National Park Service Chihuahuan Desert Network Inventory and Monitoring Program

Chihuahuan Desert Network Vital Signs Monitoring Plan: Phase II Final Report

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IN MEMORY
DR. WILLIAM "BILL" H. REID
November 11, 1933 - May 11, 2006

This plan is dedicated to Bill Reid, our friend and colleague. Bill played an integral role in the early stages of the CHDN I&M program, leading the biological inventory field efforts for several years and serving as the first network coordinator and data manager of this fledgling program. Bill significantly contributed to the Phase I report by writing the Climate Summary Report of CHDN park units and the Phase I Water Quality Assessment report, despite being seriously ill during those months. Bill's contributions laid the foundation for future work and direction of the network. Bill always had a love for education and adventure, as evidenced in his life experiences. Though Bill is known by his National Park Service colleagues as a talented and dedicated ecologist, this was a career move he undertook later in life. Bill was first involved with designing rockets in the Apollo space program for NASA. Bill was also a prolific writer, having published hundreds of articles and papers, as well as several novels. His enthusiasm and unwavering dedication for his work, the natural world, and to his friends and family were an inspiration for everyone he encountered. Bill will be sorely missed.

Executive Summary

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's (NPS) ability to manage park resources "unimpaired for the enjoyment of future generations." The NPS has implemented a strategy to programmatically institutionalize natural resource monitoring that will ensure that parks possess scientific information needed for effective decision making and resource protection. The effort includes 270 park units with significant natural resources. These parks have been grouped into 32 monitoring networks linked by geographic location and ecological similarities. The network organization will facilitate collaboration, information sharing, and economies of scale in natural resource monitoring. Parks within each of the 32 networks collaborate and share funding and professional staff to plan, design, and implement an integrated, long-term monitoring program.

The Chihuahuan Desert Inventory and Monitoring Network (CHDN) is composed of seven NPS units within the states of New Mexico and Texas. The member parks are Amistad National Recreation Area, Big Bend National Park, Carlsbad Caverns National Park, Fort Davis National Historic Site, Guadalupe Mountains National Park, Rio Grande Wild & Scenic River (administered by Big Bend National Park), and White Sands National Monument.

The complex task of developing ecological monitoring requires a front-end investment in planning and design to ensure that monitoring will meet the most critical information needs and produce ecologically relevant and scientifically credible data accessible to managers in a timely manner. The CHDN monitoring program is being developed over five years, with specific objectives and reporting requirements for each of three planning phases. The first planning step involved compiling and organizing relevant science information and conducting detailed park scoping meetings to identify the most important resources and issues for each park. The second step was to collaborate with regional scientists to develop conceptual ecological characterization models of the predominant CHDN ecosystems. The network held several park-based scoping meetings and workshops between the winter of 2004 and the summer of 2006 to identify and evaluate vital signs for long-term monitoring. During those workshops, park managers, subject-matter experts from the scientific community, and CHDN staff identified and evaluated resources and potential indicators as candidates for monitoring. Following the workshops, the CHDN Technical Committee and the Board of Directors met to approve a list of high priority vital signs. The diversity of ecosystems in CHDN parks, the geographic distribution of these parks, and differences in resource management priorities among parks are challenges facing the network. However, the vital signs prioritization process revealed that parks share a number of similar resource management issues and monitoring needs. The CHDN has identified 38 vital signs that would represent a comprehensive monitoring program. However, the current level of funding will not enable CHDN to monitor all 38 vital signs. CHDN expects that 15-20 vital signs will be further evaluated in the Phase III process, and, based on the experiences of other networks currently beginning implementation, the CHDN

Inventory and Monitoring (I&M) program will be able to fund monitoring for 5-10 vital signs. Water quality monitoring continues to be fully integrated within the CHDN monitoring program.

This document is the second of three scheduled reports that precede the final CHDN monitoring plan. This Phase II Vital Signs Monitoring Report includes: 1) monitoring goals and the planning process used to develop the monitoring program, 2) summaries of existing information concerning park natural resources and resource management issues across the network, 3) a conceptual model framework for CHDN park ecosystems, and 4) descriptions of the prioritization and selection processes for vital signs. The draft of the Phase III report is due December 15, 2007 and will include the above topics, as well as: 1) a sampling framework for aquatic and terrestrial ecosystems in parks, 2) monitoring protocols, 3) a description of the network's approach to data management, and 4) information on program administration, funding, and operations. The final monitoring plan is due September 30, 2008.

Acknowledgments

The Chihuahuan Desert Network (CHDN) continues to benefit immensely from the work of 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 model concepts from the Sonoran Desert, Northern Colorado Plateau, and Southern Colorado Plateau Networks for Chapter 2. In Chapter 3, CHDN utilized information from the Central Alaska and Southern Plains Networks. 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 greatly 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 the following reviewers: Chapter 1 & Appendices G and H – Cathy Hoyt and Michael Powell; Chapter 2 – Kris Havstad, Jeff Herrick, Nicole Sikula and Walt Whitford; Chapter 3 and Appendix P – Melissa Siders and Diana Whittington; Phase II Water Quality report – Gary Rosenlieb and anonymous reviewers; entire report – Bruce Bingham and Kris Johnson. K. Johnson, Rayo McCollough, and Teri Neville, all of Natural Heritage New Mexico, provided diligent editing and production of the Phase II report. The Administrative Offices for Carlsbad Caverns and Guadalupe Mountains National Parks, fondly referred to as the "Town Office" continue to provide support, as does the Division of Natural Resources Stewardship and Science at Carlsbad Caverns National Park.

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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 (NPS 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 for conducting long-term monitoring of ecosystem function and health, based on various environmental indicators (vital signs). Each network links parks that share geographic and natural resource characteristics, allowing improved efficiency and the sharing of staff and resources.

This report covers the Chihuahuan Desert Inventory and Monitoring Network (CHDN), 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 seven national park units in New Mexico and Texas (Table 1.1, Figure 1.1). The parks range in size from almost 200 ha (500 ac) at Fort Davis National Historic Site (NHS) to over 300,000 ha (800,000 ac) at Big Bend National Park (Appendices A, B and C). Six of the seven CHDN park units are located in the Northern Chihuahuan Subregion of the Chihuahuan Desert Ecoregion (Figure 1.2). Amistad National Recreation Area is situated primarily within the Tamaulipan Thornscrub (Mezquital) Ecoregion of southern Texas and northeastern Mexico.

Table 1.1. List of park units in the CHDN.

Unit	State	Park Code	Hectares	Acres
Amistad National Recreation Area	TX	AMIS	23,186	57,292
Big Bend National Park	TX	BIBE	324,226	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	34,972	86,416
Rio Grande Wild and Scenic River*	TX	RIGR	2,090	5,164
White Sands National Monument	NM	WHSA	58,168	143,733
		Total	461,760	1,141,008

* 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. Park units of the Chihuahuan Desert Inventory & Monitoring Network (produced by CHDN, and adapted from Dinerstein et.al. 2000).

The CHDN Vital Signs Monitoring Plan is being developed over a multi-year period following specific guidance from the NPS Washington Office (WASO) (NPS 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.

This Phase II Report includes Chapter One (Introduction and Background), revision of Chapter Two (Conceptual Models), and drafts of Chapter 3 (Vital

Signs) and Chapter 11 (Literature Cited) of the monitoring plan. Other chapters will be developed and finalized for the Phase III Report (Long Term Monitoring Plan). Appendices are included in a separate document. This Phase II report presents the CHDN framework and approach to planning for vital signs monitoring and sets the stage upon which the program will be developed.

Figure 1.2. Boundary of the Chihuahuan Desert Ecoregion and location of CHDN park units (produced by CHDN and adapted from Dinerstein et.al. 2000).

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 (completed)
Phase II	Continued conceptual model development; vital signs prioritization; selection and rationale	October 2006 (completed)
Phase III Peer review	Monitoring & sampling design	October 2007
Phase III Initial Draft	Monitoring & sampling design	December 2007

1.1. Integrated Natural Resource Monitoring

The purpose of the NPS Vital Signs Monitoring Program relates directly to the mission of the national park system. In this section, we review the justifications for integrating natural resource monitoring; the legislation, policy, and guidance that direct the program; and the goals of the monitoring program. An overview of the CHDN approach to vital signs monitoring is 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. Addressing these issues requires 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 ways to characterize and determine trends in the condition of parks and other protected areas, assess the efficacy of management practices and restoration efforts, and 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 park 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 which may originate outside park 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 regional, national, or international effort may be required to understand and manage the resource.

Natural resource monitoring is important for two reasons. First, monitoring data help 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; animals; and the various ecological, biological, and physical processes that act on these resources. 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 approach restoration or, when 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, it provides the information needed for effective, science-based managerial decision making and resource protection (Figure 1.3). 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, grouped into 32 I&M networks.

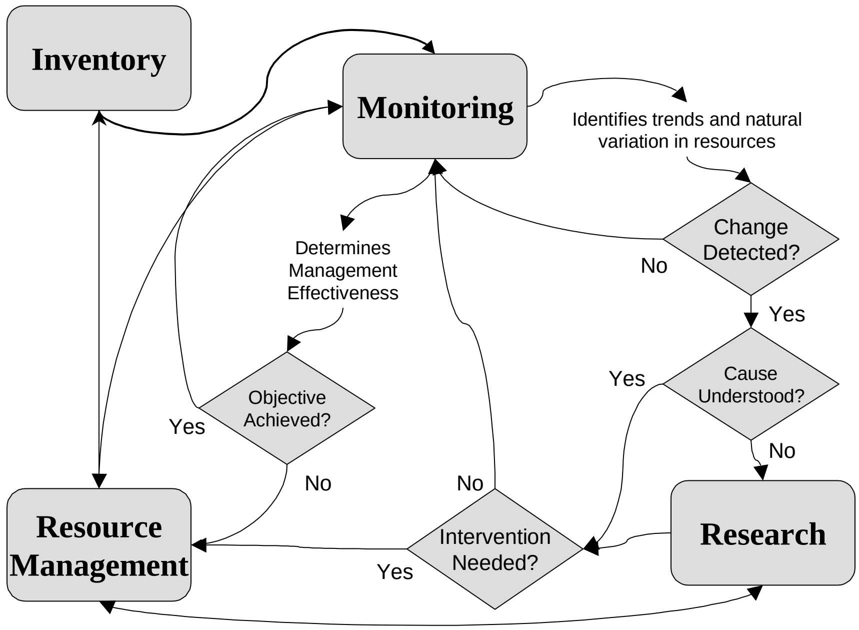


Figure 1.3. Relationships between monitoring, inventories, research, and natural resource management activities in national parks.

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. The US Geological Survey (USGS) is also closely involved with the prototype parks and provides an additional source of funding in program design and protocol development. Thus, these centers of excellence 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 USC. 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 USC. 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 NPS 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, additional legislation is intended not only to 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. NPS units are among some of the most secure areas for sustaining populations of threatened and endangered species and represent natural resources that are compromised in other parts of the country. Therefore, the particular guidance offered by federal environmental legislation and policy is an important component of the development and administration of a natural resource inventory and monitoring system in the national parks. Legislation, policy, and executive guidance all have important and direct bearing on the development and implementation of natural resource monitoring in the national parks. Relevant federal legal mandates are summarized in Appendix D.

