National Park Service Chihuahuan Desert Network
Inventory and Monitoring Program

Chihuahuan Desert Network Vital Signs Monitoring Plan: Revised Phase I Report

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Cover Photo: Cesar Mendez, Rancho Ojo Caliente, Chihuahua, Mexico

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Being last is not always the worst, as the Chihuahuan Desert Network (CHDN) has benefited immensely from the networks that have gone before us. In particular, CHDN borrowed extensively from the Central Alaska, Southwest Alaska, and Cumberland-Piedmont Networks for the development of Chapter 1. CHDN used text and models from the Sonoran Desert Network, and the Northern Colorado Plateau and Southern Colorado Plateau Networks for much of the background information in Chapter 2. Various I&M Networks, across the country, have been helpful in answering questions, providing advice to this network, and commiserating (e.g., Mojave Desert Network, Northern Great Plains Network and many others). Collectively, the staffs of the I&M Networks are among the most dedicated, bright and creative individuals working on monitoring issues in federal and state land management agencies. We are proud to be associated with them. The CHDN Board of Directors and Technical Committee have provided extensive support and guidance. We really appreciate the excitement you have shown for our program. This report has benefited greatly from the thoughtful review of the CHDN Board of Directors and Technical Committee and an anonymous reviewer. The staffs at Carlsbad Caverns and Guadalupe Mountains National Parks were gracious hosts to our network in providing excellent office space and administrative support for the first years of this network. Additional support was, and is still being, provided by the staff in the Administrative Offices for Carlsbad Caverns and Guadalupe Mountains National Parks; fondly referred to as the “Town Office”. They patiently answered a myriad of questions of the CHDN employees.

CHAPTER 1: INTRODUCTION AND BACKGROUND

In 1999, the National Park Service (NPS) launched the Natural Resource Challenge, a program designed to strengthen natural resource management in the nation's national parks (National Park Service 1999). The single biggest undertaking of the Challenge was to expand ongoing park inventory and monitoring efforts into an ambitious comprehensive nationwide program. The Service-wide Inventory and Monitoring (I&M) program was introduced to 270 parks identified as having significant natural resources. Under this program, parks have been organized into 32 networks to conduct long-term monitoring of ecosystem function and health, and other environmental indicators (vital signs). Each network links parks that share geographic and natural resource characteristics, allowing for improved efficiency and the sharing of staff and resources. A map of the I&M networks can be viewed in the website: http://science.nature.nps.gov/im/monitor/networks2.htm.

This report covers the Chihuahuan Desert Inventory and Monitoring Network (CHDN) which is one of the 32 networks included in the NPS Service-wide Inventory and Monitoring program, and one of seven networks in the Intermountain Region. CHDN is composed of 7 National Park Units in New Mexico and Texas (Table 1.1, Figure 1.1). CHDN park units are located almost exclusively in the Northern Chihuahuan subregion of the Chihuahuan Desert Ecoregion. The parks range in size from almost 200 ha (500 ac) at Fort Davis National Historic Site to over 300,000 ha (800,000 ac) at Big Bend National Park (Appendix A, B, C).

Table 1.1. List of park units in the Chihuahuan Desert Network.

Unit	State	Park Code	Hectares	Acres
Amistad National Recreation Area	TX	AMIS	23,185	57,292
Big Bend National Park	TX	BIBE	324,232	801,163
Carlsbad Caverns National Park	NM	CAVE	18,926	46,766
Fort Davis National Historic Site	TX	FODA	192	474
Guadalupe Mountains National Park	TX	GUMO	35,272	86,416
Rio Grande Wild and Scenic River*	TX	RIGR	3885	9600
White Sands National Monument	NM	WHSA	58,169	143,733
		Total	464,544	1,145,444

* RIGR is administered by BIBE, and the overlap is limited to the 209 river km (127 river miles) between Big Bend and the Terrell - Val Verde County Lines.

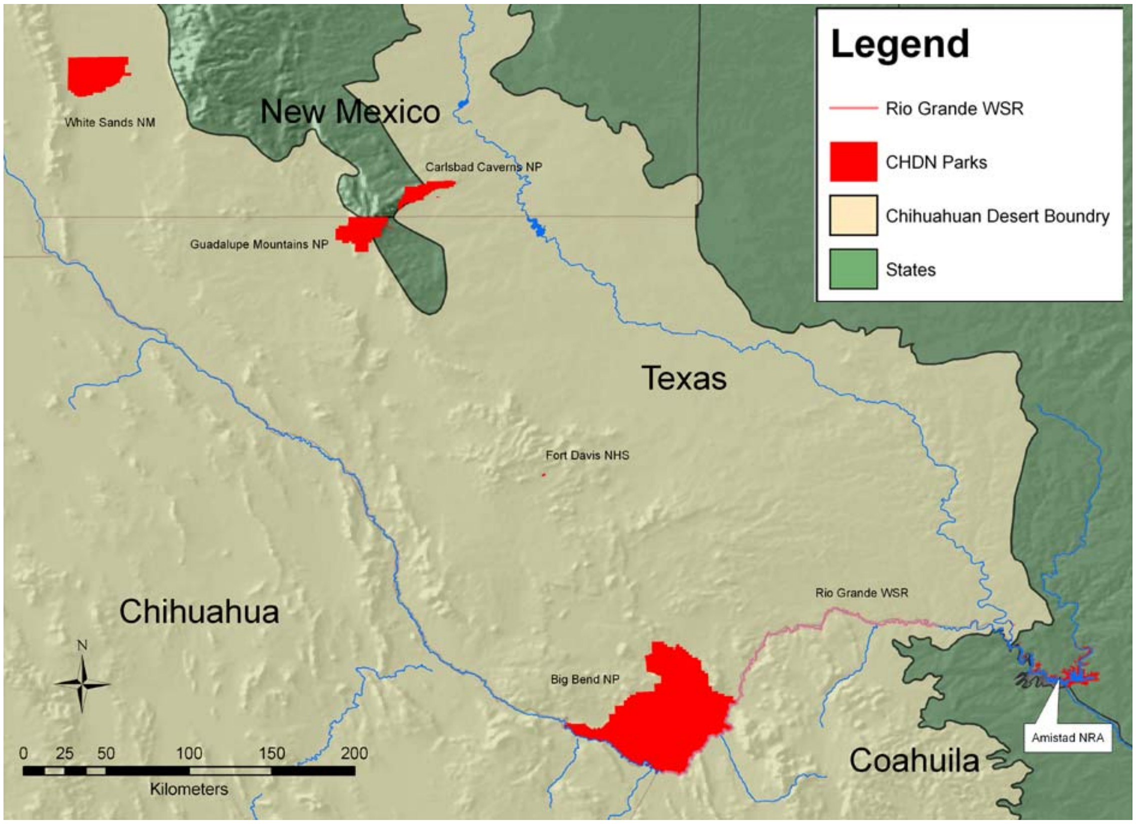


Figure 1.1. Map of CHDN park units. This map shows the location of the seven parks within the Chihuahuan Desert.

The CHDN Vital Signs Monitoring Plan is being developed over a multi-year period following specific guidance from the NPS Washington Office (WASO) (National Park Service 2003). Networks are required to document monitoring planning progress in three distinct phases (Table 1.2), and to follow a standardized reporting outline. Each phase of the report requires completion of specific portions of the outline.

The Phase I Report includes drafts of Chapter One (Introduction and Background) and Chapter Two (Conceptual Models) of the monitoring plan. Other chapters will be developed and finalized for the Phase II and Phase III Reports. This document presents the CHDN framework and approach to planning for vital signs monitoring and sets the stage upon which the program will be developed.

Table 1.2. Three-phase planning process for development of the CHDN Monitoring Plan.

	Goals and Tasks	CHDN Deadlines
Phase I	Description of monitoring objectives and network overview; Initiating conceptual model development	October 2005
Phase II	Cont. conceptual model development; vital signs prioritization; selection and rationale	October 2007
Phase III Peer-review	Monitoring & sampling design	October 2008
Phase III Initial Draft	Monitoring & sampling design	December 2008

1.1 INTEGRATED NATURAL RESOURCE MONITORING

The purposes of the Vital Signs Monitoring Program in the National Park Service relates directly to the purposes of the national park system. In this section, we review the justifications for integrating natural resource monitoring, the legislation policy and guidance that directs the program, and the goals of the monitoring program. An overview of the network approach to vital signs monitoring are also included.

1.1.1 Justification for Integrated Natural Resource Monitoring

Knowing the condition of natural resources in national parks is fundamental to the network's ability to manage park resources, "*unimpaired for the enjoyment of future generations*" (Organic Act 1916). National park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the benefit of park resources. For years, managers and scientists have sought for a way to characterize and determine trends in the condition of parks and other protected areas, to assess the efficacy of management practices and restoration efforts, and to provide early warning of impending threats.

National parks are part of larger ecosystems, and must be managed in that context. The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because most parks are open systems, with threats such as air and water pollution, or invasive species, often times, originating outside of the park's boundaries. An ecosystem approach is further needed because no single spatial or temporal scale is appropriate for all system components and processes; the appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level, and in some cases may require a regional, national or international effort to understand and manage the resource.

Natural resource monitoring is important for two reasons. First, monitoring data helps to define the typical limits of natural variation in park resources and when put into a landscape context, monitoring provides the basis for determining meaningful change in ecosystems. Second, monitoring results may also be used to determine what constitutes impairment, and to identify the need to initiate or change management practices.

The intent of the NPS monitoring program is to track a subset of valued resources and indicators of overall ecosystem condition, known as “vital signs.” This subset of resources and processes is part of the total suite of natural resources that park managers are directed to preserve: including water, air, geological resources, plants, and animals, and the various ecological, biological, and physical processes that act on these resources. In situations where natural areas have been so highly altered that physical and biological processes no longer operate (e.g., control of fires and floods in developed areas), information obtained through monitoring can help managers understand how to develop the most effective approach to restoration or in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

Monitoring is a central component of natural resource stewardship in the National Park Service, and in conjunction with natural resource inventories and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.2). The NPS strategy to institutionalize inventory and monitoring throughout the agency consists of a framework (Framework for National Park Service Inventory and Monitoring) having three major components: (1) completion of 12 basic resource inventories upon which monitoring efforts can be based; (2) a network of 11 experimental or “prototype” long-term ecological monitoring (LTEM) programs begun in 1992 to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters in approximately 270 parks with significant natural resources that have been grouped into 32 I&M networks.

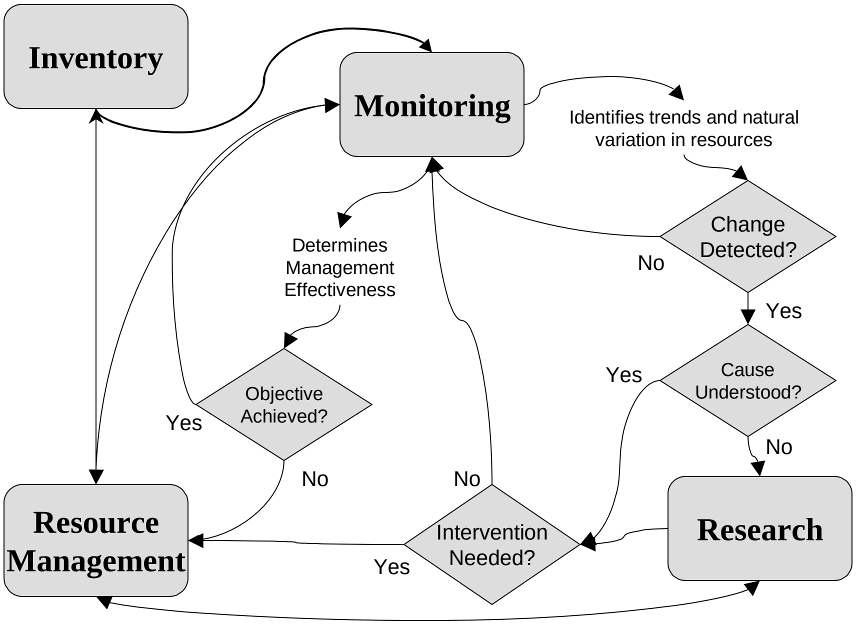


Figure 1.2. Relationships between monitoring, inventories, research, and natural resource management activities in National Parks.

The network approach facilitates collaboration, information sharing, and economies of scale in natural resource monitoring and provides parks with a minimum infrastructure for initiating natural resource monitoring that can be built upon in the future. Additionally, the prototype parks are able to serve as "centers of excellence" due to their higher funding and staffing levels, as well as USGS involvement and funding in program design and protocol development. These centers are able to do more extensive and in-depth monitoring and continue research and development work to benefit other parks.

1.1.2 Legislation, Policy and Guidance

With the passage of the National Park Service Organic Act of 1916 (16 U.S.C. 1 § 1), the mission of the National Park Service was established and defined, and through it, Congress implied the need to monitor natural resources and guarantee unimpaired park services:

> "*The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified … , which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations*."

Congress reaffirmed the declaration of the Organic Act vis-à-vis the General Authorities Act of 1970 (16 U.S.C. 1a-1a8), and effectively ensured that all park units be united into the 'National Park System' by a common purpose of preservation, regardless of title or designation. Two decades later, park service management policy reiterated the importance of this protective function of the NPS to "understand, maintain, restore, and protect the inherent integrity of the natural resources" (NPS Management Policies 2001).

More recent and specific requirements for a program of inventory and monitoring park resources are found in the National Parks Omnibus Management Act of 1998 (P.L. 105-391). The intent of the Act is to create an inventory and monitoring program that may be used:

> "*to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources.*"

Subsequently, in 2001, NPS management updated previous policy and specifically directed the Service to inventory and monitor natural systems in efforts to inform park management decisions:

> "*Natural systems in the national park system, …, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions*" (2001 NPS Management Policies).

In addition to the legislation directing the formation and function of the National Park System, there are numerous other legislation intended to not only protect the natural resources within national parks and other federal lands, but to address concerns over the environmental quality of life in the United States. As NPS units are among some of the most secure areas for sustaining populations of threatened, endangered species, and represent natural resources that are otherwise compromised in other parts of the country, the particular guidance offered by federal environmental legislation and policy is an important component to the development and administration of a natural resource inventory and monitoring system in the National Parks. Legislation, policy and executive guidance all have an important and direct bearing on the development and implementation of natural resource monitoring in the National Parks. Relevant federal legal mandates are therefore summarized in Appendix D.

1.1.2.1 Park Specific Enabling Legislation

The CHDN includes three National Parks, one National Monument, one National Historic Site, and one National Recreation Area. In 1970, Congress elaborated on the 1916 NPS Organic Act, saying all of these designations have equal legal standing in the National Park system. Park specific enabling legislation (Table 1.3), as well as international programs, collectively, influences the natural resources management on NPS lands in the CHDN. The enabling legislation of an individual park provides insight into the natural and cultural resources and resource values for which it was created to preserve, and, in some cases, specific guidance for the direction and emphasis of resource management programs, including inventory and monitoring (Table 1.3).

Table 1.3. Enabling legislation for each CHDN park unit.

Enabling Legislation	Summary Content
AMIS (P.L. 101-628**)**	Amistad National Recreation Area was established on November 28, 1990 following the construction of Amistad Dam along the Rio Grande river its purpose is to *"….provide for public outdoor recreation use and enjoyment of the lands and waters associated with the United States portion of the reservoir known as Lake Amistad, located on the boundary between the United States and Mexico; and protect the scenic, scientific, cultural and other value contributing to the public enjoyment of such lands and waters…."*
BIBE (49 Stat. 393)	Big Bend National Park was established on June 20, 1935 "…*for the use of the public for recreational park purposes…within the boundaries to be determined ….. within the area of approximately one million five hundred thousand acres..."*
CAVE **(**1679 Stat. 1929)	Carlsbad Cave National Monument was created on October 25, 1923 "…*a limestone cavern….. of extraordinary proportions and of unusual beauty and variety of natural decoration…beyond the spacious chambers that have been explored, other vast chambers of unknown character and dimensions exist…"*
FODA (75 Stat. 488)	Fort Davis National Historic Site was established on September 8, 1961authorized"...*for the purpose of establishing a national historic site…set aside as a public national memorial to commemorate the historic role played by fort in the opening of the West…"*
GUMO (P.L.89-667 80Stat. 920)	Guadalupe Mountains National Park was established on October 15, 1966 *"...in order to preserve in public ownership an area….possessing outstanding geographical values together with scenic and other natural values of great significance…"*
RIGR (P.L. 95-625 sec. 702)	Rio Grande Wild and Scenic River was officially establish on November 10, 1978, through the addition of the Wild and Scenic Act set in 1968 the segment of the river *"….is to protect water quality and to preserve in a free-flowing condition certain rivers with outstandingly remarkable natural, cultural, or recreational values for the enjoyment of present and future generations…the United States side of the river and such plan shall include, but not be limited to, the establishment of a detailed boundary which shall include an average of not more than 160 acres per mile…*"

WHSA (47 Stat 2551)	White Sands National Monument was established on January 18,1933 in order to *"…preserve the white sand and additional features of scenic, scientific, and educational interest…"*

Treaties and conventions relevant to this region have also been documented, and have been of great significance throughout history (Appendix E). There has also been international concern to improve environmental quality along the border region. Through various meetings of national officials, action is being taken at a bi-national level.

1.1.2.2 Other United States-Mexico Border Cooperative Arrangements

The U.S. and Mexico are involved in a number of cooperative programs. Several of these programs may be relevant to the CHDN's monitoring efforts. These programs are described below.

Additional border programs include:

- **The Border Environment Cooperation Commission (BECC) -** established in 1933, this autonomous, bi-national organization which supports local communities and other project sponsors in developing and implementing environmental infrastructure projects related to the treatment of water and wastewater, and the management of municipal solid waste.

- **La Paz agreement**- The U.S. Environmental Protection Agency (EPA) formally began working with its counterparts in the Mexican government under this agreement in 1983 to protect, improve and conserve the environment of the border region.

- **The Border XXI Program**- In 1992, the environmental authorities of the U.S. and Mexico released the Integrated Environmental Plan for the Mexican-United States Border Area. This was considered the next phase of bi-national planning, which included Air, Water, Hazardous Waste, Pollution Prevention, Emergency Response, Environmental Health, Natural Resources, Environmental Information, and Cooperative Enforcement and Compliance Work Groups.

- **The Border 2012 Framework**- This program is to protect the environment and public health in the U.S.-Mexico border region, consistent with the principles of sustainable development. In this program, sustainable development is defined as "conservation-oriented social and economic development that emphasizes the protection and sustainable use of resources, while addressing both current and future needs and present and future impacts of human actions."

- **The North American Agreement on Environmental Cooperation (NAAEC)-** was approved as a side agreement to NAFTA. The Commission for Environmental

Cooperation (CEC) was established under this agreement to address regional environmental concerns, help prevent potential trade and environmental conflicts, and to promote the effective enforcement of environmental law.

Figure 1.3. Students from Cd. Chihuahua, Mexico and Las Cruces, New Mexico on a fieldtrip in the Organ Mountain, New Mexico. Photo by Cesar Mendez.

Mexico also has concerns about the protection of the water and overall environmental quality. Therefore, they have established and operate under their own laws and standards (Table 1.4). Understanding the role or purpose of relevant Mexican laws and policies is important to the CHDN, as there is only one other network, the Sonoran Desert Network that has a park unit along the Mexico-U.S. border. The CHDN is also unique in that it shares the Rio Grande River, one of the longest North American rivers.

Table 1.4. Mexican Laws (Leyes) and Standards (NOMs).

Law or Standard	Subject
Ley de Aguas Nacionales Law of National Waters	Water quality standards
Ley General para las Prevención y Gestión Integral de los Residuos General Law for the Prevention and Integral Management of Residues (Waste)	Water quality protection
Ley General del Equilibrio Ecológico y la Protección al Ambiente General Law for the Ecological Balance and Environmental Protection	Environmental protection
Norma Oficial Mexicana NOM-001-SEMARNAT-1996 Mexican Official Norm NOM-001-SEMARNAT (Secretariat of the Environment and Natural Resources)-1996	Discharge contaminant standard
NOM-087-ECOLOGIA-2002 Mexican Official Norm NOM-087-ECOLOGIA (ECOLOGY)-2002	Environmental protection

1.1.2.3 Government Performance and Results Act

The Government Performance and Results Act (GPRA) of 1993 require the NPS to set goals and generate annual reports to substantiate results or progress. Categories have been established to guide park management and help organize their monitoring plan of action. GPRA goals with specific relevance to the inventory and monitoring program include the servicewide goal pertaining to natural resource inventories. This goal specifically identifies the objective of inventorying the resources of the parks as an initial step in protecting and preserving park resources (GPRA Goal Ib1) (Table 1.5). The vital signs monitoring plan identifies the indicators or “vital signs” of the network (GPRA Goal Ib3a) which will be complete for CHDN in Fiscal Year 2006. CHDN plans to implement vital signs monitoring, detecting trends in resource condition (GPRA Goal Ib3b) in Fiscal Year 2008. In addition to the national strategic goals, each park has a five-year plan with specific park GPRA goals relevant to natural resource monitoring and management. In determining their individual goals, parks can better report on the condition of their resources. The intention is to conserve or restore the overall integrity of the ecosystem and to serve the public.

