially, throughout its course until permanently disappearing near the canyon entrance and provides McKittrick Canyon with a year-round source of water that supports a diverse flora and fauna. Physical and biotic changes occur with increased distance from the canyon entrance. As the canyon narrows upstream, the stream gradient increases from 100 to 317 ft/mi (19 to 60 m/km) (Meyerhoff and Lind, 1987). Pools, the primary aquatic habitat, are connected by short, shallow riffles. Pools vary from 0.5 to 3.3 ft (15 to 100 cm) in depth with an average depth approximately 1 ft (30 cm). Riffles are 0.5 to 0.6 ft (15 to 20 cm) deep. Water temperature varies little along the stream course, a consequence of alternating subterranean and surface flow (Meyerhoff and Lind, 1987).

Petersen (2002) assessed the physical aspects of stream habitat for McKittrick Creek as part of her study on the ecology of fishes in McKittrick Creek. McKittrick Creek is a low gradient (mean = 1 - 2%) stream with a pool:riffle ratio of approximately 1:2. Substrate was dominated by cobble (27%), gravel (30%), and bedrock (36%). The streambed was covered with travertine granules and in many areas the bed is "accreted into a stucco-like material" (Petersen, 2002). The highest travertine concentrations are found in the lower reaches of the creek where, in general, the gradient and velocity are lower.

KellerLynn (2008) provides a description of travertine and its genesis in McKittrick Creek:

> The waters of McKittrick Creek are laden with calcium carbonate. As the water splashes over the creek bed, dissolved calcium carbonate is released and deposited. Calcium carbonate also precipitates from very limy spring water, which loses calcium carbonate as it is warmed by the atmosphere, thus decreasing the solubility of calcium carbonate. The hard dense deposit that results is travertine; a spongy or less compact variety is tufa. Algae, which use the carbon dioxide in the water are often abundant on calcium carbonate deposits in the spring-fed pools, and likely play a role in precipitation of calcium carbonate.
>
> These travertine deposits have an important effect on the streambed and the course of the creek. Travertine cements the gravel of the streambed sealing it so that the water cannot run underground. Dams also form across the stream creating pools. Floods occur every few years, changing the flow of the stream and altering the deposition of travertine. After each flood, travertine deposits gradually re-cement the streambed.

The Texas Legislature designated South and North McKittrick Canyon Creek and Choza Creek as "Ecologically Unique". As per 16.051(f) of the Texas Water Code, this designation solely means that a state agency or political subdivision of the State may not finance the actual construction of a reservoir in a river or stream section designated under this subsection.

Wetlands and Riparian Areas

Wetlands represent transitional environments between terrestrial and aquatic systems where the water table is at or near the surface or the land is covered by shallow water (Cowardin *et al*., 1979). Flora within these wetland systems exhibit extreme spatial variability, triggered by very slight changes in elevation. Temporal variability is also great because the surface water depth is highly influenced by changes in precipitation, evaporation and/or infiltration. Cowardin *et al*. (1979) developed a wetland classification system that is now the standard in the federal government. In this system, a wetland must have one or more of the following attributes: (1) at least periodically, the land supports predominately hydrophytes; (2) the substrate is predominately undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. There are four federal government agencies responsible for identifying and delineating wetlands: the U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and Natural Resources Conservation Service.

Riparian areas and wetlands, typically associated with springs and seeps, occur at the interface between land and water. While collectively these areas represent only a very small proportion of the landscape in the park, their hydrologic and ecologic importance is significant. Individually and collectively, these areas provide many critical functions including water supply, maintenance of water quality, essential habitats for flora and fauna, and maintenance of the park's biodiversity. The importance of these areas and their natural functions is magnified by the fact that the park is arid, which makes all water-related areas especially valuable.

Cienegas are small isolated spring-fed wetlands that occur in desert areas, including GUMO, Typically, cienegas are associated with marshy areas where the ground is wet due to seepage from a shallow water table or springs. Mountain springs can create small wetlands in some of the mid-level elevations at GUMO. Cienegas and mountain springs provide enough water for plants and animals that do not normally survive in the desert, resulting in habitat for a greater variety of species (Texas Parks and Wildlife, 2007).

Natural riparian zones are some of the most diverse, dynamic, and complex biophysical habitats in the terrestrial environment (Naiman *et al*., 1993). The riparian zone encompasses that stream channel between low and high watermarks and that portion of the terrestrial landscape from the high watermark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman and Decamps, 1997). Riparian buffers are integral to the health of GUMO's surface waters, such as McKittrick Creek, for many reasons (Table 1).

Canyons in the park contain Interior Riparian Deciduous Woodland in the bottoms and Madrean Evergreen Woodland on mesic slopes. The Interior Chaparral community is prevalent on south-facing canyon walls and slopes. McKittrick Creek is by far the largest flowing stream in the park. It supports a diverse riparian zone at the bottom of a steep canyon. The riparian vegetation along McKittrick Creek may be described as travertine vegetation with travertine describing the parent geologic material of stream bed.

Table 1. Importance of riparian buffers (Chesapeake Bay Program, 2006).

Filtering Runoff: Rain that runs off the land can be slowed and infiltrated in the riparian area, which helps settle out sediment and runoff contaminates before they reach streams. Trees provide deep root systems that hold soil in place, thereby stabilizing streambanks and reducing erosion.
Canopy and Shade: Cool stream temperatures maintained by riparian vegetation are essential to the health of aquatic species. Shading moderates water temperatures and protects against rapid fluctuations that can harm stream health and reduce fish spawning and survival.
Leaf Food: Leaves from the riparian forest fall into streams and are trapped on woody debris (fallen trees and limbs) and rocks where they provide food and habitat for small bottom-dwelling creatures (i.e., crustaceans, amphibians, insects and small fish), which are critical to the aquatic food chain.
Habitat: Riparian forests offer a tremendous diversity of habitat. The layers of habitat provided by trees, shrubs and grasses and the transition of habitats from aquatic to upland areas make these areas critical in the life stages of many species.

Major trees along the riparian zone of McKittrick Creek include the dominant little walnut, river walnut, or Texas black walnut (*Juglans microcarpa*) and such local associate species as velvet ash (*Fraxinus velutina*), Texas madrone or lady's leg (*Arbutus texana*), bigtooth maple (*Acer grandidentatum*), and the composite shrub, seepwillow baccharis (*Baccharis salicifolia*).

Riparian tree density is greatest in the lower region of the creek with substantial canopy cover. This provides a substantial source of leaf litter to the stream. In the upper canyon, tree density decreases and hence there is less leaf fall into the stream.

The dominant herbaceous species along much of McKittrick Creek is the same plant that dominates the Everglades of south Florida -- sawgrass (*Cladium jamaicense*). At the very edge of this desert stream a major grasslike plant more common to the Gulf Coast has found a suitable environment.

Choza Creek is a small, perennial stream that supports relatively pristine riparian vegetation. Slow growing, the Texas madrone approach one meter in diameter along its course.

Ground Water

Western Texas relies on ground water for most of its water supply. Approximately 75 percent of the region's water supply comes from two major aquifers [the Edwards-Trinity and the Hueco-Mesilla Bolsons] and six minor aquifers [Bone Spring-Victorio Peak, West Texas Bolsons, Capitan Reef Complex, Rustler Igneous, and Marathon] (Texas Water Development Board, 2007).

The regional hydraulic gradient is towards the east-southeast. Ground water in the Permian Shelf and Basin facies (Figure 6) flows in this direction, while the high permeability of the Capitan Shelf Margin facies causes it to act like a drain and carry water away towards the north and northeast (Hiss, 1975, 1980; Uliana, 2001).

Capitan Reef Aquifer

GUMO is located astride the Capitan Shelf Margin facies, which contains the Capitan Reef Aquifer, a relatively narrow strip of limestone formations (10 to 14 miles wide) that formed along the shelf edge of the ancestral Permian Sea (Figure 7). The reef formations are exposed in the Guadalupe Mountains (Far West Texas Water Planning Group, 2006).

The Capitan Reef Aquifer is composed of up to 2,360 feet of massive, cavernous dolomite and limestone. Water-bearing formations include the Capitan Limestone, Goat Seep Limestone, and most of the Carlsbad facies of the Artesia Group, including the Grayburg, Queen, Seven Rivers, Yates, and Tansill formations. Water is contained in solution cavities and fractures that are unevenly distributed within these formations (Texas Water Development Board, 2007).

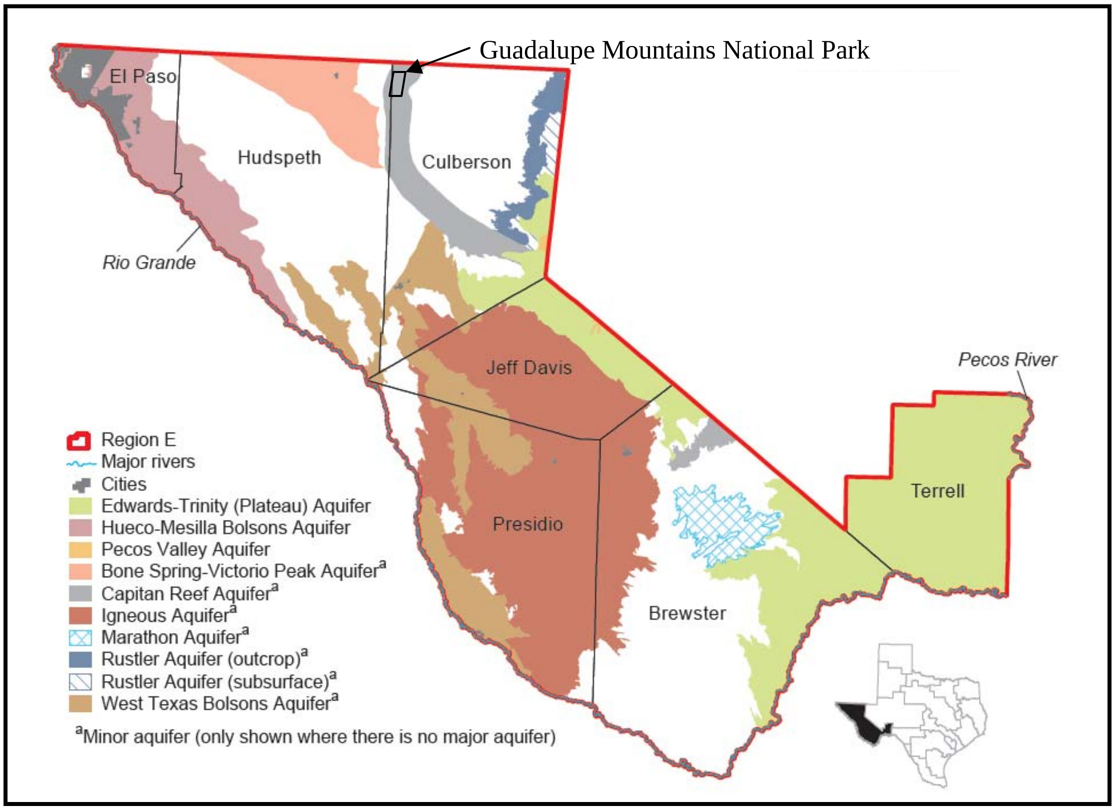

Figure 7. Western Texas Aquifers (Texas Water Development Board, 2007).

These carbonate rocks (limestone and dolomite) produce an environmentally sensitive karst terrain. In a karst landscape, much of the ground water flow takes place in pipe-like or sheet-like voids that have been created and/or enlarged by the solvent action of circulating water. Consequently, karst aquifers are heterogeneous and ground water does not follow all the rules of typical ground water movement, as developed for homogeneous media (Duigon, 1997). Recharge to a karst aquifer can be diffuse, as widespread precipitation infiltrates the overlying soils and sediments. Recharge can also be concentrated, as surface runoff is directed into a sinkhole or losing stream. The development of the network of solution conduits joining recharge and discharge depends on topography, lithology, and geologic structure (Duigon, 1997).

The Capitan Reef Aquifer is considered a "minor aquifer" in Texas, characterized by high primary porosities and permeabilities, extensive karstification, and regional fracture trends (Uliana, 2001). Measured transmissivities average 5,390 ft^2/day (Gates and others, 1980) and reach 16,200 ft^2/day (Reed, 1965). In New Mexico, the aquifer is capable of providing large quantities of fresh water and is a significant water source for the City of Carlsbad (Ashworth and Hopkins, 1995).

The Capitan Reef Aquifer is recharged primarily by rainfall (ranging from about 14 to 24 inches (36 - 61 cm) annually) over the Guadalupe, Glass, and Apache mountains (Ashworth and Hopkins, 1995). Reef rocks are exposed in these areas, and it is likely that water enters the aquifers through fractures and karst features. Muller and Price (1979) estimated that effective annual recharge of the Capitan Reef Complex aquifer is 12,500 acre-ft. According to GUMO's geologist, during the wet season, shallow ground water seepage has been observed on the surface along the west side of the park with seasonal ponding occurring in some of the low lying areas, west of the sand dunes (Bell, pers. comm., 2008). It is unclear if there is a connection between this seepage and seasonal ponding.

Bone Spring-Victorio Peak Aquifer

The Bone Spring-Victorio Peak Aquifer is another "minor aquifer" located immediately west of GUMO, in northern Hedspeth County (Figure 7). The principal water-bearing units in the aquifer are the Bone Spring and Victorio Peak limestones, with a combined total thickness up to 2,000 ft (610 m). Both formations produce water from solution cavities along fractures.

The Bone Spring–Victorio Peak Aquifer boundaries, as defined by the Texas Water Development Board, are in the Dell Valley irrigation area in northeastern Hudspeth County (Ashworth and Hopkins, 1995; Texas Water Development Board, 2002). The delineated extent of the aquifer is based on the occurrence of irrigable land that overlies the Bone Spring and Victorio Peak limestones, the location of a dominant fault to the south, and the edge of the Salt Basin to the east (Ashworth and Flores, 1991). The Bone Spring–Victorio Peak aquifer extends north into Crow Flats in New Mexico.

Recent studies suggest that the currently defined aquifer has a broader hydrologic connection to the surrounding area (Figure 8). Mayer (1995) and Mayer and Sharp (1998) showed through water-level mapping and a ground water flow model that the Dell Valley area receives ground water flow not only from the north, but also from the west.

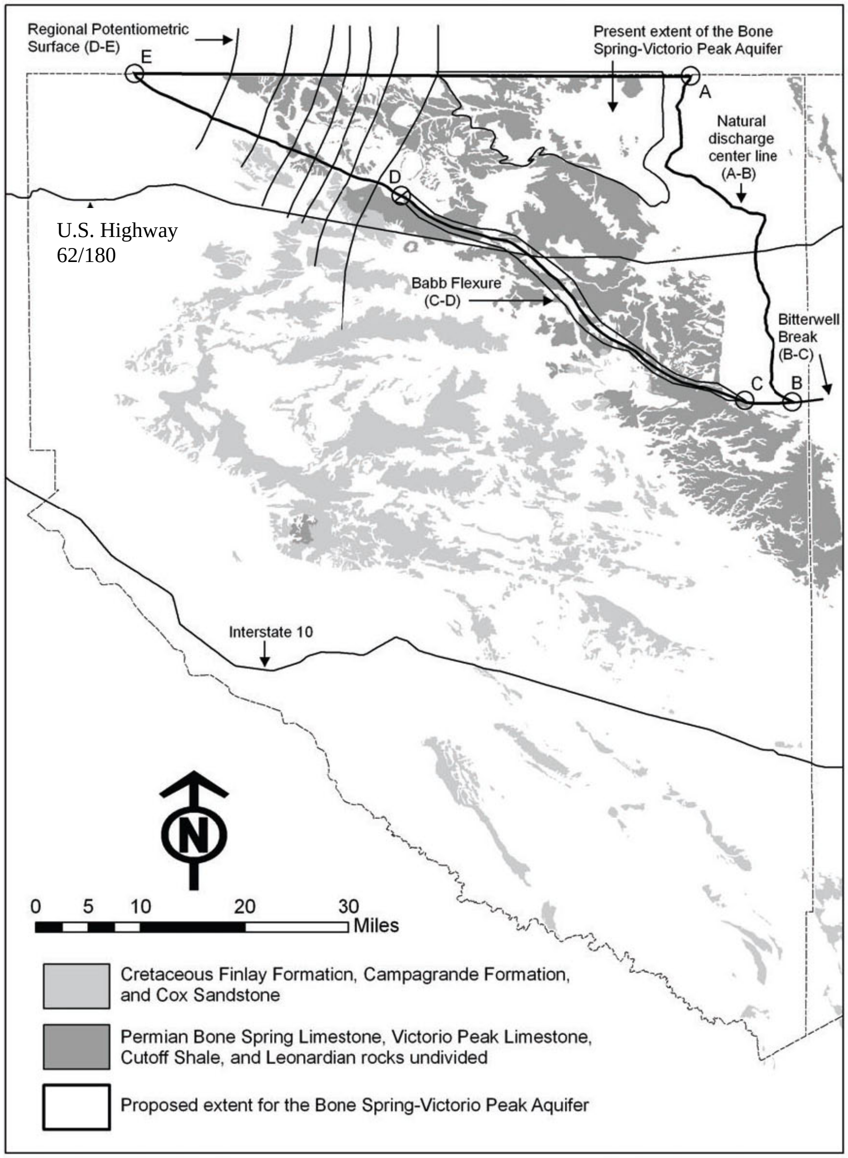

Figure 8. Proposed new boundary for the Bone Spring-Victorio Peak Aquifer (George *et al*., 2005).

Based on the above information, George *et al.* (2005) proposed a new boundary for the Bone Spring–Victorio Peak aquifer in Texas that is focused on containing all of the ground water flowing into the Dell Valley and is based on geologic and hydrogeologic information instead of the extent of irrigable lands. This boundary is defined on the east by the center line of the Salt Basin, which is the original, pre-development discharge area for the ground water flow system (A to B, Figure 8). Figure 9 illustrates the primary structural geologic features along the western side of GUMO including; the Diablo Plateau, the Salt Basin, and the Guadalupe Mountains. The Salt Basin Graben provides a structural barrier for the Spring-Victorio Peak aquifer boundary.