1.1.2.1 Park-Specific Enabling Legislation

The CHDN includes three National Parks (NP), one National Monument (NM), one National Historic Site (NHS), one National Recreation Area (NRA), and one Wild and Scenic River (WSR). In 1970, Congress elaborated on the 1916 NPS Organic Act by declaring that all these designations have equal legal standing in the National Park system. Park-specific enabling legislation (Table 1.3), as well as international programs, collectively influence the natural resource management on NPS lands in the CHDN. The enabling legislation of an individual park provides insight into the natural and cultural resources values it was created to preserve and in some cases gives 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. 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 values 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 1.5 million ac…"
CAVE (1679 Stat. 1929)	Carlsbad Caverns 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…." This park unit was elevated to Park status in 1930.
FODA (75 Stat. 488)	Fort Davis National Historic Site was established on September 8, 1961 "...for the purpose of establishing a national historic site…set aside as a public national memorial to commemorate the historic role played by the fort in the opening of the West…"
GUMO (P.L.89-667 80 Stat. 920)	Guadalupe Mountains National Park was established on October 15, 1966 "...in order to preserve in public ownership an area….possessing outstanding geological 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 established on November 10, 1978, through the addition of the Wild and Scenic Rivers Act of 1968. This 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 ac per mile…."
WHSA (47 Stat 2551)	White Sands National Monument was established on January 18, 1933 to "…preserve the white sand and additional features of scenic, scientific, and educational interest…."

Historically significant treaties and conventions relevant to the region have also been documented (Appendix E). Due to international concern for environmental quality in the border region, national officials have met and initiated bi-national action.

1.1.2.2 United States-Mexico Border Cooperative Arrangements

The US and Mexico are involved in a number of cooperative programs (Figure 1.4). Several of these programs may be relevant to CHDN monitoring efforts:

- **The Border Environment Cooperation Commission (BECC).** Established in 1933, this autonomous, bi-national organization 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 US Environmental Protection Agency (EPA) formally began working with its counterparts in Mexico under this agreement in 1983 to protect, improve, and conserve the environment of the border region.

- **The Border XXI Program.** In 1992, US and Mexico environmental authorities 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** is designed to protect the environment and public health in the US-Mexico border region, consistent with the principles of sustainable development. This program defines sustainable development 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)** is a corollary agreement of the North American Free Trade Agreement (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 promote the effective enforcement of environmental law.

Figure 1.4. Students from Cd. Chihuahua, Mexico and Las Cruces, New Mexico on a field trip in the Organ Mountain, New Mexico. Photo by Cesar Mendez.

Due to concerns about water and overall environmental quality, Mexico has established its own laws and standards (Table 1.4). Mexican laws and policies are uniquely relevant to the CHDN because of its location on the Mexico-US border (only one other network, the Sonoran Desert Network, has a park unit located along the border). The CHDN is also unique in sharing the Rio Grande with Mexico.

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 requires the NPS to set goals and generate annual reports to substantiate results or progress. The service-wide GPRA goal for natural resource inventories is relevant to the inventory and monitoring program. This goal identifies inventories of park resources as an initial step toward 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 for CHDN will be completed in fiscal year 2006. The 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 park-specific GPRA goals relevant to natural resource monitoring and management. Once the CHDN monitoring plan is implemented, parks will be better able to report on the condition of their resources.

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

Goal #	GPRA Goal	Parks with this Goal*
Ia1B	Exotic Plants	AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA
Ia1E	Land Health	BIBE, CAVE, FODA, GUMO
Ia2A	Candidate Species	AMIS, CAVE, BIBE, RIGR,
Ia2C	Invasive Animal Species	AMIS, BIBE, CAVE, GUMO, RIGR, WHSA
Ia4A	Surface Water Quality (Rivers)	AMIS, BIBE, CAVE, FODA, RIGR, WHSA
Ia4B	Water Quality (Lakes)	AMIS, BIBE, CAVE
Ia4C	Water Quantity (Protected and/or Restored)	BIBE, CAVE, GUMO, 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

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 base management decisions (White and Bratton 1980, Jones 1986). Gathering data over long periods may reveal correlations between ecosystem attributes and promote understanding of the ecosystem (Halvorson 1984). A monitoring program may also provide an early warning of the effects of human activities (Davis 1989).

The goals of natural resource monitoring in parks are 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 sustain those ecosystems. The NPS-wide I&M Program has developed long-term goals to comply with legal requirements, fully implement NPS policy, and provide park managers with the data required to understand and manage park resources.

Service-wide goals for vital signs monitoring for the NPS are as follows:

1. Determine status and trends in selected indicators of the condition of park ecosystems, to allow managers to make informed decisions and to work 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, more altered environments.

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

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

These NPS-wide monitoring goals guide the scope and direction of the CHDN program. The program is expected to include effects-oriented monitoring to detect changes in the status or condition of selected resources, stress-oriented monitoring to meet certain legal mandates (e.g., Clean Water Act), and effectiveness monitoring to measure progress toward 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.

1.1.4 CHDN Approach to Vital Signs Monitoring

The CHDN recognizes the NPS Monitoring Program as a unique opportunity to advance understanding of the ecosystems that encompass CHDN parks. This understanding will result from the monitoring data to be collected, analyzed, interpreted, and reported. Further, scientific information to be conducted in each of the network parks should be integrated with monitoring efforts to improve understanding of the holistic functioning of ecosystems within the network. An understanding of ecosystem function will facilitate management that leaves parks "unimpaired for the enjoyment of future generations." At the most basic level, to evaluate appropriate ecosystem function and identify resource changes, the bounds of natural variability must be known.

The CHDN monitoring program will focus on general ecological function because previous research and monitoring efforts by other agencies within desert grasslands and shrublands, particularly within the Chihuahuan Desert, have provided a sound foundation (Havstad, et al 2005, Pellant, et al. 2005). The CHDN program will initially emphasize service-wide goals 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 aim of the CHDN is to monitor ecosystems to detect change in ecological components, including hydrologic function, biotic integrity, and soil site stability and function. Where possible, the CHDN will consider the Comprehensive Wildlife Conservation Strategies (CWCS) recently developed by the states of New Mexico and Texas (NMGF 2005, TPWD 2005). These CWCS are required by all states and cover such areas as inventory and monitoring of priority species in each state. Although many networks may not have participated in the development of CWCS, the CHDN is committed to being an active partner in these programs.

The network is also highly committed to establishing the foundation for a monitoring program that will last in perpetuity. Over time the information gained from the monitoring program is expected to provide valuable data that will support appropriate management decisions in the network parks. Management issues should be considered in designing the monitoring program. However, management issues change and therefore should not limit the program. A well designed monitoring program will be applicable to future issues, including ones currently unforeseen.

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, with park-specific information described in Appendix A. The physical and natural issues relevant to CHDN parks are discussed, and 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) Ecoregion (which covers AMIS) is often included within the Chihuahuan Desert Ecoregion, but, where appropriate, references will made be specifically to this ecoregion.

1.2.1 Chihuahuan Desert Overview

Deserts are seldom regarded as important reservoirs of biological diversity, but some deserts are extraordinarily rich in species, rare plants and animals, specialized habitats, and unique biological communities. The Chihuahuan Desert, shared by two nations, 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. It 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 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 1.5).

The diversity of the Tamaulipan Thornscrub is not as high as that of the Chihuahuan Desert, but it still supports over six hundred species of plants and animals. The region is particularly rich in tree species, including two endemics, and birds (Ricketts et al. 1999).

1.2.1.1 Physiography and Climate

Most of the Chihuahuan Desert Ecoregion lies between 900 and 1,500 m (about 3,000 to 5,000 ft) above sea level, although foothill areas and some isolated mountain ranges in the central portion of the ecoregion may rise to more than 3,000 m (about 10,000 ft) (Figure 1.6). Schmidt (1979) notes the relative uniformity of climate within the ecoregion - hot summers and cool to cold, dry winters (Figures 1.7 and 1.8). 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 G). This desert has more rainfall than other warm desert ecoregions, with precipitation typically ranging from 150 to 500 mm (6 to 20 inches) annually, averaging about 235 mm (10 inches) (Figure 1.9) (Schmidt 1979).

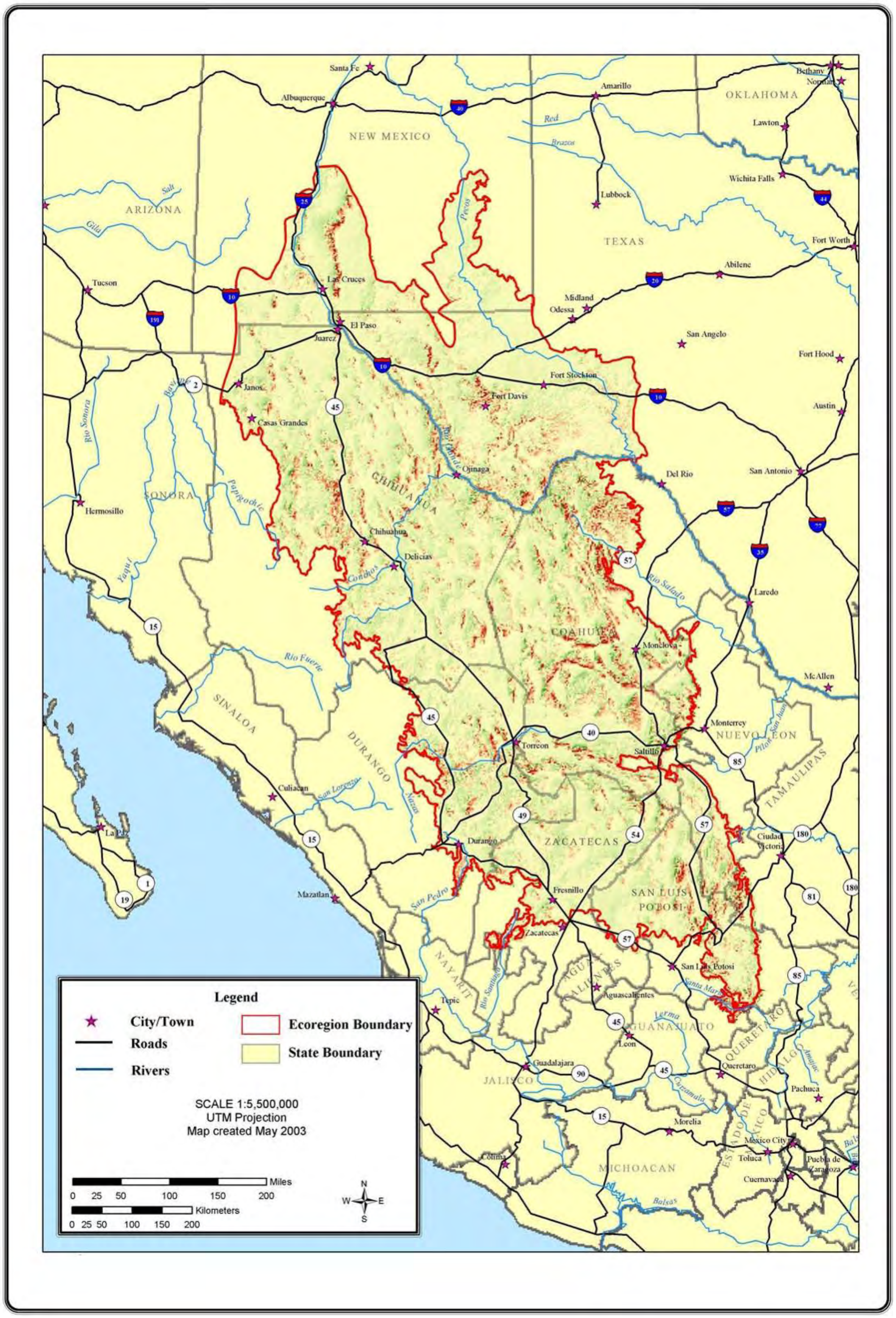


Figure 1.5. Chihuahuan Desert Ecoregion boundary (Pronatura Noreste et al. 2004).