Table 1.5. GPRA goals specific to CHDN parks and relevant to more that one unit.*

Goal #	GPRA Goal	Parks with this goal
Ia1B	Exotic Plants	*AMIS, BIBE, FODA, RIGR, WHSA*
Ia1E	Land Health	*BIBE, CAVE, FODA, GUMO*
Ia2A	Candidate Species	*AMIS, BIBE, RIGR,*
Ia2C	Invasive Animal Species	*AMIS, BIBE, RIGR, WHSA*
Ia4A	Surface Water Quality-Rivers	*AMIS, BIBE, FODA, RIGR, WHSA*
Ia4B	Water Quality (lakes)	*AMIS, BIBE*
Ia4C	Water Quantity-Protected and or restore	*BIBE, RIGR*
Ib3A	Vital Signs Identified	*AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA*
Ib3B	Vital Signs Monitored	*AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA*

* GPRA goals for all units are available in Appendix F

1.1.3 Goals for NPS Vital Signs Monitoring

The overall goal of natural resource monitoring in parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. The NPS-wide I&M Program has developed long-term goals to comply with legal requirements, fully implement NPS policy, and to provide park managers with the data required to understand and manage park resources:

Servicewide goals for vital signs monitoring for the National Park Service are as follows:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.

2. Provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.

3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.

4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.

5. Provide a means of measuring progress towards performance goals.

These NPS-wide monitoring goals guide the scope and direction of the CHDN's program. The program will likely include effects-oriented monitoring to detect changes in the status or condition of selected resources, stress-orientated monitoring to meet certain legal mandates (e.g., Clean Water Act), and effectiveness monitoring to measure progress towards meeting performance goals. The NPS-wide goals also acknowledge the importance of understanding inherent ecosystem variability in order to interpret anthropogenic change and recognize the potential role of ecosystems found in NPS park units as reference sites for more degraded ecosystems.

An effective monitoring program provides information that can be used in multiple ways. The most widely identified application of monitoring is to provide information on which to make better-informed management decisions (White and Bratton 1980, Jones 1986). Another use of monitoring information is that by gathering data over long periods, correlations between different attributes may become apparent, and resource managers gain a better general understanding of the ecosystem (Halvorson 1984). A monitoring program may also provide an early warning of the effects of human activities before they are noticed elsewhere (Davis 1989).

1.1.4 CHDN Approach to Vital Signs Monitoring

The CHDN recognizes the National Park Service Monitoring Program as a unique opportunity to advance our understanding of the ecosystems that encompass our network of parks. This understanding will come in the form of the monitoring data that will be collected, analyzed, interpreted, and reported. Further, we recognize that while scientific work will be conducted in each of the network parks, this information needs to be incorporated with our monitoring efforts to improve our understanding of the holistic functioning of ecosystems within our network. An understanding of our ecosystem function is important because it will best allow us to fulfill the legislative mandate to manage parks in a manner that leaves them "unimpaired for the enjoyment of future generations." At the most basic level, we cannot evaluate appropriate ecosystem function when the bounds of natural variability are not known. Similarly, in this situation, reliable identification of resource trends is also difficult.

We have initially chosen to focus the CHDN monitoring program on general ecological function because of the sound foundation that previous research and monitoring efforts conducted by other agencies within desert grasslands and shrublands, particularly within the Chihuahuan Desert (Havstad, et al 2005, Pellant, et al. 2005),. In so doing, the CHDN program will initially be emphasizing servicewide goals numbers 1, 3, and 4 listed above. These goals concern determining status and trends of ecosystem condition, understanding the dynamics of park ecosystems, and providing data to meet legal mandates. The focus of the CHDN is to build a holistic picture of change across the ecosystems of the network. Specifically, we desire to monitor ecosystems to detect change in ecological components, including hydrologic function, biotic integrity and soil site stability and function. In addition, and where possible, the CHDN will consider the Comprehensive Wildlife Conservation Strategy (CWCS) recently developed by the states of New Mexico and Texas (NMGF 2005, TPWD 2005). These CWCSs are required by all states, and cover such areas as inventory and monitoring of priority species of each state. Though many networks may not have participated in the development of CWCSs, the CHDN is committed to being an active partner in these programs.

Our network is also highly committed to establishing the foundation of a monitoring program that will last in perpetuity. We anticipate that over time the information gained from the monitoring program will provide valuable data that will aid appropriate management decisions in the network parks. Thus management issues should be considered in design of the monitoring program, yet those issues should not limit the program because management issues change. A well-designed monitoring program will be applicable to future issues, including ones that we cannot foresee.

1.2 ECOLOGICAL CONTEXT OF THE CHIHUAHUAN DESERT NETWORK

This section sets the scene for monitoring in the ecosystems found in the Chihuahuan Desert Network, though park specific information is described in Appendix A. The physical and natural issues that are relevant to CHDN parks are discussed. However, a broader discussion of the Chihuahuan Desert will provide greater context to the park units located in the CHDN. The northwestern edge of the Tamaulipan Thornscrub (Mezquital) (which covers AMIS) is often included within the Ecoregion of the Chihuahuan Desert, but where appropriate references will made be specifically to this ecoregion.

1.2.1 Chihuahuan Desert Overview

Deserts, by their very name, are seldom regarded as important reservoirs of biological diversity, but some deserts are extraordinarily rich in species, rare plants and animals, specialized habits, and unique biological communities. The Chihuahuan Desert shared by two nations (U.S. and Mexico) is the most biologically diverse desert in the Western Hemisphere and one of the most diverse arid regions in the world. The eastern boundary of the Chihuahuan Desert is one of the oldest and richest centers of plant evolution on the North American continent (Dinerstein, et al. 2000). The Ecoregion encompasses some 70 million hectares. The region extends nearly 1,500 km from south of Albuquerque, New Mexico to 250 km north of Mexico City, including much of the Mexican states of the Chihuahua, Coahuila, Durango, Zacatecas and San Luis Potosi, as well as large parts of southern New Mexico and the Trans-Pecos region of Texas (Figure 1.4).

The diversity of the Tamaulipan Thornscrub is not as divers as the Chihuahuan Desert to the northwest, this Ecoregion still supports over six hundred species of plants and animals. The region is particularly rich in tree species (Ricketts et al. 1999).

1.2.1.1 Physiographic and Climate

Most of the Chihuahuan Desert ecoregion lies between 900 and 1500 m (about 3,000 to 5,000 feet), although foothill areas and some isolated mountain ranges in the central portion of the Ecoregion may rise to more than 3000 m (about 10,000 feet) (Figure 1.5). Schmidt (1979) notes the relative uniformity of climate within the ecoregion; hot summers and cool to cold, dry winters (Figures 1.6 and 1.7). This uniformity is due to the more-or-less equal distance of most areas of the desert from moisture sources (Gulf of Mexico and the Sea of Cortez), the uniformity of elevation of surrounding mountain masses, and the position of the desert on the continent which results in little frontal precipitation. As a result the Chihuahuan Desert has a high percentage of its precipitation falling in the form of monsoonal rains during the summer months (Dinerstein et al. 2000, Ropelewski et al. 2005, Appendix xx). This desert has more rainfall than other warm desert ecoregions, with precipitation typically ranging from 150 to 500 mm (6 to 20 inches) annually, and the average for this being about 235 mm (10 inches) (Figure 1.8) (Schmidt 1979).

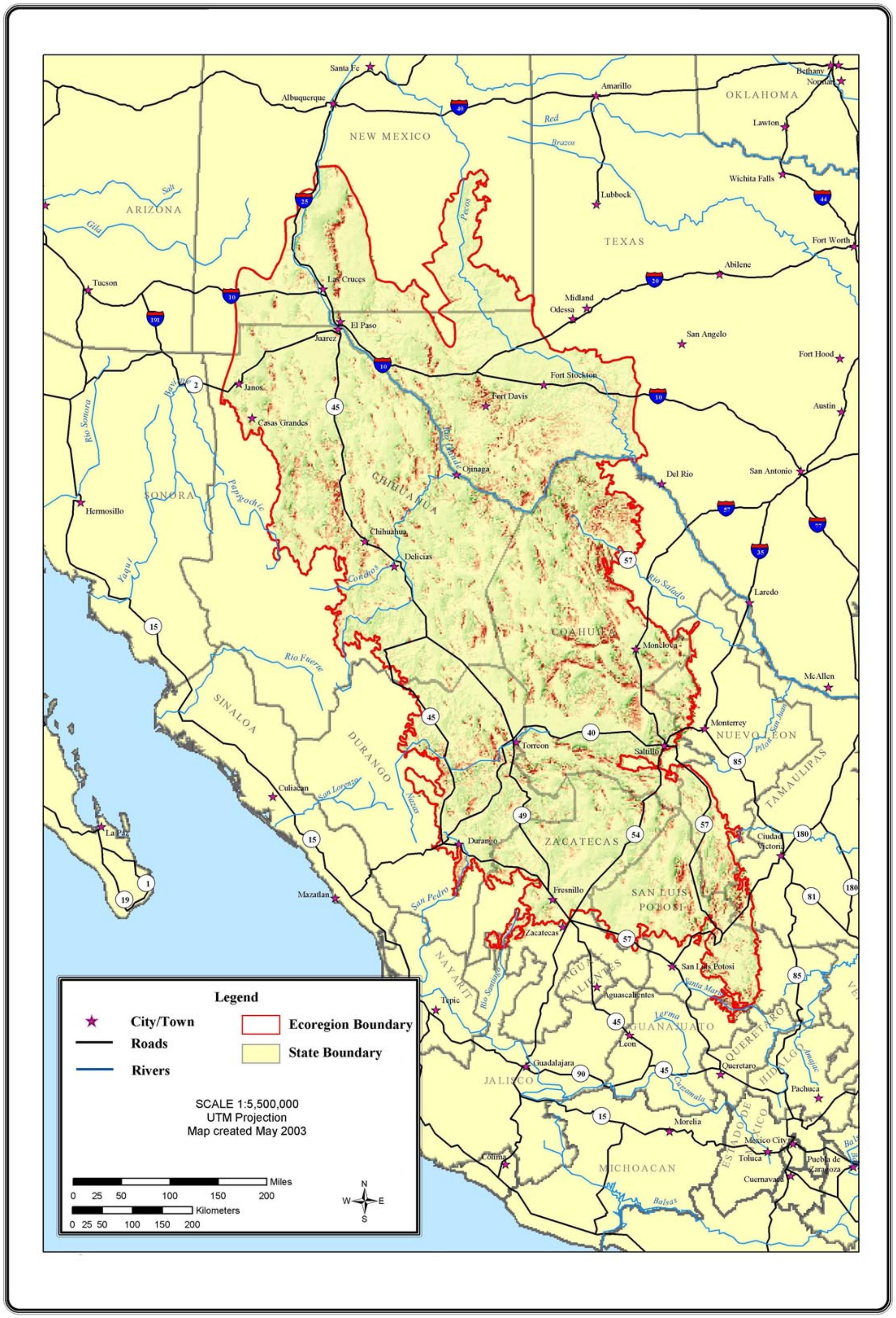


Figure 1.4. The Chihuahuan Desert Ecoregion boundary (from Pronatura Noreste et al., 2004)

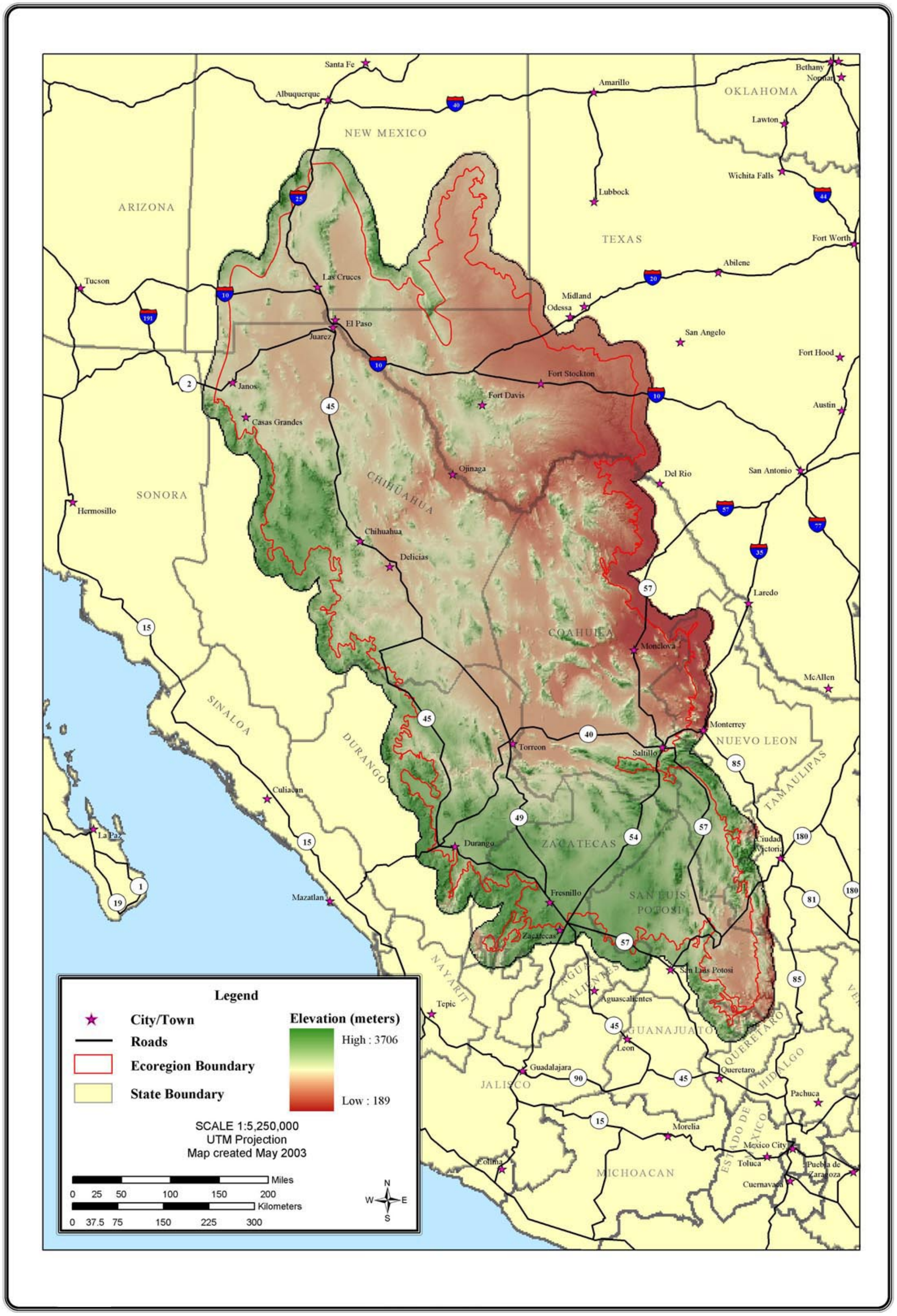


Figure 1.5. Topography of the Chihuahuan Desert (from Pronatura Noreste et al., 2004)

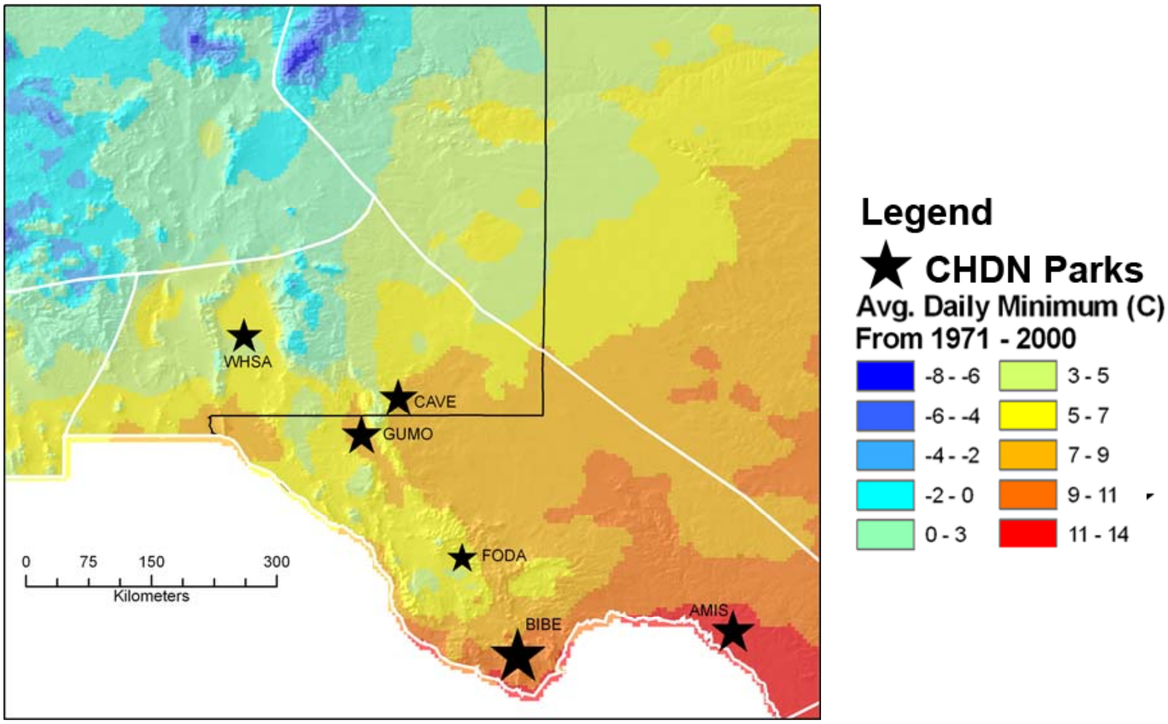


Figure 1.6. Average daily minimum temperatures within the U.S. portion of the Chihuahuan Desert. Location of CHDN parks is shown.

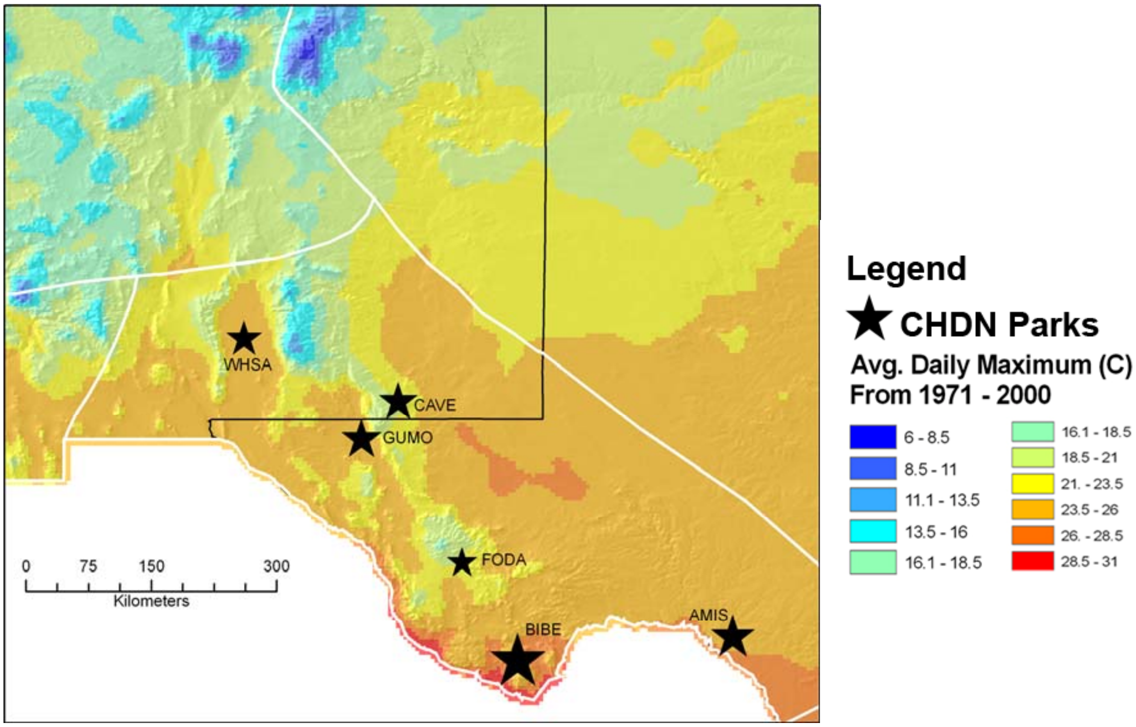


Figure 1.7. Average daily maximum temperatures within the U.S. portion of the Chihuahuan Desert. Location of CHDN parks is shown.