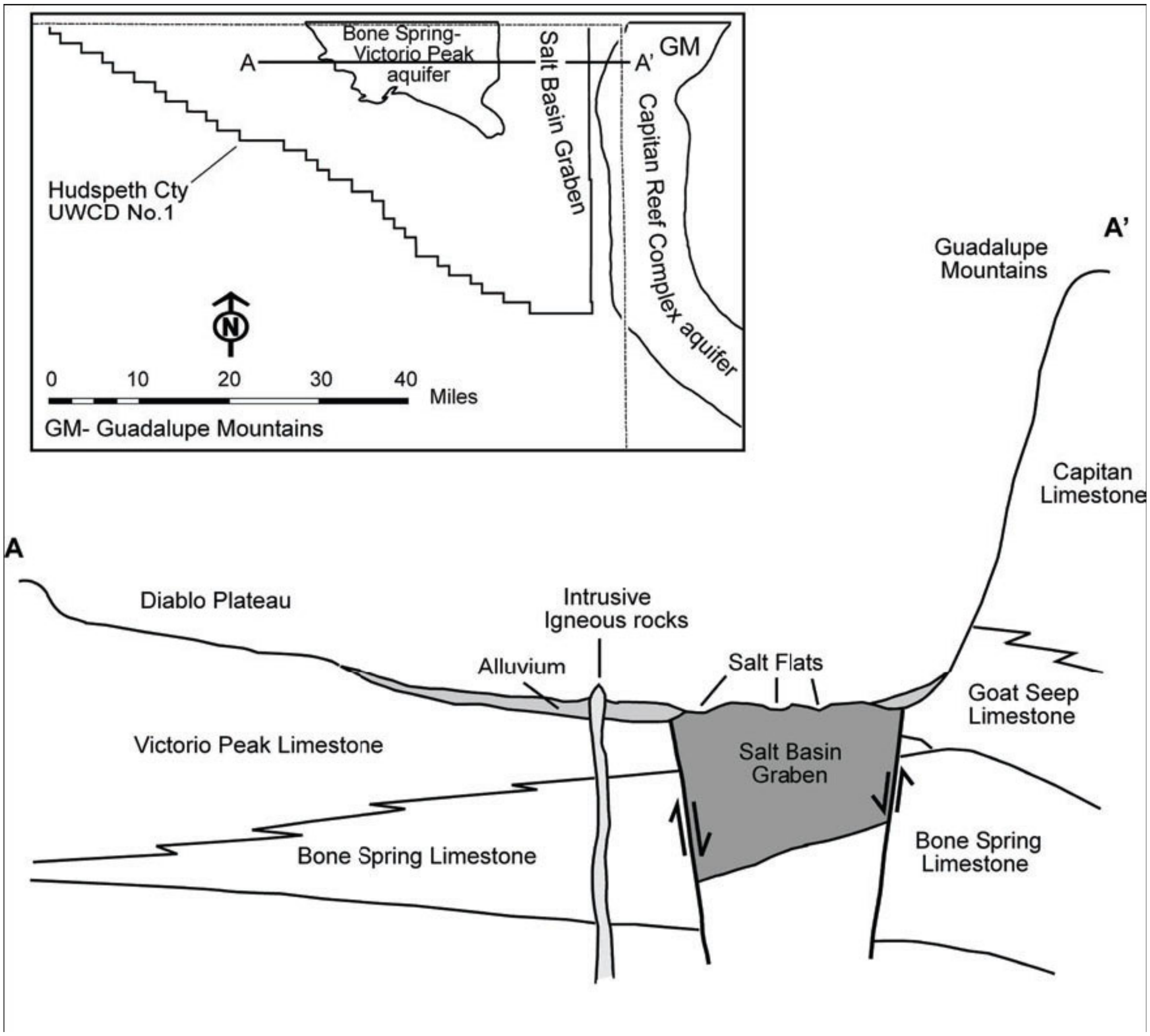

Figure 9. Generalized geologic and structural cross-section along Guadalupe Mountains National Park's western boundary (George *et al*., 2005).

The Bone Spring-Victorio Peak southern boundary follows the Bitterwell Break (B to C, Figure 8; Goetz, 1977; Boyd and Kreitler, 1986) out of the Salt Basin, a feature that reportedly corresponds to a ground water divide (Nielson and Sharp, 1985; Boyd and Kreitler, 1986). Bitterwell Break is a Tertiary normal fault that deforms the sediments of the Salt Basin. Moving westward, the southern boundary transfers from the Bitterwell Break to the Babb Flexure, a structural hinge or bend in the rocks (C to D, Figure 8; King, 1965; Goetz, 1977; Boyd and Kreitler, 1986). The southern boundary follows the Babb Flexure, which coincides with a ground water flow line, to the northwest. The mapped extent of the Babb Flexure does not reach the state line. Therefore, a flow line based on the potentiometric surface of Mayer (1995) and Mayer and Sharp (1998) extends from the Babb Flexure to the state line (D to E, Figure 8). The northern extent of the aquifer in Texas is then defined by the state line with New Mexico [see

Mayer (1995) and Mayer and Sharp (1998) for information and extent of the aquifer in New Mexico]. George *et al.* (2005) proposed this new boundary to the Texas Water Development Board for approval as part of the 2007 State Water Plan.

Ground water in northern Hudspeth County flows regionally towards the east-northeast from the Diablo Plateau to the Salt Basin (Ashworth, 1995). Within the Salt Basin, ground water is drawn upwards towards the surface by evaporation through the capillary fringe in the salt flats (Boyd and Kreitler, 1990). Significant amounts of ground water also flow into the Dell Valley area from the Sacramento Mountains in New Mexico through a set of northwest-southeast trending fractures (Mayer, 1995). Kreitler and others (1990) have postulated that there may be some southeasterly subsurface flow through Permian carbonate rocks below the Salt Basin. Farther south in Culberson County, ground water flow within the Salt Basin is to the southeast (Angle, 2001). In Dell Valley, ground water flow is probably controlled by the orientation and concentration of solution cavities developed along prominent fractures and bedding planes (Ashworth, 1995). In the irrigation season, ground water flows toward pumping centers.

Recharge to the Bone Spring–Victorio Peak aquifer is sourced from the Sacramento River, the Diablo Plateau–Otero Mesa, and irrigation return flow. The primary source of recharge to the aquifer occurs through the Sacramento River in New Mexico (Scalapino, 1950; Ashworth, 1995). A broad regional fracture zone, extending from the Sacramento Mountains to the Salt Basin near Dell City, is a major conduit for ground water to flow into Texas (Mayer, 1995).

Most of the recharge in the Diablo Plateau occurs through fractures along arroyos, which allow relatively rapid recharge to the aquifer. In the Dell Valley area, recharge occurs through irrigation return flow. Logan (1984) estimated that 35 percent of ground water pumped returns to the aquifer. Davis and Gordon (1970), however, estimated a return-flow as high as 50 percent, while the Hudspeth County Underground Water Conservation District (2002) estimated a leaching fraction, or return flow, of 30 percent.

The hydraulic properties of the carbonate aquifers of Dell Valley and the surrounding Diablo Plateau area are highly variable on a small scale. In many parts of the Dell Valley area, one well produces at a rate of more than 2,000 gallons per minute while another well 100 ft (30.5 m) away produces less than 100 gallons per minute (Scalapino, 1950). This variability is due to numerous fractures that were produced by faulting and subsequently enlarged by dissolution (Kreitler and others, 1987, 1990; Ashworth, 1995; Mayer, 1995; Mayer and Sharp, 1998; Mullican and Mace, 2001). On a relatively larger scale, the limestones and dolomites of the aquifers are extremely transmissive. Wells in the Bone Spring-Victorio Peak aquifer in the Dell City area have produced approximately 98,500 acre-ft per year for 30 years with only 33 ft (10 m) of drawdown (Kreitler and others, 1990). Individual wells, sited using lineament analysis and aerial photographs, can produce 2,000 to 3,000 gallons per minute.

<u>Seeps and Springs</u>

Seeps include those springs whose discharge is diffuse and generally immeasurable as there is not a defined channel or opening where the discharge is concentrated. The sources of the water supplying seeps may be local, in which case the seep will respond rapidly to rainfall or drought. Seeps may also be the outlet for underground water that has traveled for long distances. Such seeps do not fluctuate rapidly in response to precipitation. Seeps with well established hydrophilic or phreatophytic vegetation around them are likely to be fed by distant sources. Seeps of this type are important for the vegetation they support, and in turn for the wildlife supported by the vegetation. While the flow is generally small and diffuse, seeps of all kinds can be a source of emergency water supply to wildlife or park visitors by providing enough water in surface troughs or depressions to be useful.

Springs are a special class of seeps and are characterized by well-defined flow path(s) which lend them to capture and development. Springs represent the most important source of water for wildlife in the backcountry, and knowledge of their characteristics, in terms of the temporal distribution of flow and water quality, is important. Like seeps, springs may be fed by bodies of permeable materials recharged by local precipitation, or fed through long pathways from distant recharge points. The water quality of springs and seeps can be a good indicator of distance to the source. Springs and seeps with highly mineralized waters and/or temperatures higher than the mean annual air temperature are likely fed by distant sources, while springs with low mineral content are likely fed from local sources. The distance from the spring or seep to its source is important, because springs with distant sources will have significantly less fluctuation in flow in response to variations in annual precipitation than will springs with local sources.

Seeps and springs in GUMO are crucial for maintenance of ecological stability and wildlife health within the Chihuahuan Desert environment. Loss or failure of any of these springs would cause significant environmental stress, even though discharge rates of most are relatively small. Most springs, such as Frijole Spring, are also historic areas used by pioneers, early ranchers, and settlers. Remains of their homesteads and structures used to manage spring outflow and direct water usage are still visible in and near the springs. The National Park Service is directed to preserve these historic elements and cultural landscapes against unnatural impacts from continued human use, as well as to protect the spring's water quality and quantity from human induced impairment (Far West Texas Water Planning Group, 2006). Some of the major springs at GUMO are listed in Table 2 with limited discharge data.

Table 2. Some of the major springs at Guadalupe Mountains National Park (Far West Texas Water Planning Group, 2006).

Name	Discharge (gpm)	State Identification
Bone Spring	2-3	none
Dog Canyon Spring	<1	none
Frijole Spring	6-13	47-02-801
Goat Spring	1	none
Guadalupe Spring	6-10	47-02-701
Juniper Spring	<1	47-02-502
Manzanita Spring	10-38	47-02-802
Smith Spring	13-55	47-02-501
Upper Pine Spring	8-13	47-02-803

Additional information, including discharge data, on GUMO springs is summarized in Appendix A.

Water Wells

The park has acquired several water wells (at least 10) with the purchase of additional lands on the west side of the park. Most of these wells served as stock wells and/or domestic supply wells on ranches. An inventory of these wells is needed to plan future development of visitor facilities. Any wells that are not being used should be closed to prevent cross-contamination of the aquifer(s) (Martin and Long, 1997).

The search for potable water supplies at GUMO has been a long and expensive affair. Providing water for park staff and visitors continues to be expensive due to the extreme depths to ground water, which result in large expenses to operate and maintain wells (Martin, 1998).

Developed areas and visitor contact areas in the park now have adequate water supplies. Wells at Dog Canyon (well depth = 3,006 ft (916 m)) and Pine Springs (well depth = 2,572 ft (784 m)) could be equipped with larger pumps if more water is needed in these areas. Other areas in the park now having public water supplies will probably not experience increased demand, but if they did, additional wells could be constructed in the same target aquifers to supply the needed water. Several wells on the west side of the park, acquired from various ranching operations, would probably not be converted to a public supply well due to poor water quality (Martin, 1998).

The basin-fill sediments underlying Salt Flats are predominately lacustrine (deposited as lake bottom sediments) clay and sand saturated with saline water. Most of the basin-fill sediments would be considered a poor aquifer because of the low permeability and saline water (Gates *et al.*, 1980). Several wells are completed in the basin-fill sediments, but are generally low yield stock wells, which produce salty water. These wells were generally powered by windmills, but most are now abandoned and in various stages of disrepair. These wells include; Red Well, Lewis Well, Ables Well, Eclipse Well, Red Sand Dune Well, and PX Well (Martin, 1998).

The most promising potential source of potable ground water supplies for the west side of the park is the alluvial sediments of Bone Springs Draw. The Bone Springs Draw drainage basin encompasses several square miles. Precipitation and runoff from the basin is funneled through a break in the adjacent bedrock hills (Patterson Hills to the south). Runoff from the drainage basin infiltrates into the alluvium and flows underground toward the west through the opening between bedrock hills on either side of Bone Spring draw (Martin, 1998).

On the north side of the park (Dog Canyon and PX Flat) ground water is extremely scarce. Only a few low yielding springs (more properly seeps) furnish water for wildlife. In Dog Canyon, wells have been drilled to depths of 1500 ft (457 m) without obtaining water (Leggatt, 1971). A successful water supply well for Dog Canyon was drilled to 3,006 ft (916 m) and includes a 10,000-gallon tank to store water pumped from the well.

Water Quality

The NPS Water Resources Division (WRD) completed a comprehensive summary of existing surface water quality data for GUMO and the immediate surroundings, the *Baseline Water Quality Inventory and Analysis, Guadalupe Mountains National Park* (National Park Service, 1997). This document presents the results of surface water quality data retrievals for GUMO from six of the U.S. Environmental Protection Agency's (EPA) national databases: (1) Storage and Retrieval (STORET) water quality database management system; (2) River Reach File (RF3); (3) Industrial Facilities Discharge (IFD); (4) Drinking Water Supplies (DRINKS); (5) Water Gages (GAGES); and (6) Water Impoundments (DAMS).

Surface water resources in this GUMO study area include the creeks draining the North, South, and Main McKittrick, and other canyons; Bone, Manzanita, Choza, Smith, Upper Dog, and many other springs; and numerous draws and intermittent streams. Based on the data inventories and analyses contained in this report, surface waters within the study area appear to be generally of good quality with some indications of impacts from human activities.

The Capitan Reef Aquifer generally supports water of poor quality and yields small to large quantities of moderately saline to brine water. Analysis of water samples from 17 reef facies wells in Texas indicates an average total dissolved solids concentration (TDS) of 3,059 mg/L and an average chloride concentration of 881 mg/L (Brown, 1997). These samples also indicate that the primary constituents are sodium, chloride, and sulfate. Because of the low quality, water pumped from the Capitan Reef Aquifer in Texas is primarily used for oil reservoir waterflooding operations in Ward and Winkler Counties, with a small amount used for irrigation of salt-tolerant crops in Pecos and Culberson Counties (Ashworth and Hopkins, 1995). Water of the freshest quality is located on and near areas of recharge where the reef is exposed at the surface in the Guadalupe Mountains, including GUMO. The city of Carlsbad, New Mexico, uses Capitan water for a municipal supply.

On the west and southwest sides of the park, wells in alluvial deposits (Salt Flats) or in the Capitan Reef yield sufficient water, but the sulfate and chloride content generally is too high for public use. The Pure Water Well #3, west of the old Williams Ranch, taps both alluvium and the limestone (Goatseep Limestone), and was tested in 1971 at 24 gpm, but the water contained 360 mg/L sulfate and 380 mg/L chloride (Leggatt, 1971).

In general, the basin deposits fronting the Capitan Reef yield only small quantities (< 5 gpm) of water that commonly are too highly mineralized for public supply use. On the other hand, the alluvium along McKittrick Draw yielded sufficient quantities (20-100 gpm) of good quality water. In the western and southwestern parts of the park, bolson deposits and the Capitan Reef yield large supplies (as much as 300 gpm) of water, but the sulfate and chloride content exceeded the limits recommended by the U.S. Public Health for public supply (Leggatt, 1973).

The current surface water monitoring program in McKittrick Canyon has evolved from various research projects started by Texas Tech University in the 1970s. Water quality monitoring by university personnel on a regular basis began in the mid 1980’s. The park took over the monitoring program in 1993. Water samples were collected monthly from four sites in the canyon for pH, dissolved oxygen, ions and nutrients. Limited monitoring, primarily to access flows, has occurred for springs and seeps in the park. Little or no information is known about the chemical and biological characteristics of these resources (Martin and Long, 1997).

Since the legislatively mandated goal of nondegradation guides ground water programs, the state has not developed standards for pollutant discharge to ground water. However, the state has developed surface water quality standards applicable for certain water bodies that are protective of ground water affected by surface water. The state's policy requires that ground water be kept reasonably free of contaminates that would interfere with present uses or impair future uses, and the quality of ground water be restored if feasible (Texas Groundwater Protection Committee, 2003).

Significant differences in major ion compositions exist between the Bone Spring–Victorio Peak and other aquifers in the area. Samples from Cretaceous carbonates on the Diablo Plateau have relatively higher sodium concentrations compared to Permian carbonates but fairly equal concentrations of bicarbonate, sulfate, and chloride. The Bone Spring–Victorio Peak aquifer is characterized by low bicarbonate, high sulfate, and a wide range of calcium and sodium values. Major ions from the Bone Spring–Victorio Peak aquifer define four major and two minor hydrochemical facies (George *et al*., 2005).

The Bone Spring-Victorio Peak Aquifer water quality is generally slightly saline, with total dissolved solids (TDS) of 1,000 to 3,000 mg/L. In the Dell Valley area, TDS increase to 3,000 to 10,000 mg/L (Texas Water Development Board, 2007).

In the Dell Valley area, since the beginning of agricultural development in the late 1940s, irrigation has affected natural geochemical processes involving mineral dissolution and reprecipitation. Ground water in the area has shifted from a calcium-sulfate water type before 1950 to a mixed calcium-sodium-sulfate-chloride type after 1950. Salinity has increased over time due to irrigation (George *et al*., 2005).

Climate Change

Current science projects changes in temperature and precipitation as a result of climate change. Some changes related to water resources are direct consequences of the shifts in temperature and precipitation:

- Greater evaporative loss from soils and plants (evapotranspiration);
- Less runoff and more soil drought for a given amount of precipitation;
- Smaller mountain snowpacks;
- Earlier snowmelt; and
- Reduced ground water recharge.

Runoff is sensitive not only to precipitation, but also to temperature – higher temperatures cause more evapotranspiration. Even if annual precipitation does not change, the effect of projected increases in temperature would be less runoff and therefore less stream flow. For example, a mean annual temperature increase of 7.2° F has been estimated to reduce runoff by 10 to 20% in the Colorado River basin (Nash and Gleick 1991, 1993). Thus, the effect of substantial increase in precipitation could be largely or completely eliminated by the projected temperature increases. A recent analysis of climate model output estimates that runoff in the mid-latitude western U.S. could decrease by more that 10% in the mid-21st century (Milly *et al.*, 2005).

Covich *et al.* (2003) reported that global warming is expected to reduce montane snowpacks, increase stream temperatures, advance seasonal hydrographs, reduce soil infiltration, and increase evaporation. More rapid runoff and higher peak flows would increase bank erosion and sediment transport, and silt up spawning gravels. Earlier snowmelt and higher temperatures are expected to result in lower summer stream flow (Poff *et al.*, 2002). Lower dissolved oxygen and warmer waters will stress many species of fish and invertebrates and increase mortality, particularly in late summer.

Spring peak flows during snowmelt are forecast to be lower and earlier. The trend in western North America in the 20th century has been earlier snowmelts and thus earlier spring (because of warmer spring temperatures) runoff and this trend is projected to accelerate with continued global warming (Hamlet *et al.*, 2005, Stewart *et al.*, 2005). Earlier snowmelt increases the risk of winter and spring flooding and summer shortage of water (Smith, 2004). Other effects include:

- reduced surface water availability, especially during summer months;
- less water available to sustain aquatic systems;
- decreases in dissolved oxygen;
- reductions in stream flow in late summer (Poff *et al.*, 2002);
- less instream habitat for invertebrates and fish;
- significant changes in species composition and productivity;
- warming of ground water and spring-fed streams; and
- adverse effects on eggs and larvae of fish.