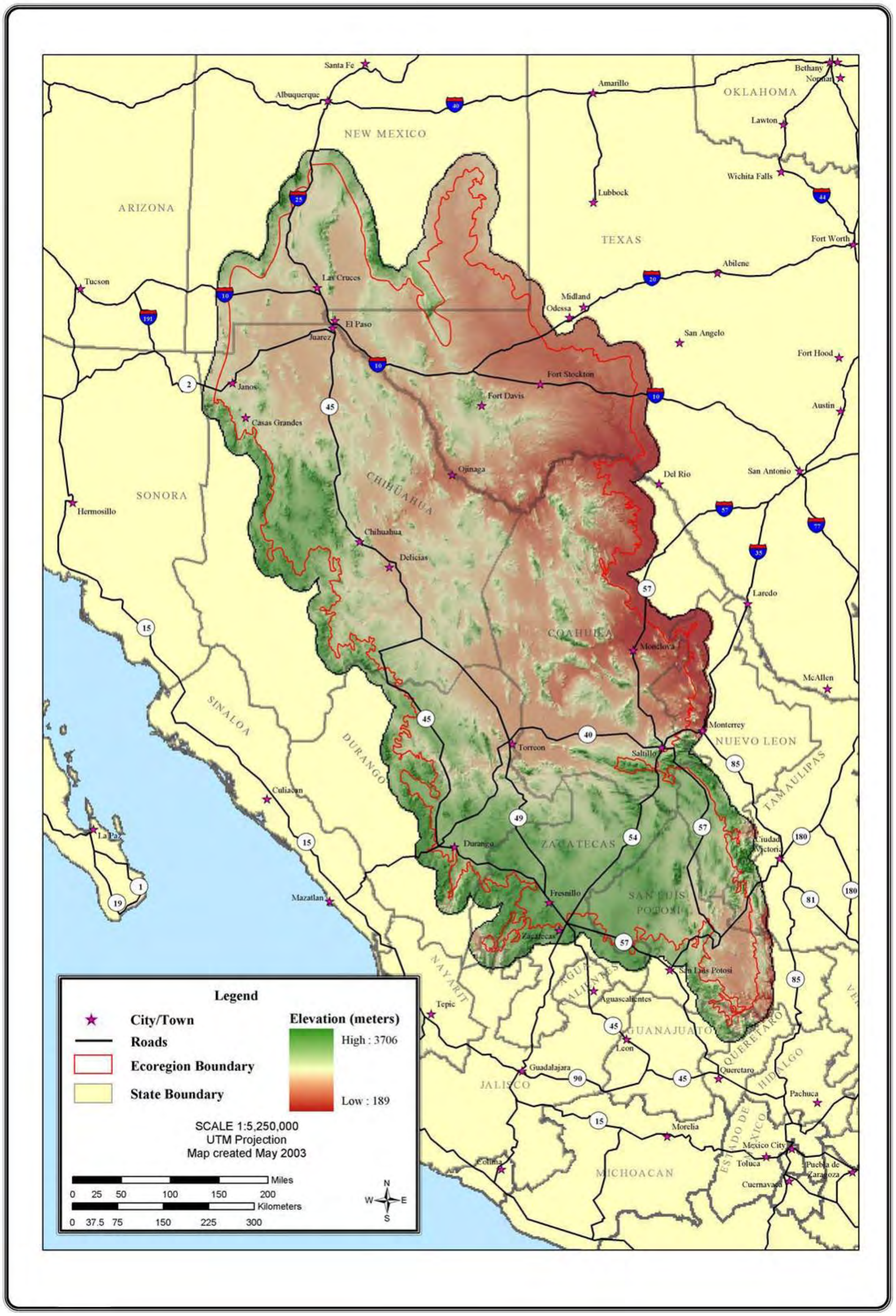


Figure 1.6. Topography of the Chihuahuan Desert (Pronatura Noreste et al. 2004).

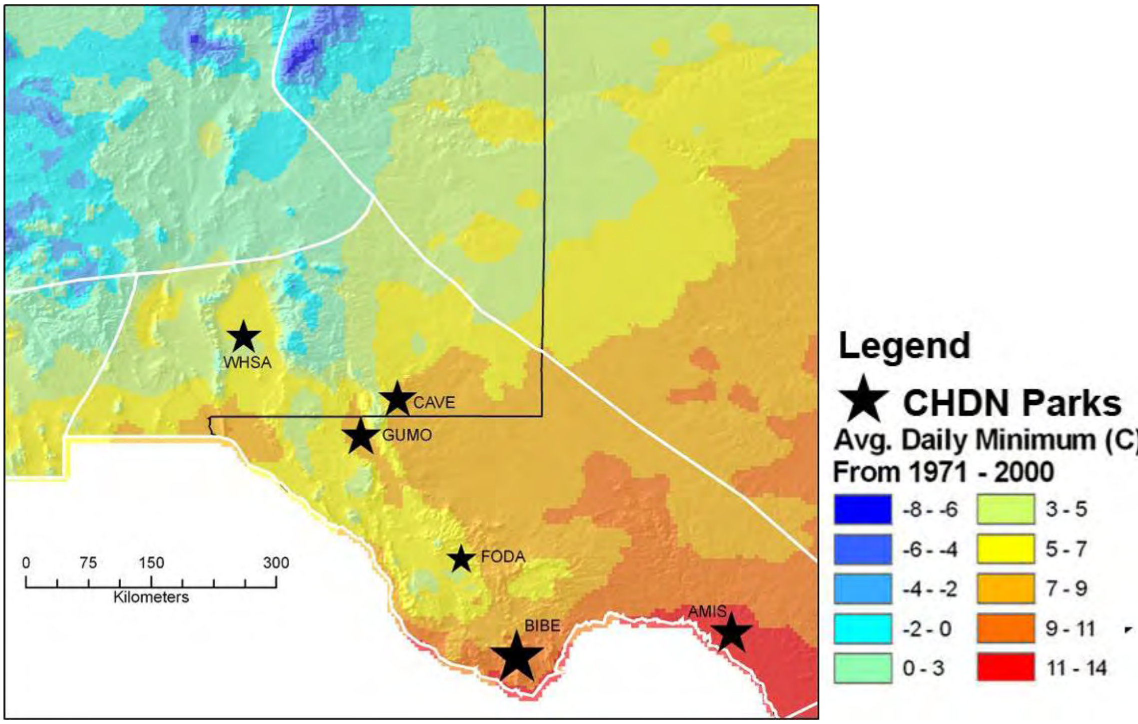


Figure 1.7. Average daily minimum temperatures within the US portion of the Chihuahuan Desert, showing location of CHDN parks.

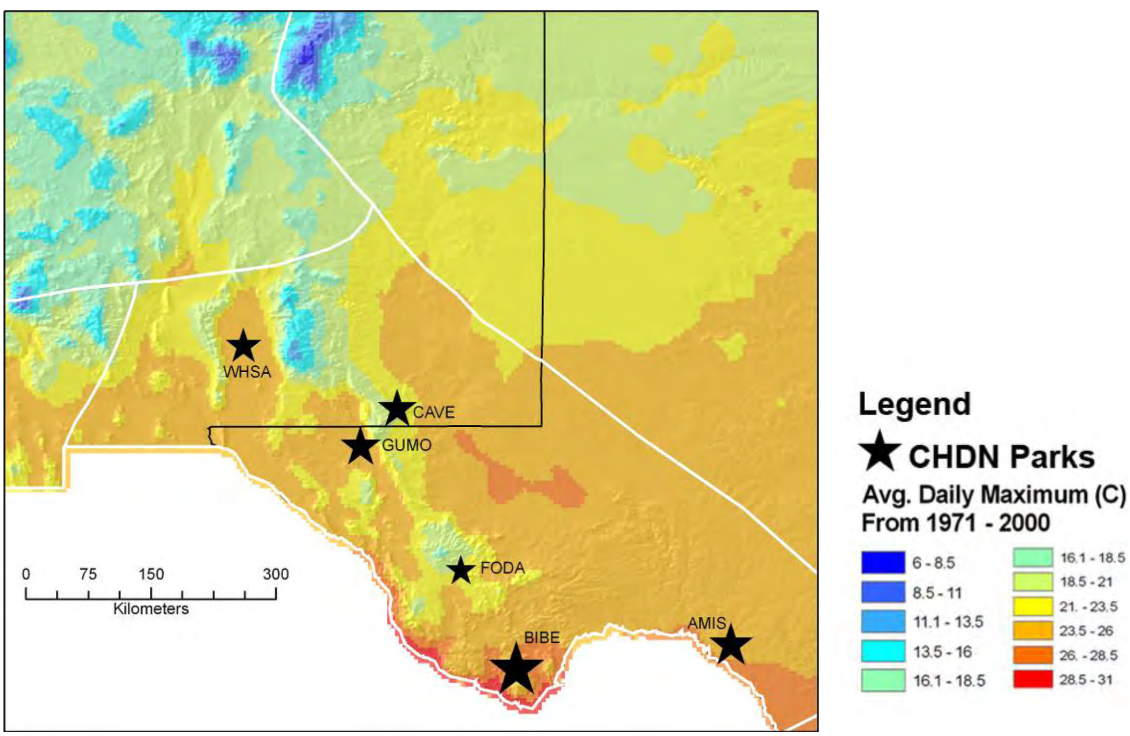


Figure 1.8. Average daily maximum temperatures within the US portion of the Chihuahuan Desert, showing location of CHDN parks.

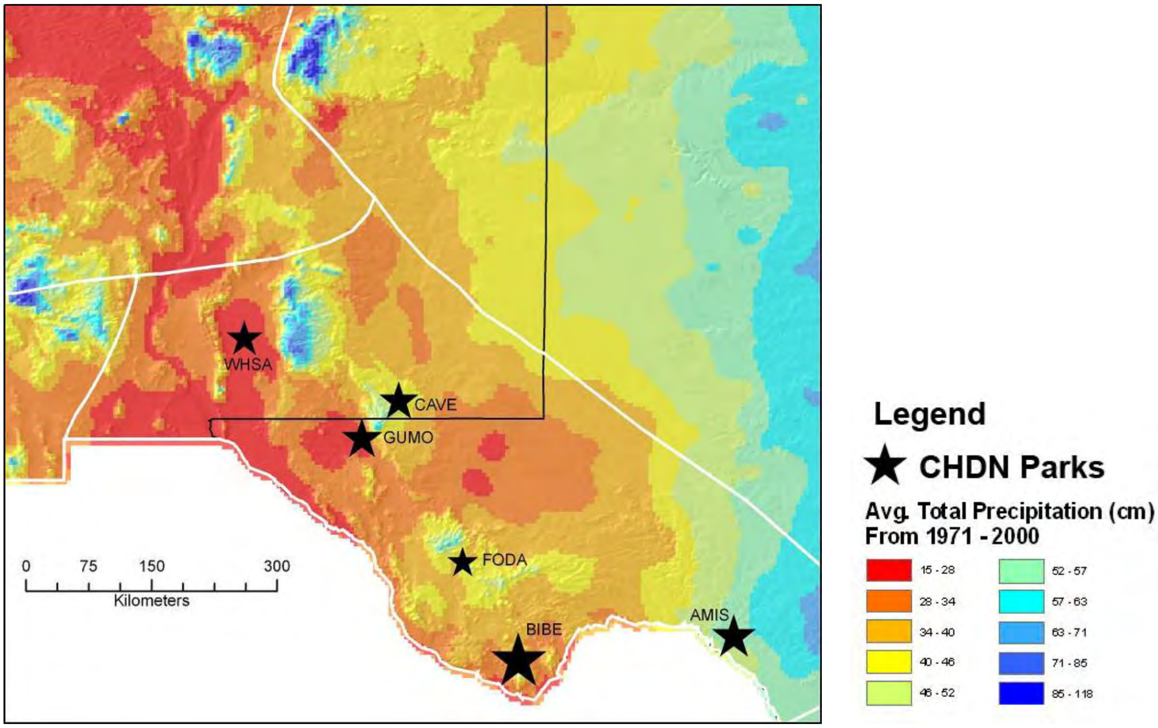


Figure 1.9. Average total precipitation within the US portion of the Chihuahuan Desert, showing location of CHDN parks.