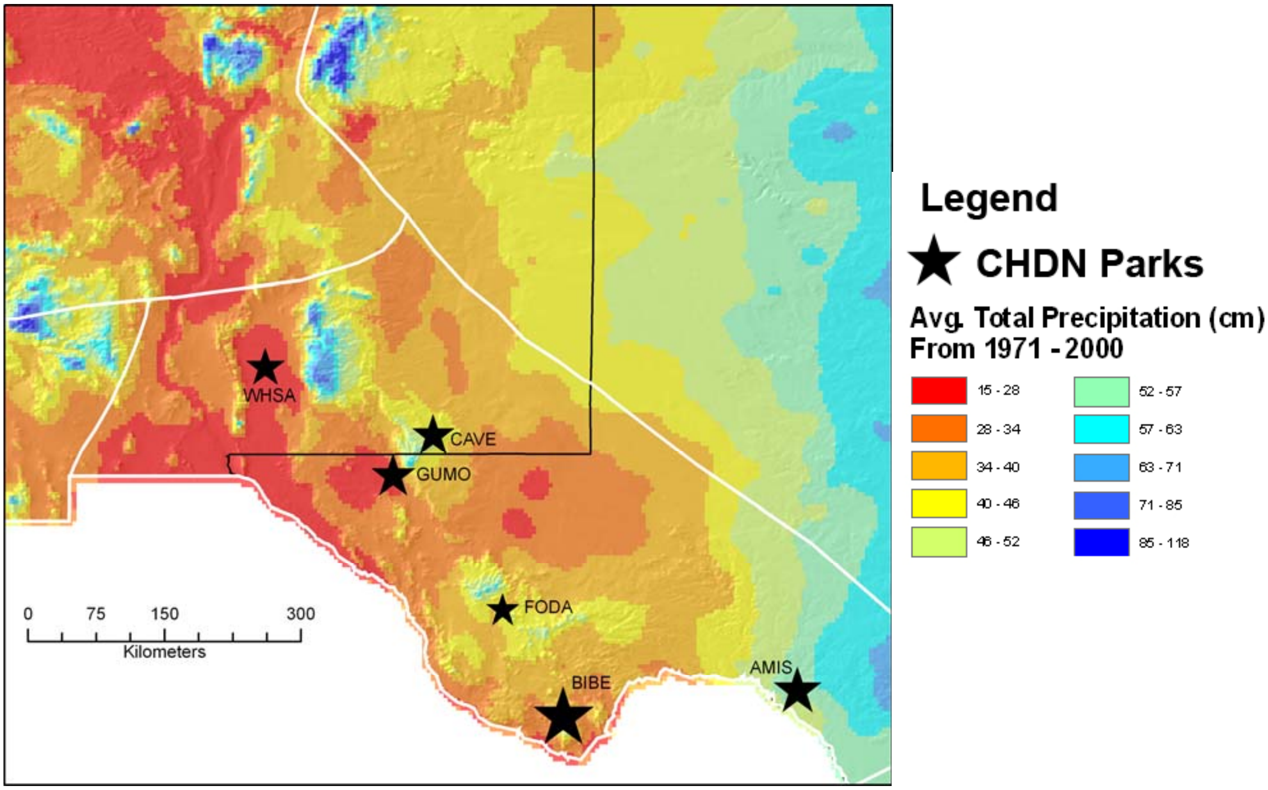


Figure 1.8. Average total precipitation within the U.S. portion of the Chihuahuan Desert. CHDN park locations are shown.

In the Tamaulipan Thornscrub, elevation increase northwesterly from sea level near the Gulf Coast to a base of about 300 m near the northern boundary of the Ecoregion (Ricketts et al. 1999). Rainfall tends to increase from west to east, but in general this Ecoregion has higher, more evenly distributed rainfall than the Chihuahuan Desert.

1.2.1.2 Vegetation

The Chihuahuan Desert (Figure 1.9) is a rather recent phenomenon – as recently as 9,000 years ago this area was much more mesic and dominated by coniferous woodland, typically of piñon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) (Wells, 1974; Allen et al., 1998, Van Devender, 1990). Miller (1977) suggests that the region served as a post-Pleistocene dispersal route for many organisms, and that as aridity increased the result was isolation, differentiation, and extinction that led to the unique Chihuahuan biota of today. Johnston (1977) indicates that the Sierra Madre Oriental, which forms the eastern boundary of the Chihuahuan Desert, is one of the oldest and richest centers of plant evolution on the North American continent. Johnston maintains that the northern Chihuahuan Desert, which lies on the Mexican Plateau, is essentially a broad physiographic expansion of the Sierra Madre Oriental. Johnston further indicates that

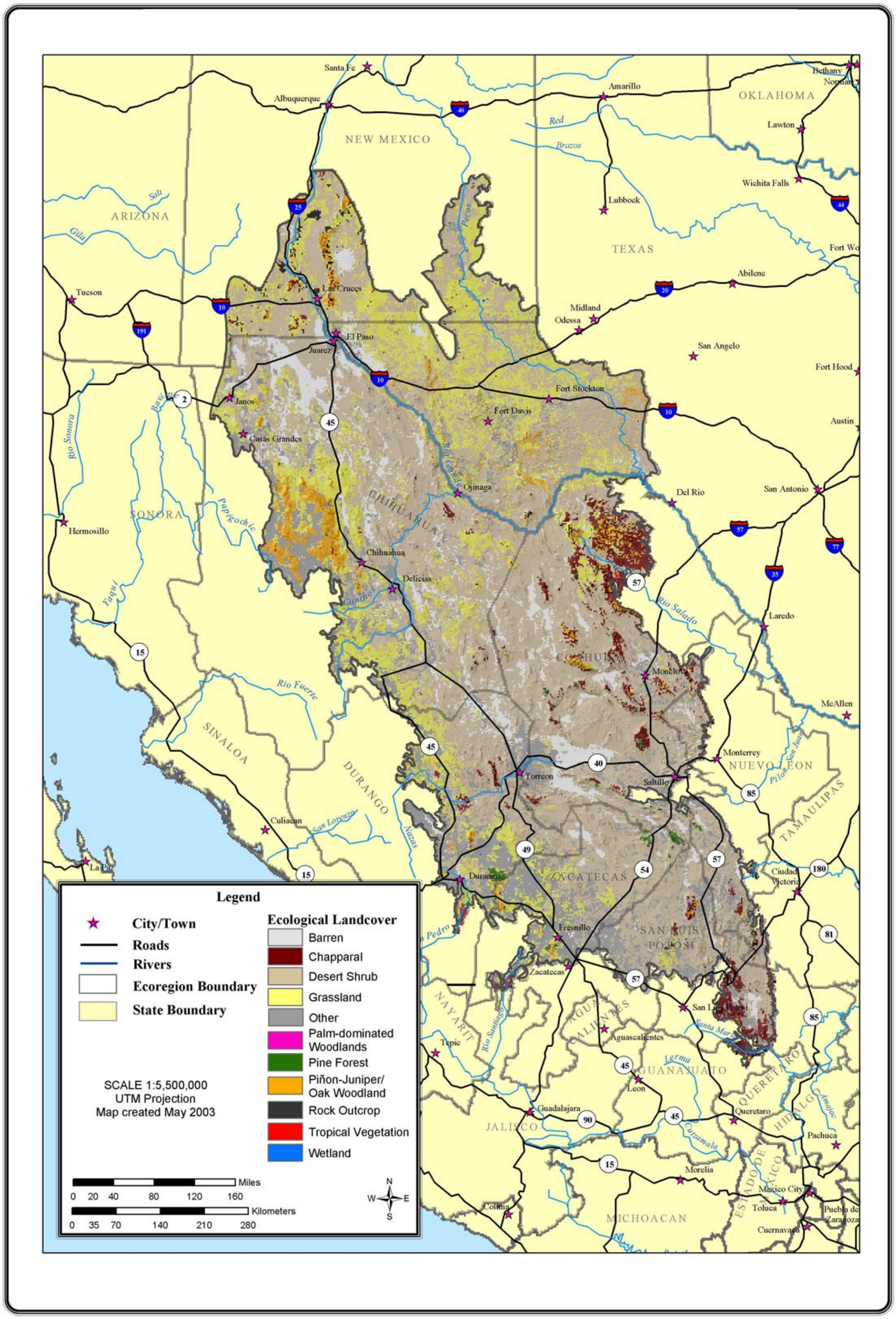


Figure 1.9. Landcover within the Chihuahuan Desert. (from Pronatura Noreste et al., 2004)

there are at least 1,000 endemic plant taxa in the Chihuahuan Desert, an astonishing richness of biodiversity. This high desert area is a center for endemism of yuccas and cacti (Hernandez and Barcenas 1995). As many as 350 of the 1500 known species of cacti occur here. Four other plant families (grasses, euphorbs, asters, and legumes) also show high levels of endemism across the desert's many basins (Dinerstein et al. 2000).

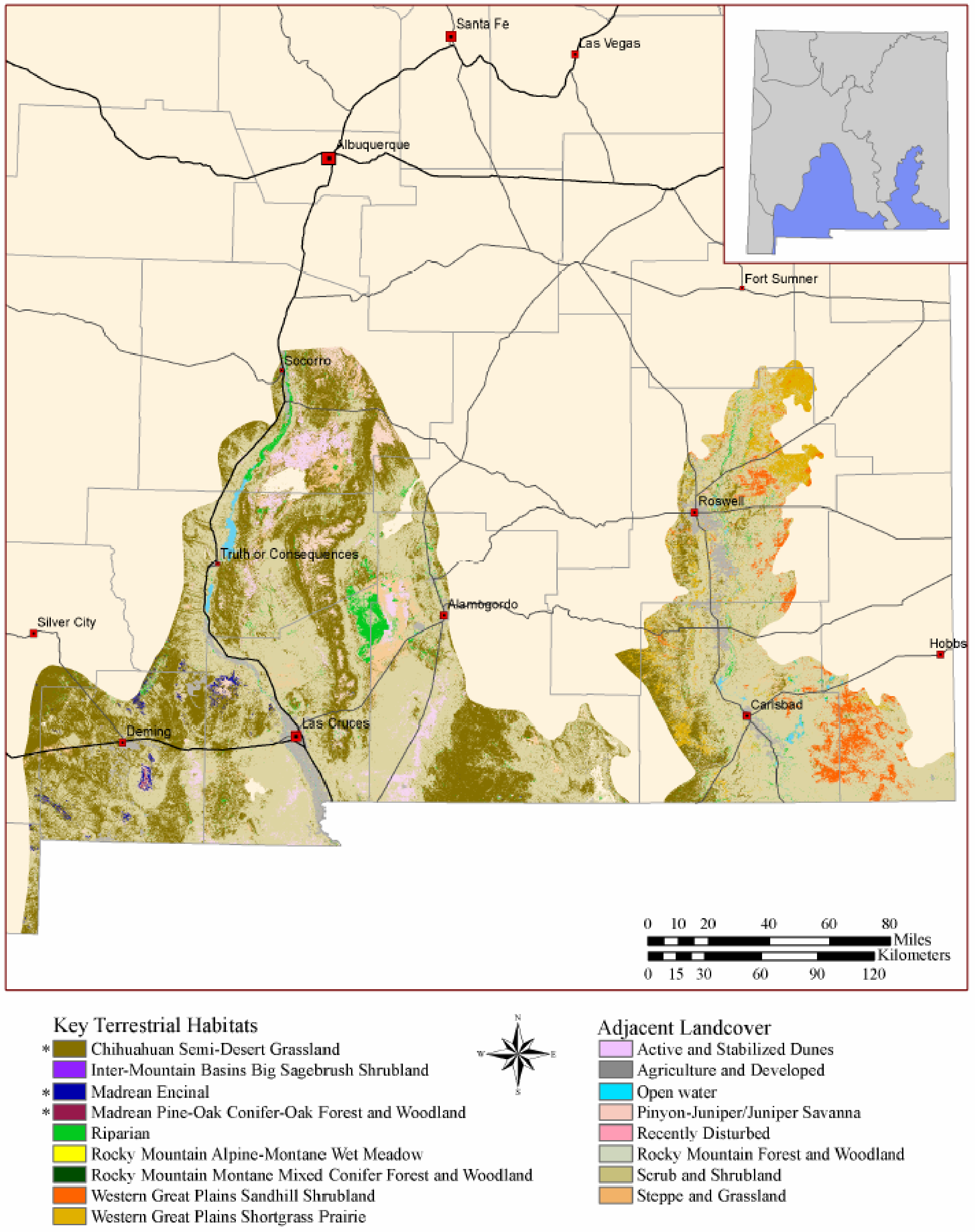
Dick-Peddie (1993) notes that the Chihuahuan Desert Scrub vegetation type is younger still, possibly no older than 4,000 years. Likewise, in the last 70 to 250 years, there has been a rapid shift from areas dominated by Desert Grasslands to scrub (Donart 1984). The cause of this shift appears to be primarily the extremely large concentrations of domestic livestock. Other contributing factors include climate change and fire suppression (Dick-Peddie 1993) (Table 1.6, Figure 1.10).

Table 1.6. Terrestrial habitat types of the Chihuahuan Desert.

I. Desert Scrub and Woodlands
    A. *Larrea* desert scrub
    B. Mixed Desert scrub
    C. Yucca woodland
    D. *Izotal* (*Dasylierion-Yucca-Agave*)
    E. *Prosopis* scrub
    F. *Gypsophilous scrub*
    G. Lowland riparian woodland
    H. Playa

II. Grasslands
    A. Grama grassland
    B. Sacaton grassland
    C. Tobosa grassland
    D. Gypsum grassland
    E. Lowland riparian marshland

III. Montane Chaparral and Montane woodlands
    A. Montane chaparral
    B. Juniper-pinyon woodland
    C. Pine-oak woodland
    D. Mixed-conifer forest
    E. Montane deciduous woodland



The source of data is the Southwest Regional Gap Analysis Project (SWReGAP). For information regarding methods, results, and data accuracy, refer to <http://fws-nmcfwru.nmsu.edu/swregap/>.

Figure 1.10. Key terrestrial habitats in the Chihuahuan Desert Ecoregion in New Mexico. Adjacent land cover types are given to provide an indication of vegetation surrounding key habitats. Key habitats are designated with an asterisk (*). The source of data is the Southwest Regional Gap Analysis Project (SWReGap). (from NMWCS document).

Figure 1.11. Dense stand of lechuguilla, Big Bend NP, Texas.

Thus shrublands are now synonomous with the Chihuahuan Desert, and make over 55% of the area. In the U.S., the boundaries are driven by the contiguous distributions of creosote bush (*Larrea tridentata*), and tarbush (*Flourensia cernua*) (Dick-Peddie 1993). Lechuguilla is also considered a signature plant of the U.S. portion of the Chihuahuan Desert (Figure 1.11).

A second significant vegetation type is Desert Grasslands which make up almost 30% of the area (Dick-Peddie 1993, Pronatura Noreste et al., 2004). Significant portions of the region are covered in grama grasslands (*Bouteloua* spp.), though the dominant is black grama (*B. eriopoda*). Other grass species considered diagnostic are tobosa (*Hilaria mutica*), bushmuhly (*Muhlenbergia porteri*), and burrograss (*Scleropogon brevifolius*). Mesic swales are dominated by tobosa (*Hilaria mutica*) and giant sacaton (*Sporobolus wrightii*). These grasses were probably the species early Spanish explorers encountered when they excitedly reported grasses that were “belly high to a horse” (Tweit 1995).

Forested mountain ranges also rise abruptly from the desert, many of which are home to a unique mix of desert and montane plant and animal species. These mixed conifer forests, oak, and pinyon-juniper woodlands comprise approximately 10% of the area. In south-central New Mexico, wind-blown soils form one of the largest gypsum dunefields in the world. Additionally, influences from three ecoregions (Chihuahuan desert, Edward’s Plateau savanna and Tamaulipan mezquital [thorn scrub]) come together in the Devils River area of Texas.

In the Tamualipan mezquital, trees such as acacia species, and mesquite (*Prosopsis glandulosa*) dominate. Common shrubs include chaparro (*Zizyphus obtusifolia*), common bee-brush (*Aloysia wrightii*), prickly pear, and various cholla species. Some grasslands occur within this region. The most common grasses found include curly mesquite grass (*Hilaria belangeri*), hooded finger grass (*Chloris cucullata*), *Bouteloua* spp.) and *Muhlenbergia* spp.

Some distinctive and unique habitat types in the Chihuahuan Desert include yucca woodlands, playas, and gypsum dunes (Figure 1.12).

Figure 1.12. Gypsum dunes ripple in White Sand National Monument, New Mexico.

Other habitat types include a diverse array of freshwater habitats, including large rivers, numerous seeps and springs, and smaller perennial and ephemeral streams (Table 1.7). The Rio Grande (Río Bravo delNorte), fed by its major tributaries the Pecos River and the Río Conchos, is the only major through-flowing stream in the Chihuahuan Desert. The larger Río Grande system is home to native minnow, sucker, catfish, killifish, and sunfish species, two species of gar (*Lepisosteus oculatus, L. osseus*), and a rare sturgeon (*Scaphirhynchus platorhynchus*). Rivers draining into the interior, such as the Río Nazas located north of Durango, contain unique assemblages of minnows, suckers, and pupfish. Isolated basins, such as the Tularosa in New Mexico and Cuatrociénegas in Coahuila, have given rise to numerous endemic fish species including several pupfish (*Cyprinodon* spp.), cichlids (*Cichlasoma* spp.) and poeciliids (*Gambusia marshi* and *G. longispinis*) (Miller 1977, Minckley 1977). What most strongly distinguishes the freshwater biota of the Chihuahuan Desert is not the number of species, but the high degree of local endemism, a globally outstanding feature (Dinerstein et al. 2000).

Table 1.7. Freshwater habitat types in the Chihuahuan Desert.

I. Warm springs
  A. high salinity
  B. low salinity

II. Cool springs
  A. high salinity
  B. low salinity

III. Large rivers & floodplain

IV. Perennial streams
  A. high gradient
  B. medium gradient
  C. low gradient

V. Ephemeral streams
  A. high gradient
  B. medium gradient
  C. low gradient

VI. *Lagunas*
  A. permanent
  B. temporary

VII. *Ciénegas*

VIII. Subterranean habitats

1.2.1.3 Fauna

The Chihuahuan Desert supports more than 120 species of mammals, 450 species of birds, 110 species of fish, and more than 170 species of amphibians and reptiles. The functioning of the Chihuahuan Desert is dependent on its high invertebrate diversity, which is a reflection of numerous plant communities. Keystone invertebrates within the desert grasslands are the subterranean termites (order Isoptera), major consumers of dead plant material and animal dung. Fifty percent of all photosynthetically fixed carbon in desert grasslands is consumed by them (Whitford *et al*. 1995). There are also more specialized freshwater assemblages of invertebrates associated with playas, such as clam shrimp (*Eulimnadia texana*), water fleas (*Moina wierejskii*), and fairy shrimp (*Streptochephalus texanus*), upon which migrating waterfowl depend. There are others associated with soil, such as nanorchestid and tydeid soil mites, which are essential for nutrient cycling in a dry climate. An invertebrate tied to the yucca woodlands, the yucca moth (*Tegeticula yuccasella*), lays her egg in the ovary of the yucca, rolls pollen into a ball, and then inserts the ball into the flower, thereby ensuring fertilization of the seeds on which her young will feed. The semi-arid Madrean region further has the richest diversity of bee species in the world (Ayala and Bullock 1993). Monarch butterflies also rely on the riparian vegetation to rest during their migration.

The Chihuahuan Desert was one of the few ecoregions where grizzly bears, wolves, and jaguars could be found at the same locality. Other wide-ranging mammals found in this region include pronghorn antelope (*Antilocapra Americana*), collared peccary or javelina (*Dicotyles tajacu*), mule deer (*Odocoileus hemionus*). Unfortunately this list includes non-native ungulates as well as, Barbary sheep or Aoudad (*Ammotragus lervia*) and oryx or gemsbok (*Oryx gazelle*). Small rodents (woodrats, groundsquirrels, mice) and meso-carnivores (e.g., ringtail cat [*Brassariscus astus*], skunks and fox spp.) are very common.. This desert region is also well-known for its high diversity of bats. A note of significance is that the largest remaining black-tailed prairie dog (*Cynomys ludovicianus*) towns on the continent, and the only populations of the endemic Mexican prairie dog (*Cynomys mexicanus*) occur in the Chihuahuan Desert.