Aquatic Biological Resources

McKittrick Creek may be characterized as a semi-isolated, perennially-flowing, discontinuous, desert mountain stream. This characterization has drawn several investigators to study the aquatic macroinvertebrates of this stream system (Lind 1969, 1971, 1979; Meyerhoff and Lind 1987a, b; Green 1993). Lind (1979) collected 11,000 individuals from 41 taxa in three habitats during two seasons over a 5-year period from 1967-1972. Meyerhoff and Lind (1987b) sampled only one habitat during one season and found 16,600 individuals from 13 taxa. Green (1993) sampled approximately 300,000 individuals from over 80 taxa in three habitats and all seasons over a 2-year period. The large discrepancy in the number and type of taxa between these three studies is largely due to the different levels of sampling. Additionally, flash floods that may alter the creek substrate and hence the faunal composition occurred in McKittrick Creek in the late 1970s and mid-1980s after Lind's study and after Green's completion of his field studies. The work of Green (1993) is the most thorough and represents what may be called the reference condition for macroinvertebrate assemblages in McKittrick Creek.

Green (1993) employed multivariate statistical techniques using the distributions of the most common taxa among sample sites to determine sample site groups based on similarities in taxa distributions. Three clusters were identified that included two sample sites in the first cluster; six in the second cluster; and four in the third cluster (Green, 1993). These site clusters have importance with regard to the number and location of sites selected for any future monitoring of the aquatic macroinvertebrate community in McKittrick Creek. Additionally, Green found 12 taxa in riffles with three of these limited to riffle habitat; 16 taxa in runs with three being primarily found in this habitat; 18 taxa in pools, six of which were primarily found in pools. This variability in species richness across habitat types also has importance in the establishment of any future monitoring program.

As part of her study on the fishes of McKittrick, Petersen (2002) briefly studied a different aspect of the macroinvertebrate community – the drifting of invertebrates through the water column. She collected seasonal invertebrate drift samples from 2000-01. The annual drift average was 40 organisms/100 m^3 composed primarily of *Stratiomyidae* (soldier fly) larvae, *Chironomidae* (midges) and *Simuliidae* (blackflies).

Apart from this past work on McKittrick Creek, biological studies of the other perennial stream in the park, Choza Creek, or of known springs/seeps have been very few, primarily qualitative to semi-quantitative in sample design, and inconsistent as far as sampling techniques. Thus, reference conditions have not yet been established.

Lind (1971) sampled benthic taxa from Smith and Choza springs; both springs had eight species and the taxonomic composition of these species was similar.

Walsh and Worthington (1996) conducted a biotic assessment of Manzanita Spring. Of note is their identification of three flora – hardstem bulrush (*Schoenoplectus acutus*); tall fescue (*Festuca pratensis*), a non-native species; and another non-native, an Asian tumbleweed (*Salsola collina*). They further suggest that the species richness of the spring was reduced by its initial dredging in 1929, especially for the mollusk community.

Anderson and Mueller (2003) characterized the plant and animal communities at Choza, Smith and Juniper springs. Choza Spring had the highest plant, bird, and small mammal diversity of the three springs. Choza Spring was the only spring that supported a fish population, indentified as green sunfish (*Lepomis cyanellus*).

Rainbow trout (*Oncorhynchus mykiss*) were stocked into McKittrick Creek by adjacent landowners in the 1920s (Petersen, 2002). This initial stocking continues to be self-sustaining. In an ecological study of the fishes of McKittrick Creek, Petersen (2002) also found longear sunfish (*Lepomis megalotis*). She reported biomass and population estimates for rainbow trout in McKittrick Creek as 13 kg/ha and 689 #/ha. Estimates for longear sunfish were 31 kg/ha and 3382 #/ha, respectively.

Petersen (2002) referred to the longear sunfish as a native species. However, the prevailing opinion, given historical records, is that no fish were native to McKittrick Creek or the park (www.nps.gov/history/history/online_books/gumo/report1/; National Park Service, 1997b). Armstrong (Guadalupe Mountains National Park, pers. comm., 2008) mentioned that smallmouth bass (*Micropterus dolomieu*) were also stocked into McKittrick Creek at the same time as rainbow trout; however, no smallmouth bass exist in the park today. No records have been found that verify the presence of fish in McKittrick Creek prior to the 1920s stocking (National Park Service, 1997b).

Lind (1979) stated that the lower section of McKittrick Creek supports rainbow trout, green sunfish and yellow-belly sunfish (now redbreast sunfish, *L. auritus*). These two *Lepomis* species were not found by Petersen (2002). It is possible these species are no longer extant in the creek; however, it is more likely that their presence is a misidentification.

Dick (no date) identified green sunfish, bluegill (*L. macrochirus*), and yellow belly sunfish (now redbreast sunfish) in Manzanita Spring, and bluegill and yellow sunfish in Choza Spring. The presence of fish is uniequivocal; however, the identifications are suspect. Additionally, Walsh and Worthington (1996) identified only green sunfish from Manzanita Spring.

Given that there is no source population for any species of fish, i.e., the streams/springs are not ‘functionally’ tributary to the Pecos River drainage, and that any stocking would have ceased when the park was established, it is indeed puzzling that the fish communities of these small aquatic habitats have such an inconsistent documentation.

As far as aquatic and wetland vegetation for all aquatic systems in the park, most information has been anecdotally described as part of the above studies. For example, Dick (no date) noted aquatic vegetation at Choza Spring included algae (*Spirogyra* sp.); watercress (*Nasturtium oficinale*), stoneworts (*Chara* sp.) – limited identifications of aquatic vegetation were noted for other springs. Meyerhoff and Lind (1987b) and Green (1993) identified aquatic and streamside vegetation as part of sample site descriptions. However, Walsh and Worthington (1996) provide a fairly exhaustive, yet qualitatively-sampled, vegetation list for Manzanita Spring. Anderson and Mueller (2003) semi-quantitatively sampled the riparian vegetation of Choza, Smith and Juniper springs. They state that the Choza Spring riparian area is one of the most biologically diverse sites in the park. They believe that the Choza Spring is in danger of being impacted by a crown fire.

Air Quality

One of the purposes of the Clean Air Act’s Prevention of Significant Deterioration Program is “to preserve, protect, and enhance the air quality in parks….” (42 U.S.C. 7470(2)) Under the Program, Congress designated 158 areas as Class I, including national parks exceeding 6,000 acres and wilderness areas exceeding 5,000 acres, in existence on August 7, 1977 when the Act was amended. These areas, which include GUMO, receive the highest protection under the Clean Air Act. Despite this protection, GUMO experiences poor air quality at times.

The air quality related values (AQRVs) of GUMO are those resources that are potentially sensitive to air pollution, including vegetation, wildlife, water quality, soils, and visibility. Congress gave Class I area managers “an affirmative responsibility to protect the air quality related values” of Class I areas (42 U.S.C. 7475(d)(2)(B)).

Visibility

At present, visibility has been identified as the most sensitive AQRV in the park and has been monitored since 1988; other AQRVs may also be very sensitive, but have not been sufficiently studied. Visibility includes not only how far you can see, but how well you can see (i.e., color, form, contrast detail). Although visibility in the park is still superior to that in many parts of the country, visibility in the park is often impaired by light-scattering pollutants (haze). Haze is composed of sulfate, nitrate, ammonium, carbon, and organic fine particles and comes from a variety of natural and anthropogenic sources.

Vegetation

Vegetation in the park may be affected by ozone or nitrogen compounds deposited on soils or waters. Ozone may cause either visible foliar injury or may reduce growth and reproduction in sensitive species. Certain species have been found to be more sensitive than others to ozone. Within ozone-sensitive species, a plant's response depends on variables including ozone concentrations and cumulative doses, climate, soil moisture, and plant genotype. A 2004 assessment concluded that the risk of visible foliar injury from ozone to vegetation in GUMO was relatively low because ozone concentrations and long-term exposures are relatively low, and soil moisture is often low, precluding plant uptake (Kohut, 2007). However, several ozone-sensitive plant species occur in the park, including *Pinus ponderosa* (ponderosa pine) and *Rhus trilobata* (skunkbush), and sensitive species may be impacted if ozone concentrations increase.

Vegetation may also be affected by atmospheric deposition of nitrogen compounds. Nitrogen is a fertilizer and may induce enrichment of terrestrial ecosystems or eutrophication of aquatic ecosystems. While beneficial to crops and some forests, nitrogen can cause detrimental effects in natural ecosystems that have evolved under low nitrogen conditions, have short growing seasons and sparse vegetation. These systems, typical of much of GUMO, have little capacity to assimilate excess nitrogen. Certain plant species, including invasive grasses, are able to take advantage of the extra nitrogen, increasing at the expense of native species. Excess nitrogen in the Mojave Desert, for example, has been found to promote increases in alien, invasive annual grasses with subsequent decreases in native plants. The increase in alien annual grasses provided increased fuel for wildfires (Brooks, 2003). In arid shrublands in California, increased nitrogen deposition resulted in a shift from native shrubs and grasses to exotic Mediterranean grasses, again increasing fuels for fires and altering the hydrological regime (Allen *et al*., 1998). In a survey of results from over 900 species in a variety of ecosystems across the U.S., Suding and colleagues (2005) found that nitrogen fertilization in natural ecosystems caused plant species loss that ranged from more than 60% for rare species to 10% for common species, with significant effects to biodiversity.

Surface Waters and Soils

Surface waters and soils in GUMO are likely to be well-buffered and, as a result, insensitive to acidic atmospheric deposition because of an abundance of base cations in park soils and rocks. Nitrogen deposition may alter nutrient cycling in soils, or cause eutrophication of waters, but no research has been done in the park to evaluate these potential effects.

Chihuahuan Desert Network, Inventory and Monitoring Program

The Chihuahuan Desert Network (CHDN) Inventory and Monitoring (I&M) program, with input from the seven network parks, have identified 25 indicators of ecological condition. These indicators, which are commonly called “vital signs” have been grouped into seven monitoring protocols based on the ability to co-locate and/or co-measure these vital signs. An essential component of vital signs monitoring is the portrayal of how vital signs yield information about the condition of park resources. Thus, two of these protocols, *Air Quality* and *Water Quality* and *Quantity* will be directly relevant to the park in adding to their understanding of two important physical resources. Some of the work completed by the CHDN (e.g., vital sign indicators) has been applied in the later sections of this report.

Guadalupe Mountains National Park Purpose and Significance

The *purpose statements* of a NPS unit communicate the reason(s) for which it was set aside and preserved by Congress. The purpose statements for GUMO's physical resources are listed below (National Park Service, GUMO draft General Management Plan 2008).

Purpose Statements

- to preserve an area possessing outstanding, globally unique geological features together with scenic, natural, and cultural values of great significance.
- to manage a designated wilderness area where the earth and its community of life are untrammeled, and where humans are visitors who do not remain.
- to provide opportunities for visitors to understand, enjoy, appreciate, and experience the unique nature of the park.
- to provide educational and research opportunities that enhance stewardship and wider understanding of resources.

Significance statements define what is most important about the national park's resources and values and are based on the *purpose* of why the national park was created. The GUMO *significance statements* that apply to natural resources, including geologic, water and air resources, are (National Park Service, GUMO draft General Management Plan 2008):

Physical Resource Significance Statements

- GUMO is situated at the western terminus of the world's most extensive and well-exposed fossil reef, including related shelf and basinal rocks, which have achieved international designation as the world's best example of Middle Permian geology.
- GUMO is an island within an arid sea where an interface of Chihuahuan Desert, Rocky Mountains, and Great Plains flora and fauna was isolated by environmental changes. It contains relict and endemic montane, canyon, and aquatic species in a delicate balance created by elements of physical geography, latitude, climate, and hydrology.
- Rugged and windswept, the Guadalupe Mountains provide wilderness opportunities to experience the unaltered dynamic of life in a remote landscape resplendent in its isolated beauty and inspirational solitude.

Fundamental and Other Important Physical Resources

It is important for NPS units to identify the resources and values critical to achieving the park's *purpose* and maintaining its *significance*. Identifying the "fundamental" and "important" resources and values at GUMO ensures that all planning is focused on what is truly most significant about the national park. The following priority resources listed below were identified as *fundamental* (Table 3) or *important* during the development of the GUMO General Management Plan (National Park Service, GUMO draft General Management Plan 2008).

Fundamental Physical Resources

Table 3. Fundamental Physical Resources

Geologic Resources	Water Resources	Air Resources
Capitan Reef and Related Deposits	Natural hydrologic processes (ground water, perennial streams, springs and seeps)	Views of the Western Escarpment
Western Escarpment	McKittrick Canyon riparian corridor	Views of canyons throughout the park
Salt Basin	Wilderness Character	Wilderness Character
El Capitan		
Guadalupe Peak		
McKittrick Canyon		
Gypsum Dunes		
Montane/Sky Island		
Wilderness Character		

Other Important Physical Resources

Geologic Resources: Caves and Karst

Desired Conditions

Desired conditions are qualitative descriptions of the integrity and character for a set of resources and values that park management has committed to achieve and monitor. *Desired conditions* were developed in the GUMO *General Management Plan* for the park's priority resources and presented in this section.

Management Zones and Desired Conditions

The preferred alternative in GUMO's draft GMP/EIS divides the park into five different management zones (Figure 10), each with specific management prescriptions. These management prescriptions articulate the vision for the national park that park managers will strive to achieve (*desired condition*). The management zones and desired resource conditions for each zone are listed in Table 4 (National Park Service, GUMO draft General Management Plan 2008).

Physical Resources and Desired Conditions

Resource-specific desired conditions were developed for GUMO's physical resources and listed below under Geologic Resources, Water Resources, and Air Resources.

Geologic Resources

The park's geologic resources are preserved and protected as integral components of the park's natural systems. Paleontological resources, including both organic and mineralized remains in body or trace form, are protected, preserved, and managed for public education, interpretation, and scientific research. Natural soil resources and processes function in as natural a condition as possible, except where special considerations are allowable under policy. Caves and karst are managed in accordance with approved management plans to perpetuate the natural systems associated with the caves and karst.

Water Resources

Surface water and ground water are protected and water quality meets or exceeds all applicable water quality standards. Watersheds are managed as complete hydrologic systems. Natural fluvial processes that create habitat features are protected. Natural floodplain values are preserved or restored. The natural and beneficial values of wetlands are preserved and enhanced.

Air Resources

Air quality in the park meets national ambient air quality standards for criteria pollutants and protects air quality-sensitive resources. Natural visibility conditions exist in the park and scenic views of the landscape are not impaired by human activities.

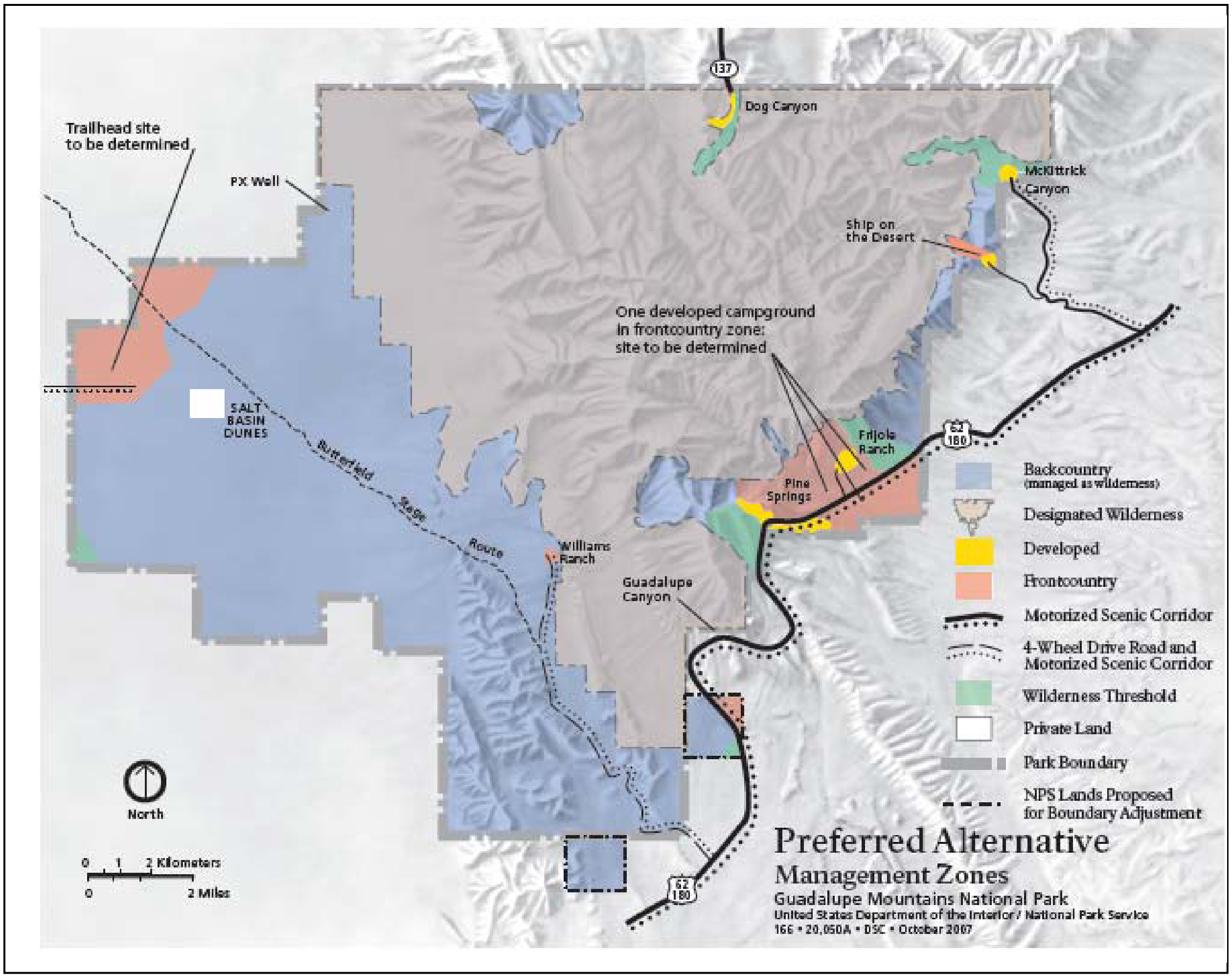

Figure 10. Guadalupe Mountains National Park Management Zones for preferred alternative (National Park Service, GUMO draft General Management Plan 2008).

Table 4. Guadalupe Mountains National Park Management Zones and Desired Conditions for natural resources (National Park Service, GUMO draft General Management Plan 2008).

Designated Wilderness	*Desired Condition:* In these undisturbed natural settings, natural processes predominate. Visitor access and use improvements are primitive or absent. Significant cultural resources could be present and, as appropriate, are stabilized and preserved. Access could be challenging. Visits are self-directed. Visitors experience a sense of high adventure and risk, solitude, and wilderness. Chances for encounters with other people are extremely low.
Backcountry	*Desired Condition:* Same as Designated Wilderness Zone.
Wilderness Threshold	*Desired Condition:* Minimally disturbed nautral settings are managed for a low level of human intervention and development. Significant cultural resources are stabilized and preserved as necessary. Access to and throughout these areas could be moderately challenging. Visitors experience a moderate sense of risk, adventure, and remoteness. Chances of encounters with other people are low.
Frontcountry	*Desired Condition:* Lands are natural in appearance with a moderate level of human intervention and development. Natural systems could be modified. Significant cultural resources are preserved or rehabilitated for operational or visitor use. Access presents a low to moderate challenge and a low level of adventure and risk. Encounters with other visitors are common.
Developed	*Desired Condition:* The landscape includes natural features, but is highly modified and managed for visitor use. Significant cultural resources are preserved or rehabilitated for operational or visitor use. Areas are easily and conveniently accessed by foot, bicycle, or motor vehicle from improved roads or trails. Frequent encounters with large numbers of visitors and staff are expected.
Motorized Scenic Corridor	*Desired Condition:* This prescription applies to moderately to highly modified and managed vehicular corridors passing through natural settings. The corridors are accessible for automobiles, bicycles, or hikers. Visitors experience landscapes with diverse, scenic features and frequent encounters with other people and vehicles.
Park-wide	*Desired Condition:* Natural resources are protected, restored, and maintained. Cultural resources are preserved, stabilized, and protected. Nonrenewable geologic and paleontological resources are protected, conserved, and maintained. Scenic vistas from within and outside the park boundaries are protected from significant intrusions. Wilderness is managed to retain its primeval character and natural conditions.