In the Tamaulipan Thornscrub, elevation increases 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 larger amounts of more evenly distributed rainfall than the Chihuahuan Desert.

1.2.1.2 Vegetation

The Chihuahuan Desert (Figure 1.10) 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 pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) (Wells 1974, Allen et al. 1998, Van Devender 1990). Miller (1977) suggested that increasing aridity of the Chihuahuan Desert resulted in isolation, differentiation, and extinction that led to the unique Chihuahuan Desert biota of today. 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. The northern Chihuahuan Desert, which lies on the Mexican Plateau, is essentially a broad physiographic expansion of the Sierra Madre Oriental (Johnston 1977).

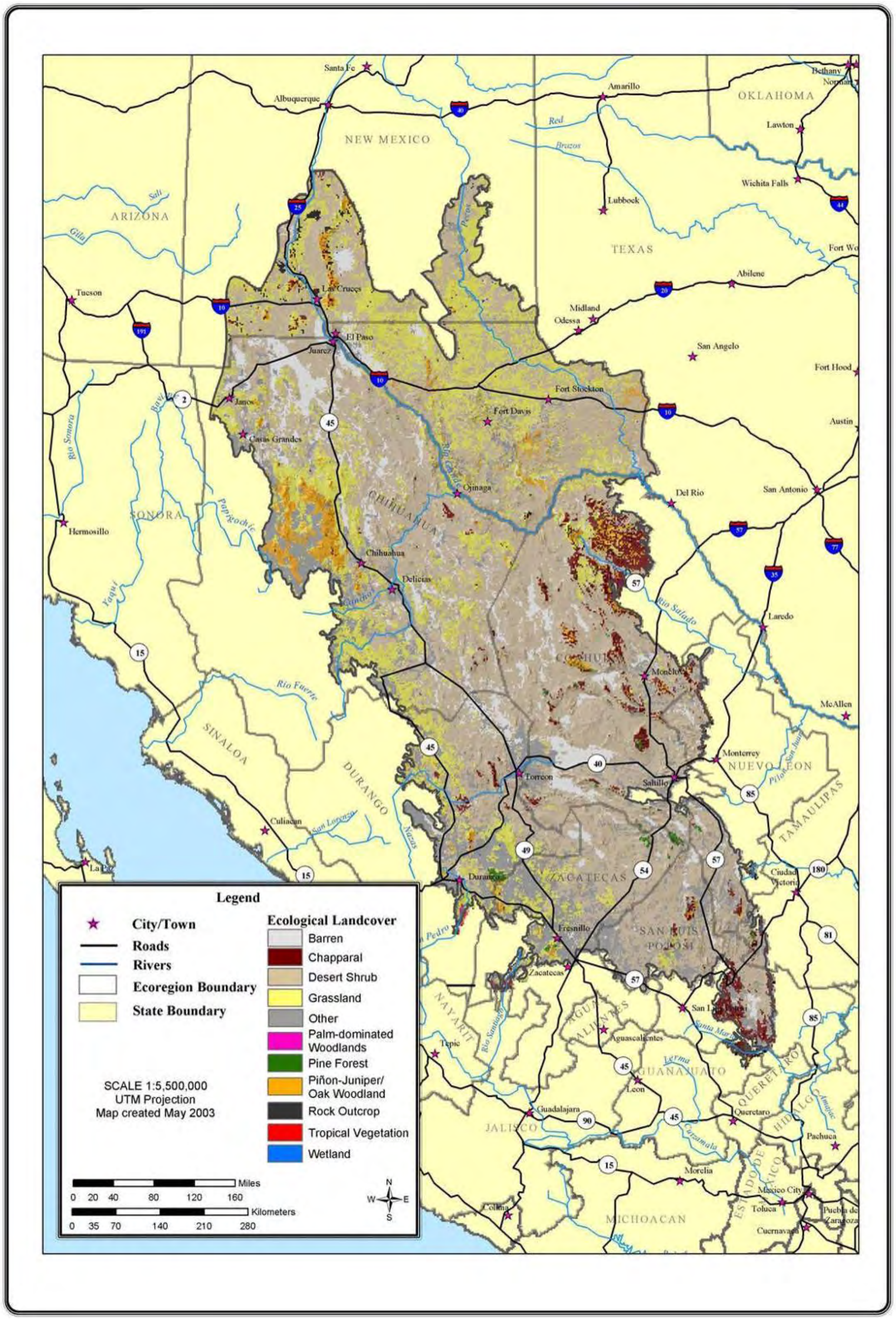


Figure 1.10. Land cover within the Chihuahuan Desert. (Pronatura Noreste et al. 2004).

At least 1,000 endemic plant taxa occur in the Chihuahuan Desert, an astonishing richness of biodiversity (Johnston 1977). 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 many basins of the desert (Dinerstein et al. 2000).

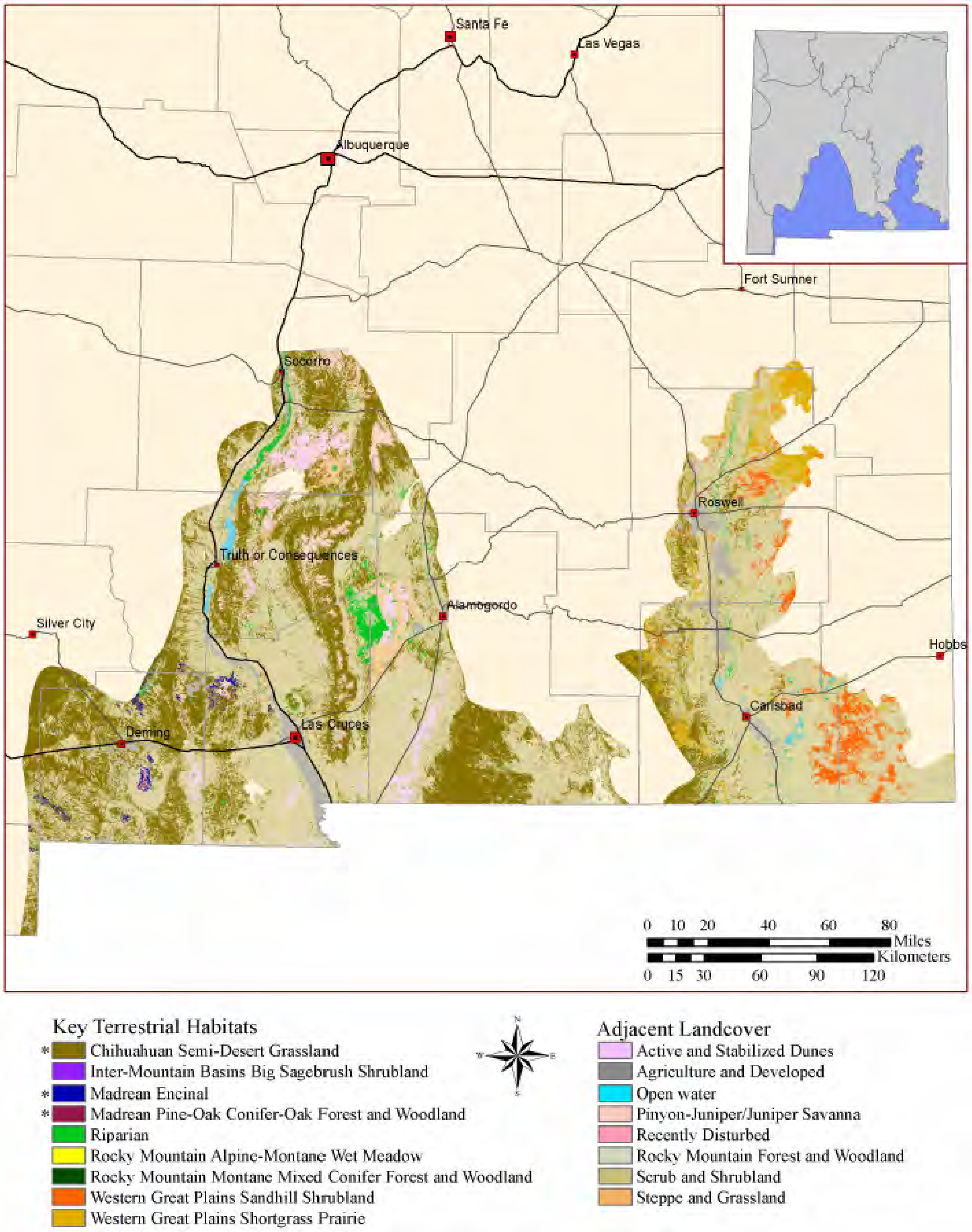
The Chihuahuan Desert Scrub habitat type is younger than other Chihuahuan Desert vegetation types, possibly no older than 4,000 years (Dick-Peddie 1993). In the last 70- 250 years, a rapid shift has occurred from areas dominated by desert grasslands to desert scrub vegetation (Donart 1984). The primary cause of this shift appears to be extensive livestock grazing. Other contributing factors include climate change and fire suppression (Dick-Peddie 1993) (Table 1.6, Figure 1.11).

Table 1.6. Terrestrial habitat types of the Chihuahuan Desert. (adopted from Dinerstein et al. 2000)

I. Desert Scrub and Woodlands
- A. Larrea Desert Scrub
- B. Mixed Desert Scrub
- C. Yucca Woodland
- D. Izotal (Dasylirion-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 1.11. Key terrestrial habitats in the Chihuahuan Desert Ecoregion, New Mexico. Adjacent land cover types provide an indication of vegetation surrounding key habitats. *=key habitats. Data from Southwest Regional Gap Analysis Project (SWReGap) (from New Mexico Department of Game and Fish 2005).

As a result, the Chihuahuan Desert is now considered synonymous with shrublands, which comprise over 55% of the area. In the US, the boundaries are determined 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 US portion of the Chihuahuan Desert (Figure 1.12).

Figure 1.12. Dense stand of lechugilla and sotol at Big Bend National Park.

A second significant habitat type is Desert Grassland, which makes 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.), but the dominant species 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*). These grasses were probably the species encountered by early Spanish explorers when they excitedly reported grasses that were "belly high to a horse" (Tweit 1995).