Neotropical migratory birds utilize riparian corridors along the Pecos River and the Rio Grande. The Chihuahuan Desert grasslands serve as wintering grounds for a large proportion of North American Great Plains birds including a number of significantly declining species such as mountain plover (*Charadrius montanus*), ferruginous hawk (*Buteo regalis*) and Baird’s sparrow (*Ammodramus bairdii*). Some of the common bird species include the Greater Roadrunner (*Geococcyx californianus*), Curve-billed Thrasher (*Toxostoma curvirostra*), Scaled Quail (*Callipepla squamata*), and Scott’s Oriole (*Icterus parisorum*).

Ricketts (1999) indicates that at least 18 species of reptiles and amphibians are endemic to the Chihuahuan Desert, including the bolson tortoise (*Gopherus flavomarginatus*), black softshell turtle (*Trionyx ater*), and the Chihuahuan fringe-toed lizard (*Uma exsul*) (Figure 1.13). Several lizards whose range is centered in the Chihuahuan Desert include the Texas banded gecko (*Coleonyx brevis*), greater earless lizard (*Cophosaurus texanus*), and several species of spiny lizards (*Scelpoprus* spp.). Representative snakes include the Trans-Pecos rat snake (*Elaphe subocularis*), Texas blackheaded snake (*Tantilla atriceps*), and western coachwhip (*Masticophis flagellum testaceus*).

Figure 1.13. Little White Whiptail adapted to gypsum dunes. Photo by J. Borgmeyer.

A striking number of endemic fish occur in the Chihuahuan Desert – nearly half of the species in the ecoregion are either endemic or of limited distribution. Most of these are relict pupfish (Cyprinodontidae), shiners (Cyprinidae), livebearers (Poeciliidae), and Mexican livebearers (Goodeidae) found in isolated springs in the closed basins of the region. The best known of these aquatic basins is Cuatro Ciénegas in central Coahuila, but other significant areas of endemism include the Rio Nazas, Media Luna, the Guzman Basin (Miller 1974; Minkley 1974; Minkley et al., 1991), and the Pecos Plain. At least one undescribed species of trout (*Oncorhynchus* sp.) occurs in the Chihuahuan Desert ecoregion as an evolutionary isolate in headwater streams in the Sierra Madre Occidental (Hendrickson et al., 1999).

1.2.1.4 Modification of Natural Processes and Ecological Drivers

Changes in natural processes and ecological drivers (e.g., drought, fire management, ecological sustainability and integrity, depletion and diversion of water resources, grazing, or loss of keystone species), particularly from human activities over the last few centuries have resulted in extensive alteration of natural habitats across the Chihuahuan Desert. However, some habitats are more resilient or resistant to these modifications. Aquatic systems, especially ephemeral habitats, may be considerably altered by drought conditions. Other ecosystems may have the ability to maintain or rebound to conditions of diversity, integrity, and sustainable ecological processes following such disturbances.

Climate Change and Drought

Drought has probably been the principal historical source of disturbance in the Chihuahuan Desert Climate change may occur in the Southwest from increased atmospheric concentrations of CO_2 and other “greenhouse” gases. Effects may include increased surface temperatures, changes in the amount, seasonality, and distribution of precipitation, more frequent climatic extremes, and a greater variability in climate patterns. Such changes may affect vegetation at the individual, population, or community level and precipitate changes in ecosystem function and structure (Weltzin and McPherson 1995). They will likely affect competitive interactions between plant and animal species currently coexisting under equilibrium conditions (Ehleringer *et al.* 1991).

Plants respond differently to changes in atmospheric gases, temperature and soil moisture, in part based on their C_3 or C_4 photosynthetic pathways (Johnson *et al*. 1993). For example, increases in winter precipitation favor tree establishment and growth at the expense of grasses. Increases in temperature and summer precipitation favor grasslands expanding into woodlands (Bolin *et al*. 1986).

Drought (an extended period of abnormally dry weather) is one of the principal factors limiting seedling establishment and productivity (Schulze *et al*. 1987, Osmond *et al*. 1987). Soil moisture gradients are directly altered by drought conditions. The distribution and vigor of some plant communities may be controlled primarily by soil moisture gradients (Pigott and Pigott 1993). Drought and climate change can potentially have a substantial effect on New Mexico's habitats.

Grazing

Desert grassland quality and area have been drastically reduced since the onset of European settlement in the ecoregion (Dick-Peddie 1993). While bison inhabited this region within the past 1000 years, evidence that large grazing herbivores played a dominant role in maintaining these desert grasslands, as they did in the Great Plains, is not strong (Monger *et al*. 1998). Instead, the Chihuahuan Desert grasslands are the result of a dynamic interaction of climate, granivory, herbivory, and fire. These processes produced a mosaic of grassland, shrubland, and savanna that has fluctuated greatly in character and extent over the last 10,000 years. The processes governing the condition of these vegetation communities have been altered in the last 500 years of settlement, primarily as a direct result of livestock grazing. Historic and, in some cases, contemporary overgrazing is the single most important factor triggering the most serious and pervasive changes in grassland quality. Overgrazing can be defined as the repeated removal of above-ground biomass and disturbance of the soil surface leading to reduced plant vigor and increased mortality. Overgrazing is often associated with increased soil erosion, further reducing the potential for re-establishment of grassland species. Concurrent with the loss of grasslands has been increased erosion and reduction in grassland dependent species (MacMahon 1988).

Depletion and Diversion of Water Resources

The extensive loss of natural water sources for agricultural, industrial, and domestic uses by human populations, its diversion, and the onslaught of numerous introduced aquatic species, have caused the Chihuahuan aquatic biota to be one of the most threatened in the world. The acute loss of riparian habitats and water sources has reduced the range and population densities of many native terrestrial vertebrates and invertebrates dependent on them for water, refuge, or habitat during some portion of their life history (Dinerstein et al. 2000).

Many aquifer water tables have been lowered due to increased populations and, in return, water usage. This has caused many springs in the Trans-Pecos to run dry preventing water from reaching streams that once flowed. Endangered fish species, many times endemic to specific springs, must compete with non-native fish species. Due to an increase in the human population, habitat loss is also a factor. Other issues such as contamination of water sources from nearby pollution and overuse of riparian areas are also affecting the desert oases negatively.

Fire Management

For thousands of years, wildfires have been an integral process in New Mexico and southwestern forest and grassland ecosystems. Prior to 1900, naturally occurring wildfires were widespread in all western forests at all elevations (Swetnam 1990). From an ecological perspective, fire may be the most important disturbance process for many western forests (Hessburg and Agee 2003). Ecosystem processes and patterns are influenced and shaped by fire. These include soil productivity and nutrient cycling, seedling germination and establishment, plant growth patterns, vegetative plant community composition and structure, and plant mortality rates (Beschta *et al.* 2004).

Tree-ring and fire-scar data for the Southwest indicate that past fires were frequent and widespread (with an elevation range of variability) at least since AD 1700 (Swetnam and Baisan 1996). Within ponderosa pine and lower mixed-conifer forests and woodlands in New Mexico, naturally-occurring wildfires were frequently of low-intensity and helped maintain stands of older trees with an open, park-like structure (Moir and Dieterich 1988). Higher elevation, mixed conifer and spruce-fir forests (wetter forest types) exhibited less frequent fire return intervals and fires were generally stand-replacing fires of higher intensity (Pyne 1984, Agee 1993).

The extent to which fire occurred in southwestern grasslands varied geographically and is related to climatic variables such as seasonal and annual rainfall and physiographic variables such as elevation, slope and aspect (Archer 1994). Fire may have been rare in desert grasslands and limited in extent due to low biomass and a lack of continuity in fine fuels (Hastings and Turner 1965, York and Dick-Peddie 1969). In more mesic grassland and savanna systems where fire was a prevalent and recurring force, pre-historic frequency and intensity appear to have been regionally synchronized by climatic conditions (Swetnam and Betancourt 1990).

The elimination of high-frequency, low-intensity wildfires across New Mexico and the Southwest coincided with the reduction and/or elimination of fine herbaceous fuels caused by improper grazing practices (Savage and Swetnam 1990, Swetnam 1990, Swetnam and Baisan 1996). These grazing practices further reduced grass competition, thereby increasing tree and shrub establishment (Archer 1994, Gottfried *et al.* 1995), which further altered natural fire cycles. Since the early 1900s, systematic fire suppression efforts have further curtailed the natural fire regimes that historically kept ponderosa pine, mixed conifer and spruce-fir stand densities and fuel loads relatively low. Fire suppression allowed the development of ladder fuels and the accumulation of heavy fuel loads. Catastrophic, stand replacing crown fires are now the standard, rather than the exception as a result of these changes (Covington and Moore 1994).

Land management practices and fire suppression have had adverse effects on many New Mexico habitats through fragmenting, simplifying, or destroying habitats, and greatly modifying disturbance regimes (Dick-Peddie 1993). These human-caused changes have created conditions that are outside of the evolutionary and ecological tolerance limits of native species (Beschta *et al.* 2004). Cumulatively, these practices have altered ecosystems to the point where local and regional extirpation of sensitive species is increasingly common. As a result, the integrity of many terrestrial and aquatic ecosystems has been severely degraded at the population, community, and species levels of biological organization (Frissell 1993).

Ecological Sustainability and Integrity

When biotic and abiotic disturbances are modified or removed from New Mexico’s ecosystems, plant and animal diversity and ecological sustainability are lost (Benedict *et al.* 1996). Ecological sustainability is essentially the maintenance (or restoration) of the composition, structure, and processes of the ecosystem over time and space. Likewise, ecosystem integrity incorporates the concept of functioning and resilience. It includes: 1) maintaining viable populations, 2) preserving ecosystem representation, 3) maintaining ecological processes, 4) protecting evolutionary potential, and 5) accommodating human use (Grumbine 1994). The loss of ecological sustainability and integrity will thus affect species that are closely tied to specific habitats or ecosystems.

Loss of Keystone Species

Keystone species, such as beavers (*Castor canadensis*), bison (*Bison bison*), and prairie dogs (*Cynomys* sp.), are species that have a large overall effect, disproportionate to their abundance, on the structure or function of habitat types or ecosystems. If a keystone species is extirpated from a system, other species that are closely associated with the keystone species will also disappear. In New Mexico, several keystone species have either been completely removed or have experienced significant population reductions in their historic range. With their removal or reduction in population levels, other species population levels variously decline or benefit.

1.2.2 Chihuahuan Desert Network Overview

The following sections describe the range of environmental conditions and anthropogenic influences prevalent in the Chihuahuan Desert Network region. An account of each CHDN unit, including maps, and some species accounts for each park and network appear in Appendices A, B, and C.

The CHDN includes seven widely separated park units located from south central New Mexico into south Texas (Figure 1.1). The parks are location within the Chihuahuan Desert, more specifically in the subregion known as Northern Chihuahuan (Dinerstein et al. 2000, Pronatura Noreste et al. 2004). These park units, ranging in size from 192 to 324,232 hectares (Table 1.1), are all located in or within a transitional zone of the Chihuahuan Desert, one of the most biologically diverse arid regions in the world. One park unit, Amistad National Recreation Area (NRA), falls only partially within the Chihuahuan Desert (Figure 1.1). Amistad NRA is primarily located in the biogeographic province known as Tamualipan Shrubland or Thornscrub, though it is influenced by both Chihuahuan Desert and Edward’s Plateau biogeographical provinces (Rich, et al. 2004).

These seven parks represent the nation’s most significant preserved natural, cultural, and recreational values in the Chihuahuan Desert landscape. Most of the CHDN parks were established for conservation and preservation of significant natural and geologic resources (i.e., caverns of Carlsbad Caverns NP, NM, Figure 1.14).

Figure 1.14. Hall of Giants, Carlsbad Caverns NP, New Mexico.

The exception is Fort Davis NHS which was established primarily for cultural reasons, however this unit also contains significant natural resources (Figure 1.15).

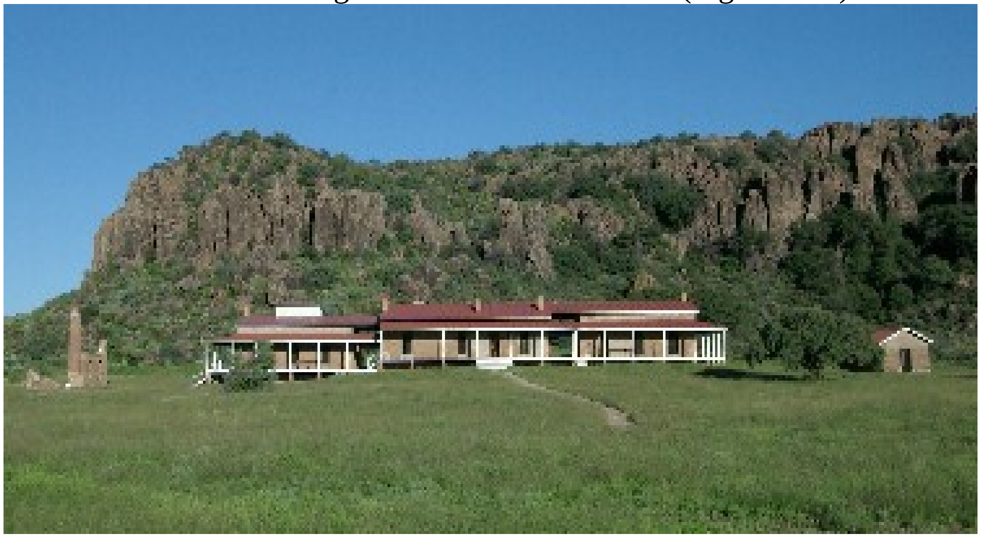


Figure 1.15. Officer’s Quarters at Fort Davis National Historic Site.

The landscape within the CHDN is a series of basins and ranges (Figure 1.5). The majority of this landscape in the Northern Chihuahuan subregion, where CHDN parks are located, consists of desert shrublands (50%). Desert grasslands, approximately 25% of this desert region, are often mosaics of grass and shrub. And mixed-conifer forests and woodlands comprise approximately 10% of this subregion. In south-central New Mexico, wind-blown soils form one of the largest gypsum dunefields in the world. Additionally, influences from three ecoregions (Chihuahuan Desert, Edward's Plateau Savanna and Tamaulipan Mezquital [thorn scrub]) come together in the Devils River area around Amistad NRA. Parks within the CHDN contain a wide range of biotic communities and abiotic conditions (Table 1.8).

Table 1.8. Biophysical Summary of CHDN parks.

Park	Annual Precip. (mm.) *	Mean Annual Temp (° C)	Elevation Range (m.)	Terrestrial Habitat Type (after Table 1.6)	Aquatic Habitat Type (after Table 1.7)
AMIS	482	20.7	282 - 364	IB, IE, IG	IIB, III, IVC, VIII
BIBE	359	19.2	548 - 2387	IA, IB,ID, IE,IG, IIA, IIB, IIC, IIE, IIIA, IIIB, IIIC	IB, IIB, III, IVC, VABC
CAVE	438	16.5	1096 - 1992	IA, IB, IC, ID, IE, IIB, IIE, IIIB,	IIB, VB, VIII
FODA	403	15.9	1487 - 1622	IB, IIA, IIIA	VC
GUMO (near HQ)	398	14.9	1105 - 2667	IB, ID, IF, IG, IH, IIA, IIIA, IIIC, IIID, IIIE	IIB, IVA, IVC, VA, VB, VC
GUMO (near dune fields)	231	16.5	n/a	n/a	
RIGR	no data	no data	360 - 616	IB, ID, IE, IG, IIIA, IIIB	IB, III,
WHSA	262	15.0	1185 - 1290	IA, IB, IF, IH IIB, IID	VC

* See Appendix G for additional climate summaries for CHDN parks, and Appendix H for additional details of terrestrial habitat types.

1.2.3 Individual Park Summaries

1.2.3.1 Amistad National Recreation Area (NRA), resulting from construction of Amistad Dam in 1969, contains 43,250 water acres and 14,042 land acres. The park is located at a convergence of the Chihuahuan Desert, the Edwards Plateau Savannah, and the Tamaulipan Mezquital Ecoregions (Ricketts et al. 1999). Riparian, shoreline, inundation zone and upland desert ecosystems support terrestrial species diversity. Aquatic species occur in the lake and sections of the Devils, Rio Grande, and Pecos rivers. The most significant threats facing AMIS include exotic plant and aquatic species invasions, visitor and commercial fishing effects on natural resources, and water quality. (http://www.nps.gov/amis/home.htm)

1.2.3.2 Big Bend National Park (NP), established in 1944, includes 801,163 acres, and is the largest protected area representative of the Chihuahuan Desert. The park was designated in 1976 as a U.S. Biosphere Reserve. Big Bend also includes 533,900 acres of recommended wilderness, and administers the 190-mile Rio Grande Wild and Scenic River. Species diversity is increased due to inclusion of the Rio Grande and the Chisos Mountains, a 50-square mile range that is home to numerous relict and isolated populations. Major threats to the largest park unit in the CHDN include groundwater mining, water quality degradation, significant reduction in air quality, expansion of nonnative plants distribution and border issues involving Mexico. (http://www.nps.gov/bibe/home.htm)

1.2.3.3 Carlsbad Caverns National Park (NP), established in 1923, includes 46,766 acres, of which 33,125 acres are Designated Wilderness. The park was designated a World Heritage Site on December 6, 1995 which indicates the significance of the park's cave and other resources. Surface elevations range from 3,595 to 6,520 ft, and include fossilized reef uplands and diverse incised canyons. Management issues facing this park are two-fold – both terrestrial and cave systems must be addressed. Visitor impacts to subsurface resources, groundwater mining, and oil and gas exploration impacts to park's watershed are all pressing issues. (http://www.nps.gov/cave/home.htm)

1.2.3.4 Fort Davis National Historic Site (NHS), established in 1963, is in the Davis Mountains, Texas' most extensive mountain range. The 474-acre park preserves fort structures and interprets the era of westward migration and the late 19th century U.S. Army. Natural resources include a striking blend of desert, woodland, and grassland, a historic cottonwood grove, and associated faunal communities. As the only park unit established for cultural reasons, and the smallest unit in the network, special considerations are given to ensure its needs are not overlooked. Groundwater dynamics, invasive plant species, and sustaining the historic cotton grove are concerns this park's staff have expressed. (http://www.nps.gov/foda/Fort_Davis_WEB_PAGE/HOME.htm)

1.2.3.5 Guadalupe Mountains National Park (NP), established in 1972, consists of 86,416 acres, of which 46,850 are Designated Wilderness. The park preserves the world's most significant fossilized reef outcrops of Permian age limestone, designated as an International Benchmark Standard for Geology, and the Chihuahuan Desert resources that occur upon it. Elevation-related environmental diversity ranges from lowland salt basin to relict conifer forests, including Texas' highest point at 8,749 feet. Facing ambitious groundwater withdrawal plans from the city of El Paso, TX, groundwater quantity & quality, as well as increasing impacts to the area's air quality are significant concerns of this unit. (http://www.nps.gov/gumo/gumo/home.html)

1,2,3,6 Rio Grande Wild and Scenic River (RS) Created in 1976 under the Wild and Scenic Rivers Act, the Rio Grande Wild and Scenic River encompasses 315 river km (196 river miles) from the Chihuahua-Coahuila State Line in Mexico to the Terrell Val

Verde County Line in the United States. As mentioned above, for planning purposes and project implementation, the BIBE-RIGR overlap is considered and is limited to the 209 river km (127 river miles) between Big Bend and the Terrell Val Verde County Line. Water quality and quantity issues and all associated impacts to aquatic systems rank as the important issues facing this unit. Additionally, exotic plant species and Mexican border issues (trespass grazing, fires set by illegal aliens, etc) also pose significant problems. (http://www.nps.gov/rigr/)

1.2.3.7 White Sands National Monument (NM) established in 1933, at the northern end of the Chihuahuan Desert lies the Tularosa Basin. In the heart of this basin lies one of the world's great natural wonders, encompasses 143,733 acres in south central New Mexico, and preserves approximately half of the world’s largest gypsum sand dune field. Amount of Gypsum Sand in the White Dunes is approximately 4.5 billion tons. Issues around groundwater quantity (proposed massive withdrawals by the city of Alamogordo, NM), and there impacts to dune formation and processes are the major issues facing this park. (http://www.nps.gov/whsa/home.htm)

1.2.4 Integration of Water Quality with Monitoring

Water is a scarce and precious resource in the Chihuahuan Desert (Figure 1.16). The much-altered Rio Grande River, and its major tributaries the Rio Conchos (in Mexico), the Pecos (in New Mexico & Texas) and Devils Rivers (in Texas) are subject to great flow variation. Water—or its scarcity—is a driving force in park ecosystems adapted to this region’s aridity. Further, since the majority of Chihuahuan Desert precipitation is the result of intense, local thunderstorms, its occasional, great overabundance is also of ongoing management concern.

Figure 1.16. Pray for running water sign in Hidalgo County, New Mexico. Photo by Cesar Mendez.