Indicators and Target Values

Indicators are selected to provide a barometer of health for GUMO's "Fundamental" and "Important" physical resources. Target values ("Reference Condition" and "Management Target") are established for the respective indicator parameters to distinguish between acceptable and unacceptable function of natural systems. Although not comprehensive in evaluating natural resource health, appropriate indicators provide a cost-effective way for park managers to monitor progress in maintaining or achieving target values that meet the national park's *desired conditions* for physical resources presented earlier.

The indicators and respective target values recommended for GUMO's water, geologic, and air resources are discussed in the following sections. If minimal or no data exists for a particular indicator, tentative values with lower confidence "interim values" or no value will be selected. In such cases, the strategy will be to collect data that provide the information needed to establish credible target value(s).

One of the criteria for selection of indicators was feasibility for park staff…"Are the evaluation requirements (i.e., sampling) for the respective indicators reasonable based on park staff resources?" Additional indicators and target values that would be appropriate to monitor when additional staff resources become available are included in Appendix E.

Geologic Resources

Specimen Abundance at Paleo Localities

Indicators for the park's paleontological resources are based on inventories with set objectives. The principle objectives of a paleontological resource inventory include:

- Gather baseline paleontological resource data.
- Inventory known paleontological localities and specimens.
- Identify issues, threats, etc. related to park paleontological resources.
- Develop partnerships for accomplishing paleontological projects.
- Document field localities including mapping, GPS data acquisition and photo monitoring.

Table 5 is a summary of the geologic resource vital signs and monitoring methods.

Table 5. Geologic resource vital signs and monitoring methods.

Vital Signs and Methods	Expertise	Special	Cost Equipment*	Personnel	Labor Intensity+
<u>Erosion (Geologic Factors)</u>					
Repeat Photography	Volunteer	No	$	Individual	Low
Erosion Stakes	Volunteer	No	$	Individual	Low
Technology-Enhanced	Scientist	Yes	$$$	Group	High
<u>Erosion (Climatic Factors)</u>					
Climatic Records	Volunteer	No	$	Individual	Low
Repeat Photography	Volunteer	No	$	Individual	Low
Technology-Enhanced	Scientist	Yes	$$$	Group	High
<u>Catastrophic Geohazards</u>					
Geologic Assessment	Volunteer	No	$	Individual	Low
Digital Mapping	Scientist	Yes	$$	Group	Medium
Technology-Enhanced	Scientist	Yes	$$$	Group	High
<u>Hydrology / Bathymetry</u>					
Repeat Photography	Volunteer	No	$	Individual	Low
Digital Mapping	Scientist	Yes	$$	Group	Medium
Technology-Enhanced	Scientist	Yes	$$$	Group	High
<u>Human Access / Public Use</u>					
Repeat Photography	Volunteer	No	$	Individual	Low
Digital Mapping	Scientist	Yes	$$	Group	Medium
Technology-Enhanced	Scientist	Yes	$$$	Group	High

*Cost: $ = <$1,000; $$ = $1,000 to $10,000; $$$ = >$10,000
+Labor Intensity: Low = <few hours; Medium = <full day; High = >full day

The change in specimen abundance at paleo localities (a.k.a the "Actual Loss" score) is measured by the Paleontological Locality Condition Assessment Form criteria. The frequency of monitoring is determined by the rates at which natural processes and/or human-related activities potentially impact each paleontological locality. Cyclic monitoring will be conducted at regular intervals, approximately every 1 - 10 years. The target values will be based upon acceptable limits as defined to minimize the loss of scientifically significant specimens or information due to natural processes or human factors.

GUMO Actual Loss Target Value = 20

Dunes, Dune Fields, and Sand Sheets

The salt basin dunes are geologically significant and contain unusual plant associations and rare species. The dunes developed under a range of climatic and environmental conditions. Wind speed and direction, along with moisture and sediment availability formed the dunes. Additionally, dune formation, stability and reactivation are influenced by climatic change and/or human disturbances. Sand movement is inhibited by moisture and vegetation cover. Monitoring of formation and movement along the margins of the dunes can also be used as an indicator of near-surface moisture conditions. Changes in dune morphology can indicate drought, variations in wind velocity and direction, or human disturbances.

Monitoring includes changes in size, shape and position of individual dunes and dune fields utilizing repeated ground, aerial, or satellite surveys (i.e. LIDAR). The frequency of monitoring is every 5 to 10 years. Testing the use of LIDAR in understanding and documenting dune dynamics is currently occurring at White Sands National Monument through the CHDN Inventory and Monitoring Program. Knowledge gained from this project will be applied to the dune fields at GUMO in future monitoring efforts. Past and future dune activity can be constructed by correlating temperature, precipitation records and utilizing paleorecords for remnant Quaternary dunes in North America. Target values are based on acceptable limits for active dune areas on park lands, as well as on associated ground water levels.

GUMO Percent Change in Spatial Extent of Dunes, Dune Fields and Sand Sheets Target Value ≤ natural variability as determined by changes in size, shape and position of the dunes utilizing LIDAR survey analysis.

GUMO Shallow Ground Water Target Elevation at Dunes, Dune Fields and Sand Sheets = no change from natural seasonal ground water elevations.

Cave and Karst Photo-Monitoring and Inventory/Survey

The monitoring of caves in the park ensures that the proper protection is afforded to natural and cultural cave resources. Caves determined to be environmentally sensitive and/or containing significant paleontological resources should have baseline data gathered. Photo-monitoring of the caves, documentation of cave features and resources (both natural and cultural) will consist of photo points that are recoverable and linked to cartographic survey points. The frequency of monitoring is every 5 to 10 years. Additionally, the monitoring plan (with protocols) that Carlsbad Caverns National Park has drafted will also assist monitoring of this physical resource at GUMO.

In addition to photo-monitoring, a companion inventory will be performed. An inventory/survey will include a cave's features, biota, cultural and paleontological resources. The survey will determine the number and identification of cave species which use the twilight or dark zones in the cavern. Cultural resource surveys will be conducted at the entrances and in the twilight zone areas as well as into the dark zone of the caves to define and describe historic use of the cavern. Paleontological resources should be surveyed using indicator and monitoring protocols developed for the park's paleontological inventories. Target values are based on acceptable limits or no change to the current condition as a baseline is developed after the inventory phase.

GUMO Cave and Karst Photo-Monitoring = no change from established baseline condition from cave.

GUMO Cave and Karst Inventory/Survey = no change from established baseline condition from cave.

Water Resources

Building from the NPS Chihuahuan Desert Inventory and Monitoring Network (CHDN) water quality vital signs, the U.S. Environmental Protection Agency ambient water quality criteria, and the Texas Commission on Environmental Quality Benthic Index of Biotic Integrity (BIBI) and Habitat Quality Index (HQI) indicator parameters for water resources were selected for GUMO with associated target values.

The water-resource vital signs identified by the NPS CHDN include (Huff *et al.*, 2006):

1) Surface waters: water temperature, pH, specific conductance, turbidity, bacteria, abundance/density of macroinvertebrates, dissolved inorganic constituents, dissolved oxygen, nutrients, concentrations of anthropogenic organic compounds, sediment load and chemical composition.
2) Ground water: water temperature, pH, specific conductance, dissolved inorganic constituents, anthropogenic organic compounds, and ground water elevation.

From the CHDN vital signs list the following water resource indicators were selected during GUMO's RSS workshop:

- Nutrients (total phosphorus and total nitrogen)
- Turbidity

In addition to this selected group, spring discharge was added as an alternative to ground water elevation. There are limited wells in the park, which are screened at varying depths, making correlations with target aquifers difficult or impossible.

Benthic Index of Biological Integrity (BIBI) and Habitat Quality Index (HQI) were also included as an indicator to evaluate aquatic biological integrity and physical stream habitat, respectively.

Values that do not meet the selected "targets" for the respective indicators may lead to additional indicators selected from the CHDN vital signs recommendation list (i.e., bacteria, dissolved oxygen, pH, water temperature, etc.). If staff and/or financial resources increased in the future, additional vital signs could be included to better evaluate water quality and quantity. Some of these additional indicators and target values are included in Appendix E.

Nutrients

Nutrients such as nitrogen and phosphorus are important for life in all aquatic systems. In the absence of human influence, streams contain a background level of nutrients that is essential to the survival of the aquatic plants and animals in that system.

In excess, nutrients can lead to the eutrophication of a water body. Eutrophication often decreases the level of dissolved oxygen available to aquatic organisms. Prolonged exposure to low dissolved oxygen values can suffocate adult fish or lead to reduced recruitment. Increased nutrient loads are also thought to be harmful to humans by causing toxic algal blooms.

In Texas, nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use. Site-specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing (Texas Natural Resource Conservation Commission, 2006).

Unfortunately, "excess" is a difficult determination to make because nutrient concentrations vary widely and interact with many other biological and physical conditions that can lead to undesirable effects. Factors that can influence nutrient criteria include: geographic region, waterbody types, seasonality, and designated uses. As a result, there is no state criterion for nutrient concentrations.

Since many states do not have nutrient-specific criteria, the U.S. Environmental Protection Agency (EPA) developed guidance (assessment tools and control measures) for specific waterbodies and ecological regions across the country, using reference conditions (conditions that reflect pristine or minimally impacted waters) as a basis for developing nutrient criteria. Since GUMO has very minimal nutrient data, these ecoregion nutrient criteria were selected as "interim" nutrient target values for GUMO.

An ecoregional approach was chosen by EPA to develop nutrient criteria appropriate to each of the different geographical and climatological areas of the country. The EPA established reference conditions for the respective regions by choosing the upper 25th percentile (75th percentile) of a reference population of streams. The 75th percentile represents minimally impacted conditions. GUMO is located in Nutrient Ecoregion II (Western Forested Mountains) and III (Xeric West), as defined by the EPA (see Appendix B). Interim nutrient target values were selected for total phosphorus and total nitrogen for rivers and streams in these two regions using the procedures described by U.S. Environmental Protection Agency (2000b; 2000c).

GUMO "Interim" Nutrient Target Values: Total Nitrogen: ≤ 1.0 mg/L and Total Phosphorus ≤ 18 µg/L

Turbidity

Turbidity is another vital sign selected from the CHDN list for GUMO during the RSS workshop, which can be easily monitored by park staff on a scheduled frequency. Turbidity values that exceed the selected "target" should be compared with the BIBI and HQI data to determine if the aquatic environments are stressed. If so, additional indicators selected from the CHDN vital signs recommendation list (i.e., sediment load) may be warranted. If staff resources increased in the future, additional vital signs listed in Appendix E could be included to better evaluate physical aspects of GUMO's water resources.

Turbidity refers to how clear the water is. High concentrations of particulate matter can modify light penetration, cause streams and ponds to fill in faster, and smother benthic habitats - impacting both organisms and eggs. As particles of silt, clay, and other organic materials settle to the bottom, they can suffocate newly hatched larvae and fill in spaces between rocks which could have been used by aquatic organisms as habitat. Fine particulate material also can clog or damage sensitive gill structures, decrease their resistance to disease, prevent proper egg and larval development, and potentially interfere with particle feeding activities. If light penetration is reduced significantly, macrophyte growth may be decreased which would in turn impact the organisms dependent upon them for food and cover. Reduced photosynthesis can also result in a lower daytime release of oxygen into the water. Effects on phytoplankton growth are complex depending on too many factors to generalize.

Sources for elevated turbidity in streams and ponds can originate from accelerated erosion (poor trail design that concentrates runoff, visitor-impacted riparian areas that reduce filtration of runoff) or elevated phytoplankton (from nutrient enrichment such as inadequate septic systems or runoff from horse corrals), which can modify light penetration in the water body.

Similar to nutrients, the same EPA preferred method for establishing reference conditions for Ecoregions II and III (Appendix B) was used to select an interim turbidity target value since adequate park data does not exist. Choosing the upper 25th percentile (75th percentile) of a reference population of streams and interim target value was selected for turbidity. Interim turbidity target values were selected for GUMO (U.S. Environmental Protection Agency, 2000b; 2000c).

GUMO "Interim" Turbidity Target Value: $\leq$ 4.0 formazin turbidity unit (FTU)

Spring and Stream Discharge

The quality, quantity, and flow of ground water are important to GUMO's cultural landscape, natural resources, and park operations. Ground water recharges the surface water features at the park, such as streams, ponds, seeps, springs and wetlands. GUMO also uses ground water as a potable water supply, with wells located inside the national park to satisfy the park and visitor use needs.

Currently, GUMO does not have a baseline for seasonal ground water elevations, flow direction and flow velocity for the aquifer(s) that support natural resources and park operations. Since there are limited spring discharge data recorded from the past four or five decades, these values will be used as "interim target values" until park-specific hydrogeology can be better defined through installation and monitoring of ground water wells and existing wells screened at the appropriate aquifer depth(s).

The following four springs and McKittrick and Choza creeks in GUMO were selected to evaluate aquifer trends in water quantity. Specific discharge data for these springs and others are summarized in Appendix A.

1. *Smith Spring* (6100 ft (1859 m) msl): Located on the east facing slope of the Guadalupe Escarpment. The spring issues from the Bell Canyon limestone formation.

Smith Spring "Interim" Discharge Target Value $\geq$ 8 gallons per minute (gpm)

2. *Guadalupe Spring* (5740 ft (1750 m) msl): Located in Guadalupe Canyon which flows between El Capitan and Guadalupe Peak. The spring issues from jointed limestone of the Cherry Canyon Formation.

Guadalupe Spring "Interim" Discharge Target Value ≥ 5 gpm

3. *Frijole Spring* (5500 ft (1676 m) msl): Located at the Frijole Ranch Headquarters, the spring rises from the jointed limestone of the Cherry Canyon Formation.

Frijole Spring "Interim" Discharge Target Value ≥ 2 gpm

4. *Bone Spring*: Located five miles (8 km) west of Pine Springs, the springs issue from the Brushy Canyon Formation at the contact with the underlying Bone Spring Limestone.

Bone Spring "Interim" Discharge Target Value ≥ 2 gpm

5. *South McKittrick Creek*, which has perennial flow, was selected to evaluate aquifer trends in water quantity and to evaluate surface stream health of the creek. Unfortunately minimal discharge data exists for establishing a target value.

South McKittrick Creek Discharge Target Value: no change from natural seasonal baseline data

6. *Choza Creek* begins at Choza Spring and supports a narrow riparian habitat that extends for almost a mile to the southeast. It gains volume at one point immediately north of Highway 62/180. Unfortunately minimal discharge data exists for establishing a target value.

Choza Creek Discharge Target Value: no change from natural seasonal baseline data

Benthic Macroinvetebrates

Biological integrity refers to the capacity to support and maintain a balanced, integrated, and adaptive biological system having the full range of elements (e.g., populations, species, assemblages) and processes (e.g. biotic interactions, energy dynamics, biogeochemical cycles) expected in a region's natural habitat (Karr *et al.*, 1986). The biological integrity of water resources is jeopardized by altering one or more of five classes of environmental factors: 1) alteration of physical habitat, 2) modifications of seasonal flow of water, 3) changes in the food base of the system, 4) changes in interactions within the stream biota, and 5) chemical contamination (Karr, 1992).

Managers of water resources are increasingly being called upon to evaluate the biological effects of their management decisions, for no other aspect of a stream gives a more integrated perspective about the condition of a stream and its biota. Widespread recognition of this and the continued degradation of our water resources stimulated numerous efforts to improve our ability to track aquatic biological integrity (Davis and Simon, 1995). Comprehensive, multi-metric indexes (Barbour *et al.*, 1995***)*** were first developed in the Midwest for use with fishes (the Index of Biotic Integrity (IBI); Karr *et al.*, 1986), and modified for use in other regions of the U. S. (Miller *et al.*, 1988) and with invertebrates (Ohio Environmental Protection Agency, 1988; Plafkin *et al.,* 1989). The conceptual basis of the multi-metric approach has now been applied to a variety of aquatic environments (Davis and Simon, 1995).

Multi-metric indices of biotic integrity are the most common indicators of stream condition in use today. Just over a decade ago, 42 states used multi-metric indices of biological condition (U.S. Environmental Protection Agency, 1996). In 1998, Maryland developed fish (FIBI; Roth *et al.*, 1998) and benthic macroinvertebrate (BIBI; Stribling *et al.*, 1998) indices of biotic integrity as part of the Maryland Biological Stream Survey. These indices develop their expectations for the structure and function of biological assemblages from reference sites. This approach compares the ecological attributes of biological assemblages to assemblages at minimally-disturbed sites which by definition have high scores. These attributes, called metrics, quantify biological aspects of assemblages that correlate well with human influence, such as species composition, trophic composition, and abundance. These metrics, singularly or in aggregate, provide both numeric and narrative descriptions of resource condition, which can be compared among watersheds, across a single watershed, and over time (Karr, 1981).

The Texas Commission of Environmental Quality uses rapid bioassessment protocols as cost-effective screening tools for evaluating the biotic integrity of benthic macroinvertebrate assemblages. This method is referred to as the Benthic Index of Biotic Integrity (BIBI). The Texas Surface Water Quality Monitoring Procedures (> http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-416/index html >) provide a detailed description of sampling and analysis protocols for the BIBI.

Harrison (2008) recently modified the BIBI that was developed for Texas streams to better account for inherent stream conditions that exist in the Southern Deserts and Southern Texas Plains ecoregions of West Texas. This modified BIBI is represented in Table 6 and used to select a BIBI target value range for GUMO.

GUMO Benthic Index of Biological Integrity Target Value ≥ 21

Table 6. Metrics, scoring criteria, and interpretation of final scores for a Benthic IBI developed specifically for the Southern Deserts and Southern Texas Plains Ecoregions (after Harrison *draft*, no date). (note: percentage of reference site samples (n=40) in each category are shown in parentheses.)