Wooded mountain ranges, home to a unique mix of desert and montane plant and animal species, rise abruptly from the desert. These mixed conifer forests and 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, preserved in part at White Sands National Monument. Additionally, influences from three ecoregions (Chihuahuan Desert, Edwards Plateau Savanna and Tamaulipan Thornscrub) come together in the Devils River area of Amistad National Recreation Area, Texas.

In the Tamualipan Mezquital, trees such as acacia (*Acacia* spp.) and mesquite (*Prosopsis glandulosa*) dominate. Common shrubs include chaparro (*Zizyphus obtusifolia*), common bee-brush (*Aloysia wrightii*), prickly pear, and various cholla species (*Opuntia* spp.). 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 1.13). 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).

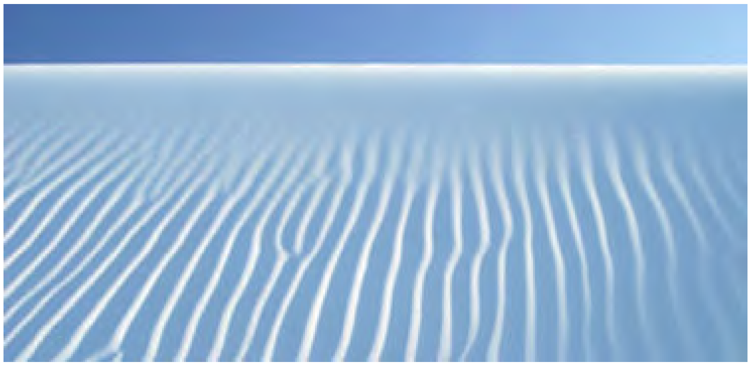


Figure 1.13. Gypsum dunes at White Sands National Monument, NM.

In the Chihuahuan Desert, the Rio Grande (Río Bravo del Norte) is fed by its major tributaries, the Pecos River and the Río Conchos. The larger Río Grande system is home to native minnow, sucker, catfish, killifish, 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). The primary distinguishing feature of the Chihuahuan Desert freshwater biota is not the number of species, but the high degree of globally outstanding local endemism (Dinerstein et al. 2000) (Table 1.7).

Table 1.7. Freshwater habitat types of the Chihuahuan Desert. (adopted from Dinerstein et al. 2000).

I. Warm springs	V. Ephemeral streams
A. high salinity	A. high gradient
B. low salinity	B. medium gradient
	C. low gradient
II. Cool springs	VI. Lagunas
A. high salinity	A. permanent
B. low salinity	B. temporary
III. Large rivers & floodplains	VII. Cienegas
IV. Perennial streams	VIII. Subterranean habitats
A. high gradient	
B. medium gradient	
C. low gradient	

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. Chihuahuan Desert function depends on its high invertebrate diversity, which is a reflection of numerous plant communities. Subterranean termites of the order Isoptera consume dead plant material and animal dung and serve as keystone invertebrates within the desert grasslands. Fifty percent of all photosynthetically fixed carbon in desert grasslands is consumed by these termites (Whitford et al. 1995). Specialized freshwater assemblages of invertebrates associated with playas, such as clam shrimp (*Eulimnadia texana*), water fleas (*Moina wierejskii*), and fairy shrimp (*Streptochephalus texanus*), provide food for migrating waterfowl. Other invertebrates associated with soil, such as nanorchestid and tydeid soil mites, are essential for nutrient cycling in the dry climate. The semi-arid Madrean region has the richest diversity of bee species in the world (Ayala and Bullock 1993), and monarch butterflies rely on the riparian vegetation to rest during their migration.

Figure 1.14. Little white whiptail lizard adapted to dunes.

The Chihuahuan Desert is one of the few ecoregions where grizzly bears, wolves, and jaguars were once found at the same locality. Other wide ranging mammals found in this region include pronghorn antelope (*Antilocapra americana*), collared peccary or javelina (*Dicotyles tajacu*), and mule deer (*Odocoileus hemionus*). Unfortunately, the list of mammals includes non-native ungulates as well: Barbary sheep or aoudad (*Ammotragus lervia*) and oryx or gemsbok (*Oryx gazelle*). Small rodents (woodrats, ground squirrels, mice) and meso-carnivores (ringtail cat [*Brassariscus astutus*], skunks, and fox species) are common. This desert region is also well known for its high diversity of bats. 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 use riparian corridors along the Pecos River and the Rio Grande. 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 common bird species include the greater roadrunner (*Geococcyx californianus*), curve-billed thrasher (*Toxostoma curvirostra*), scaled quail (*Callipepla squamata*), and Scott's oriole (*Icterus parisorum*). At least 18 species of reptiles and amphibians are endemic to the Chihuahuan Desert, including the bolson tortoise (*Gopherus flavomarginatus*) (Ricketts 1999), black softshell turtle (*Trionyx ater*), Chihuahuan fringe-toed lizard (*Uma exsul*), and the little white whiptail (*Aspidoscelis gypsi*) (Figure 1.14). Several lizard ranges are centered in the Chihuahuan Desert; for example, the Texas banded gecko (*Coleonyx brevis*), greater earless lizard (*Cophosaurus texanus*), and several species of spiny lizards (*Sceloporus* spp.). Representative snakes include the Trans-Pecos rat snake (*Elaphe subocularis*), Texas blackheaded snake, (*Tantilla atriceps*), and western coachwhip (*Masticophis flagellum testaceus*). A surprising number of endemic fish occurs 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* spp.) 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. Some habitats are more resilient or resistant to these modifications than others. 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 disturbance.

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). These factors 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 CB3 B or CB4 B 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 is one of the principal factors limiting seedling establishment and productivity (Schulze et al. 1987, Osmond et al. 1987). The distribution and vigor of some plant communities may be controlled primarily by soil moisture gradients, which are directly altered by drought (Pigott and Pigott 1993).

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 1,000 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, Chihuahuan Desert grasslands are the result of dynamic interactions among 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. Historical 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 have been increased erosion and reduction in grassland-dependent species (MacMahon 1988).

Depletion and Diversion of Water Resources

The Chihuahuan Desert aquatic biota is one of the most threatened in the world, owing to the extensive loss of natural water sources to agricultural, industrial, and domestic use by humans; water diversion; and the onslaught of numerous introduced aquatic species. 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 human populations and their water usage. Low water tables have caused many springs in the Trans-Pecos to run dry, preventing water from reaching once flowing streams. Due to an increase in the human population, habitat loss is also a factor. Endangered fish species, often endemic to specific springs, must compete with non-native fish species. Other issues such as water pollution and overuse of riparian areas also negatively affect desert oases.

Fire Management

For thousands of years, wildfires have been an integral process in 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). Fire influences ecosystem processes and patterns such as 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 (varying with elevation) 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). Wetter forest types such as higher elevation mixed conifer and spruce-fir forests experienced 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 was 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 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 (Frissell 1993).

Ecological Sustainability and Integrity

When biotic and abiotic disturbances are modified or removed from ecosystems, plant and animal diversity and ecological sustainability are lost (Benedict et al. 1996). Ecological sustainability is essentially the maintenance (or restoration) of the natural composition, structure, and processes of the ecosystem over time and space. Likewise, ecosystem integrity incorporates function 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* spp.), have large overall effects, 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 closely associated with the keystone species will be affected. In New Mexico, several keystone species have either been completely removed or have experienced significant population reductions in their historic ranges. With their removal or population reduction, other species 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 located 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 ha (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 NRA, falls only partially within the Chihuahuan Desert (Figure 1.2). Amistad NRA is primarily located in the Tamaulipan Thornscrub ecoregion, but it is influenced by both Chihuahuan Desert and Edwards Plateau Ecoregions (Rich et al. 2004).

The seven parks represent the most significant natural, cultural, and recreational values in the Chihuahuan Desert. Most of the CHDN parks were established for conservation and preservation of significant natural and geologic resources (e.g., caverns of Carlsbad Caverns National Park, NM, Figure 1.15). The exception is Fort Davis NHS, which was established primarily for cultural reasons but also contains significant natural resources (Figure 1.16).

Figure 1.15. Hall of Giants, Carlsbad Caverns National Park, NM.


Figure 1.16. Officers' quarters, Fort Davis National Historic Site.

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	IA, IB, IE, IF, IH, IIA, IIB, IID	VIB
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.**

The landscape within the CHDN is a series of basins and ranges (Figure 1.6). The majority (50%) of this landscape in the Northern Chihuahuan Subregion, where CHDN parks are located, consists of desert shrublands. Desert grasslands, covering approximately 25% of the subregion, are often mosaics of grass and shrub. Mixed-conifer forests and woodlands comprise approximately 10% of the subregion. In south-central New Mexico, wind-blown soils form one of the largest gypsum dune fields in the world. Additionally, influences from three ecoregions (Chihuahuan Desert, Edward's Plateau Savanna and Tamaulipan Mezquital) 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).

1.2.3 Individual Park Summaries

1.2.3.1 Amistad National Recreation Area

Amistad NRA (AMIS) is centered at Amistad Reservoir, which was formed by construction of Amistad Dam in 1969. AMIS contains 43,250 ac of water and 14,042 ac of land. The park is located at a convergence of the Chihuahuan Desert, Edwards Plateau Savannah, and 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 Devil's River, Rio Grande, and Pecos River. The most significant threats facing AMIS include exotic plant and aquatic species invasions, visitor and commercial fishing effects on natural resources, and water quality.

1.2.3.2 Big Bend National Park

Big Bend National Park (BIBE), established in 1944, covers 801,163 ac and is the largest protected area representative of the Chihuahuan Desert. The park was designated in 1976 as a US Biosphere Reserve. BIBE also includes 533,900 ac 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 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 plant distribution, and border issues involving Mexico.

1.2.3.3 Carlsbad Caverns National Park

Carlsbad Caverns National Park (CAVE), established in 1923, covers 46,766 ac, of which 33,125 ac are Designated Wilderness. On December 6, 1995, the park was designated a World Heritage Site, which indicates the significance of the caverns and other park 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 the park watershed are pressing issues.

1.2.3.4 Fort Davis National Historic Site

Fort Davis NHS (FODA), established in 1963, is in the Davis Mountains, the most extensive mountain range in Texas. The 474-acre park preserves fort structures and interprets the era of westward migration and a late 19th century US Army fort. 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 consideration is given to ensure its needs are not overlooked. Groundwater dynamics, invasive plant species, and sustaining the historic cottonwood grove are concerns expressed by park staff.

1.2.3.5 Guadalupe Mountains National Park

Guadalupe Mountains National Park (GUMO), established in 1972, includes 86,416 ac, of which 46,850 are Designated Wilderness. The park preserves the world's most significant fossilized reef outcrops of Permian age limestone, portions of which were designated as an International Benchmark Standard for Geology, and the Chihuahuan Desert resources that occur upon it. Elevation-related environmental diversity ranges from a lowland salt basin to relict conifer forests, including the highest point in Texas, at 8,749 ft. The park faces ambitious groundwater withdrawal plans from the city of El Paso, TX. Groundwater quantity and quality, increasing impacts to air quality, invasive plant and animal species, rural sprawl, adjacent wildlife corridor, and habitat fragmentation are significant concerns for this unit.