Surface water in this regions can be characterized as having a low density of intermittent streams and very few associated rivers, most of which originate in distant mountainous areas. Flow rates are low to moderate, except during periods of heavy rain, when large amounts of surface runoff can occur. Dendritic drainage pattern has developed on dissected mountain slopes, largely without bedrock structural control. Playa lakes are common following periods of rains, but are ephemeral in the hot, dry climate prevalent in this ecoregion.

Water quality and water quantity are high priority issues at CHDN parks (Appendix I), thus according to NPS mandates and policy, parks must characterize and monitor water quality and plan for the protection of their water resources. Ground water, while not the general focus, but where appropriate, will be included in monitoring plans. Guadalupe Mountains NP's sand dunes and White Sands NM's shallow water table are two parks where inclusion of ground water monitoring will be productive. The completeness of current monitoring and historic water data for each CHDN park varies widely. The three parks that include the Rio Grande River (Amistad NRA, Big Bend NP, Rio Grande WSR) must address a situation different from the others. Also, White Sands NM, surrounded by intensive military and contractor activity, poses special issues. A detailed summary of threats to each individual park is outlined below (Table 1.9).

Table 1.9. Threats to CHDN park water resources.

Amistad National Recreation Area – Receives surface flows from all surrounding lands and three significant rivers.
Threats:
• Deposition from atmospheric pollution
• Sedimentation pollutants or contaminants from Rio Grande River inflow
• Sedimentation pollutants or contaminants from Devils and Pecos River inflow
• Runoff from Mexican sources to the Rio Grande River
• Runoff from US sources exterior to the park
• Hydrocarbons from US and Mexican watercraft
• Possible fecal matter and debris from undocumented aliens in transit
• Possible debris and fecal matter from US and Mexican watercraft
• Hydrocarbons and debris from US and Mexican boat launch sites
• Camping area runoff
Big Bend National Park – Receives flow from one major river and from Mexican lands along that river**.**
Threats:
• Deposition from atmospheric pollution
• Sedimentation pollutants or contaminants from Rio Grande River inflow
• Runoff from Mexican sources to the Rio Grande
• Waste water effluent discharges from Presidio and Ojinaga
• Permitted wastewater discharge to tributary Terlingua Creek
• Mexican livestock in and adjacent to the Rio Grande
• Several contaminants possibly released in potential Rio Grande Village flooding
• Runoff from in-park concessions and camping areas
• Runoff and infiltration from all Panther Junction park facilities
• Runoff and infiltration from gasoline station west of Panther Junction
• Runoff and infiltration from all Chisos Basin concessionaire and park facilities
• Fecal matter from dispersed camping and hiking activities, especially along the Rio Grande River and its tributaries
• Camping debris and fecal matter near springs and seeps
• Possible fecal matter and debris from undocumented aliens in transit
• Vandalism by aggressive pothunters and others in and around springs and seeps
• Hydrocarbons and debris from River Road users
Carlsbad Caverns National Park – Receives no significant surface flows from surrounding lands
Threats:
• Deposition from atmospheric pollution
• Runoff and infiltration to caves from all headquarters area park facilities

- Oil and gas industry

Fort Davis National Historic Site – Receives surface flows from adjacent Davis Mountains State Park and development lands of adjacent Ft. Davis TX.

Threats:

- Deposition from atmospheric pollution
- Groundwater infiltration from adjacent urban sources
- Groundwater infiltration from park facilities
- Flood inflows to Hospital Canyon Arroyo (NPS 1999)

Guadalupe Mountains National Park -- Receives no significant surface flows from surrounding lands. The Salt Basin dune field is hydrologically connected to Basin ground waters.

Threats:

- Deposition from atmospheric pollution
- Runoff and infiltration from park facility areas
- Runoff from US 62-180 through park
- Camping area runoff
- Hiker fecal matter from trail through McKittrick Canyon
- Possible groundwater changes from water large scale withdrawal development in the Salt Basin

Rio Grande Wild and Scenic River -- Receives surface flows from all surrounding lands and input from Rio Grande.

Threats:

- Deposition from atmospheric pollution
- Sedimentation pollutants or contaminants from Rio Grande River inflow
- Runoff from Mexican sources to the Rio Grande
- Runoff from US sources exterior to the park
- Possible fecal matter and debris from river users
- Possible fecal matter and debris from undocumented aliens in transit

White Sands NM -- Receives surface and groundwater flows from surrounding lands.

Threats:

- Deposition from atmospheric pollution
- Runoff from surrounding military facilities, including range Road 7
- Isolated cottonwood stands occur at a number of dune field locations. Their presence implies perennial ground water of rather high quality. Precipitations catching clay lenses or local higher quality, subsurface flows have been

suggested as reasons for their persistence. This lack of understanding leads, therefore, to no known threats to these subsurface resources, but it suggests a need for better understanding the matter
• Groundwater transport into park from surrounding military facilities
• Infiltration from park headquarters area facilities
• A park concern is the possible drop of water table from basin groundwater resource development

Water quality monitoring in the Vital Signs program include five core parameters: water column temperature, specific conductance, pH, dissolved oxygen (DO), and flow rates. These parameters are general indicators of water system health, inexpensive tests, and important field study information useful for the interpretation of other studies. Standardization of water quality monitoring at this level will enable data sharing and comparison among parks and with other jurisdictions. Tentative monitoring needs have been recognized (Appendix J).

Figure 1.17. Hot Springs Rapids, Rio Grande WSR, Texas. Photo by NPS.

The Clean Water Act (1972) includes section 303(d) which identifies impaired water resources throughout the country. The CHDN has recognized that the water recourses of the parks, whether in the form of precipitation or in existing surface water bodies, are a primary component of the entire network ecosystem. The CHDN has three sections that are officially designated as impaired water (Reid and Reiser 2005). Two of those sections directly affect three parks, Amistad NRA, Big Bend NP and Rio Grande WSR. The third section affects the northern area of Carlsbad Caverns NP. In this third section the cause of impairment is unknown. This is a unique circumstance, among the majority of parks within all of the I&M networks. In the remaining parks Fort Davis NHS, Guadalupe Mountains NP and White Sands NM, there are no impairments under Section 303(d).

1.2.5 The Integration of Air Quality with Monitoring

Air pollution damages resources and values that national parks have been set aside to protect. The NPS has responsibility to remedy and prevent damage to air quality and related values. Comprehensive scientific information is essential to understand and document air quality conditions and effects of air pollution on park resources. More than ten years of monitoring in several parks shows that air pollution is degrading visibility, injuring vegetation, changing water and soil chemistry, contaminating fish and wildlife, and endangering visitor and employee health. Information generated through the existing network of NPS air quality monitoring stations and related research programs has been used by NPS managers to secure substantial pollution reductions at specific industrial facilities, to persuade States to limit emissions from new pollution sources, and to bolster the U.S. Environmental Protection Agency's (EPA) promulgation of more stringent air pollution regulations.

Under the Clean Air Act (42 USC 7401-7671q, as amended in 1990), park managers have a responsibility to protect air quality and related values from the adverse effects of air pollution. Protection of air quality in national parks requires knowledge about the origin, transport, and fate of air pollution, as well as its impacts on resources. In light of those requirements, to help Chihuahuan Desert Network, the Intermountain Region Air Resource Division has produced a summary on air quality issues and pollutants, as it pertains to our network (Appendix K). To be effective advocates for the protection of park air resources, the CHDN needs to know the air pollutants of concern, existing levels of air pollutants in parks, park resources at risk, and the potential or actual impact on these resources. Through previous monitoring our network has obtained some current status of the air quality of our park units (Figure 1.18). Nevertheless, future plans and projects need to be set up for continuous monitoring. Air quality was identified as potential vital sign for the network because of its importance as both an anthropogenic and natural driver of change.

Currently, our network has three park units (Big Bend NP, Carlsbad Caverns NP, Guadalupe Mountains NP) designated as Class 1 air quality units under the Clean Air Act. The other four units are designated as Class 2 air quality units. Class 1 units receive the highest protection under the Clean Air Act. Air quality issues of concern in the CHDN include atmospheric deposition effects and visibility impairment from fine particle haze. Atmospheric nitrogen deposition can cause changes in soil that affect soil microorganisms, plants, and trees. Excess nitrogen can cause changes in plant community structure and diversity, with native species being replaced by invasive and exotic species. Nitrogen and sulfur deposition can also have an acidifying effect on soils and water, decreasing buffering capacity and eventually reducing pH. Sulfur and nitrate pollutants from an accelerated oil and gas development around Carlsbad Caverns NP are also a major concern for this park unit. Oil and gas development was identified during a vital signs workshop. In addition, research in Big Bend NP has found a rapid, major decrease in soil pH in Big Bend grasslands. Studies were initiated in 2003 to assess the impacts of atmospheric nitrogen deposition and climate change on desert ecosystems.

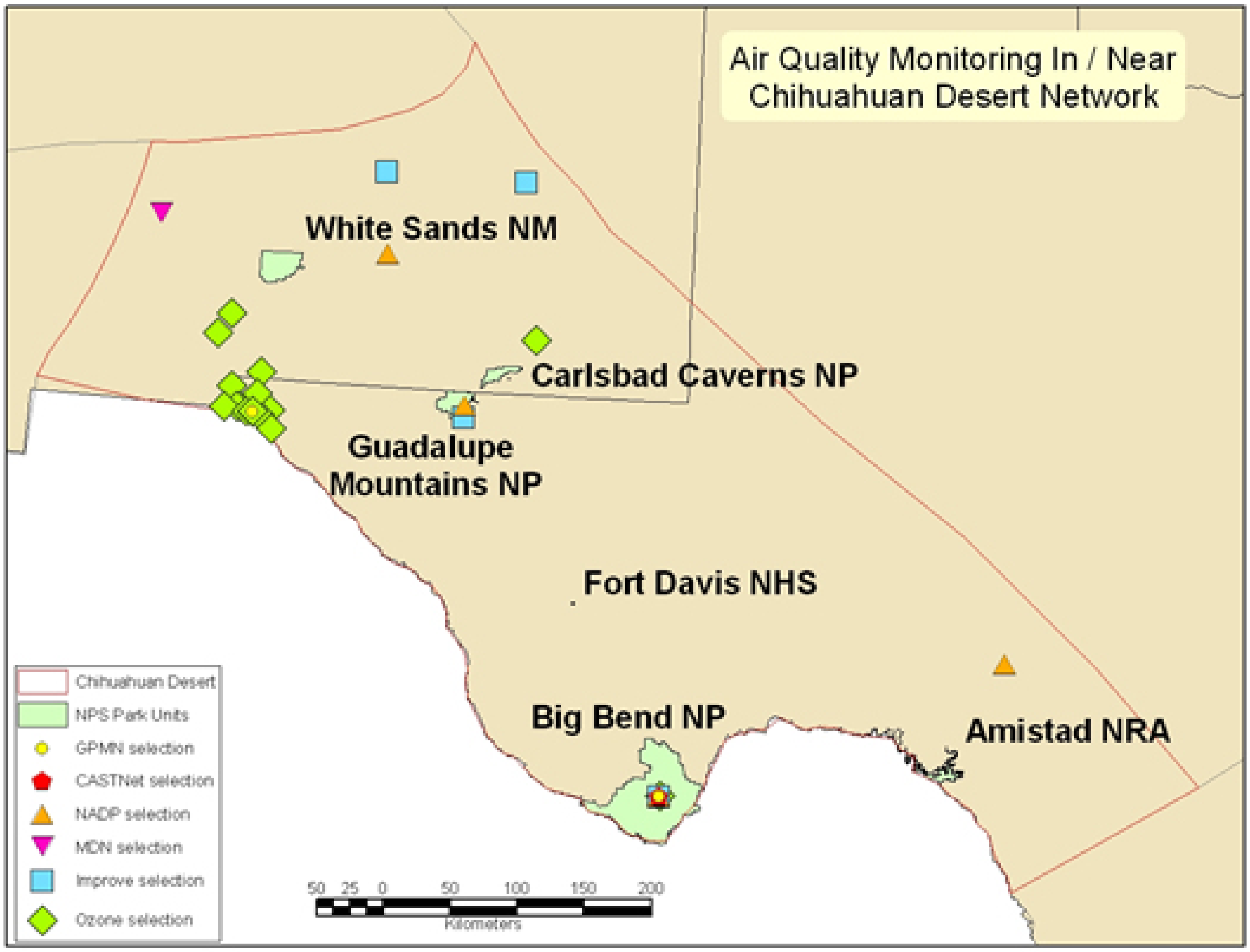


Figure 1.18. NPS air quality monitoring stations locations in the CHDN. Map provided by NPS Air Resources Division.

Some ozone analysis has also been summarized (NPS 2004). The information on ozone values represents a 5-yr average of annual values from 1995-1999. The CHDN presently have two parks (Amistad NRA, Carlsbad Caverns NP) that exceeded the ozone standard (0.8 ppm or 80 ppb). These levels are high enough to cause foliar damage, however, Amistad NRA is the only park considered to have a moderate risk. In general, ozone is not currently a significant concern for vegetation because no ozone sensitive plant species have been identified at Amistad NRA. Though one ozone sensitive plant species (*Rhus* trilobata) has been identified at Carlsbad Caverns NP, the level of soil moisture significantly constrains the uptake of ozone, and reduces the likelihood of foliar injury occurring. The other park units in the network have a low risk rating. Ozone sensitive plant species that occur at other network parks include: ponderosa pine (*Pinus ponderosa*) and skunkbush (*Rhus trilobata*) found in Big Bend NP and Guadalupe Mountains NP, and black cherry (*Prunus serotina*) and skunkbush found in Ft. Davis NHS.

Another component of assessing air quality is air quality related values (AQRV). AQRV are resources that may be adversely affected by a change in air quality. The resource can include visibility or a specific scenic, cultural, physical, biological, ecological, or recreational resource. The following table (Table 1.10) identifies natural resource AQRV of each of the parks in the CHDN. The list is based on best available information relative to park resources and pollution sensitivity, and will be updated as new information becomes available.

Table 1.10. Air quality related values of Chihuahuan Desert Network parks. AQRV are designated with an X. "Unknown" indicates there is not enough park-specific information available to determine if the resource is an AQRV.

Park	Visibility[1]	Vegetation[2]	Surface Waters[3]	Soils[4]	Fish and Wildlife[5]	Night Skies[6]
Amistad NRA	X	X	No	Some soils may be sensitive to eutrophication	Unknown	X
Big Bend NP	X	X	Some tinajas may be sensitive to eutrophication or acidification	Some soils may be sensitive to eutrophication	Unknown	X
Carlsbad Caverns NP	X	X	No	Some soils may be sensitive to eutrophication	Unknown	X
Fort Davis NHS	X	X	No	Some soils may be sensitive to eutrophication	Unknown	X
Guadalupe Mountains NP	X	X	No	Some soils may be sensitive to eutrophication	Unknown	X
Rio Grande WSR	X	No	No	Some soils may be sensitive to eutrophication	X	X
White Sands NM	X	X	No	Some soils may be sensitive to eutrophication	Unknown	X

[1] The NPS has identified visibility as a sensitive AQRV in every unit of the National Park System.

[2] Ozone-sensitive plant species have been identified in the park (http://www2.nature.nps.gov/air/Pubs/ozonerisk.htm and updated at http://science.nature.nps.gov/im/apps/npspp/).

[3]Surface waters in the park are susceptible to acidification or eutrophication from atmospheric deposition of hydrogen ions, nitrogen and/or sulfur.

[4] Soils in the park are susceptible to acidification or eutrophication from atmospheric deposition of hydrogen ions, nitrogen and/or sulfur.

[5]Fish and/or wildlife collected in or near the park have elevated concentrations of mercury and/or other toxic pollutants (e.g., chlordane, PCBs).

[6]Dark night skies, which can be degraded by air pollution, possess value as scenic, natural, and scientific resources

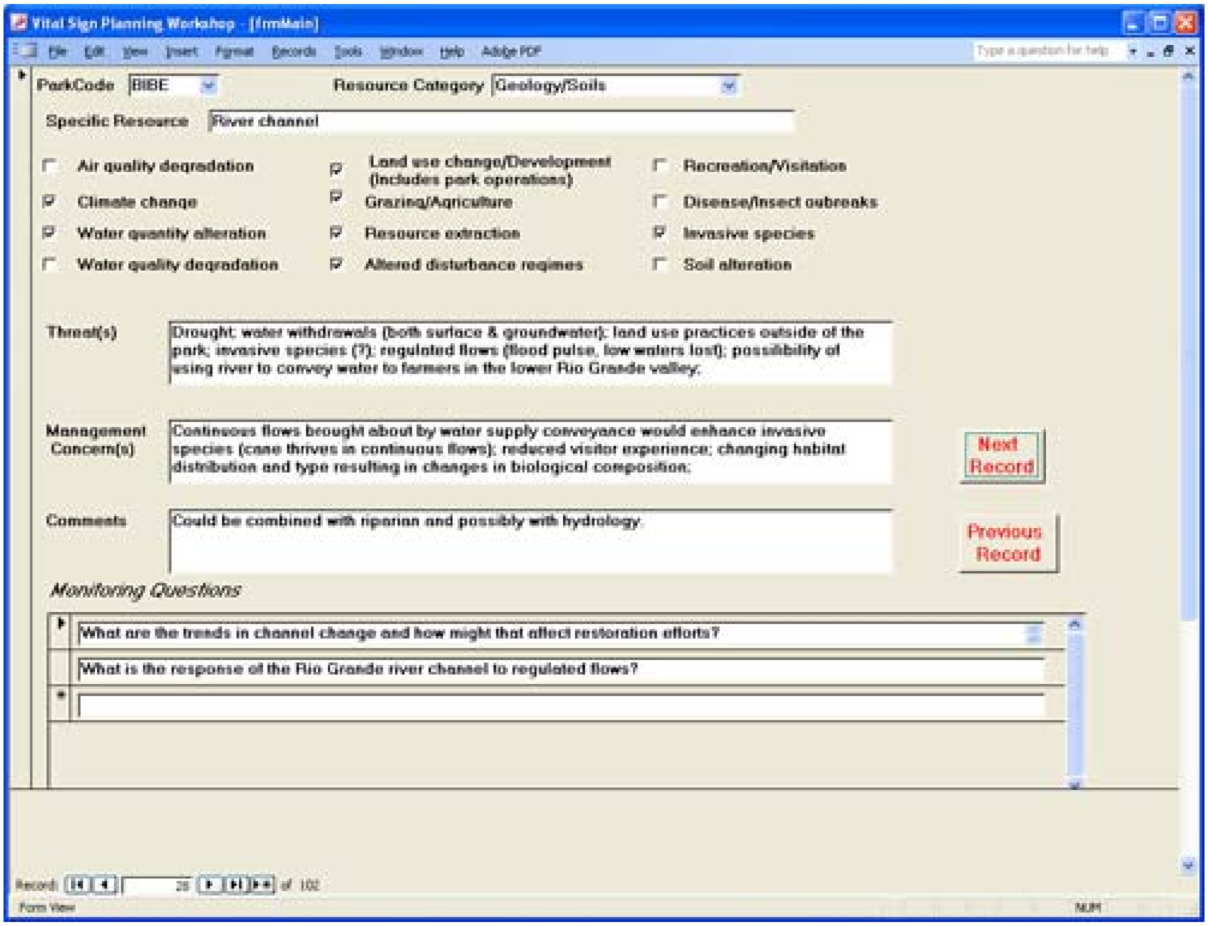
With future funding, the network can track concentrations of compounds known to be generated by industrial activities and to act as pollutants in both wet and dry deposition. The network may also track composition and concentrations of particulates that affect visibility. Because our network is part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program in the Air Resources Division, ozone concentrations will be further monitored as well. Air quality is very important to our network and we hope for air quality improvements through the I&M program.

1.3 VITAL SIGNS - PARK NATURAL RESOURCES AND MANAGEMENT PRIORITIES

In this section the CHDN approach to the initial list of potential vital signs is presented. Important management issues for CHDN parks were identified through a variety of methods, including interviews with park staff, park-based vital signs scoping meetings, review of park planning documents, and review of peer-reviewed literature. Additionally, regionally important issues were identified through discussions with natural resource personnel from other agencies and non-governmental organizations, and documents produced by other agencies and organizations were reviewed.

1.3.1 Park Interviews and Park-Based Scoping for Vital Signs Identification

Superintendents, division chiefs, park natural resources staff, other park staff and other multi-park staff (i.e., Exotic Plant Management Team Program Manager) were interviewed (one-on-one), prior to conducting park scoping sessions. Interview questions covered management issues, threats to park resources, species of concern, past and current monitoring projects, with particular interest in those that had documentation, monitoring needs, priority of those monitoring needs, and current cooperators. These sessions allowed CHDN to hear directly from the park staffs what their most important resources were and their initial thoughts on their biggest monitoring needs. This information was essential in laying the foundation for a monitoring program that will meet park needs. All responses were kept anonymous so as to encourage complete and frank discussions of the issues facing these land managers. Interviews lasted between 1-3 hours each. A total of 28 staff was interviewed. Summaries of responses were provided back to the park prior to the park vital signs scoping meetings. A summary of responses by park are found in Appendix L). This information was then entered into an Access database for use at the individual park scoping sessions (Figure 1.19).