	Scoring Criteria			
Metric	**4**	**3**	**2**	**1**
Taxa Richness	>23	18 - 23	6 - 17	<10
	(15.0%)	(35.0%)	(30.0%)	(20.0%)
Number of Ephemeroptera Taxa	>5	4 - 5	2 - 3	<2
	(10.0%)	(45.0%)	(40.0%)	(5.0%)
Percent of N as Trichoptera	4.54 - 20.99	1.85 - 4.54	0.01 - 1.84	>21.00 or 0
	(25.0%)	(25.0%)	(20.0%)	(30.0%)
% Chironomidae	7.07 - 24.50	0.92 - 7.07	0.01 - 0.91	>24.50 or 0
	(20.0%)	(25.0%)	(7.5%)	(47.5%)
% Diptera	0.65 - 2.72	2.73 - 7.99	8.00 - 23.59	>23.6 or <0.65
	(20.0%)	(35.0%)	(25.0%)	(20.0%)
Percent of Trichoptera as Hydropsychidae	0 - 32.14	32.14 - 63.3	63.3 - 99.99	nt or 100
	(17.5%)	(17.5%)	(15.0%)	(50.0%)
Biotic Index	<2.28	2.28 - 3.95	3.95 - 4.56	>4.56
	(25.0%)	(27.5%)	(25.0%)	(22.5%)
Number of Intolerant Taxa	>10	9 - 10	7 - 8	<7
	(20.0%)	(20.0%)	(35.0%)	(25.0%)
Percent Collector-Gatherer	<4.83	4.83 - 22.33	22.34 - 37.09	>37.09
	(25.0%)	(25.0%)	(25.0%)	(25.0%)

Aquatic Life Use

Exceptional ≥27
High 21 - 26
Intermediate 18 - 20
Limited <18

Stream Habitat

Physical stream habitat is the physical template upon which the biological structure of stream communities is built; without adequate habitat the biological potential of streams is limited. Not surprisingly, stream health, as determined by the condition of biological communities, has been shown to be directly correlated to physical habitat quality (Rankin, 1995; Roth *et al*., 1996). Degradation of the physical habitat is among the leading causes of stream impairment nationwide (U.S. Environmental Protection Agency, 2000) and a critical factor affecting stream biodiversity (Allan and Flecker, 1993). An important component of any assessment program is, therefore, a sound habitat assessment approach. Together, chemical and physical data are used to assess water quality independently and also help identify stressors responsible for degraded biological conditions.

Habitat degradation can result from a variety of human activities occurring within the stream itself or in the surrounding riparian zone and watershed. Urban development, agriculture and livestock grazing are well-known examples of human activities affecting streams at a broader scale. Alone or in combination these human activities may cause changes in vegetative cover, sediment loads, hydrology, and other factors influencing stream habitat quality. In watersheds affected by anthropogenic stress, riparian forests can ameliorate inputs of nutrients, sediments, and other pollutants to streams. They also provide other functions such as shade, and inputs of leaf litter and large woody debris.

Table 7 describes the Habitat Quality Index (Surface Water Quality Monitoring Procedures: http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-416/index html) as currently used by the Texas Commission of Environmental Quality. This index is comprised of nine habitat measurements with each measurement being scored into four scoring categories.

GUMO Habitat Quality Index Target Value ≥ 20

Table 7. Habitat parameters and scoring categories for the Habitat Quality Index for Texas streams.

Habitat Parameter	Scoring Category			
Available Instream Cover	**Abundant** >50% of substrate favorable for colonization and fish cover; good mix of several stable (not new fall or transient) cover types such as snags, cobble, undercut banks, macrophytes	**Common** 30-50% of substrate supports stable habitat; adequate habitat for maintenance of populations; may be limited in the number of different habitat types	**Rare** 10-29.9% of substrate supports stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed	**Absent** <10% of substrate supports stable habitat; lack of habitat is obvious; substrate unstable or lacking
Score_________	4	3	2	1
Bottom Substrate Stability	**Stable** >50% gravel or larger substrate; gravel, cobble, boulders; dominant substrate type is gravel or larger	**Moderately Stable** 30-50% gravel or larger substrate; dominant substrate type is mix of gravel with some finer sediments	**Moderately Unstable** 10-29.9% gravel or larger substrate; dominant substrate type is finer than gravel, but may still be a mix of sizes	**Unstable** <10% gravel or larger substrate; substrate is uniform sand, silt, clay, or bedrock
Score_________	4	3	2	1
Number of Riffles To be counted, riffles must extend >50% the width of the channel and be at least as long as the channel width	**Abundant** ≥ 5 riffles	**Common** 2-4 riffles	**Rare** 1 riffle	**Absent** No riffles
Score_________	4	3	2	1
Dimensions of Largest Pool	**Large** Pool covers more than 50% of the channel width; maximum depth is >1 meter	**Moderate** Pool covers approximately 50% or slightly less of the channel width; maximum depth is 0.5-1 meter	**Small** Pool covers approximately 25% of the channel width; maximum depth is <0.5 meter	**Absent** No existing pools; only shallow auxiliary pockets
Score_________	4	3	2	1
Channel Flow Status	**High** Water reaches the base of both lower banks; < 5% of channel substrate is exposed	**Moderate** Water fills >75% of the channel; or <25% of channel substrate is exposed	**Low** Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed	**No Flow** Very little water in the channel and mostly present in standing pools; or stream is dry
Score_________	3	2	1	0

Table 7 continued.

Habitat Parameter	Scoring Category			
Bank Stability	**Stable** Little evidence (<10%) of erosion or bank failure; bank angles average <30°	**Moderately Stable** Some evidence (10-29.9%) of erosion or bank failure; small areas of erosion mostly healed over; bank angles average 30-39.9°	**Moderately Unstable** Evidence of erosion or bank failure is common (30-50%); high potential of erosion during flooding; bank angles average 40-60°	**Unstable** Large and frequent evidence (>50%) of erosion or bank failure; raw areas frequent along steep banks; bank angles average >60°
Score________	3	2	1	0
Channel Sinuosity	**High** ≥ 2 well-defined bends with deep outside areas (cut banks) and shallow inside areas (point bars) present	**Moderate** 1 well-defined bend <u>or</u> ≥ 3 moderately-defined bends present	**Low** <3 moderately-defined bends <u>or</u> only poorly-defined bends present	**None** Straight channel; may be channelized
Score________	3	2	1	0
Riparian Buffer Vegetation	**Extensive** Width of natural buffer is >20 meters	**Wide** Width of natural buffer is 10.1-20 meters	**Moderate** Width of natural buffer is 5-10 meters	**Narrow** Width of natural buffer is <5 meters
Score________	3	2	1	0
Aesthetics of Reach	**Wilderness** Outstanding natural beauty; usually wooded or unpastured area; water clarity is usually exceptional	**Natural Area** Trees and/or native vegetation are common; some development evident (from fields, pastures, dwellings); water clarity may be slightly turbid	**Common Setting** Not offensive; area is developed, but uncluttered such as in an urban park; water clarity may be turbid or discolored	**Offensive** Stream does not enhance the aesthetics of the area; cluttered; highly developed; may be a dumping area; water clarity is usually turbid or discolored
Score________	3	2	1	0
Total Score____________				

HABITAT QUALITY INDEX

26 - 31	**Exceptional**
20 - 25	**High**
14 - 19	**Intermediate**
≤ 13	**Limited**

Air Resources

Atmospheric Deposition of Nitrogen and Sulfur Compounds

Nitrogen (N) and sulfur (S) deposition can cause acidification of lakes, streams, and soils; N deposition can also cause fertilization and eutrophication, leading to unwanted changes in species abundance and composition and changes in soil nutrient cycling. Certain ecosystems are more sensitive to N or S deposition, including high elevation areas in the West, deserts, arid grasslands, upland areas in the East, and N-limited areas (certain lakes and coastal estuaries). N and S can accumulate in ecosystems such that even low rates of deposition may eventually harm ecosystem components. In some cases, these effects may be irreversible. Soils and waters in GUMO have relatively high acid-buffering capacity because of the presence of base cations (e.g., calcium, magnesium) and therefore N or S deposition is unlikely to cause acidification. N deposition, however, may affect park ecosystems through unnatural enrichment, since N is a plant nutrient. Park ecosystems have evolved under low N conditions. Because precipitation is limited and vegetation is sparse in many parts of the park, ecosystems have limited capacity to uptake and process N. Excess N may give a competitive advantage to some plant species over others, reducing biodiversity. In the arid ecosystems of Mojave National Preserve and Joshua Tree National Park, N deposition has been found to favor invasive plant species.

The effects of atmospheric deposition of nitrogen and sulfur compounds in complex ecosystems are difficult to monitor and, therefore, deposition itself is used as a surrogate for effects. Atmospheric N and S enter ecosystems through wet (rain and snow) and dry (dryfall and gases) deposition. Ideally, both wet and dry pollutant deposition should be measured and used to calculate total deposition in the park. However, dry deposition is not monitored at the park because of its relatively high cost. Wet deposition has been monitored in GUMO since 1984 as part of the National Atmospheric Deposition Program (NADP), which has over 200 sites nationwide. The NADP data provides a long-term, high-quality record of deposition that can be analyzed both temporally and spatially.

The target values for N and S wet deposition are based on several factors, including natural background deposition estimates and deposition effects on ecosystems. Estimates of natural background deposition for total (wet and dry) deposition are approximately 0.25 kilograms per hectare per year (kg/ha/yr) in the West and 0.50 kg/ha/yr in the East for either N or S. For wet deposition only, this is roughly equivalent to 0.13 kg/ha/yr in the West and 0.25 kg/ha/yr in the East. The proportion of wet to dry deposition varies by location but, in general, wet deposition is approximately one-half of total deposition. Ecosystem responses have been documented at very low levels of deposition (e.g., 3 kg/ha/yr total deposition, or about 1.5 kg/ha/yr wet deposition) (Fenn *et al*., 2003; Krupa, 2002). Evidence is not currently available that indicates that wet deposition amounts less than 1 kg/ha/yr cause ecosystem harm. Therefore, for parks lacking quantitative deposition-response information, including GUMO, an “interim” target value of 1 kg/ha/yr wet deposition of either N or S is recommended. In the “2006 Annual Performance & Progress Report: Air Quality in National Parks,” parks with wet N and S deposition less than 1 kg/ha/yr were considered to have “good” air quality in terms of deposition (National Park Service, 2006b).

GUMO Wet Deposition of Nitrogen or Sulfur “Interim” Target Value ≤ 1 kg/ha/yr

Visibility

GUMO was established to preserve the “outstanding geological values together with scenic and other natural values of great significance” in the park. Scenic values include visibility, that is, not only how far you can see but how well you can see. Air pollution causes haze and reduces visibility in many national parks, including GUMO. GUMO has identified good visibility, or “Unobstructed Views,” as a management goal.

In 1977, Congress established as a national goal “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution.” GUMO is a Class I area and the NPS has been working with the State of Texas to define natural conditions for visibility at the park as part of the State’s plan to make progress towards natural visibility conditions. The Environmental Protection Agency requires States to track visibility using an index for haze called deciview, so for GUMO the RSS goal for “unobstructed views” will also be tracked using the deciview index. The deciview index is computed from measurements of fine particles in the atmosphere, including sulfate, nitrate, carbon, and organics less than 2.5 microns in diameter (PM2.5) and coarse particles less than 10 microns in diameter (PM10).

The deciview index is scaled so that a reading of zero deciviews would represent an atmosphere free of particles. For the purposes of tracking the goal of "unobstructed views" the deciview index is computed for the 20 percent most and 20 percent least impaired days on a yearly basis. The State of Texas, with concurrence from NPS, has determined that the 20 percent most impaired days for any given year at GUMO should not exceed 12 deciviews. The 20 percent least impaired days should not exceed 2 deciviews. This range of 2 to 12 deciviews represents the estimated range of impairment that would result from natural biological and geological events such as periodic forest fires and sandstorms. Having measured visibility meet these values would be consistent with the goal of having unobstructed views.

GUMO Deciview Index Target Value for the 20% most impaired days ≤ 12 deciviews

GUMO Deciview Index Target Value for the 20% least impaired days ≤ 2 deciviews

Physical Resources Evaluation: Current Condition vs Target Value

With indicator parameters and target values established in the previous section, the condition of GUMO's priority physical resources can now be evaluated for resources with sufficient indicator data. Comparing the current condition of the priority resource with the established target or interim target value(s) will determine the "health" of that specific resource. As new data is made available, these condition assessments can be further refined. By identifying which indicators and sampling locations achieve or do not achieve the selected target value, park management can then begin to correlate influences (stressors) for the impacted physical resources.

Additional data/information is included in this section when it helps to expand on the health of a particular resource.

Geologic Resources

Specimen Abundance at Paleo Localities

No comprehensive systematic inventory of paleontological resources has occurred at the park due to the overwhelming scope of the task. The park geologist has estimated that approximately 27,000 acres in the park can be classified as having a high potential to contain fossil resources. In April, 1998, a preliminary assessment of paleontological resources at GUMO was conducted by Vincent Santucci (NPS). A geological scoping session, sponsored by the NPS Geologic Resources Division, was held in March 2001; however, a formal paleontological scoping session has never occurred at GUMO. The Chihuahuan Desert I&M Network recently released a Paleontological Resource Summary (Santucci, *et al*., 2007). This report provided a general overview, brief description of the geology and a literature review of the paleontological resources of the park.

However, a formal inventory of those resources was initiated in 2000. To date, 338 paleo localities have been documented in the park. Over the last few years, the park has utilized the Paleontological Locality Condition Assessment form to assess the condition of the known resources. The form allows for each paleontology locality to be evaluated for condition. There is a maximum score of 170 points and the higher the score, the better the condition of the locality. Localities with a total score higher than 90 are considered to be in good condition. Localities with a total score between 50 and 90 are considered to be in fair condition and some management action may be warranted. Localities with a total score of less than 50 are considered to be in poor condition and management activities need to be increased to improve the condition of the site. At GUMO, of the 50 localities surveyed, 48 have an actual loss score equal to 20. Thirty additional localities have been evaluated using a different form without any point scoring.

There are 27 caves documented within GUMO. Most of these are administratively closed to the public. Since the 1930s the Guadalupe Mountains have been recognized for their significant Pleistocene/Holocene cave fossils. Of global significance, four of the ten known ground sloth dung localities in the world occur in Guadalupe Mountains National Park. The ground sloth dung is documented from Lower Sloth Cave, Upper Sloth Cave, Dust Cave, and Williams Cave (Spaulding and Martin, 1979). A review of Guadalupe Mountains paleontological resources was included in a comprehensive inventory of paleontological resources associated with NPS caves (Santucci *et al.,* 2001).

Dunes, Dune Fields, and Sand Sheets

Currently, the park has not developed a monitoring plan for the Salt Basin Dunes, which should include monitoring seasonal changes in shallow ground water elevations. In 1987, the western park boundary was expanded to include a significant portion of these gypsum dunes. Outside of White Sands National Monument, these are the only other gypsum dunes known to exist in the U.S. The dunes have an active front approximately 50 ft (15 m) high and the parabola alignment of the limbs indicates that the dunes are advancing to the northeast. To the southwest, nearer the playa margins, the gypsum dunes are mostly stable and covered with vegetation. The Chihuahuan Desert Network Vital Signs Monitoring Plan recognizes the geomorphic processes of dune formation, stability and reactivation and has designated them as high priority vital signs for monitoring in the network.

Cave and Karst Photo-Monitoring and Inventory/Survey

Due to shortfalls in staffing and budget, no systematic cave inventory and monitoring exists. A permitting process for research and recreational wild caving is in effect.

There are 27 identified caves within the park boundaries with many more likely to exist. Most of these caves are administratively closed to the public. Glori Cave is currently the largest known cave in the park with approximately 600 ft (183 m) of surveyed passage. The caves in the park are generally dry, though many are decorated with delicate speleothems. As a result of post-formation erosion, caves at GUMO differ significantly from the nearby cave systems of Lechuguilla Cave and Carlsbad Caverns. In comparison, the caves in the park are fewer in number, have smaller footprints and have smaller passageways, though several consist of deep vertical pits.

The first cave management plan for the park was completed in 1972 to establish procedures for inventorying and maintaining known caves. The plan contained monitoring, protection and restoration protocols for cave resources and outlined cave research requirements. In 1991, a cave management plan was written with specific objectives in mind. Like the 1972 plan, the 1991 plan was drafted to address the protection of the cave systems, education and recreational opportunities and scientific study. In addition to these objectives, the 1991 plan also classified the caves in management categories based on their resource and hazard characteristics and established regulations, guidelines and permit stipulations to ensure maximum safety for the visitor and preservation of cave resources.

Water Resources

Water Quality Analysis of Six Springs in GUMO

In 1975, six springs were sampled in GUMO for a variety of water quality parameters, including nutrients and turbidity (Dick, no date). The springs were; Mazanita, Frijole, Smith, Guadalupe, Choza, and Upper Pine.

Nutrients

Low nutrients concentrations recorded in 1975 show no pollution in six springs in the park. The nutrients detected were explained by the decomposition of detritus in the springs. Guadalupe Spring had the highest nitrate concentration (1.3 mg/L), which is slightly above the 1.0 mg/L total nitrogen interim target value. Total nitrogen is the sum of nitrate and total kjeldahl nitrogen (organic and ammonia nitrogen). The ammonia nitrogen value for the same sample was below the detection limit (< 0.1 mg/L). The higher concentrations of nitrate occurred in springs having the most aquatic vegetation.

The nitrate concentrations in the 1975 study were much lower than those found by Lind (1971). Lind found nitrate concentrations to be 10 mg/L in Manzanita Spring, 50 mg/L in Choza Spring, and 50 mg/L in Upper Pine Spring, exceeding the total nitrogen “interim” target value (1.0 mg/L). The differences in the nitrate concentrations could be attributed to point source pollution, varying sampling techniques or lab/field sampling errors. In 1972, a nitrate concentration of 38 mg/L was reported at a spring in North McKittrick Creek (National Park Service, 1997a).

Turbidity

Turbidity did exceed the 4.0 FTU interim target value for three of the six springs sampled in 1975 (Dick, no date); Smith Spring, Guadalupe Spring, and Choza Spring (Table 8). Very high levels of turbidity for a short period of time may not be significant and may even be less of a problem than a lower level that persists longer.

Table 8. 1975 turbidity values (FTU) for Guadalupe Mountains National Park springs (Dick, no date; National Park Service, 1997a).

Spring Name	06/26/75	07/18/75	10/01/75
Manzanita	< 5	< 5	< 5
Frijole	< 5	< 5	< 5
Smith	5	5	< 5
Guadalupe	< 5	5	< 5
Choza	< 5	5	< 5
Upper Pine	< 5	no sample	< 5

(Note: Both NTU's (nephelometric turbidity units) and FTU’s (formazin turbidity units) are interchangeable turbidity units)

Additional Data/Information on GUMO Water Quality

Dissolved Oxygen (DO) - Manzanita, Smith, and Choza springs showed the highest dissolved oxygen levels. High DO in the Manzanita Spring pond is attributed to photosynthesis from algae and macrophytes. Smith Spring also forms a pond where photosynthetic activity occurs along with the natural oxidation that occurs as spring water flows down rocks through the canyon. Choza Springs DO is elevated by a rich growth of algae, which occurs the entire length of the spring (Dick, no date).

pH – The pH values in all springs were relatively constant in each individual spring; however, there were changes in response to temperature changes (Dick, no date).

Fecal Coliform - Fecal coliform bacteria was not found in any of the six springs samples (Dick, no date).

Metals – the six springs showed trace amounts of heavy metals probably due to geologic formations (Dick, no date).