1.2.3.6 Rio Grande Wild and Scenic River

Created in 1976 under the Wild and Scenic Rivers Act, the Rio Grande WSR (RIGR) encompasses 315 river km (196 river miles) from the Chihuahua-Coahuila State Line in Mexico to the Terrell-Val Verde County lines in Texas. Implementation of projects specific to the Rio Grande WSR is limited to the 209 river km (127 river miles) between Big Bend National Park and the Terrell-Val Verde County lines. The portion of the Rio Grande that runs through Big Bend National Park (106 river km) is excluded. Water quality and quantity issues and all associated impacts to aquatic systems are important issues facing this unit. Additionally, exotic plant species and Mexican border issues (trespass grazing, fires set by illegal immigrants, etc.) also pose significant problems.

1.2.3.7 White Sands National Monument

At the northern end of the Chihuahuan Desert in the heart of the Tularosa Basin lies one of the world's great natural wonders. White Sands NM (WHSA), established in 1933, encompasses 143,733 ac in south central New Mexico. The monument preserves approximately half of the world's largest gypsum sand dune field. The white dunes contain approximately 4.5 billion tons of gypsum sand. Issues around groundwater quantity, especially proposed massive withdrawals by the city of Alamogordo, NM, and the associated impacts to dune formation and processes are the major issues facing this park.

1.2.4 Integration of Water Quality with Monitoring

Water is a scarce and precious resource in the Chihuahuan Desert (Figure 1.17). The much altered Rio Grande and its major tributaries the Rio Conchos (Mexico), Pecos River (NM and TX), and Devils River (TX) are subject to great flow variation. Water and its scarcity are driving forces in park ecosystems adapted to this arid region. Further, because the majority of Chihuahuan Desert precipitation is the result of intense, local thunderstorms, the occasional great overabundance of water is also of ongoing management concern.

Figure 1.17. Pray for running water sign in Hidalgo County, New Mexico. Photo by Cesar Mendez.

Surface water in the region is found in sparse, intermittent streams and very few associated rivers, most of which originate in distant mountainous areas (Figure 1.18). Flow rates are low to moderate, except during periods of heavy rain, when large amounts of surface runoff can occur. Dendritic drainage patterns have 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. According to NPS mandates and policy, parks must characterize and monitor water quality and plan for the protection of water resources. Groundwater, while not the primary focus, will be included in monitoring plans where appropriate; for example, the shallow water tables in the sand dunes of Guadalupe Mountains National Park and White Sands National Monument. The completeness of current monitoring and historic water data vary widely among parks. The presence of the Rio Grande presents issues for three parks (Amistad NRA, Big Bend National Park, Rio Grande WSR). 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 inflow
• Sedimentation pollutants or contaminants from Devils and Pecos River inflow
• Runoff from Mexican sources to the Rio Grande
• Runoff from US sources exterior to the park
• Hydrocarbons from US and Mexican watercraft
• Possible fecal matter and debris from undocumented workers 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 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

Big Bend National Park – Receives flow from one major river and from Mexican lands along that river.
• 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 and its tributaries
• Camping debris and fecal matter near springs and seeps
• Possible fecal matter and debris from undocumented workerss 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 undocumentedworkers in transit

White Sands National Monument—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. Precipitation-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
• The possible drop of water table from basin groundwater resource development

Water quality monitoring in the Vital Signs Program includes five core parameters: water column temperature, specific conductance, pH, dissolved oxygen (DO), and flow rates. These parameters are general indicators of water system health, are inexpensive to test, and provide field data useful for the interpretation of other studies. Standardization of water quality monitoring will allow data sharing and comparison among parks and with other jurisdictions. Tentative monitoring needs have been identified (Appendix J).

Figure 1.18. Hot Springs Rapids, Rio Grande WSR, Texas. Photo by NPS.

Section 303(d) of The Clean Water Act (1972) identifies impaired water resources throughout the country. The CHDN has recognized that park water resources, whether in the form of precipitation or in surface water bodies, are crucial components of the network ecosystems. Three CHDN sections are officially designated as impaired water (Reid and Reiser 2005). Two of those sections directly affect three parks, Amistad NRA, Big Bend National Park and Rio Grande WSR. The third section affects the northern area of Carlsbad Caverns National Park, where the cause of impairment is unknown. Lack of cause for a Section 303 (d) impairment is a unique circumstance among the majority of parks in all I&M networks. No Section 303(d) impairment exists in the remaining parks: Fort Davis NHS, Guadalupe Mountains National Park, and White Sands NM.

1.2.5 Integration of Air Quality with Monitoring

Air pollution damages resources and values that national parks are mandated to protect. The NPS has the responsibility to remedy and prevent damage to air quality and related values. Comprehensive scientific information is essential to understanding and documenting air quality conditions and effects of air pollution on park resources. More than ten years of monitoring in several parks indicates that air pollution is degrading visibility, injuring vegetation, changing water and soil chemistry, contaminating fish and wildlife, and endangering visitor and employee health. An existing network of NPS air quality monitoring stations and related research programs has generated data used by NPS managers to secure substantial pollution reductions at specific industrial facilities, persuade states to limit emissions from new pollution sources, and bolster the EPA's enforcement 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 of the origin, transport, and fate of air pollution, as well as its impacts on resources. In light of those requirements, the NPS Air Resource Division has produced a summary of air quality issues and pollutants, as they pertain to the Chihuahuan Desert Network (Appendix K). To be effective advocates for the protection of park air resources, CHDN staff need 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 information on current status of park air quality (Figure 1.19). Nevertheless, ongoing monitoring is needed. Air quality was identified as a potential vital sign for the network because of its importance as both an anthropogenic and natural driver of change.

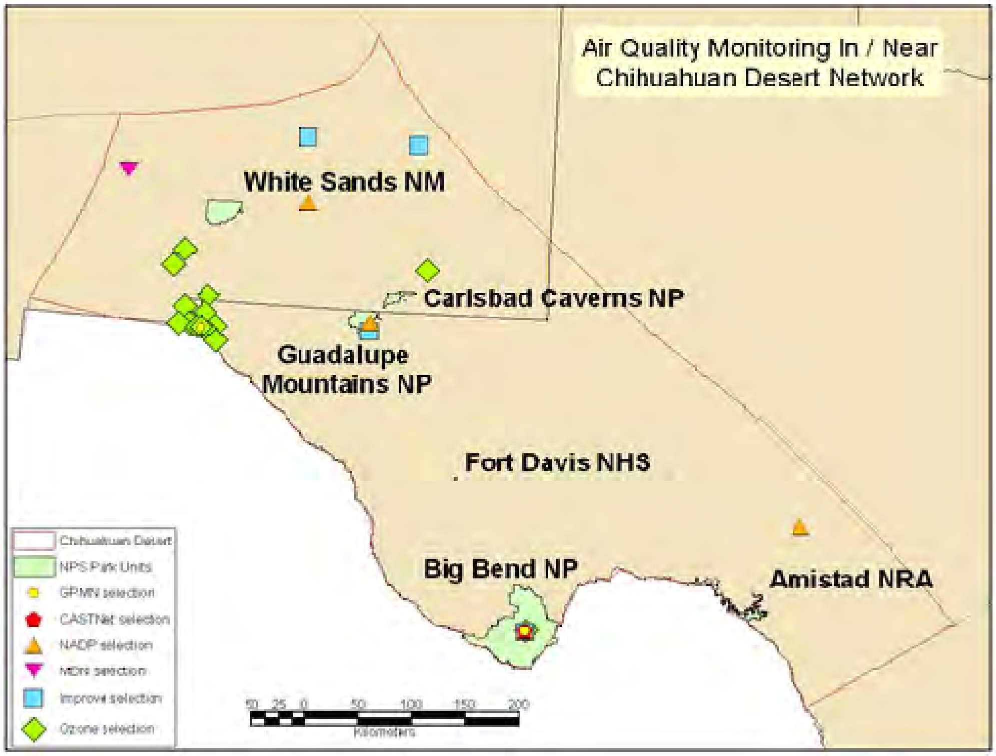


Figure 1.19. NPS air quality monitoring stations locations in the CHDN. Map provided by NPS Air Resources Division.

Currently, three CHDN park units (Big Bend National Park, Carlsbad Caverns National Park, Guadalupe Mountains National Park) are 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 accelerated oil and gas development around Carlsbad Caverns National Park and Guadalupe Mountains National Park are also a major concern. In addition, research in Big Bend National Park has found a major, rapid 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.

NPS has summarized five-year averages of annual ozone values from 1995-1999 (NPS 2004). Two CHDN parks (Amistad NRA and Carlsbad Caverns National Park) are considered at moderate risk from ozone. These two parks exceeded the ozone standard with values of 0.8 ppm, levels that could cause foliar damage. Even though Amistad NRA is considered to be at moderate risk, no ozone-sensitive plant species have been identified there. One ozone-sensitive plant species (skunkbush, *Rhus trilobata*) has been identified at Carlsbad Caverns National Park, although the level of soil moisture significantly constrains the uptake of ozone and reduces the likelihood of foliar injury. The other parks in the network have a low risk rating, due to lower ozone levels, though ozone-sensitive plant species occur at other network parks. These plants include ponderosa pine (*Pinus ponderosa*) and skunkbush at Big Bend National Park and Guadalupe Mountains National Park, and Southwestern chokecherry (*Prunus serotina*) and skunkbush found at Ft. Davis National Historical Site, Guadalupe Mountains National Park, and Big Bend National Park.

Air-quality-related values (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. Table 1.10 identifies natural resource AQRV of each CHDN park. The list is based on the best available information on pollution sensitivity of park resources and will be updated as new information becomes available.

Table 1.10. Air quality-related values (AQRV) of CHDN parks.

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 National Park	X	X	Some tinajas may be sensitive to eutrophication or acidification	Some soils may be sensitive to eutrophication	Unknown	X
Carlsbad Caverns National Park	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 National Park	X	X	Some tinajas may be sensitive to eutrophication or acidification	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

X - AQRV. "Unknown" indicates insufficient park-specific information to determine if resource is AQRV for the park.

[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 theI&M program.

1.3 Vital Signs – Park Natural Resources and Management Priorities

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. Regionally important issues were identified through discussions with natural resource personnel from other agencies and non-governmental organizations. Documents produced by other agencies and organizations were reviewed. This section presents the CHDN approach to the initial list of potential vital signs.

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

Prior to park scoping sessions, superintendents, division chiefs, park natural resource staff, other park staff, and other multi-park staff (e.g., Exotic Plant Management Team Program Manager) were interviewed one-on-one during the fall of 2004. Interview questions covered management issues, threats to park resources, species of concern, and past and current monitoring projects. Particular interest was given to those that had documentation, priority of monitoring needs, and current cooperators. The sessions allowed CHDN to hear directly from the park staffs on their most important resources and their initial thoughts on their greatest monitoring needs. This information was essential to developing a monitoring program that will meet park needs. All responses were kept anonymous to encourage complete and frank discussions of the issues. Interviews ranged from one to three hours. Twenty-eight staff members were interviewed. Summaries of responses were provided to the park prior to the park vital signs scoping meetings (Appendix L). This information was then entered into an Access database for use at the individual park scoping sessions (Figure 1.20).