ParkCode BIBE

Resource Category Geology/Soils

Specific Resource River channel

☐ Air quality degradation
☑ Climate change
☑ Water quantity alteration
☐ Water quality degradation
☑ Land use change/Development (includes park operations)
☑ Grazing/Agriculture
☑ Resource extraction
☑ Altered disturbance regimes
☐ Recreation/Visitation
☐ Disease/Insect oubreaks
☑ Invasive species
☐ Soil alteration

Threat(s): Drought; water withdrawals (both surface & groundwater); land use practices outside of the park; invasive species (?); regulated flows (flood pulse, low waters lost); possibility of using river to convey water to farmers in the lower Rio Grande valley;

Management Concern(s): Continuous flows brought about by water supply conveyance would enhance invasive species (cane thrives in continuous flows); reduced visitor experience; changing habitat distribution and type resulting in changes in biological composition;

Comments: Could be combined with riparian and possibly with hydrology.

Monitoring Questions

What are the trends in channel change and how might that affect restoration efforts?

What is the response of the Rio Grande river channel to regulated flows?

Figure 1.19. Screen from Big Bend NP Vital Signs Scoping meeting.

CHDN staff conducted park scoping meetings at all 6 CHDN parks from December 2004 through April, 2005. At each park, natural resource staff gave CHDN staff a tour and overview of the park natural resources, and any additional relevant information in the form of reports, maps, and GIS coverages that had not been previously obtained was collected, if available. CHDN invited the natural resource staff plus superintendents to the meeting. Parks were welcome to invite any additional staff or outside people they thought would be pertinent to the discussion. A total of 41 people participated at these Vital Signs Scoping meetings. CHDN staff preceded the park scoping session with an overview presentation on the Inventory & Monitoring Program, Vital Signs selection process, and introduction to conceptual ecological modeling.

Following the presentation, the database entries were reviewed, and edited in real time. At the end of the meetings, park-centric lists of vital signs and issues had been obtained.

This was the first step in identifying pressures on resources and ecosystems important in the network. Vital signs are considered a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic, and may be compositional (the variety of elements in the system), structural (organization or patterns of the system), or functional (ecological processes)
(from http://science.nature.nps.gov/im/monitor/vsm.htm#Definitions)

Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976).The Chihuahuan Desert shares several primary stressors that arise from their arid landscape, geological activity, and histories of human occupation. Common stressors arise from both natural and anthropogenic sources. Stressors cause significant changes in the ecological components, patterns and processes in natural systems. These stressors are recognized to affect multiple ecosystems, and are often recognized as possible threats to human health or safety. They fall into several broad categories: air/climate, water, biotic interaction or alteration. The main stressors and drivers have been identified by CHDN (Table 1.11). Each park in the network has evaluated which stressors were impacting resources of concern for their park (Appendix M).

Table 1.11 Common stressors throughout the CHDN parks.

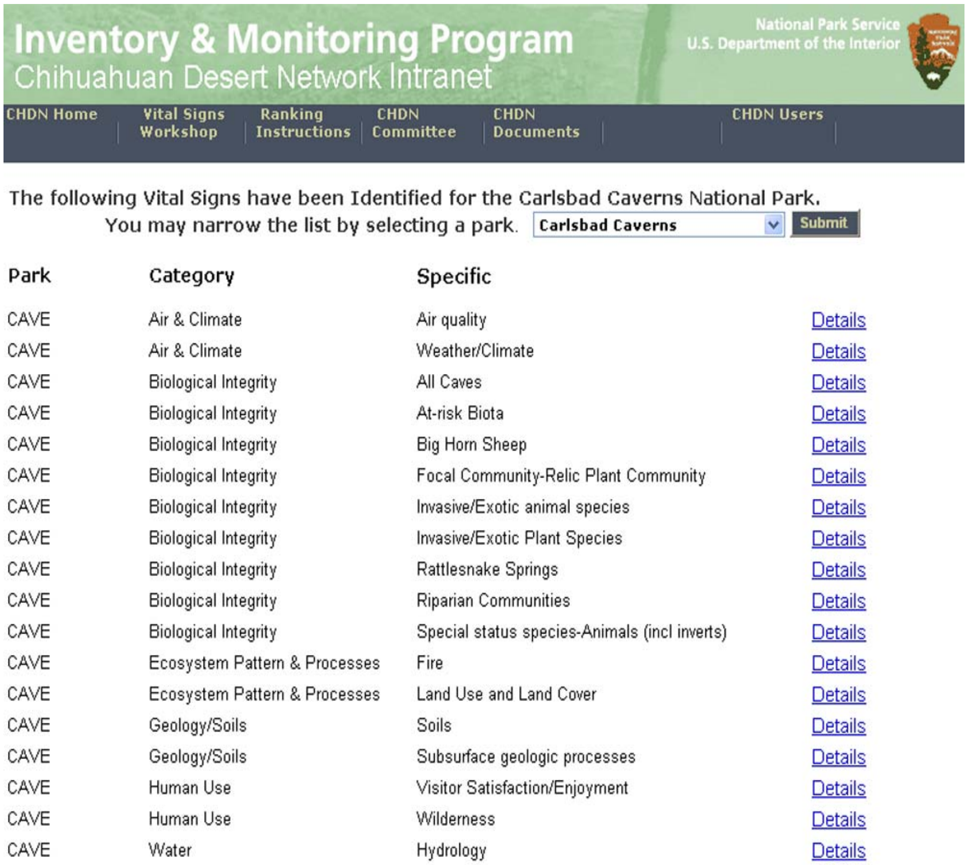
STRESSORS
Air Quality
Climate
Altered Disturbance Regimes
Water Quality
Water Quantity
Land Use Change
Historic/early Grazing
Resource Extraction
Invasive species
Recreation
Disease
Soil Alterations

In addition to associating stressors impacting specific resources of concern, additional threats to park resources were also identified (Table 1.12). These threats included both historical and current events. The table below describes threats that were mentioned more that once among the network. These elements, stressors, threats, and resources of concern will provide useful information in the development of conceptual models specific to the CHDN.

Table 1.12. Significant threats in CHDN parks.

THREATS
Air Pollution
- Industry in Mexico
Water Quality Degradation
- In ground water
- In surface water
Water Quantity Depression
- Changes in river flow
- Drought
Overgrazing
- Historically
- Current
Increased Development
- Ranching activities
Exotic Species
- Feral animal
- Introduced
Human Cause Wild Fire
- Recreation
- Holiday fire works
Oil and Gas Development
- Spills
Global Warming
- Climate change

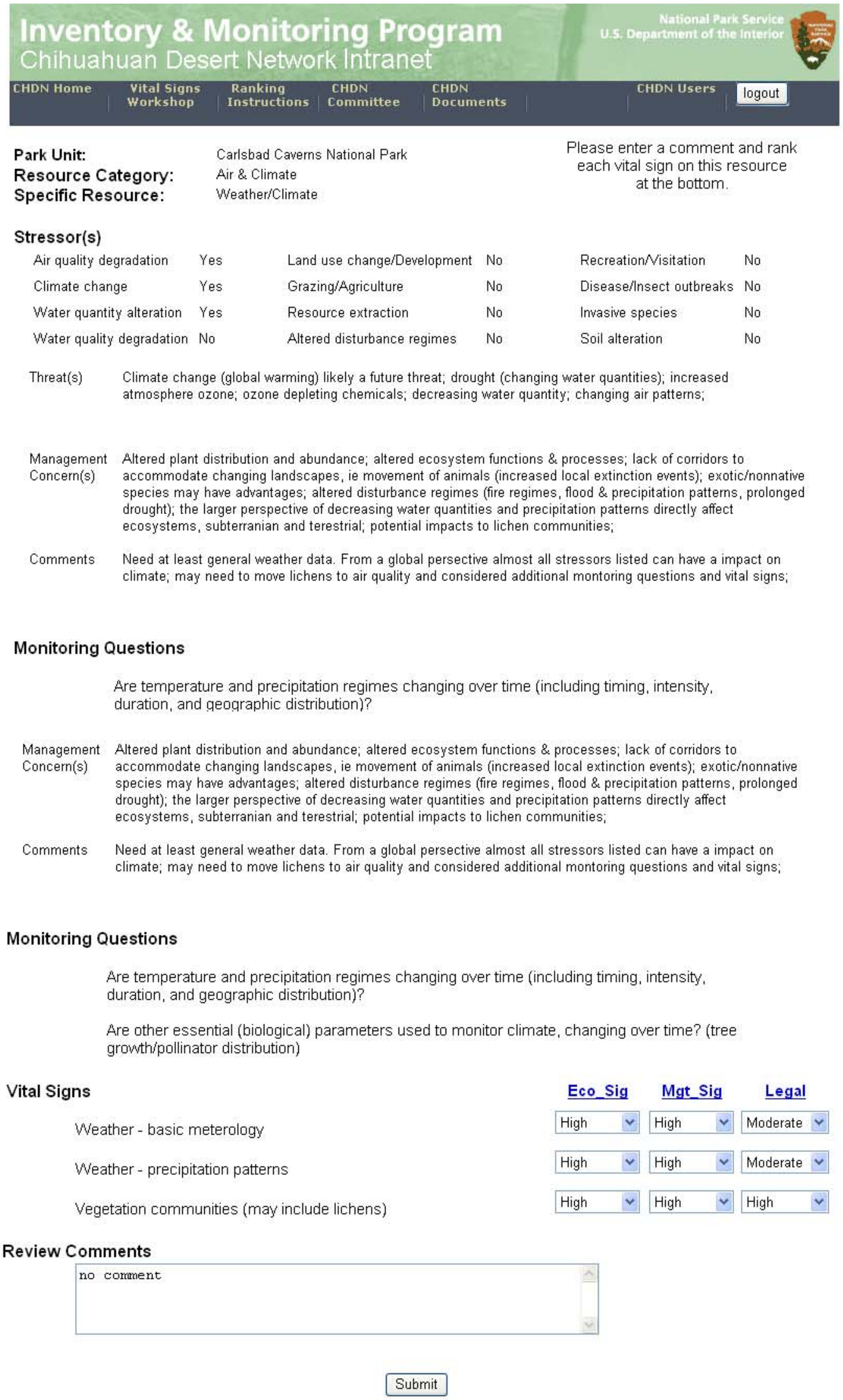
Upon completing the scoping meetings at each park, CHDN staff made this information available on the CHDN's intranet site as an on-line database application. This allowed for preliminary park-based prioritization of issues and vital signs for each park. Only registered users had access to review the park entries for the scoping meetings they attended. The site was also password secured (Figures 1.20 and 1.21).



The following Vital Signs have been Identified for the Carlsbad Caverns National Park.
You may narrow the list by selecting a park.

Park	Category	Specific	
CAVE	Air & Climate	Air quality	Details
CAVE	Air & Climate	Weather/Climate	Details
CAVE	Biological Integrity	All Caves	Details
CAVE	Biological Integrity	At-risk Biota	Details
CAVE	Biological Integrity	Big Horn Sheep	Details
CAVE	Biological Integrity	Focal Community-Relic Plant Community	Details
CAVE	Biological Integrity	Invasive/Exotic animal species	Details
CAVE	Biological Integrity	Invasive/Exotic Plant Species	Details
CAVE	Biological Integrity	Rattlesnake Springs	Details
CAVE	Biological Integrity	Riparian Communities	Details
CAVE	Biological Integrity	Special status species-Animals (incl inverts)	Details
CAVE	Ecosystem Pattern & Processes	Fire	Details
CAVE	Ecosystem Pattern & Processes	Land Use and Land Cover	Details
CAVE	Geology/Soils	Soils	Details
CAVE	Geology/Soils	Subsurface geologic processes	Details
CAVE	Human Use	Visitor Satisfaction/Enjoyment	Details
CAVE	Human Use	Wilderness	Details
CAVE	Water	Hydrology	Details

Figure 1.20. Example of initial screen available to participants of Carlsbad Caverns NP Vital Signs scoping meeting.



Park Unit: Carlsbad Caverns National Park
Resource Category: Air & Climate
Specific Resource: Weather/Climate

Please enter a comment and rank each vital sign on this resource at the bottom.

Stressor(s)

Air quality degradation	Yes	Land use change/Development	No	Recreation/Visitation	No
Climate change	Yes	Grazing/Agriculture	No	Disease/Insect outbreaks	No
Water quantity alteration	Yes	Resource extraction	No	Invasive species	No
Water quality degradation	No	Altered disturbance regimes	No	Soil alteration	No

Threat(s) Climate change (global warming) likely a future threat; drought (changing water quantities); increased atmosphere ozone; ozone depleting chemicals; decreasing water quantity; changing air patterns;

Management Concern(s) Altered plant distribution and abundance; altered ecosystem functions & processes; lack of corridors to accommodate changing landscapes, ie movement of animals (increased local extinction events); exotic/nonnative species may have advantages; altered disturbance regimes (fire regimes, flood & precipitation patterns, prolonged drought); the larger perspective of decreasing water quantities and precipitation patterns directly affect ecosystems, subterranian and terestrial; potential impacts to lichen communities;

Comments Need at least general weather data. From a global persective almost all stressors listed can have a impact on climate; may need to move lichens to air quality and considered additional montoring questions and vital signs;

Monitoring Questions

Are temperature and precipitation regimes changing over time (including timing, intensity, duration, and geographic distribution)?

Management Concern(s) Altered plant distribution and abundance; altered ecosystem functions & processes; lack of corridors to accommodate changing landscapes, ie movement of animals (increased local extinction events); exotic/nonnative species may have advantages; altered disturbance regimes (fire regimes, flood & precipitation patterns, prolonged drought); the larger perspective of decreasing water quantities and precipitation patterns directly affect ecosystems, subterranian and terestrial; potential impacts to lichen communities;

Comments Need at least general weather data. From a global persective almost all stressors listed can have a impact on climate; may need to move lichens to air quality and considered additional montoring questions and vital signs;

Monitoring Questions

Are temperature and precipitation regimes changing over time (including timing, intensity, duration, and geographic distribution)?

Are other essential (biological) parameters used to monitor climate, changing over time? (tree growth/pollinator distribution)

Vital Signs	Eco_Sig	Mgt_Sig	Legal
Weather - basic meterology	High	High	Moderate
Weather - precipitation patterns	High	High	Moderate
Vegetation communities (may include lichens)	High	High	High

Review Comments

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no comment
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Figure 1.21. View of screen where participant ranked vital signs/issues.

The responses were compiled, and discussed during a technical committee meeting in November 2005. This database will serve as a framework for vital signs development over the next three years. A complete list of the issues and the park rankings are found in Appendix N.

1.3.2 Network-wide and Park Specific Issues

This process led to the identification and aggregation of issues important at both the network and park scale. The on-line evaluation process made a preliminary determination of high priority issues across the network (Table 1.13). Ratings resulted in 18 high priority network issues out of a total of 140 issues that were reviewed.

Table 1.13. Issues ranked as moderate to high concern in multiple parks. (At least one park had to have ranked the issue as high.)

Resource Issue/Potential Vital Sign	Air/Climate	Biol Integrity	Ecosystem P & P	Geology/Soils	Human Use	Water
Air chemistry	🟦					
Ozone	🟦					
Particulate pollution/Visibility	🟦					
Weather & climate	🟦					
Wet and dry deposition	🟦					
Diversity of species within native and altered habitats		🟩				
Exotic animals & plants		🟩				
Grassland vegetation		🟩				
Poaching of special status species		🟩				
Populations & distribution of special status species		🟩				
Fire events			🟥			
Fuel dynamics (distribution & loading)			🟥			
Land cover, pattern and land use changes over time			🟥			

Soil & sediment erosion				■		
Night skies degradation					■	
Soundscape degradation					■	
Water quality impacts by visitors					■	
Animal utilization						■

Issues of high concern may likely end up in the list of selected vital signs. Actual prioritization and selection of vital signs will occur in Fiscal Year 2006. The vital signs will then be ranked by several defined criteria and final selection by the technical committee.

In addition to the network wide issues, there may be potential vital signs that should be considered in vital signs selection that are not high priority for the network but are very high priority for an individual park. Table 1.14 is a list of 19 issues that were ranked as high priority by an individual park based on scoping sessions and on-line ranking application.

Table 1.14. High priority issues identified by an individual park.

Resource Issue/Potential Vital Sign	AMIS	BIBE	CAVE	FODA	GUMO	WHSA
AIR & CLIMATE						
Historic vegetation data					■	
Pollinator distribution					■	
Tree growth bands					■	
BIOLOGICAL INTEGRITY						
Oak mott age structure & other special woodlands	■					
Water fluctuation regimes impacts to wildlife	■					
Black bear food supply		■				
Bats			■			
Broad-ranging Species (mt. lion, mule deer)			■			
Historic cottonwood grove				■		
Elevational migration of plant communities					■	
Pop. & distribution of "white-coloration" species						■
ECOSYSTEM PATTERN & PROCESSES						

GEOLOGY & SOILS						
Soil & sediment erosion		■				
Stream channel characteristics		■				
Cave microclimate			■			
Cave/karst processes			■			
Caves/karst features			■			
HUMAN USE						
WATER						
Contaminant levels in fish	■					
fish communities	■					
Siltation rates	■					
TOTAL	**5**	**3**	**5**	**1**	**4**	**1**

Issues that were germane to only a single park were not surprising. Guadalupe Mountains NP has the highest elevations of any park in the network, thus their strong concerns over impacts of climate change was reflected in issues under Air & Climate, as well as concerns of elevation migration of habitat types under Biological Integrity. Likewise, Carlsbad Caverns NP's most significant feature, their magnificent caves, was also appropriately highlighted in this process. And lastly, Amistad NRA, with its water-based park, had issues primarily related to the reservoir that is located within their park unit.

1.4 MONITORING DESIGN AND THE THREE PHASE PROCESS

1.4.1 Designing an Integrated Monitoring Program for CHDN

Monitoring is an on-going effort to better understand how to sustain or restore ecosystems, and serves as an "early warning system" to detect declines in ecosystem integrity and species viability before irreversible loss has occurred. One of the key initial decisions in designing a monitoring program is deciding how much relative weight should be given to tracking changes in focal resources and stressors that address current management issues, versus measures that are thought to be important to long-term understanding of park ecosystems. Should vital signs monitoring focus on the effects of known threats to park resources or on general properties of ecosystem status. Woodward et al. (1999), and others have described some of the advantages and disadvantages of various monitoring approaches, including a strictly threats-based monitoring program, or alternate taxonomic, integrative, reductionist, or hypothesis- testing monitoring designs (Woodward et al. 1999). The approach adopted by CHDN agrees with the assertion that the best way to meet the challenges of monitoring in national parks and other protected areas is to achieve a balance among different monitoring approaches (termed the "hybrid approach" by Noon 2003). A multi-faceted approach for monitoring park resources was adapted, based on both integrated and threat-specific monitoring approaches and building upon concepts presented originally for the Canadian national parks (Figure 1.22 ; from Woodley et al. 1993 in SOPN 2005). This system segregates indicators into one or more of four broad categories:

1. ecosystem drivers that fundamentally affect park ecosystems;
2. stressors and their ecological effects;
3. focal resources of parks; and
4. key properties and processes of ecosystem integrity.