Potable Water

Potable water used for GUMO's facilities is obtained from ground water wells near the facilities. Based on samples collected, the quality of ground water for personal consumption meets all required drinking water standards.

Spring Discharge

Spring discharge has been recorded intermittently over the years for select springs at GUMO and discharges from 1968 to 1979 are presented in Appendix A. The range in discharge for springs selected for monitoring are presented in Table 9.

Table 9. Discharge range for select springs in Guadalupe Mountains National Park.

Spring	Discharge Range (gallons per minute)
Smith Spring	8 – 48
Guadalupe Spring	5 - 7
Frijole Spring	2 - 4
Bone Spring	2 - 3

McKittrick Creek Discharge

According to Petersen (2002), McKittrick Creek stream velocity varied from a mean of 0.07 ft/s (0.02 m/s) in the upper reaches to 0.20 – 0.23 ft/s (0.06 - 0.07 m/s) in the lower reaches. Green (1993) determined the mean velocity of three habitat types to be: 1) riffles approximately 1.64 ft/s (0.5 m/s), 2) runs approximately 0.07 ft/s (0.2 m/s), and 3) pools approximately 0.20 ft/s (0.06 m/s).

Benthic Macroinvetebrates

The current condition of benthic macroinvertebrate assemblages with respect to the BIBI is unknown. Current benthic macroinvertebrate assemblages need to be assessed to provide baseline, reference condition.

Stream Habitat

The current condition of stream habitat is unknown with respect the HQI. Current stream habitat conditions need to be assessed using HQI. That assessment will provide the baseline, reference condition.

Air Resources

Atmospheric Deposition of Nitrogen and Sulfur Compounds

Based on monitoring conducted from 1998-2006, wet N deposition in the park is approximately 1.9 kg/ha/yr; wet S deposition is 1.6 kg/ha/yr. Both N and S deposition are elevated well above natural conditions, and above the target value of 1 kg/ha/yr for either S or N. S deposition is unlikely to acidify resources in the park, but N deposition may affect soils and vegetation in the park.

Trends in deposition were reported in the 2006 Air Quality Conditions and Trends Report (Air Resources Division, 2007). For the period 1996-2005, S deposition in GUMO decreased significantly, while N deposition was unchanged. The decrease in S deposition is likely due to sulfur dioxide emissions reductions required under the Clean Air Act.

Visibility

Based on monitoring conducted from 2000 to 2004, the 20 percent most impaired days at GUMO averaged 17 deciviews. For the same period the 20 percent least impaired days averaged 6 deciviews. These readings indicate that human-caused impairment is prevalent at GUMO during that timeframe. The goal for visibility on the 20 percent most impaired days for any given year at GUMO should not exceed 12 deciviews. The 20 percent least impaired days should not exceed 2 deciviews.

Trends in visibility were reported in the 2006 Air Quality Conditions and Trends Report (Air Resources Division, 2007). For the period 1996-2005, visibility was worse on the most impaired days, while visibility improved on the least impaired days.

Stressors

In evaluating natural resources at GUMO, the identification of stressors is critical for development of appropriate management strategies to restore or protect the management targets for physical resources. Stressor identification assists NPS management with the formulation of approaches that address impaired natural systems. This section identifies some of the known stressors at GUMO, under common themes, that influence physical resources at the national park.

Geologic Resources

Oil and Gas

The regional economy of western Texas and southeastern New Mexico is significantly based on oil and gas production. Recently, the local area has undergone increased oil and gas development in response to U.S. energy demands. Along the park's boundaries, there is a high probability that oil and gas operations will directly affect park resources.

Hiking Trails

Over time, hiking trails deteriorate by natural process and by wear from recreational traffic. The magnitude of trail deterioration is determined by characteristics of the trail, its environment, and the recreation use the trail receives (Cole, 1987). Sediment yield during precipitation events on trails can enter a waterbody and can degrade water quality through increased turbidity and total dissolved solids. Aquatic habitat can also be negatively impacted from increased sediment yields by covering the natural substrate through increased sediment deposition. GUMO should evaluate current trail designs, closing unwanted access and redesigning trails, as needed, to minimize soil erosion and sedimentation into surface waters at GUMO.

Vandalism and/or Theft of Paleontological Resources

Human-related impacts to paleontological resources may arise from the activities of visitors, permittees or contractors. The removal of paleontological resources is often prohibited by laws, regulations, and policies, and disregards resource management goals, and the scientific and educational values of fossils. Therefore, any monitoring program or prescription for paleontological resources should consider strategies for identifying, understanding, and evaluating the impacts of vandalism and theft on fossils.

Water Resources

Regional Development

Human activity can affect water resources. Overuse of water from aquifers can lower the water table to the point that springs stop flowing. Flow in the Capitan Reef Aquifer has been affected by the incision of the Pecos River and by development of petroleum and ground water resources (irrigation and potable water needs) over the last 70 years (Hiss, 1975, 1980; Uliana, 2001).

The city of El Paso has recently purchased approximately 29,000 acres overlying the Capitan Reef Aquifer in northwestern Culberson County (Far West Texas Water Planning Group, 2006). The Far West Texas Planning Group recommended an integrated water management strategy to meet needs in El Paso. The combined strategies include municipal conservation, direct reuse of reclaimed water, increases from the Rio Grande managed conjunctively with local ground water, and imports of desalinated ground water from more remote parts of the planning area. One of the strategies includes a $500-million project to import desalinated brackish ground water from Dell City to El Paso, providing 50,000 acre-feet per year (Texas Water Development Board, 2007).

Since the late 1940s, pumping of the Bone Spring-Victorio Peak Aquifer has been the principal means of discharge for the aquifer. Significant amounts of ground water have been pumped and are being pumped from the aquifer in the Dell Valley area. Pumping to the south and west of the Dell Valley area is limited to scattered wells used for livestock or domestic purposes. Water levels have declined in the Dell Valley area from 5 to 60 ft (1.5 to 18.3 m), with an average of about 30 ft (9.1 m) over a period of 55 years. These declines are likely due to irrigation pumping. However, water levels over the last 30 years have been relatively constant except for the last few years when water levels have declined due to drought (Texas Water Development Board, 2007).

At the end of glacial time, (approx. 10,000 years ago) the salt lakes were full, standing about 12 m above their low point. In the 1920s, there was typically water in the lakes, but now irrigation pumping has so lowered the water table that the Salt Flats are dry (Brune, 1981).

Several pumping tests from wells on the Diablo Plateau showed no measurable drawdown during extended periods of production (pumping tests with discharges of less than 20 gallons per minute typically lasting 48 hours or longer; Kreitler and others, 1990). The Far West Texas Regional Water Planning Group encountered similar results on the plateau in northwest Hudspeth County, where wells produced 40 to 300 gallons per minute for 48 hours with no drawdown (FWTRWPG, 2001).

Wastewater Treatment Systems

Ground water and surface water quality can be threatened by point source pollution from septic systems. These pollutants may affect nutrient and bacterial levels, and promote accelerated eutrophication.

The historic Pratt Cabin is approximately 2.5 miles (4 km) up McKittrick Canyon and is a popular destination for day hikers. In the past, sewage disposal was via pipes leading to an unlined cesspool, approximately 20 ft (6.1 m) deep , which intersects the water table. There was no treatment of the sewage, it simply disappeared into a hole in the ground. Effluent from the cesspool probably flowed toward McKittrick Canyon, where it continues as underflow in the alluvium. Visitors to the Pratt Cabin area were obtaining drinking water from a shallow (27 ft (8.2 m)) well completed in the alluvium near the intersection of North and South McKittrick Canyon. Water samples collected from the well indicated that effluent from the cesspool was entering the well (elevated nitrate and chloride concentrations). Raw water samples from the well routinely failed bacteriological tests, however, filtration and chlorination were successful in eliminating coliform bacteria from the treated water supply. Algal blooms were reported in McKittrick Creek, downstream from the septic system (Martin and Long, 1997). Due to these problems the septic system and potable water supply at Pratt Cabin are no longer in use.

Sedimentation

Before 1905, there were no dry valley trenches in the upper stream reaches, only wet swales covered with high grasses. Overgrazing destroyed the grasses, which had only a fragile hold on the soil, and gullying began. This contributed to lowering of the water table and buried downstream springs under sediment (Brune, 1981). Also see “Hiking Trails” under Geologic Resources.

Parking Areas

Runoff from parking areas in GUMO can concentrate polluted runoff (oils, metals, etc.) from these impervious surfaces into local aquatic environments.

Horse Corral

Runoff from GUMO’s horse corral can concentrate polluted runoff (bacteria, nutrients, sedimentation, etc.) into the local aquatic environments.

Flood Hazards

All of the watersheds within GUMO should be considered flash flood prone due to steep channel gradients, high runoff potential of exposed bedrock, and the possibility of high-intensity monsoonal thunderstorms.

GUMO’s Visitor Center is located on an extensive alluvial fan and determined to be flood prone by the U.S. Army Corps of Engineers. The Pine Springs campground is located within the regulatory floodplain (Martin, 2002).

Based on hydraulic modeling, the Dog Canyon Visitor Contact Station and all associated structures are outside the regulatory floodplain. Most of the campsites appear to be marginally within the regulatory floodplain due to their location on a high terrace (about 15 feet above the channel). The group campsite is located in close proximity to the channel and should be considered in a hazardous area (Martin, 2002).

The Pratt Cabin and associated structures are located on a high terrace near the confluence on North and South McKittrick Canyons, well above and away from the stream channels. The watershed is roughly 20-square-miles and capable of producing an extreme flood of about 100,000 cfs. Past floods in the canyon reportedly have not reached the structure; however, high water has trapped individuals for a period of time (Martin, 2002).

Climate Change

Changes are expected in biotic diversity in springs in the Chihuahuan Desert. As a result of increased evaporation with increasing air temperature, declines are anticipated in water renewal rates, stream flows, the extent of and water levels in wetlands, soil moisture, and ground water levels (Schindler, 1997).

Effects of expected global warming on fish include:

- increased extinction rates for endemic fish species and isolated local populations in springs and streams of the Chihuahuan Desert;
- shifts in the distributions of cold-water fish species northward and to higher elevations (Covich *et al.,* 2003);
- increases in warm-water fish species;
- coldwater fishes to be replaced by warm water species (Covich *et al.,* 2003);
- direct adverse effects on trout reproduction (Hauer *et al.,* 1997); and
- reduced recruitment of all fish species (Northcote, 1992).

Other changes affecting fish include permanent streams becoming intermittent and shorter flow duration in temporary streams (Stanley and Valett 1991), greatly reduced area of wetted channel in ephemeral streams (Meyer *et al.,* 1999), population declines, loss of habitat, changes in the community, negative effects from changes in water quality, and crowding of fish in reduced microhabitats.

Effects of expected climate change on aquatic invertebrates include reduced total densities of macroinvertebrates in stream ecosystems, reduced size at maturity and faster development; and altered fauna of unique springs.

Expected effects of global warming on wetlands and riparian systems include drying trends; changes in structure and functioning; reduced extent of semi-permanent and seasonal wetlands (Intergovernmental Panel on Climate Change, 2001); altered composition of riparian vegetation (Meyer and Pulliam, 1991); establishment of non- native or competitive species (e.g., salt cedar, Russian olive, Siberian elm); and loss of riparian species diversity (Poff *et al.,* 2002).

Air Resources

A variety of air pollution sources affect air quality in the park, including power generating plants, natural gas compressor stations, local gas well flaring, and mobile and area sources in Texas and New Mexico, as well as more distant areas. Population growth and oil and gas drilling and production in the Southwest may result in increased air pollutant emissions, with subsequent impacts to the park. Air pollutants of concern include nitrogen oxides, sulfur dioxide, ozone, and particulates. Nitrogen oxides are emitted from any combustion source including vehicles, powerplants, drilling equipment, compressors, and fires. Ammonia is released from agricultural activities. Burning coal in powerplants releases sulfur dioxide. Coarse particles from wind-blown dust and finer particles from combustion and other processes contribute to particulate matter. Pollutants can be carried long distances in the atmosphere where they can obscure visibility, cause haze, or contribute to ozone formation. Pollutants may eventually deposit into aquatic and terrestrial ecosystems, causing acidification or eutrophication and enrichment of sensitive lakes, streams, and soils.

Strategies

The heart of a park's Resource Stewardship Strategy (RSS), as the title implies, is to identify strategies that work towards improving physical resource data collection and begin to address known stressors, moving GUMO's physical resource indicators toward their respective target value(s) and ultimately towards the resource-specific *desired conditions* established in the 2008 General Management Plan.

This section takes GUMO's resource-specific *desired conditions* and lists strategies, under common themes, for consideration in GUMO's RSS.

Geologic Resources Desired Conditions

The park's geologic resources are preserved and protected as integral components of the park's natural systems. Paleontological resources, including both organic and mineralized remains in body or trace form, are protected, preserved, and managed for public education, interpretation, and scientific research. Natural soil resources and processes function in as natural a condition as possible, except where special considerations are allowable under policy. Caves and karst are managed in accordance with approved management plans to perpetuate the natural systems associated with the caves and karst.

Paleontological Resource Inventory and Monitoring

Use of the Paleontological Locality Condition Assessment form to evaluate current known localities must suffice until a comprehensive inventory strategy is developed. The assessment form's ratings can be used as interim target values. These are based upon acceptable limits that minimize the loss of scientifically significant specimens or information due to natural processes or human factors. The lack of personnel and fiscal resources prevents the park from planning, organizing, and implementing a comprehensive paleontological inventory. Based on this fact, the following list of needs can be undertaken individually as staffing and/or funds become available:

- Continue to explore areas for undocumented paleo resources.
- Map new localities.
- Protect specific stratotype and fossil locations.
- Catalog collected and salvaged fossils of significance.
- Incorporate protection of paleontological resources into planning efforts such as a trail management plans and develop a geological resources management plan.
- Develop photomonitoring protocols (SOPs) for *in situ* and museum paleo collections.
- Partnership opportunities on research – develop a park needs list for research and market it to researchers
- Document other specimens and localities from other institutions.
- Database management and GIS inventory upkeep for paleo resources.

Cave Inventory and Monitoring

Undertake a new inventory and develop a subsequent monitoring protocol for cave resources. The lack of personnel and fiscal resources prevents the park from planning, organizing, and implementing a comprehensive cave inventory. In the interim, implement the 1991 Cave Management Plan. In addition, the following list of needs can be undertaken individually as staffing and/or funds become available:

- Perform new cave inventory
- Explore/search for new cave localities and map.
- Revise the Cave Management Plan.
- Monitor and permit cave research and exploration in the park.
- Maintain park cave permitting system.

Salt Basin Dunes Monitoring

Develop a monitoring protocol for the Salt Basin. GUMO and CHDN should coordinate respective mapping and monitoring efforts within the network. The data generated could be used for regional trend analyses, maximize monitoring efficiencies and reduce mapping and monitoring costs. The lack of personnel and fiscal resources prevents the park from implementing a comprehensive monitoring program for the Salt Basin. The following list of needs can be pursued individually as staffing and/or funds become available:

- Acquire high-resolution mapping of the dunes and surrounding source areas to evaluate dune dynamics.
- Utilize the ongoing soils mapping effort to determine extent of gypsipherous soils and dependent vegetation communities.
- Develop a ground water monitoring program through the use of shallow piezometers.
- Determine the natural range of variability of dune movement and determine dune mobility index.

Soil Stability Monitoring

Perform qualitative assessments, in association with monitoring and inventory information, to provide early warnings on soil impacts. GUMO and CHDN should coordinate their respective monitoring efforts within the network, as one of the seven CHDN monitoring protocols is *Soils and Vegetation*. This protocol will heavily rely on the *Interpreting Indicators for Rangeland Health* (Herrick *et al*., 2005). It is an established protocol that provides a preliminary evaluation of soil/site stability, hydrologic function, and biotic integrity (at the ecological site level). This will provide early warnings of potential problems and opportunities by identifying areas that are potentially at risk of degradation or where resource problems currently exist. The lack of personnel and fiscal resources prevents the park from implementing a comprehensive program to implement the *Interpreting Indicators for Rangeland Health* protocol, though the CHDN monitoring program may meet some of the park's needs regarding monitoring of soil stability. The following list of needs can be pursued individually as staffing and/or funds become available:

- Utilize the ongoing soils mapping effort to determine baseline soils data and dependent vegetation communities.
- Evaluate current trail designs, closing unwanted access and redesigning trails, as needed, to minimize soil erosion and sedimentation into surface waters.

Water Resources Desired Conditions

Surface water and ground water are protected and water quality meets or exceeds all applicable water quality standards. Watersheds are managed as complete hydrologic systems. Natural fluvial processes that create habitat features are protected. Natural floodplain values are preserved or restored. The natural and beneficial values of wetlands are preserved and enhanced.

Water Quality Monitoring Program

GUMO and Chihuahuan Desert Network (I&M) staff should coordinate sampling efforts (water quality parameters, sample methodologies, and sample locations) between their respective water quality programs at the park to assess both surface and ground water at GUMO, concentrating on four springs (Smith Spring, Guadalupe Spring, Frijole Spring, and Bone Spring) and South McKittrick and Choza creeks. As additional resources are made available, expansion of sampling locations (Manzanita Spring, etc.) and water quality parameters (dissolved oxygen, water temperature, bacteria, pH, etc.) should be assessed and implemented where feasible. For potable water supplies, GUMO should use the U.S. EPA drinking water standards (U.S. Environmental Protection Agency, 2007) as target values.

Turbidity

Turbidity samples should be collected to establish baseline and further refine the current "interim" turbidity target value of ≤ 4.0 FTU. Until this is completed, interim target values are provided based on regional EPA data.

Nutrients

Since there are no State criteria for nutrients, it is recommended that nutrient samples (total phosphorus and total nitrogen) be concurrently collected with biological and stream habitat assessments recommended in this report to examine the statistical relationship between nutrient concentrations and the assessment endpoints, such as the benthic indices of biotic integrity and habitat quality index. The EPA encourages States to apply nutrient criteria and biological criteria in tandem, with each providing important and useful information to interpret both the nutrient enrichment levels and the biological and habitat condition of the sampled waterbodies.

Once clear nutrient relationships can be correlated with water resource health, park-specific numerical criteria can be determined that support the desired conditions for GUMO's water resources. Until this has been completed, interim nutrient target values are provided based on regional EPA data.

Benthic Macroinvetebrates

Because of his extensive sampling of benthic macroinvertebrates in McKittrick Creek, Green (1993) provides the best scientific information for determining reference condition for that creek. Ostensibly, one could use Green's data to calculate the BIBI for McKittrick Creek. This would represent baseline, reference condition (*circa* 1993) for the creek. A present day determination of the BIBI would then be compared to the 1993 reference condition. If it is determined that Green's data are not amenable for use in calculating the BIBI, then a present day determination of the BIBI would serve as the baseline, reference condition.

GUMO is encouraged to seek assistance from the Texas Commission of Environmental Quality not only with the retrospective analysis of Green's data, but for any sampling of the benthic macroinvertebrate assemblage and subsequent analysis of the BIBI.

Stream Habitat

Habitat data collected in conjunction with benthic macroinvertebrate community surveys provides a holistic evaluation of the health of biological assemblages. Characteristics of physical stream habitat such as presence or absence of instream cover, substrate characteristics, and riparian integrity have important effects on benthic macroinvertebrate assemablages. Habitat characterization, therefore, is important in interpreting results and determining the cause of decreasing biotic integrity.