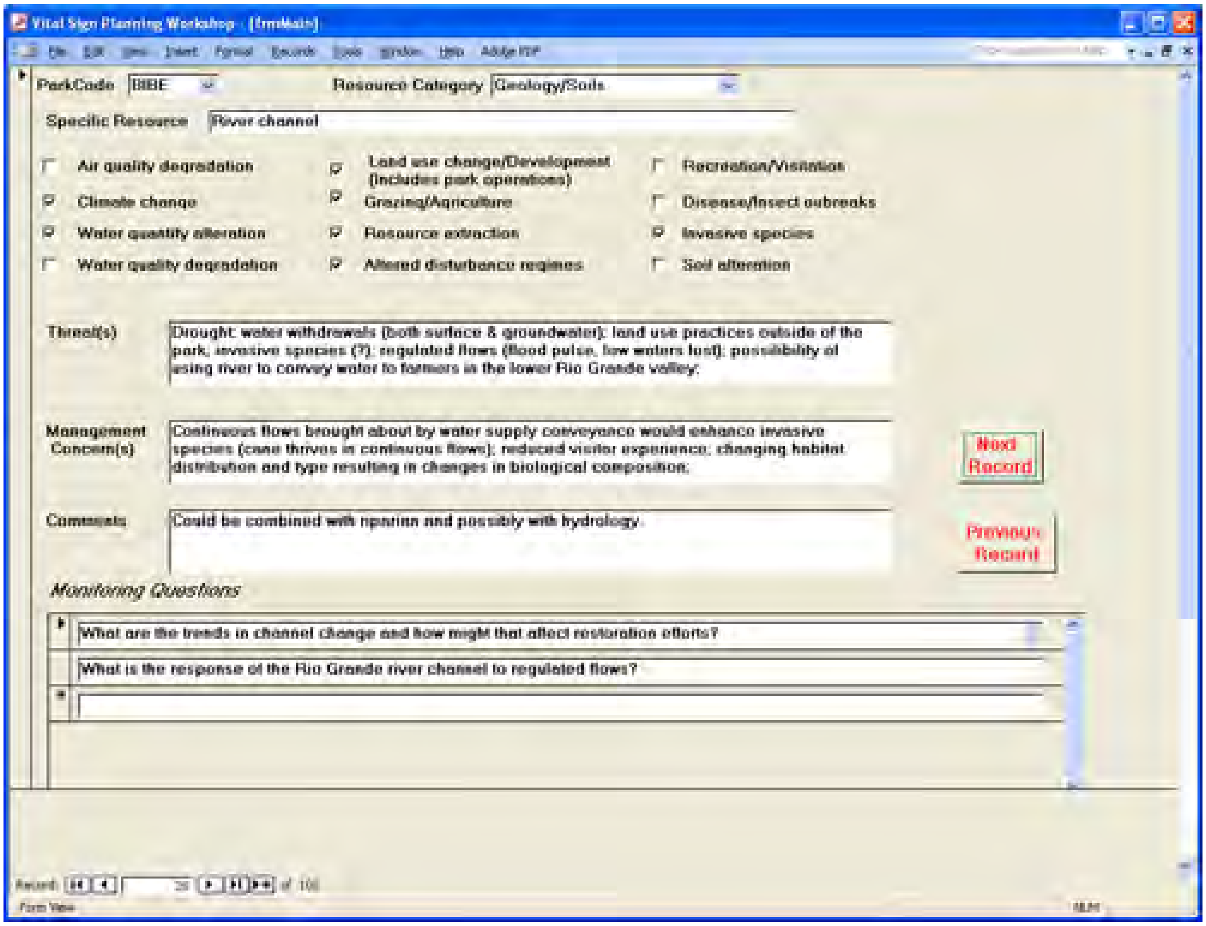


Figure 1.20. Screen from Big Bend National Park vital signs scoping meeting.

CHDN staff conducted park scoping meetings at all six 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. Additional relevant information in reports, maps, and GIS layers was collected. CHDN invited the natural resource staff and superintendents to the meeting. Parks were welcome to invite additional staff or outside people who would be pertinent to the discussion. Forty-one people participated at these vital signs scoping meetings. CHDN staff presented an overview of the Inventory & Monitoring Program, vital signs selection process, and introduction to conceptual ecological modeling. Database entries were then reviewed and edited. Meetings resulted in park-specific lists of vital signs and issues.

Vital signs are considered a subset of physical, chemical, and biological elements and processes of park ecosystems. They 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 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).

Stressors are physical, chemical, or biological perturbations to a system that are foreign to that system, or natural 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. CHDN parks share 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. 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, and 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 in 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 with resources of concern, we also identified additional threats to park resources (Table 1.12). These threats included both historical and current events. The table below describes threats mentioned more than 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 animals
Introduced Species
Human Caused Wild Fire
Recreation
Holiday fireworks
Oil and Gas Development
Contaminant Spills
Global Warming
Climate change

Upon completing the scoping meetings at each park, CHDN staff placed collected information on the CHDN 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 park entries for the scoping meetings they attended (Figures 1.21 and 1.22).

In this first attempt at ranking the vital signs, we asked which vital signs we should start with for further investigation of relevance and feasibility. Knowing that we did not have enough money to do everything but needed to start somewhere, this question seemed like a good way to get over the general reluctance to set priorities (the "But it's all important!" syndrome). The "What to do first?" question helped us to approach the initial prioritization in a quick and efficient manner. This efficiency stemmed from combining prioritization criteria, including: 1) relevance to conceptual models (ecological and management); 2) presumed feasibility, including cost, repeatability, and variability of the vital sign; and 3) relevance to park concerns. Each Technical Committee member was asked to weigh each criterion used in their ranking.

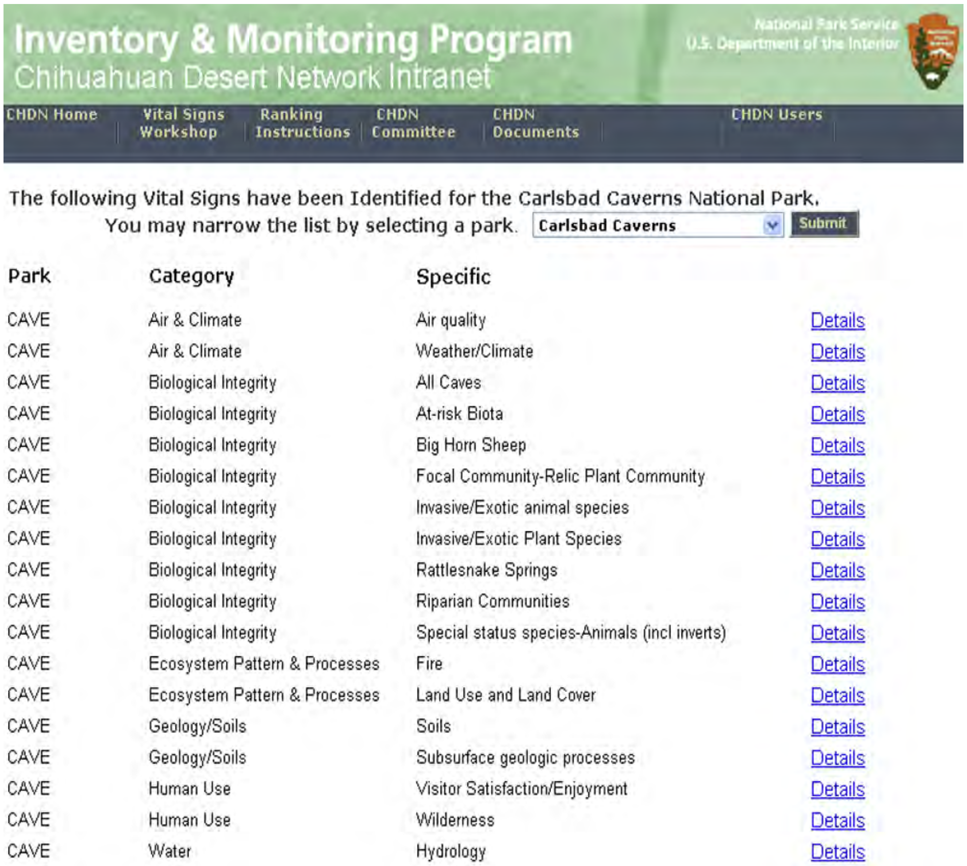
The ranking process was conducted in a modified delphi format using a web-based system. Each member of the Technical Committee was able to visit the network website, view the list of potential vital signs, and rank the lists.

They could also add any comments they felt were needed to accompany their rankings. Members were asked to rank the lists within each footing (Physical Drivers, Habitat, Fauna, Vegetation). They were also asked to rank the vital signs in a single combined list. Once everyone on the committee had entered their ranks on the website, average ranks were calculated within each footing and across all footings. These lists represented our initial attempt at ranking the network's vital signs. The comments entered by various members during the ranking process were used to highlight topics for further discussion.

This web-based ranking process worked well for avoiding "group think" because each member of the committee was asked to conduct their rankings separately. All our prior efforts to generate lists and discuss vital signs were conducted in group settings, so the web-based ranking process was a good opportunity to elucidate individual viewpoints. We were also able to analyze the ranks to assess biases based on each person's area of technical expertise and role, that of "manager," "-ologist," or home park.

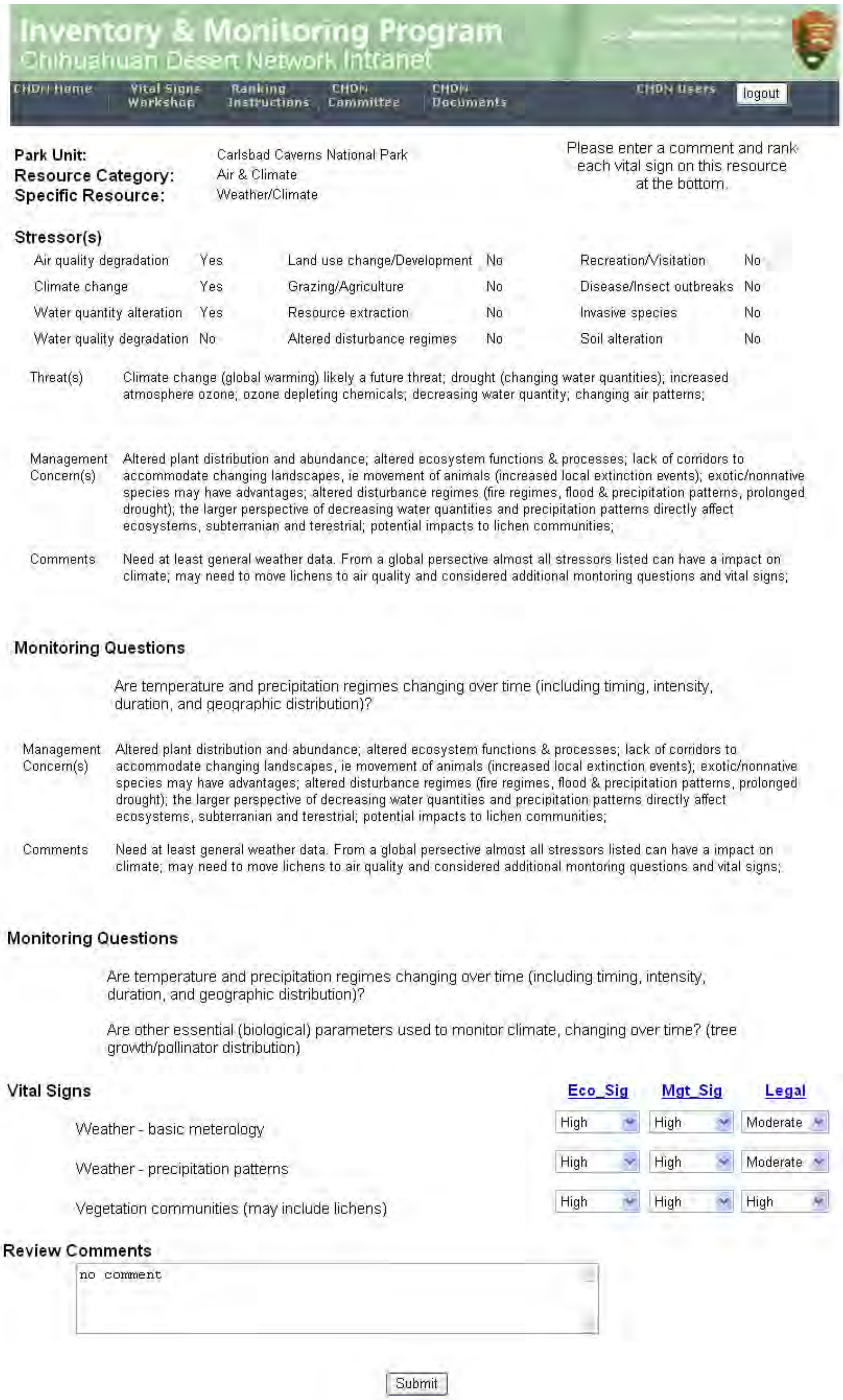
As was learned in other networks, looking at the variation among responses was as informative to understanding the priorities as looking at the average response. The variation was also helpful for highlighting topics needing further definition and discussion. We learned that there was generally good agreement about which vital signs should be ranked highest, and which should be lowest. The vital signs that ended up in the middle of the pack required further discussion to determine where they fit into the priorities. Of particular interest are those vital signs with bimodal rank distributions; i.e., some members ranked them very high and others very low. Understanding the rationale for the ranks was critical to resolving these differences.