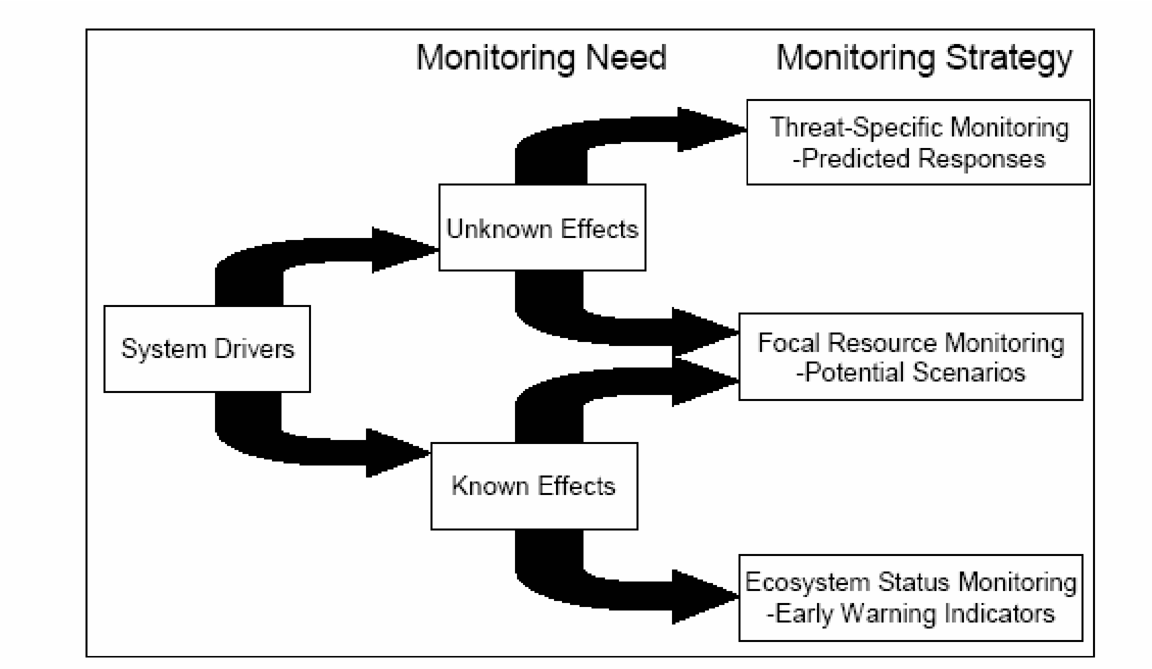

Figure 1.22. Conceptual approach for selecting monitoring indicators. (From Woodley et al. 1993 in SOPN 2005)

In cases where there is a good understanding of relationships between potential effects and responses by park resources (known effects), monitoring of system drivers, stressors, and effected park resources is conducted. A set of focal resources (including ecological processes) will be monitored to address both known and unknown effects of system drivers and stressors on park resources. Key properties and processes of ecosystem status and integrity will be monitored to improve long-term understanding and potential early warning of undesirable changes in park resources.

Natural ecosystem drivers are major external driving forces such as climate, fire cycles, biological invasions, and hydrologic cycles that have large scale influences on natural systems. Trends in ecosystem drivers will have corresponding effects on ecosystem components may provide early warning of presently unforeseen changes to ecosystems.

Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, grazing levels, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution. Monitoring of stressors and their effects, where known, will ensure short-term relevance of the monitoring program and provide information useful to management of current issues.

Focal resources, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

Our current understanding of ecological systems and consequently, our ability to predict how park resources might respond to changes in various system drivers and stressors is poor. A monitoring program that focuses only on current threat/response relationships and current issues may not provide the long-term data and understanding needed to address high-priority issues that will arise in the future. Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions, and a useful ecological indicator must produce results that are clearly understood and accepted by managers, scientists, policy makers, and the public.

While developing the strategy for vital signs monitoring, it became clear that a “one size fits all” approach to monitoring design would not be effective in the NPS considering the tremendous variability of ecological conditions, sizes, and management capabilities among parks. To develop an effective, cost-efficient monitoring program that addresses the most critical information needs of each park and integrates with other park operations, parks need considerable flexibility to combine existing programs, funding and staffing with new funding and staffing available through the Natural Resource Challenge and the various divisions of the Natural Resource Program Center. Partnerships must be developed with federal and state agencies and adjacent landowners to fully understand and manage issues that extend beyond park boundaries, but such partnerships (and the appropriate ecological indicators and methodologies involved) will differ from park to park throughout the national park system.

1.4.2 The Three Phase Process

The complicated task of developing an integrated monitoring program requires an initial investment in planning and design to: 1) guarantee that monitoring meets the most critical information needs of each park; 2) produces scientifically credible results that are clearly understood and accepted by scientists, policy makers, and the public; 3) make results readily accessible to managers and researchers. The planning process must also ensure that monitoring builds upon existing information and understanding of park ecosystems while maximizing relationships with other agencies and academia.

Each network of parks is required to design an integrated monitoring program to address the monitoring goals listed above; one that is tailored to the high-priority monitoring needs and partnership opportunities for the parks in that network. Although there will be considerable variability among networks in the final design, the basic approach to designing a monitoring program should follow five basic steps, which are further discussed in the Recommended Approach for Developing a Network Monitoring Program:

1. Define the purpose and scope of the monitoring program.
2. Compile and summarize existing data and understanding of park ecosystems.
3. Develop conceptual models of relevant ecosystem components.
4. Select vital signs and specific monitoring objectives for each; and
5. Determine the appropriate sampling design and sampling protocols.

These steps are incorporated into a 3-phase planning and design process that has been established for the network monitoring program. Phase 1 of the process involves defining goals and objectives; beginning the process of identifying, evaluating and synthesizing existing data; developing draft conceptual models; and completing other background work that must be done before the initial selection of ecological indicators. Each network is required to document these tasks in a Phase 1 report, which is then peer reviewed and approved at the regional level before the network proceeds to the next phase. Phase 2 of the planning and design effort involves prioritizing and selecting vital signs and developing draft monitoring objectives for each that will be included in the network's initial integrated monitoring program. Phase 3 entails the detailed design work needed to implement monitoring, including the refinement of specific monitoring objectives, development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and details on the type and content of various products of the monitoring effort such as reports and websites. The schedule for completing the 3-phase planning and design process was shown in Table 1, but is repeated here.

Table 1. Three-phase planning process for development of the CHDN Monitoring Plan.

	Goals and Tasks	CHDN Deadlines
Phase I	Description of monitoring objectives and network overview; Initiating conceptual model development	October 2005
Phase II	Cont. conceptual model development; vital signs prioritization; selection and rationale	October 2007
Phase III Peer-review	Monitoring & sampling design	October 2008
Phase III Initial Draft	Monitoring & sampling design	December 2008

1.5 SUMMARY OF MONITORING WITHIN CHDN AND THE REGION

A solid understanding of current and previous inventory and monitoring in network park units is an important foundation for development of the CHDN inventory and monitoring program. Documentation and review of existing work allows the network to identify where monitoring is adequate, where additional monitoring or protocol development is needed, which monitoring studies can be built upon and expanded, and what studies should be abandoned. Information was gathered from a Servicewide inventory and monitoring database, and interviews with park staff (Appendix L).

1.5.1 Existing Inventory and Monitoring in CHDN Parks

Documentation of existing inventory, monitoring and research work is envisioned as an on-going function of the CHDN data management. With frequent turnover of park natural resource management staff, the "institutional" knowledge that is often lost when employees move to new positions will at least be partially retained in these databases. This should help with program continuity over time and minimize the desire to start over with personnel changes. Park projects were only considered past or existing monitoring if measurements were taken at the same locations on several occasions. The following is a summary of the status of resource and stressor inventories and monitoring in CHDN parks (Table 1.15).

Table 1.15. Summary of the types of inventory or monitoring programs conducted at CHDN parks. Programs are grouped by categories.

	CHDN PARKS					
Category	**AMIS**	**BIBE**	**CAVE**	**FODA**	**GUMO**	**WHSA**
Air quality	M	M			M	
Climate	d	d	M	d	d	d
Earth sciences [1]		IH				I
Cave resources [2]			IM			
Paleontological		IH			I	I
Water quality and water quantity	M	M	M		M	M
Springs/seeps		I, MH	I			
Avian	MH	IH, MH, M	M, IC	IC	IC, IH	IC
Fish	M, IC	IH, M, IC	I			
Herpetofauna	IC	IC, IH	IC	IC	IC	IC, IH
Invertebrate	MH	IH	I			
Mammal	IC	IH	IH		IC, IH	IH
Vegetation	IC	MH, M		IH, MH	IH, MH	IH
Fire effects		M	M	M (adj lands)	M	
Stressors [3]		I, M	IM			M

[1] = geology, geomorphology, soils, etc. [2] = cave geology, water, biotic (including microbial), and physical attributes. [3] = exotic and invasive plants & animals, wildlife/visitor conflicts. d: data being collecting, some cases not electronically; C: CHDN inventory; H: historical inventory or monitoring data with adequate

documentation; I: short-term comprehensive inventory (1 to 2 years); M: long-term monitoring (2+ years) with adequate documentation.

1.5.2 Regional or Adjacent Lands Monitoring

Long-term regional and adjacent lands monitoring and research programs were identified for the CHDN (Appendix O). CHDN adjacent and neighboring lands are owned and/or managed by various entities, including: the Bureau of Land Management (BLM), the Bureau of Reclamation (USBR), the Forest Service (USFS), the Bureau of Indian Affairs (BIA), the U.S. Fish and Wildlife Service (USFWS), states and private entities. The following is a summary list of major monitoring activities by adjacent land owners and/or managers that have thus far been identified.

CHAPTER 2: CONCEPTUAL MODELS

2.1 Introduction to Conceptual Models

Conceptual models are visual or narrative summaries that describe the important components of an ecosystem and the interactions among them. Conceptual models help us develop a “mental picture” that is often difficult to convey in words. Models also provide scientists and managers from different disciplines a common view of landscapes and ecosystems and provide an objective, hierarchical framework for identifying attributes to monitor.

Conceptual models may be considered as “caricatures of nature” (Holling et al. 2002), designed to describe and communicate ideas about how nature works. Given the complexity of natural systems and the range of factors that influence natural processes, models provide a way to organize information. Conceptual models depicting key structural components and system drivers assist us in thinking about the context and scope of the processes that effect ecological integrity (Karr 1991). They also provide a heuristic device to expand our consideration across traditional disciplinary boundaries (Allen and Hoekstra 1992). Learning that accompanies the design, construction, and revision of models often contributes to the development of a shared perspective of system dynamics and the limits of current knowledge (Wright 2002). In addition, conceptual models can improve communication between scientists from different disciplines, between scientists and managers, and between managers and the general public. Conceptual models are useful tools that can be routinely used throughout the process of developing and implementing ecological monitoring.

2.2 Initiating Development of Conceptual Models

Developing conceptual models will help us gain an understanding of how park ecosystems work and promote communication among scientists and park managers. For example, in future modeling workshops, we can focus on topics that influence particular ecosystem processes in the network. By illustrating the workshop results in diagram form, personnel from each park in the network can have a better understanding of the ecology in their particular area. This will begin the modeling process.

2.2.1 Aspects to Consider as Conceptual Models are Developed

- Identify the structural components of the resource, interactions between components, inputs and outputs to surrounding resources, and important factors and stressors that determine the resource’s ecological operation and sustainability.

- Consider the temporal and spatial dynamics of the resource at multiple scales because information from different scales can result in different conclusions about resource condition.

- Identify how major stressors of resources are expected to impact their structure and function

Conceptual models are especially effective in network-wide, multi-park programs where the complex interactions among ecosystems within a group of parks are difficult to interpret. A conceptual model identifies or maps the physical and biological components and their links in an ecosystem. Most useful models do not try to name or describe every component of an ecosystem. Instead, they depict major components and interactions. For examples: major external activities or processes that influence the ecosystem, problems or products of human activities or natural events that alter the quality or integrity of the ecosystem and measurable changes in ecosystem structure, function, or processes.

2.3 General Conceptual Models

For purposes of monitoring, it is useful to begin with a simple, general model that summarizes ideas about ecosystem sustainability. SOPN has adopted a modified version of the interactive-control model (Jenny 1941, Chapin 1996) to serve as the general ecosystem model for SOPN conceptual model development. The Jenny-Chapin model defines state factors and interactive controls central to the functioning of sustainable ecosystems. This general model and a set of corollary hypotheses provide a theoretical foundation for aspects of the monitoring plan related to ecosystem structure and function.

Jenny (1941, 1980) proposed that soil and ecosystem processes are determined by five state factors: climate, organisms, relief (topography), parent material, and time since disturbance. Jenny's state-factor approach has been widely applied as a framework for examining temporal and spatial variations in ecosystem structure and function (e.g., Walker and Chapin 1987, Vitousek 1994, Seastedt 2001). Chapin et al. (1996) recently extended this framework to develop a set of ecological principles concerning ecosystem sustainability. They defined "...a sustainable ecosystem as one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996:1016). These ecosystem characteristics are determined by a set of four "interactive controls"–climate, soil-resource supply, major functional groups 4 of organisms, and disturbance regime– and these interactive controls both govern and respond to ecosystem attributes (Figure 9). Interactive controls are constrained by the five state factors, which determine the "constraints of place" (Dale et al. 2000).

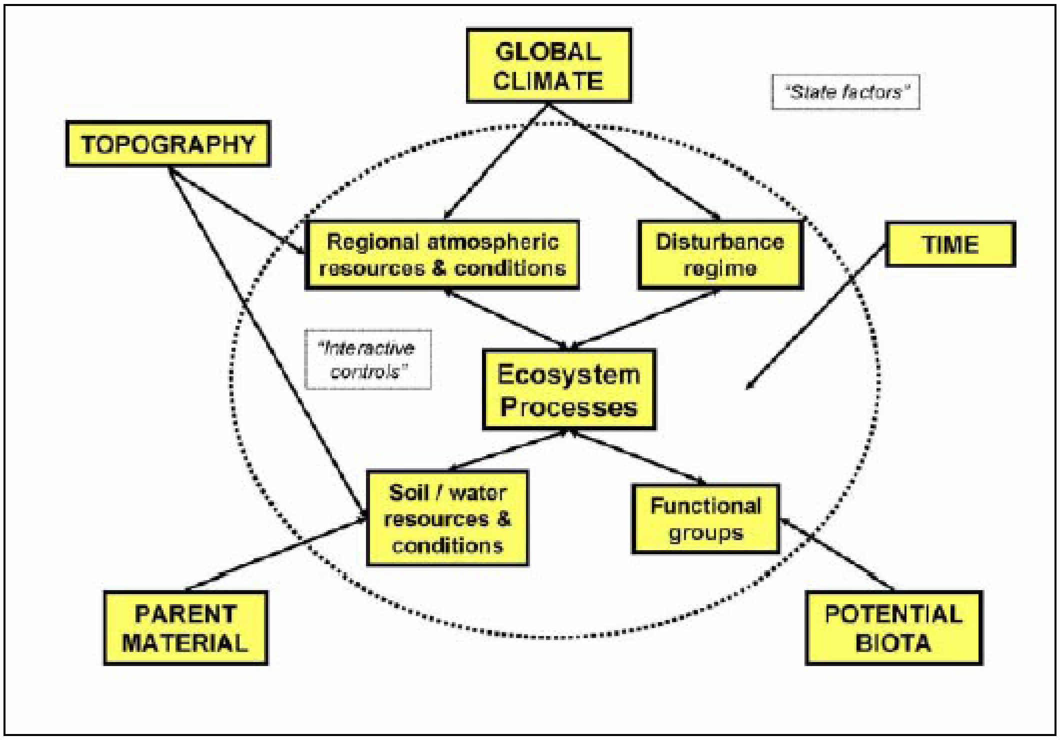

Figure 2.1. Aggregated system characterization model. Aggregated system characterization model illustrating key ecosystem processes, characteristics and sustainability as a function of a hierarchical set of state factors and interactive controls. It may be used to "set the stage" for mode detailed, system-specific process and driver models. The circle represents the boundary of the ecosystem (from Chapin et al. 1996).

By substituting water quality and quantity for soil resources in the model, the interactive-control model can be applied to aquatic as well as terrestrial ecosystems (Chapin et al. 1996). This extends the utility of the model, and it suggests further clarifications. Soil, water, and air are the media from which primary producers acquire resources. As the abiotic matrix that supports the biota, they form the foundation of ecosystems. These media also are characterized by condition attributes (e.g., temperature, stability) that affect the physiological performance of organisms. Water and air qualities are accepted concepts with legislative standards. No legislative standards exist for the comparable concept of soil quality, and the concept itself was defined only recently. Karlen et al. (1997:6) defined soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." Soil quality can be regarded as having two major components. First, an inherent component defined by the soil's inherent soil properties as determined by Jenny's (1941) five factors of soil formation. Second, there is a dynamic component defined by the change in soil function that is influenced by human management of the soil (Seybold et al. 1999). In terms of the interactive-control model, the concepts of water quality and soil quality will be used interchangeably with the more descriptive concepts of water resources and conditions and soil resources and conditions, respectively. With respect to climate as it is represented in the interactive-control model, the broader concept of atmospheric resources and conditions is more precise, encompassing climatic conditions such as temperature, resources such as precipitation and CO2, and stressors such as airborne pollutants. This is an important clarification in the context of global environmental changes.

For vital signs monitoring, a key aspect of the Jenny-Chapin model is the associated hypothesis that interactive controls must be conserved for an ecosystem to be sustained. Large changes in any of the four interactive controls are predicted to result in a new ecosystem with different characteristics than the original system (Chapin et al. 1996, Vitousek 1994, Seastedt 2001). For example, major changes in soil resources (e.g., through erosion, salinization, fertilization, or other mechanisms) can greatly affect productivity, recruitment opportunities, and competitive relations of plants, and thus can result in major changes in the structure and function of plant communities and higher trophic levels. Changes in vegetation structure can affect the ecosystem's disturbance regime (e.g., through altered fuel characteristics). These factors and processes in combination can result in a fundamentally different type of ecosystem. Under some circumstances, effects of land uses such as grazing even can affect regional atmospheric resources and conditions through alterations of vegetation and soil conditions that alter ecosystem-atmosphere exchanges of water and energy (e.g., Bryant et al. 1990, Eastman et al. 2001). Additions or losses of species with traits that have strong effects on ecosystem processes also can result in an ecosystem with fundamentally different characteristics – potentially affecting the persistence of previous ecosystem components. Species that affect soil-resource regimes, disturbance regimes, or functional-group structure are those most likely to have profound effects on ecosystem characteristics following their introduction or loss from a system (Vitousek 1990, Chapin et al. 1997). Examples with particular relevance to vital signs monitoring include invasive exotic species that alter ecosystem disturbance regimes (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998) and/or ecosystem resource regimes (Vitousek et al. 1987, Simons and Seastedt 1999).

2.4 Purposes of Conceptual Models for the CHDN

Despite the complexity of ecosystems and the limited knowledge of their functions, to begin monitoring, we must first simplify our view of the system. The usual method has been to take a species-centric approach, focusing on a few high-profile species. These are predominately species of economic, social, or legal interest. Because of the broader interest in all components of biological diversity, however, the species-centric approach is no longer sufficient. This broader interest creates a conundrum; we acknowledge the need to simplify our view of ecosystems to begin the process of monitoring, while also recognizing the need to broadened beyond the species-centric focus to consider additional ecosystem components.

One of the steps in the design of each network's long-term monitoring plan entails the development of its own conceptual models of ecological processes. These conceptual models are most relevant to the Vital Signs Monitoring Program because they will help identify possible indicators of ecosystem health. The identified indicators will provide the focus for long-term monitoring.

An important goal of the models is to depict how natural drivers (e.g., climate and natural disturbance regimes) and anthropogenic stressors (e.g., stream flow modifications) affect ecosystem structure and function. The ability of the monitoring program to detect the ecological effects of anthropogenic stressors is dependent upon interpreting trends in resource condition against the backdrop of intrinsic variation. Hypotheses concerning the effects of anthropogenic stressors on ecosystem structure and function must be grounded in an understanding of the relationship between natural drivers and the structure, functioning and dynamics of ecosystems. Undoubtedly, ecosystems and their components can be characterized on the basis of far more structural and functional attributes than can be monitored. Thus, another important goal of the models is to guide the identification of a parsimonious set of "information-rich" attributes that provides information on multiple aspects of ecosystem condition (Noon 2003).

No single conceptual model can satisfy all needs. Spatially explicit applications such as ecological resource assessments, monitoring design, and landscape-level ecological modeling ultimately will require site-specific models, but the monitoring program also requires generalized ecological models *to* facilitate communication among scientists, managers, and the public regarding ecosystems and how they are affected by human activities and natural processes.

Conceptual models provide at least two key benefits to the NPS monitoring program:

- understanding ecosystem structure, function, and interconnectedness at varying temporal and/or spatial scales enables identification of vital sign indicators for assessing ecosystem health in parks, and
- understanding the range of natural and human-induced ecosystem variability helps park managers plan adaptive management programs, determine at what threshold variances these programs should be instituted, and then measure the results of the management programs to assess their value.

The CHDN is currently planning our monitoring program in order to adequately address our monitoring goals. Vital signs or ecological indicators that indicate the health of an ecosystem will be the focus of monitoring in our network. These can be any measurable feature of the environment that provides insights into the state of the ecosystem, including compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional features (referring to ecological processes).

Other approaches to the modeling development effort may include: 1) consideration of ecosystem characterization models. These models consider a list of state variables and functions important to the ecosystem, and they also show how these components are connected by means of processes (Jorgensen 1986). One should be able to compare and contrast diagrammatic models for different systems and recognize important structural and functional similarities and differences between systems that have implications for monitoring. For example, episodic drought may be a common overriding determinant of ecosystem dynamics throughout the Chihuahuan Desert, and this would be portrayed similarly across all of the models. In contrast, the relative importance of fire as a natural driver, and the extent to which a legacy of fire suppression has altered vegetation structure varies widely across ecosystems within the Chihuahuan Desert, and thus, would be characterized by geographic or vegetative unit.