GUMO is encouraged to seek assistance in using the Habitat Quality Index currently used by the Texas Commission of Environmental Quality (Surface Water Quality Monitoring Procedures: http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-416/index html), which was described earlier in the report ("Indicators and Target Values" and Table 7). This index is comprised of nine habitat measurements with each measurement being scored into four scoring catergories.

Riparian System Assessment

Other than a cursory understanding of the presence of plant species, the riparian zones in the park are unstudied. More importantly, it is not known how healthy these areas are and if they are functioning properly, thus providing maximum ecological protection to the park's water resources.

The maintenance of healthy riparian systems is essential in obtaining and sustaining the biological diversity and uniqueness of the park's resources. Healthy riparian systems are geologically stable, with stream flow and sediment discharges in dynamic equilibrium with their upland watersheds. The systems' wetland and riparian vegetation has appropriate structural, age, and species diversity. When these attributes are maintained, riparian systems provide forage and cover for wildlife and improve water quality by filtering sediment and recycling nutrients. If, however, any of the essential attributes are missing or degraded, or if the system becomes geologically unstable, widespread erosion may occur that will degrade water quality and cause damage or loss of wetland and riparian habitats.

A riparian assessment tool, Assessing Proper Functioning Condition (Bureau of Land Management, 1995) can be used to evaluate riparian systems. This technique employs an interdisciplinary team to assess riparian area “functionality” according to 17 hydrological, vegetational, and stream geomorphological factors. It provides an initial screening tool that can separate areas that are functioning well from those in need of more intensive evaluation or management actions. In this way, money and effort can be targeted toward higher priority issues.

The assessment of the park’s riparian systems is seen as an infrequent (e.g., every 5 years), long-term effort to address the riparian functionality in the face of: 1) increased or inappropriate resource use; and 2) the effects of climate change (e.g., invasion of exotic or terrestrially-based vegetation into the riparian areas due to increase in temperatures and/or decreases in surface/ground water quantity).

Spring/Seep Systems

Although some park springs have been surveyed to determine discharge rates and aquifer affinities, broad-scale and biological surveys have been uncommon, and knowledge of spring ecosystems is very limited. Furthermore, those surveys that have been completed represent inconsistent, non-standardized sampling methods. A standardized sampling protocol is needed that will allow a more thorough understanding of the effects of disturbance on spring biota and moderate the effects of anthropogenic uses to prevent additional loss and restore spring habitat quality.

One such protocol has been developed by Sada *et al.* (2003) for the NPS Mojave Inventory and Monitoring Network. This protocol offers a three-tiered approach based on the nature of the NPS planning process: 1) assessment of resource condition; 2) if resource conditions do not meet desired conditions, then conduct surveys that address management challenges; 3) a third level of more quantitative information may be needed to address individual resource issues, which require long-term monitoring. Level 1 surveys are designed to identify and characterize spring resources, delineate the distribution of important species and salient aspects of their habitat, and to determine unique resource challenges. This protocol provides effective methods to characterize spring systems across the landscape, and information that can be used to set management and restoration priorities. Level II surveys qualitatively sample riparian and aquatic communities to determine community structure, and quantitatively sample salient physicochemical elements to identify aquifer affinities. Finally, Level III surveys quantitatively sample additional physicochemical elements to determine aquifer dynamics. In addition, they quantitatively sample riparian and aquatic communities and habitats to determine spatial and temporal variation in environmental and biotic (e.g., abundance and community structure) characteristics, and to quantitatively determine biotic and abiotic interactions. Sada *et al.* (2003) provide a description of the Level I protocol; protocols for Levels II and III will be forthcoming.

Foundations for these protocols are provided by a number of hydrological and biological studies of springs in the western U.S. and elsewhere (Ferrington, 1995; Botosaneau,1998; Meffe and Marsh, 1983; Thomas *et al*., 1996) that have examined physicochemical conditions of springs and relationships between their abiotic and biotic characteristics.

Aquifer Characterization

Elevation of the local ground water table(s) (potentiometric surface) in the immediate area of GUMO should be established to document ground water flow directions, seasonal fluctuations and overall trends in ground water levels. The direction and velocity of ground water flow will assist in the identification of threatened areas and point source pollution.

Building from the recent ground water work (well inventory) completed by the Edwards Aquifer Research and Data Center in San Marcos, Texas, GUMO should use existing ground water wells with appropriate screened intervals and add to that network of wells (installation of piezometers), as needed. It will be important to know the "screened' intervals of the wells in order to correlate the measurement to the appropriate aquifer (shallow versus deep aquifer). From the water level data, ground water flow directions can be determined for the respective aquifers. Aquifer tests (pumping tests and slug tests) can be performed on select wells define local hydraulic conductivity and flow velocities of aquifers.

Installation and monitoring of shallow piezometers are encouraged within the gypsum sand dunes to evaluate seasonal fluctuations in the shallow water table. Park staff have observed seasonal surface water that appears to originate adjacent to the escarpment and correlates with seasonal ponded areas in close proximity of the sand dune field (Bell, personal communication, 2008). Also, according to Ashworth (1995), ground water in northern Hudspeth County flows from the Diablo Plateau to the Salt Basin. Shallow ground water is important in natural sand dune processes.

Floodplain Management

Floodplains exist in the park where there are perennial and intermittent streams. In managing floodplains, the NPS will (1) manage for the preservation of floodplain values; (2) minimize potentially hazardous conditions associated with flooding; and (3) comply with the NPS Organic Act and all other federal laws and executive orders (i.e., Executive Order 11988: Floodplain Management, 2006 Park Management Policies) related to the management of activities in flood-prone areas (National Park Service, 2006a).

The watersheds within GUMO should be considered flash flood prone due to the steep channel gradients, high runoff potential of exposed bedrock and the possibility of high-intensity monsoonal thunderstorms (Martin, 2002). When it is not practicable to locate or relocate development to a site outside the floodplain, the NPS is instructed to prepare and approve a statement of findings in accordance with procedures described in Director's Order 77-2 (Floodplain Management). Requirements for development in floodplains are contained in Executive Order 11988 (National Park Service, 2006a).

Wetlands Inventory

The park is hampered in its understanding of wetland areas because no National Wetlands Inventory (U.S. Fish and Wildlife Service) maps exist for the park (U.S. Fish and Wildlife Service, 2008). National Wetlands Inventory maps are a good first step for any park in understanding its wetland resources in that they identify, classify (according to Cowardin *et al*. 1979 – the NPS standard), and map wetlands on a topographic quad basis. The maps are useful, providing a general understanding of the types and potential areal extent of wetlands that are present. However, these maps are often not ground-truthed, and the scale (1:24,000) is inadequate to delineate small wetland types, such as the seeps or springs at GUMO, or detect subtle changes that may occur with respect to habitat boundaries or species composition changes. Due to their limited accuracy and precision, National Wetland Inventory maps are only a first step in a wetlands inventory for the park.

Wetlands within GUMO should be delineated by qualified staff or certified wetlands specialists using the Cowardin *et al.* (1979) system. GUMO should conform with NPS Management Policies concerning wetlands and wetland protective actions, and in NPS DO 77-1. The spatial extent of wetlands and wetland types should be captured in a geographic information system (GIS) database and updated as new information is made available.

Wastewater Treatment

Septic systems exist in the immediate area of GUMO. These systems remove pollutants from wastewater to protect the public health and environment. Pollutants such as bacteria, viruses, nitrate, ammonia, and suspended solids can enter aquatic environments and potable water supplies if not treated properly. As a result, discharge limits are set and used to evaluate systems to make sure they stay in compliance with those standards. GUMO should determine compliance of existing septic system within the park and upgrade inadequate systems, as needed.

Parking Lot and Horse Corral Management

Runoff from parking lots and horse corrals in the park can concentrate polluted runoff (oils, metals, bacteria, sedimentation, etc.) into the local aquatic environments. GUMO should consider stormwater treatment for parking lot runoff using bioretention areas, filter strips, and other proven practices that can be integrated into the landscaped areas. Park operations should continue to include proper waste removal at horse corrals in the park and minimize sediment runoff in the devegetated areas.

Climate Change

As greenhouse gases continue to accumulate in the atmosphere, the influences from climate change on the environment will only increase. Ecological changes will range from the emergence of new ecosystems to the disappearance of others.

Unfortunately, Texas has been slow, relative to other states, in acknowledging the environmental influences from climate change. Thirty five states have climate action plans in place or under consideration, including Texas' neighbor, New Mexico. Recognizing the profound implications that global warming and climate variation could have on the economy, environment, and quality of life in the southwest, New Mexico Governor signed *Executive Order 05-033* (2005) establishing the New Mexico Climate Change Action Council and the New Mexico Climate Change Advisory Group (CCAG).

As stewards of our most precious natural resources, GUMO should evaluate what can and should be done to minimize the effects of climate change on their natural resources, and to maximize opportunities for wildlife, vegetation, and the processes that support them to survive in the face of climate change. Contacting and working with the NPS Climate Change Coordinator, Dr. Leigh Welling (970.225.3513) to identify state and local resources that can assist GUMO with an appropriate management direction should be the first step. Monitoring the outcomes from New Mexico's CCAG, would also be informative to park staff as they move forward with appropriate management actions towards climate change.

Water Rights

GUMO has an ongoing need for water to support the park's mission. This need may reflect consumptive uses by the park (e.g., domestic uses), or reflect the need to protect natural water-dependent resources (e.g., fisheries). Water rights are necessary for the park's consumptive uses and natural water-dependent resources. Such rights may be based in state or federal law, and may involve either surface or ground water (Lord, pers. comm. 2008).

In order to address the park's water rights needs, park administration must develop an understanding, on a case-by-case basis, of the park's water uses and water-dependent resources. This understanding should incorporate risks associated with water development adjacent to, or nearby, the park. With such an understanding, the park should then determine whether existing water rights, based either on state law or federal law, are sufficient to meet the park's mission. While preserving its legal remedies, the park should seek to protect its water rights and resources through state water administrators, and where appropriate, through negotiations with other competing water uses (Lord, pers. comm., 2008). GUMO should consult with the NPS Water Resources Division (Water Rights Branch) as they work through this water rights strategy for the park.

Participation in Local, State, and Regional Water Resource Management

In an arid region where ground water is critical to economic growth, numerous ground water models have been developed to quantify and project ground water availability, demands, and associated trends. With the increased water demands in the region (i.e., El Paso, minerals exploration, irrigation, etc.), water resources planning, supported by ground water models, is very complex and political. Both ground water models and regional water resources planning are summarized in Appendices C and D. GUMO is strongly encouraged to participate in these regional water planning efforts (Far West Texas Water Plan) so they are able to understand and appropriately react to future development of water resources.

Additional partnerships should be explored with the Texas Commission of Environmental Quality, Edwards Aquifer Research and Data Center (San Marcos, TX), and U.S. Geological Survey in expanding and sharing the collection of vital data for water resources.

Air Resources Desired Conditions

Air quality in the park meets national ambient air quality standards for criteria pollutants and protects air quality-sensitive resources. Natural visibility conditions exist in the park and scenic views of the landscape are not impaired by human activities.

Monitoring Atmospheric Deposition

GUMO should continue monitoring wet deposition, which is done as part of the National Atmospheric Deposition Program (NADP). GUMO personnel operate and maintain a NADP sampler, which collects weekly precipitation samples for laboratory analysis. Precipitation is analyzed for nitrate, ammonium, sulfate, hydrogen ions, and other cations and anions. Data are reported as concentrations, in milligrams per liter (mg/L), or deposition, in kilograms per hectare (kg/ha). Because the GUMO sampler is part of an over 200-site network, data can be compared spatially and temporally to other sites. Specifics on NADP can be found at http://nadp.sws.uiuc.edu/.

Monitoring Visibility

GUMO should continue to monitor and track visibility conditions, which are monitored as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. The IMPROVE network monitors atmospheric particles and aerosols on a one in three day schedule throughout the year at over 110 locations in the U.S, including a site near GUMO. Specifics on the monitoring system can be found at http:/vista.cira.colostate.edu/improve.

Given the periodic and short-term impairment events (e.g., duststorms) at GUMO, the IMPROVE network monitoring should be supplemented with a nephelometer. This instrument provides continuous measurements of aerosol extinction, a surrogate for visibility. A nephelometer would provide better time resolution of events captured on the IMPROVE filters and indicate the frequency and magnitude of visibility impairment events on days not currently monitored under the IMPROVE sampling protocol.

Participation in Local, State, and Regional Air Quality Management

GUMO is strongly encouraged to continue to participate in local, state, and regional air quality management activities. GUMO, along with the NPS Air Resources Division, should continue to provide guidance to permit applicants regarding air quality and AQRV analyses. This guidance is found in the Federal Land Managers AQRV Workgroup (FLAG) Report (National Park Service 2000). In addition, GUMO should continue to consult and advise the State of Texas on the State's plan to make progress towards natural visibility conditions.

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APPENDIX A

GUMO Spring Descriptions and Discharge Tables (gpm)

Spring Descriptions from cited references:

Smith Spring (HL-47-02-501)

Issues at 6100 feet (msl) from joints in the limestone of the Bell Canyon Formation, near its contact with the massive Capitan Limestone. The spring flows on bedrock for a distance of about 100 yards where surface flow disappears (Leggatt, 1969).

Located on the east facing slope of the Guadalupe Escarpment (42 gpm). The water plunges over a small travertine fall into the pool approx. 15 feet in diameter and 1-2 feet in depth (Dick, no date).

Frijole Spring (HL-47-02-801)

Located at the Frijole Ranch Headquarters (5500 ft msl), yields about 2 gpm for domestic and livestock use. The spring rises from jointed limestone of the Cherry Canyon Foramtion. The water is of good quality although very hard (Leggatt, 1969).

Good drinking water. Flow 2-4 gpm (Reisch, 1969).

Frijole Spring was used as a domestic source since 1880. Flows approx 11 gpm (Dick, no date). The head of the spring is now enclosed in a man-made structure and the spring water flows through a cement canal until it returns underground.

(Weeks, 2008)

Manzanita Spring (HL-47-02-802)

Located a few hundred feet northeast of Frijole Spring and directly down the slope from Smith Spring, issues at 5520 feet (msl) from thin alluvium overlying the Cherry Canyon Formation.

The spring flowed 9 gpm in 1968…local residents report that the yield is unstable. The water is hard but otherwise of good quality (Leggatt, 1969).

The pool of water is about 80 feet in diameter. Around 30 gpm. Good drinking water. If Smith Spring runs high, so does this one (Reisch, 1969).

At Manzanita Spring there is a man-made earthen pond 100 to 125 feet in diameter in which the spring surfaces. The pond is also supplied with water piped from Smith Spring. This is a major watering hole for many of the animals which inhabit the park. Green Sunfish (*Lepomis cyanellus*), Yellow Belly Sunfish (*Lepomis sp*) and Blue Gill (*Lepomis marcochirus*) inhabit the pond along with frogs and tadpoles. Large beds of *chara sp* and *Potamogeton illinvensic* were present (Dick, no date).

Choza Spring (HL-47-02-901)

Located at 5350 feet (msl) down slope from Manzanita Spring, flows 36 gpm from the upper opening and 9 gpm from an opening several hundred feet downstream. The main spring issues from joints in the flaggy limestone of the Cherry Canyon Formation (Leggatt, 1969).

A small low-volume spring located a few hundred feet from U.S. Highway 62-180. It flows from a sandstone strata into a narrow, low-gradient brook cut through soft sandstone deposits. The spring consists of very shallow pools, runs and riffles. In several shallow ponds, blue gill (*Lepomis macrochirus*) and yellow sunfish (*Lepomis sp*) were observed, along with frogs (*Rana sp*) and tadpoles (Dick, no date).

Approximately 30 gpm, good drinking water (Reisch, 1969).

Anderson and Mueller (2003) state that the Choza Spring riparian area is one of the most biologically diverse sites in the park.

Guadalupe Spring (HL-47-02-701)

The water from Guadalupe Spring was very hard and higher in sulfate content that the other springs sampled (Leggatt, 1969).

Located in Guadalupe Canyon which flows between El Capitan and Guadalupe Peak. It flows, approximately 7 gpm from a limestone bedding into a concrete vat at the surface and then down canyon (Dick, no date).

Good drinking water, approx. 10 gpm. Drinking water is carried in a 2-inch pipe to a storage tank at the Old Signal Peak filling station (Reisch, 1969). The concrete vat and pipe from spring were removed in the 1980s to restore the spring site to natural condition
A fairly complete spring inventory was conducted in the park in 1990 and 1991. The information has been compiled in a notebook with a separate section for each spring. Information provided for each spring includes; location, topographic map, description of how to get to the spring, photos, flow rate, downstream extent of flow, description of vegetation, sketch map, and location

of a camera point cross referenced to at least two witness points. Periodic estimates of flow and flow measurements have been made by various park rangers and included in the notebooks (Martin and Long, 1997).

Spring Discharge Tables from cited references:

Leggatt (1969)

Spring	Elevation	Geo. Formation	Date	Q (gpm)
Smith	6100	Bell Canyon	12/04/68 04/24/69	27 51
Juniper	5600	Cherry Canyon	02/27/69	1-2
Guadalupe	5740	Cherry Canyon		<5 est.
Frijole	5500	Cherry Canyon		<2
Manzanita	5520	Cherry Canyon	12/04/68	9
Upper Pine	6050	Cherry Canyon	12/04/68	8
Choza	5350	Cherry Canyon	12/07/68	36

Dick (no date)

Date	**Frijole**
06/26/75	11 gpm
07/70	11 gpm
02/11/72	11 gpm
05/02/74	13 gpm

Date	**Smith**
06/26/75	35 gpm

Additional Discharge Tables (gpm): data from Reisch, GUMO Park Ranger (field notes).

Date	Guadalupe
07/25/70	5
09/29/70	5
02/15/71	5
05/19/71	5
06/29/71	5
09/28/71	5
06/04/72	5
09/72	5-6
01/73	5-6
07/73	5-6
09/73	5-6
02/19/74	5-6
07/24/74	5-6
01/15/75	5-6
06/06/75	5
06/26/75 [1]	7
12/20/75	5
06/29/76	5-6
09/29/77	6
12/22/77	6

[1] Information from Water Quality Analysis of Six Springs in Guadalupe Mountain National Park, Michael Dick, Texas Water Quality Board, Dist. 4.

Date	Smith	Date	Smith
12/69	25	09/12/73	38-40
07/70	30-32	10/20/73	38-40
08/70	42	11/10/73	36
01/18/71	42	12/24/73	36
03/27/72	36	01/30/74	38
03/28/71	42	02/07/74	38
05/22/71	36	03/23/74	36
06/26/71	36	04/08/74	36
08/28/71	36-40	05/12/74	35
09/04/71	36-40	06/11/74	33
10/24/71	36-40	06/21/74	32
11/21/71	36	07/14/74	32
01/08/72	36	08/18/74	35
02/16/72	36	09/22/74	48
03/13/72	35	10/27/74	46
04/16/72	36	11/10/74	40
05/28/72	34	12/15/74	36

06/27/72	36	06/03/75	34
07/30/72	36-38	06/26/75[1]	35
08/26/72	40	12/18/75	29
09/24/72	42	02/28/76	28
10/22/72	42-44	03/10/76	26
11/09/72	40	05/06/76	20
12/17/72	36	07/09/76	13.32
01/31/73	38	09/27/76	30
02/28/73	54-56	02/02/77	20
03/31/73	48	06/05/77	22
04/20/73	42	09/29/77	8
04/23/73	42	12/26/77	18
05/21/73	36-38	02/01/78	15
06/30/73	36-38	09/79	19.26
07/31/73	36-38		
08/19/73	36-38		

[1] Information from Water Quality Analysis of Six Springs in Guadalupe Mountain National Park, Michael Dick, Texas Water Quality Board, Dist. 4.

Date	**Manzanita**
03/09/71	10
05/18/71	24
05/19/71	24
05/28/72	28-30
02/28/72	38

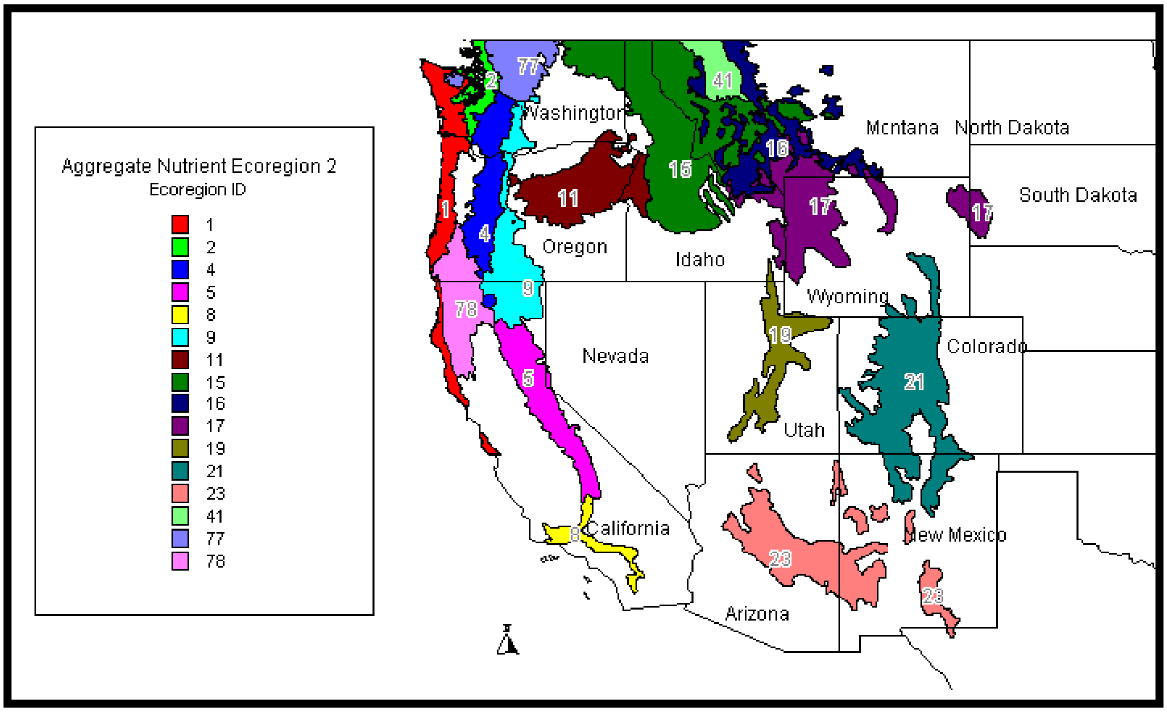
Date	**Upper Pine**
08/08/70	13.5
05/25/71	10
09/29/77	8

Date	**Bone**
09/30/77	2.5

APPENDIX B

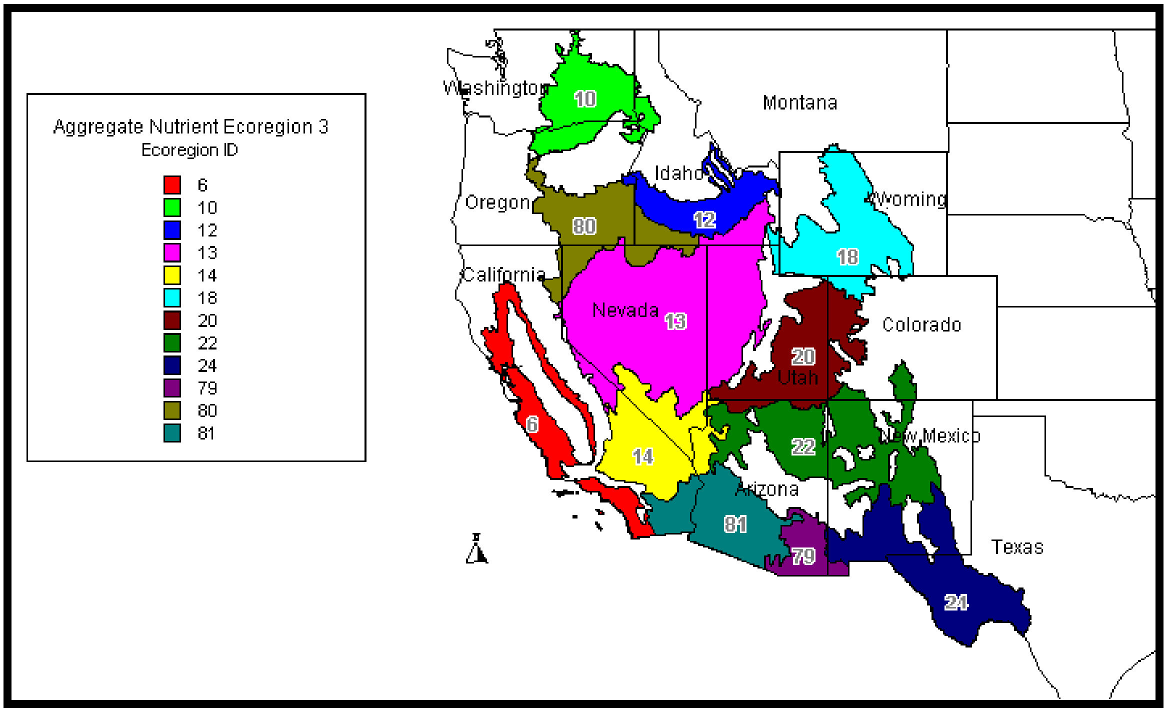
EPA Ecoregions II and III

Ecoregion II is a large, discontinuous region covering the mountainous areas of the weastern United States. There are sixteen Level III ecoregions contained within Aggregate Ecoregion II. GUMO is located within ecoregion 23.



Aggregate Ecoregion II with Level III ecoregions shown (U.S. Environmental Protection Agency, 2000b).

Ecoregion III encompasses the areas of the western United States where dry conditions prevail. There are twelve Level III ecoregions contained within the Aggregate Ecoregion III. GUMO is located within ecoregion 24.



Aggregate Ecoregion III with Level III ecoregions shown (U.S. Environmental Protection Agency, 2000c).

Appendix C

Regional Ground Water Availability Model Summary

The estimated ground water availability in 2010 for the Capitan Reef is 52,000 acre-feet per year. The water use reported for this aquifer in 2003 was 2,500 acre-feet (Texas Water Development Board, 2007).

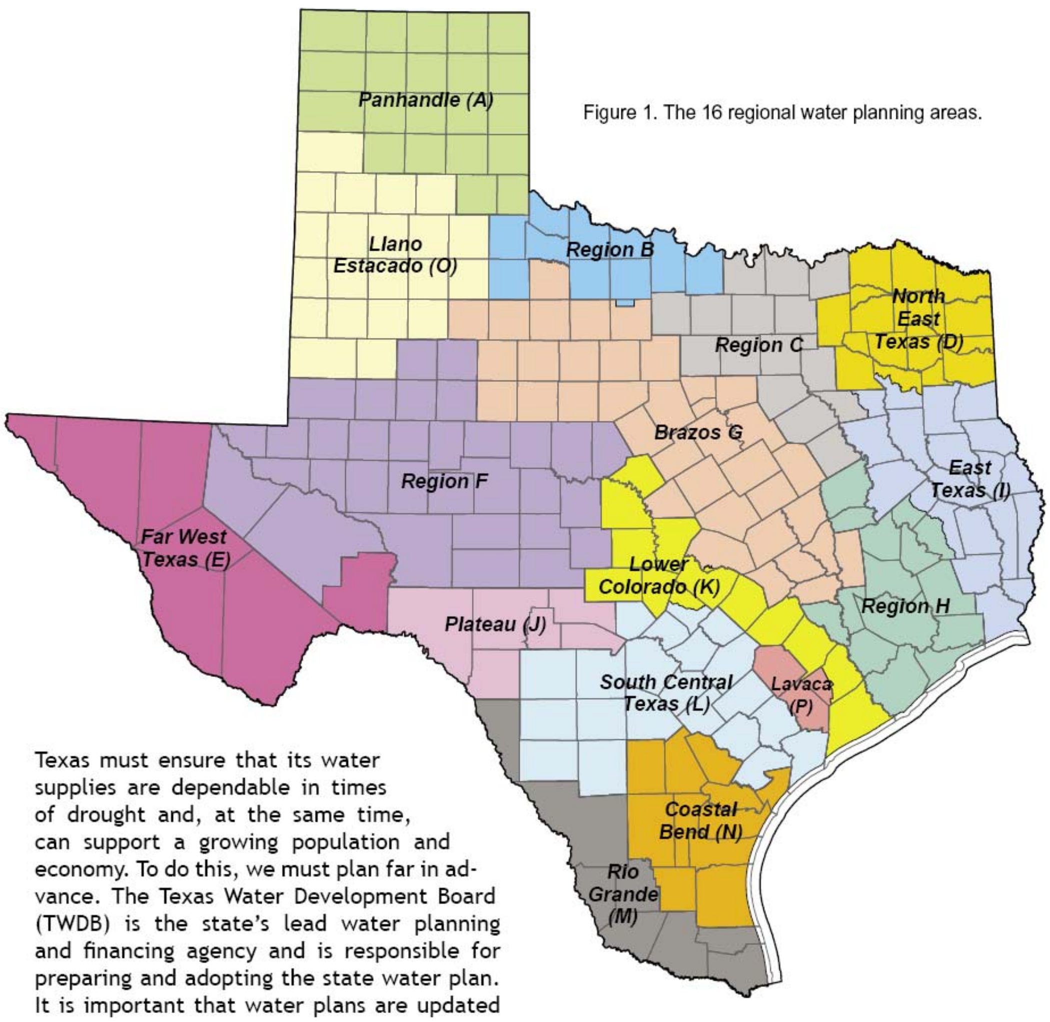
The estimated ground water availability in 2010 for the Bone Spring-Victorio Peak Aquifer is 63,000 acre-feet per year. The water use reported for this aquifer in 2003 was 150,000 acre-feet per year, exceeding what is projected to be available by 87,000 acre-feet annually (Texas Water Development Board, 2007).

The Texas Water Development Board ground water availability models are a computer-based three dimensional, numerical ground water flow models to simulate ground water flow systems at a regional scale. The models estimate current and future trends in the amount of water available for use from an aquifer. Once an initial model has been created and calibrated, it becomes a tool that ground water conservation districts, planning groups, and others can use to estimate ground water availability and predict future water levels and regional ground water flow in their aquifers based on different scenarios. To cover the state's aquifers adequately, at least 31 models are needed for the 30 major and minor aquifers in Texas. The Bone Spring Victorio Peak Aquifer model development is currently in progress. The Capitan Reef Aquifer model will be developed in the future (Texas Water Development Board, 2007).

Appendix D

Texas Water Resources Planning

Texas is divided into 16 regional water planning areas. Each planning area is represented by a planning group that consists of about 20 members representing a variety of interests, including agriculture, industry, environment, public, municipalities, business, water districts, river authorities, water utilities, counties, and power generation. Each planning group evaluates population projections, water demand projections, and existing water supplies available during drought. Based on this information, each planning group identifies who will not have enough water, recommends strategies and projects that could be implemented to obtain more water, and estimates the costs of these strategies and projects. Once the planning group adopts the regional water plan, the plan is sent to TWDB for approval. TWDB then compiles information from the regional water plans and other sources to develop the state water plan (Texas Water Development Board, 2007).



Texas 16 Regional Water Planning Areas (Texas Water Development Board, 2007).

Section 16.051 of the Texas Water Code directs the Texas Water Development Board to prepare, develop, formulate, and adopt a comprehensive State Water Plan that incorporates the regional water plans approved under Section 16.053. The State Water Plan shall provide for the development, management, and conservation of water resources and preparation for the response to drought conditions (Texas Water Development Board, 2007).

GUMO is located within the Far West (E) Region that includes seven counties and lies within the Rio Grande Basin (Figure 9). The largest economic sectors in the region are agriculture, agribusiness, manufacturing, tourism, wholesale and retail trade, government, and military. Approximately 96% of the region’s residents reside in El Paso County. Between 2010 and 2060, the population in the Far West Region is projected to increase 79 percent to 1,527,713. Its water demands will increase less dramatically with a projected increase of 9 percent. Within this projected water demand, irrigation water usage, which makes up the largest share of the demands, is projected to decrease 9 percent (Texas Water Development Board, 2007).

The Salt Basin of West Texas has been a significant source of ground water to local users in West Texas for most of the last century. In a region of normally low rainfall and high evaporation, ground water is a vital resource to municipalities, industries, and landowners in the Salt Basin. Because El Paso is facing serious water shortages in the next 20 to 30 years, city and regional planners are looking, in part, to water resources in the Salt Basin.

The Far West Texas Water Planning Group prepared the Far West Texas Plan (2006) for the Texas Water Development Board. The plan’s purpose is to provide water planners and users a reference document for long- and short-term water management recommendations. Because current and future water demand and supply sources are constantly changing, it is intended for the plan to be revised every five years or sooner, if necessary (Far West Texas Water Planning Group, 2006). The frequency of droughts in Texas is the reason Senate Bill 1 (1997) required the water supply planning process to meet water supply needs during a drought of record and is one of the reasons for the five-year cycle of review and update of the regional and state water plans.

Local ground water conservation districts (GCDs) are the state’s preferred method of ground water management. GCDs are charged to manage ground water by providing for the conservation, preservation, protection, recharging, and prevention of waste of the ground water resources within their jurisdictions. GCDs are authorized with powers and duties that enable them to manage ground water resources. The three primary GCD authorities include: permitting water wells; developing a comprehensive management plan; and adopting the necessary rules to implement the management plan. GCD’s within the immediate area of GUMO are Hudspeth County UWCD No. 1 (1957) to the west, Culberson County GCD (1998) to the south and one GCD created by not yet confirmed by voters that includes the northeastern half of Culberson County and GUMO (Texas Water Development Board, 2007).

Appendix E

Additional Indicators and Target Values

Water Resources

Chihuahuan Desert Inventory and Monitoring Network Vital Signs

The water-resource vital signs identified by the NPS CHDN include (Huff *et al.*, 2006):

3) Surface waters: water temperature, pH, specific conductance, turbidity, bacteria, abundance/density of macroinvertebrates, dissolved inorganic constituents, dissolved oxygen, nutrients, concentrations of anthropogenic organic compounds, sediment load and chemical composition.
4) Ground water: water temperature, pH, specific conductance, dissolved inorganic constituents, anthropogenic organic compounds, and ground water elevation.

Some of the target values for these vital signs are included in this appendix. If GUMO's staff/financial resources increased, these additional vital signs could be included to better evaluate water resources.

Water Temperature

Water temperature is one of the most important water quality parameters and has direct effects on water chemistry and the functions of aquatic organisms. Temperature influences the dissolved oxygen content of the water; the rate of photosynthesis by algae and other aquatic plants; the metabolic rates of organisms; the sensitivity of organisms to toxic wastes, parasites and diseases; and the timing of reproduction and migration of aquatic organisms. Factors which can affect temperature include sunlight energy (seasonal and daily changes), shade, air temperature, stream flow, water depth, inflow of ground water or surface water, and the color and turbidity (cloudiness) of the water. Other factors include soil erosion, storm water runoff, and alterations to stream morphology, substrate and flow. Based on the Texas water quality criteria for the Rio Grande Basin (Lower Pecos River and Upper Pecos River basins), GUMO's streams should not exceed 92°F (23.9°C) (Texas Commission on Environmental Quality, 2006). For GUMO, spring water discharge temperatures will be much lower and site specific water temperature target values should be established.

GUMO Water Temperature Interim Target Value = no change from established site-specific seasonal baseline.

Bacteria

Coliform bacteria occur naturally in water systems, soil, and the digestive systems of animals. While most coliform bacteria are non-pathogenic, high levels of this bacteria may indicate the presence of pathogenic organisms. *E. coli*, a pathogenic fecal coliform bacteria, is the "most common disease causing bacteria in the feces of warm-blooded animals" (U.S. Dept. of the Interior, 2001). Because most fecal coliforms are non-pathogenic, *E. coli* testing is thought to be a more specific, reliable indicator of public health hazards than testing for fecal coliform (Jackson *et al.*, 1989). Based on the water quality criteria defined by the state of Texas, a public health hazard will be presumed if *E. coli* levels exceed 126 counts/100ml based on a geometric mean of at least five samples taken over 30 days or if levels exceed 394 counts/100ml on a single sample (Texas Commission on Environmental Quality, 2006).

GUMO *E. coli* Target Value ≤ 126 counts/100 ml for 30 day 5-sample geometric mean or 394 counts/ 100 ml single sample

Dissolved Oxygen

Dissolved oxygen (DO) refers to the amount of oxygen dissolved in water. The dissolved oxygen concentration in water can directly affect reproduction and incubation, changes in species, and death of adult and juvenile fish and other organisms. Factors which affect the DO concentration in water include temperature, DO sources such as photosynthesis, DO sinks such as respiration and breakdown of organic material, and salinity. Low dissolved oxygen levels can result from algal blooms, low flows, elevated water temperature, human waste and animal waste. Based on the Texas water quality criteria for the Rio Grande Basin (Lower Pecos River and Upper Pecos River basins), GUMO's streams should equal or exceed a dissolved oxygen concentration of 5.0 mg/L (Texas Commission on Environmental Quality, 2006).

GUMO Dissolved Oxygen Target Value ≥ 5.0 mg/L

pH

pH is a measure of hydrogen (H^+) ions in a water sample, with pH values lower than 7 indicating acidity while pH values higher than 7 indicate alkalinity. At the extreme ends of the pH scale (2 or 13), physical damage to gills, exoskeleton, and fins of aquatic species can occur. Changes in pH may also alter the concentrations of other substances in water to a more toxic form and increase toxic substance mobility, making it easier for organisms to absorb. In fresh water, increasing temperature decreases pH. Some factors that may affect pH in park waters include acid rain and fertilizers. Based on the Texas water quality criteria for the Rio Grande Basin (Lower Pecos River and Upper Pecos River basins), GUMO's streams should maintain a pH between 6.5 and 9.0 (Texas Commission on Environmental Quality, 2006).

GUMO pH Target Value: 6.5 – 9.0

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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