Another modeling approach is: 2) ecosystem dynamics models. Several of the NPS service-wide goals for vital signs monitoring are oriented towards the dynamics of ecosystems or selected ecosystem components. These three service wide goals are:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.

The NPS has adopted an iterative approach of first developing general conceptual models for broadly defined ecosystem types, and then adapting and refining those models with site-specific data concerning abiotic constraints, land-use history, current condition, and specific patterns of ecosystem dynamics. Suites of models that are nested in relation to scale and process specificity are often required to depict various levels of information needed to organize hypotheses pertinent to ecosystem monitoring.

The Chihuahuan Desert Network has not yet received full funding to fully engage in the development of conceptual models, nevertheless, we have initiated the process. Ecosystems that make up our network have been delineated (Table 2.1). Specifying and delineating these areas will help us in building models adequate for the Chihuahuan Desert parks. For the purpose of initiating the development of conceptual models, ecosystems within the CHDN were divided into five types—aquatic, low elevation terrestrial, mid-elevation terrestrial, high elevation terrestrial, and unique (e.g. cave, reservoir and gypsum dunefield). CHDN will also use a combination of developing new models for network specific ecosystems and concerns, and adapting models from other I+M networks where ecosystem types are similar. Some general representative models for low, mid-, and high elevation terrestrial are shown below (adopted from Sonoran Desert Network). Models representing aquatic systems and special systems will be developed, and the general terrestrial models will be refined during Phase II.

Table 2.1 Chihuahuan Desert general ecosystem classification.

General Ecosystem	Park Unit
Desert Grasslands	all
Desert Shrublands:	
Chihuahuan	all
Tamualipan	AMIS only
Arid/Semi-arid Woodland	all except WHSA
Montane Forests	
Chisos Mts.	BIBE
Guadalupe Mts.	GUMO
Davis Mts.	near FODA
Big Rivers & Reservoir (Rio Grande, Pecos, Devils, Amistad)	AMIS, BIBE, RIGR
Perennial Streams	GUMO
Intermittent/Ephemeral Streams	all
Springs/Seeps	all (minor component at WHSA)
Playas/Salt flats	GUMO, WHSA
Gypsum Dunes & Other Dune Systems	GUMO, WHSA
Cave & Karst Systems	AMIS, BIBE, CAVE, GUMO

Several general models have been developed within the context of the Chihuahuan Desert that may be useful to the network's monitoring program. These include climate change simulation modeling for the upper Rio Grande Basin (Havstad et al. 2003), gap dynamics model of herbaceous and woody species (Peters 2001), and use of state and transitions model approach to land management in the Southwest (Stringham, et al 2003, Bestlemeyer et al. 2004). In addition, a very site-specific model is currently being developed for depicting Amistad Reservoir, to understand the ecosystem structure of Amistad, and the factors within the reservoir that will alter and influence the water quality (Groeger 2005).

These general models, as well as developing models more specific to parks in the CHDN will be developed over the next 1-2 years. Those results will be discussed in the Phase II report.

2.4.1 Low Elevation Systems

Lower elevation systems, generally below 4,500 ft, within Chihuahuan Desert Network parks include desert grasslands, desert shrublands, and chapparal (Appendix H). These systems are dominated by succulents, woody shrubs, and annual forbs and grasses. Trees are usually absent.

These systems are characterized by low precipitation and low net primary productivity but high plant diversity. In these lower elevation systems of the Chihuahuan Desert Network, vegetation community structure and composition is mainly driven by climate and geology. These drivers act to influence available water and nutrients, which directly define species assemblages. The composition and structure of vegetation communities in these systems have an impact on soil nutrients as well. Net primary productivity of desert systems is limited primarily by water, unlike many other systems. Natural and human-induced fires and herbivory also play a large role in shaping these ecosystems. Natural fire regimes of low elevation desert systems are not well known (Dick-Peddie 1993). However, introduction of several nonnative grass species, including buffelgrass (*Pennisetum ciliare*), has had major impacts on these systems, resulting in hot, widespread fires that favor the exotic species and kills native species. This feedback was depicted by D'Antonio and Vitousek (1992; Figure 2.2):

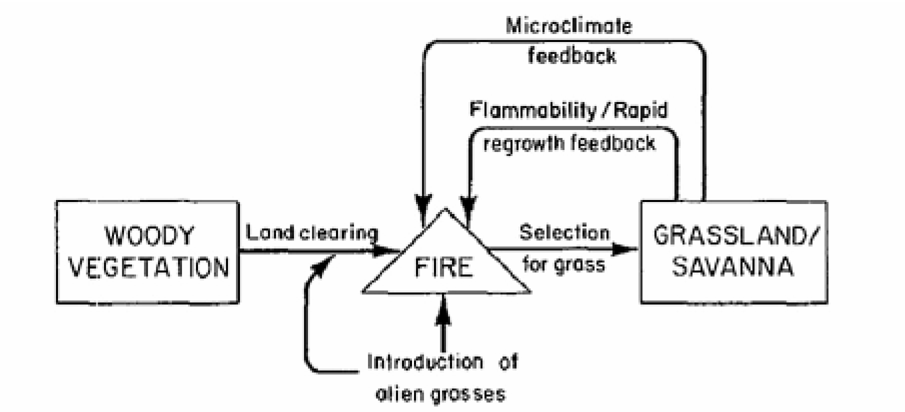

Figure 2.2. Grass/fire interaction model (from D'Antonio and Vitousek (1992).

Anthropogenic effects also play an indirect role in shaping low elevation systems through trampling, introduction of exotic plant and animal species, harvesting, and multiple types of park operations. Other stressors and drivers also have indirect influences on low elevation systems. Groundwater withdrawal is probably the most important outside influence in this system. The anthropogenic influences are depicted outside of the system in Figure 2.3.

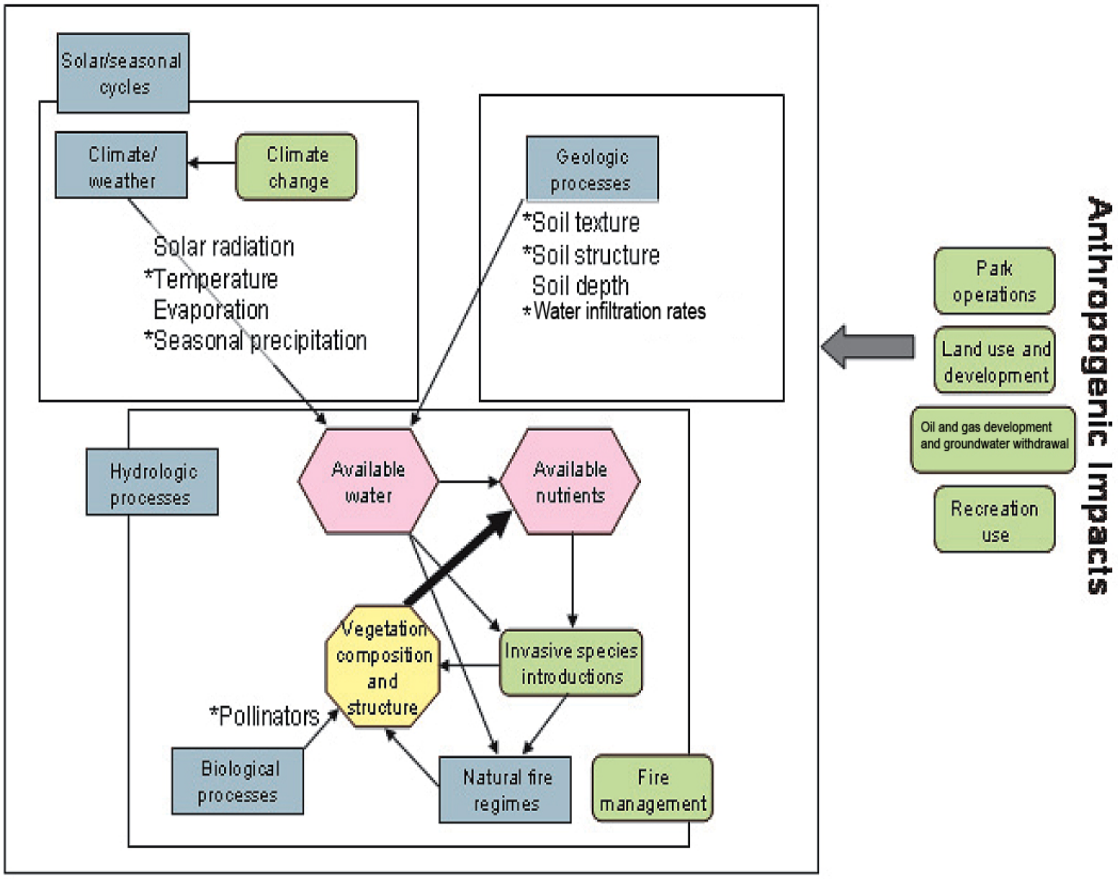

Figure 2.3. Potential Chihuahua Desert Network low elevation ecosystem model. Potential vital signs are depicted as *. (from Mau-Crimmins et al. 2005)

2.4.2. Mid-Elevation Systems

Mid-elevation systems in Chihuahuan Desert Network parks include pinyon-juniper woodlands and pine-oak woodlands which generally occur between 5,000 – 6,000 ft. Grass understories are a key feature of these systems; savannas and woodlands are characterized by sparse to complete tree canopies. In these systems, water and nutrients, primarily nitrogen, are approximately equally limiting. Many soil characteristics, including presence and composition of biological soil crusts, soil depth, texture, and water holding capacity influence available soil nutrients. These characteristics are impacted through human activities which alter soil distribution, crusts, and compaction. Fire is a relatively common and a necessary occurrence in these systems. Historically, these systems experienced fire every 5-10 years. Fire maintains the open structure of the ecosystem, conferring a competitive advantage to graminoids over most woody plants. Fire suppression, intensive grazing, and soil erosion have degraded much of the grassland ecosystem in this region, leading to encroachment by woody species and drought-resistant nonnative grasses such as Lehmann lovegrass (*Eragrostis lehmanniana*). Archer

(1989) depicted the shift from grasslands to grasslands dominated by woody species under a variety of pressures (Figure 2.4):

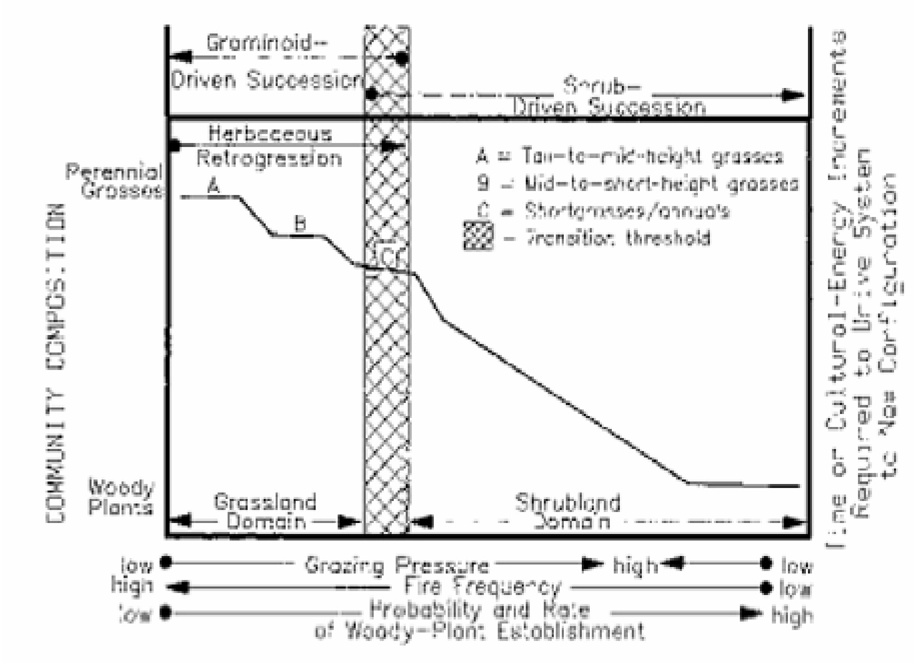

Figure 2.4. Herb/woody domination model (from Archer 1989).

Anthropogenic effects indirectly affect mid-elevation systems through trampling, introduction of exotic plant and animal species, harvesting, and multiple types of park operations. Other stressors and drivers depicted outside of the system (Figure 2.5) also have indirect influences on mid-elevation systems.

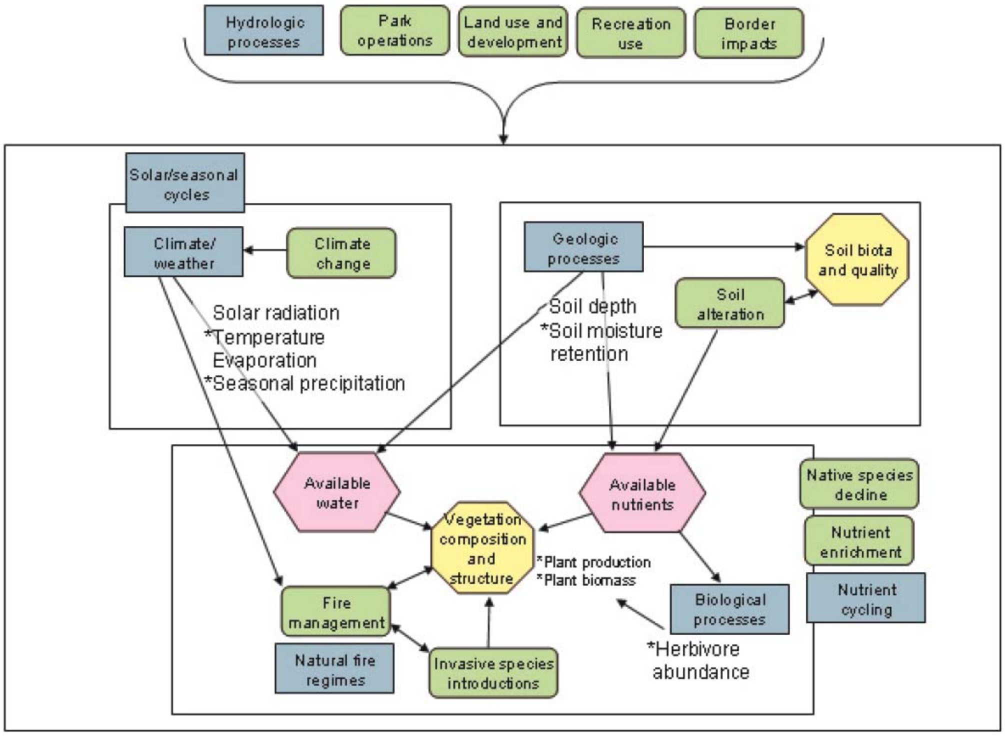

Figure 2.5. Potential Chihuahuan Desert Network mid-elevation ecosystem model (modified from Scholes and Walker 1993). Potential vital signs are depicted as *. (from Mau-Crimmins et al. 2005)

2.3.3. High Elevation Systems

High elevation systems in the Chihuahuan Desert Network include temperate deciduous forests and conifer forests. These systems are dominated by tree species and generally occur above 6,000 ft. Historically, fire was frequent in these systems but has been controlled for the past 100 years through management (Swetnam et al. 1999). Recent changes in management beliefs have resulted in the slow restoration of fire to these systems within CHDN parks. Like lower elevation systems, upper elevation systems in the Chihuahuan Desert region are mainly influenced by characteristics of climate and geology, through the availability of moisture and nutrients (Figure 2.6). The presence and introduction of nonnative species and fire management also play key roles in shaping the vegetation and soil biota composition, structure, and function of these systems. Additionally, climate change threatens to have major detrimental impacts on higher elevation systems. Predicted temperature increases combined with changes in precipitation patterns are expected to result in major shifts in species assemblages and upslope shifts in communities. Human uses also impact characteristics of these systems to varying degrees through recreational uses, proximate land use changes and development, and various park operations.

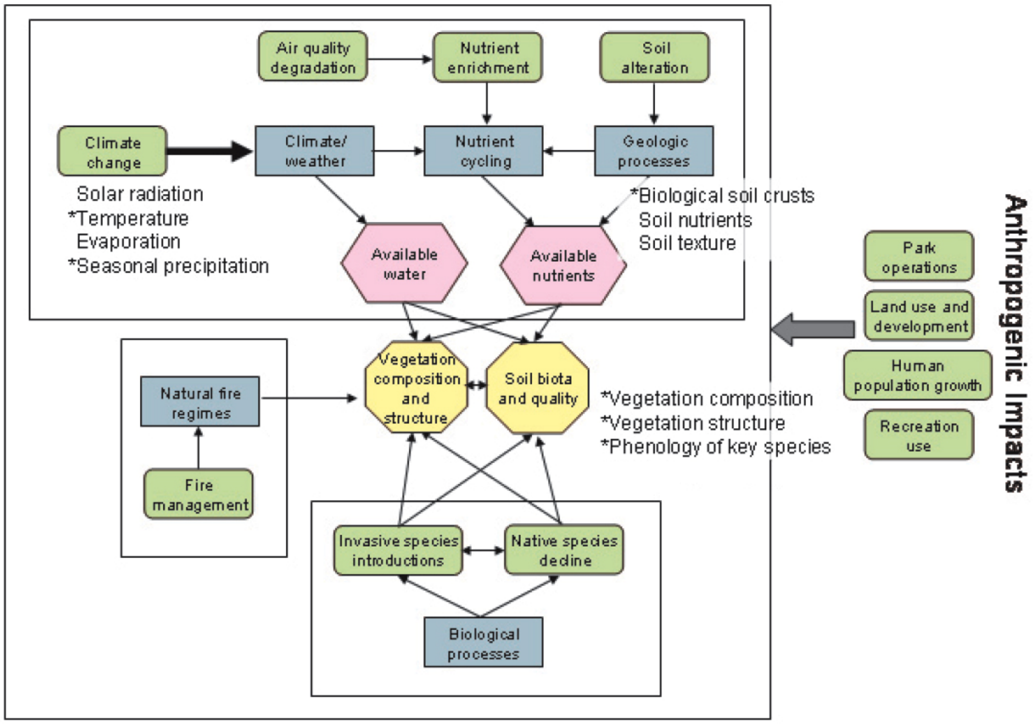

Figure 2.6. Potential Chihuahuan Desert Network high elevation ecosystem model. Potential vital signs are depicted as *. (from Mau-Crimmins et al. 2005)

2.4 SUMMARY

Conceptual modeling provides a valuable tool for identifying the important components of an ecosystem, the interactions among those components, how drivers and stressors impact the ecosystem, communication, and what measurements are possible for determining ecosystem health. Additionally, conceptual modeling provides these benefits:

- literature-based context for continued deliberations,
- multiple ecological frameworks as a basis for vital sign integration discussions,
- assessments of relevant spatial and temporal scales.

The CHDN has only begun its conceptually modeling process. However, these efforts, along with deliberate discussions on adopting a monitoring system designed for arid grassland and shrublands (Pellant et al. 2005), have revealed several potential vital signs that did not come up in park scoping sessions. Hydrologic function, soil and site stability, and measurements of biological integrity are the three pillars for assessing ecosystem function as described by Pellant et al. (2005). This perspective has been generally missing from the park managers of units in the CHDN. As we move forward in this process, the CHDN's list of potential vital signs and issues of high concern may dramatically change.

CHAPTER 3: VITAL SIGNS PRIORITIZATION – TO BE COMPLETED WITH PHASE II REPORT

CHAPTER 4: SAMPLING DESIGN – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 5: SAMPLING PROTOCOLS – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 6: DATA MANAGEMENT AND ARCHIVING – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 7: DATA ANALYSIS AND REPORTING – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 8: ADMINISTRATION / IMPLEMENTATION OF THE MONITORING PROGRAM – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 9: SCHEDULE – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 10: BUDGET – TO BE COMPLETED WITH PHASE III REPORT

CHAPTER 11: LITERATURE CITED

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GLOSSARY OF TERMS USED BY THE NPS INVENTORY AND MONITORING PROGRAM

Adaptive Management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form-"active" adaptive management-employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Attributes are any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term Indicator is reserved for a subset of attributes that is particularly information rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). See Indicator.

Ecological integrity is a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Ecosystem is defined as, "a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992).

Ecosystem drivers are major external driving forces such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., earthquakes, droughts, floods) that have large scale influences on natural systems.

Ecosystem management is the process of land-use decision making and land management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions.

Focal resources are park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

Indicators are a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2002). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Measures are the specific feature(s) used to quantify an indicator, as specified in a sampling protocol.

Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

Vital Signs, as used by the National Park Service, are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve “unimpaired for future generations,” including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).