The Technical Committee compiled and discussed the responses 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 is found in Appendix N.



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 1.21. Example of initial screen available to participants of Carlsbad Caverns National Park Vital Signs scoping meeting.



Inventory & Monitoring Program
Chihuahuan Desert Network Intranet

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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

no comment

Submit

Figure 1.22. View of screen used for ranking vital signs/issues.

1.3.2 Network-Wide and Park-Specific Issues

The scoping 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 being of moderate to high concern in multiple parks.

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						
*At least one park ranked the issue as high.						

It was expected that issues of high concern would end up in the list of selected vital signs. Ranking and selection of vital signs to be retained into the Phase III process occurred in Fiscal Year 2006 (see Chapter 3).

In addition to the network-wide issues, some potential vital signs may not be high priority for the network but could receive very high priority for an individual park. Table 1.14 includes a list of 19 issues 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 individual parks.

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 (none identified)						
GEOLOGY & SOILS						
Soil & sediment erosion						
Stream channel characteristics						
Cave microclimate						
Cave/karst processes						
Caves/karst features						
HUMAN USE (none identified)						
WATER						
Contaminant levels in fish						
Fish communities						
Siltation rates						
TOTAL	5	3	5	1	4	1

Guadalupe Mountains National Park has the highest elevations of any park in the network. Accordingly, park staff expressed concern over impacts of climate change reflected in issues under Air & Climate and concerns of elevational migration of habitat types under Biological Integrity. The magnificent caves of Carlsbad Caverns National Park were also appropriately highlighted in this process. Finally, Amistad NRA, a water-based park, had issues primarily related to the reservoir.

1.4 Monitoring Design and the Three-Phase Process

1.4.1 Designing an Integrated Monitoring Program for CHDN

The main goal of the CHDN Monitoring Program is to ensure that the results inform the management decision-making process. Monitoring also 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 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 indicators of ecosystem status? Woodward et al. (1999) and others have described some advantages and disadvantages of various monitoring approaches, including a threats-based monitoring program or alternative taxonomic, integrative, reductionist, or hypothesis testing monitoring designs (Woodward et al. 1999). The CHDN believes the best approach to the challenges of monitoring in national parks and other protected areas is to balance different monitoring approaches (termed the "hybrid approach" by Noon 2003).

Natural ecosystem drivers are major external forces such as climate, fire cycles, biological invasions, and hydrologic cycles that have large-scale influences on natural systems. Trends in ecosystem drivers that 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 foreign to that system or natural 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. A focal resource might be an ecological process such as deposition rates of nitrates and sulfates, or it could be a species that is harvested, endemic, alien, or has protected status.

Our current understanding of ecological systems, and consequently our ability to predict resource response to changes in system drivers and stressors, are 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 future high priority issues. Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions. A useful ecological indicator must also produce results that are clearly understood and accepted by managers, scientists, policy makers, and the public.

Considering the tremendous variability of ecological conditions, sizes, and management capabilities among parks, a "one size fits all" approach to monitoring design would not be effective in the NPS. Parks wish to develop an effective, cost-efficient monitoring program that addresses the most critical information needs of each park and integrates with other park operations. To do so, 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 with federal and state agencies and adjacent landowners will allow understanding and management of issues that extend beyond park boundaries. 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

Planning and design are necessary to guarantee that monitoring: 1) meets the most critical information needs of each park; 2) produces scientifically credible results understood and accepted by scientists, policy makers, and the public; and 3) produces 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. It must be tailored to the high priority monitoring needs and partnership opportunities for the parks in that network. Although there is considerable variability among networks in the final design of a monitoring program, it should follow five basic steps, which are further discussed in the Recommended Approach for Developing a Network Monitoring Program:

- Define the purpose and scope of the monitoring program.

- Compile and summarize existing data and understanding of park ecosystems.
- Develop conceptual models of relevant ecosystem components.
- Select vital signs and specific monitoring objectives for each.
- Determine the appropriate sampling design and sampling protocols.

These steps are incorporated into a three-phase planning and design process established for the network monitoring program. Phase I 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 I report, which is then peer reviewed and approved at the regional level before the network proceeds to the next phase. Phase II of the planning and design effort involves prioritizing and selecting vital signs and developing draft monitoring objectives for each sign to be included in the network's initial integrated monitoring program. Phase III entails the detailed design work needed to implement monitoring. It includes the refinement of specific monitoring objectives, development of sampling protocols, statistical sampling design, planning for data management and analysis, and specifying details on the type and content of various products of the monitoring effort, such as reports and websites. The schedule for completing the three-phase planning and design process was shown in Table 1.1.

1.5 Summary of Monitoring in the 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 service-wide 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 ongoing function of CHDN data management. With frequent turnover of park natural resource management staff, institutional knowledge 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 monitoring if measurements were taken at the same locations on several occasions. 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 inventory or monitoring programs conducted at CHDN parks.

Category			CHDN Parks			
	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		IH	
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, IH	IC, IH
Invertebrate	MH	IH	I		IH	
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), Bureau of Reclamation (BOR), Forest Service (USFS), Bureau of Indian Affairs (BIA), US Fish and Wildlife Service (USFWS), states, and private entities. A summary of major monitoring activities by adjacent land owners and/or managers that have been identified are provided in Appendix O.

1.6 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 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 its 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 of the ecosystem. It is based on the best understanding currently available of how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, 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 foreign to that system or 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 NPS, 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 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 (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).

2 Conceptual Models

2.1 Introduction to Conceptual Models

In designing its long-term monitoring plan, each network must develop its own conceptual models of the ecological processes operating in its parks. These conceptual models are instrumental to the Vital Signs Monitoring Program because they will help identify possible indicators of ecosystem health and function. The identified indicators will ultimately provide the focus for long-term monitoring.

Conceptual models are graphic or narrative summaries that display key ideas or concepts. Most are heuristic in value and are useful for diagramming function and process. Ecosystems are complex and governed by a myriad of ecological processes and interactions. Conceptual models provide a means for organizing and simplifying information and communicating complexity. Simply put, conceptual models of ecological systems help us describe and communicate ideas about how nature works. Effective models can stimulate thought about context and scope of processes that ultimately influence ecological integrity, maintenance of which is a key goal in resource conservation (Karr 1991). Sometimes these models allow expansion of knowledge across traditional disciplinary boundaries (Allen and Hoekstra 1992). The learning that accompanies development and revision of models can also provide a common understanding of system dynamics and/or the limits of current knowledge (Wright 2002). Accordingly, conceptual models can improve communication between scientists from different disciplines, between scientists and managers, and between managers and the general public. Conceptual models are therefore useful tools that can routinely be used throughout the process of developing and implementing an ecological monitoring program.

In this Chapter, we describe our modeling process and then present conceptual models for ecosystems of the Chihuahuan Desert Network. We have relied heavily on the information provided by other networks in developing these models. In particular, we have adopted much of the modeling strategy advocated by the two Colorado Plateau Networks (Thomas et al. 2004, O'Dell et al. 2005). In some cases, we have borrowed basic templates for developing CHDN-specific models. In other cases, we have incorporated applicable models with only slight modifications to reflect those components and processes more representative of Chihuahuan Desert ecosystems.

2.2 Purposes of Conceptual Models for the CHDN

An important goal of our conceptual models is to depict how natural drivers and anthropogenic stressors affect ecosystem structure and function. The ability of the monitoring program to detect the ecological effects of anthropogenic stressors depends on interpreting trends in resource condition against the backdrop of intrinsic variation. Hypotheses concerning the effects of anthropogenic stressors on ecosystem structure and function should be grounded in an understanding of the relationship between natural drivers and the structure, functioning, and dynamics of ecosystems (Brown and Havstad 2004).

Undoubtedly, ecosystems and their components can be characterized on the basis of many more structural and functional attributes than can be monitored. Thus, another important goal of the conceptual model is to guide the identification of a parsimonious set of "information-rich" attributes that provide information on multiple aspects of ecosystem condition (Noon 2003). The latter purpose can be achieved by identifying those attributes that have predictive value.

No single conceptual model can satisfy all needs. On one hand, the monitoring program 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. On the other hand, spatially explicit applications such as ecological resource assessments, monitoring design, and landscape-level ecological modeling ultimately will require site-specific, mechanistic, and predictive models. For our purposes, we will strive to develop multiple models that express a hierarchy of detail. Each model in the hierarchy can be used to identify a key set of physical and biological components and their links in an ecosystem. The models are nested such that detail increases as one moves through the hierarchy. Useful models do not try to name or describe every component of an ecosystem (Jorgensen 1986). Instead, they depict major components and interactions.

Vital signs, or indicators of ecosystem health and function, will be the focus of monitoring in the CHDN. These can be any measurable feature of the environment that provides insights into the state of the ecosystem, including compositional (the variety of elements in the system), structural (the organization or pattern of the system), or functional features (ecological processes). We will use the conceptual models described in this chapter to show the ecological relationships of selected vital signs and their role in ecological health or function. We will also use conceptual models to guide the selection of those vitals signs (described further in Section 2.6).

2.3 General Model of Ecosystem Structure and Function

Our conceptual modeling process began with acknowledging a simple, generalized model that summarizes ideas about ecosystem sustainability. Other NPS I&M networks have adopted a modified version of the interactive-control model (Jenny 1941, Chapin et al. 1996) to serve as a theoretical basis for modeling ecosystem function (Thomas et al. 2004, O'Dell et al. 2005). The Jenny-Chapin model defines state factors and interactive controls central to the functioning of sustainable ecosystems. This general model and associated set of corollary hypotheses also provide a theoretical foundation for aspects of the monitoring plan related to ecosystem structure and function.

As described by Thomas et al. (2004):

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. 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 of organisms, and disturbance regime–and these interactive controls both govern and respond to ecosystem attributes (Figure 2.1)*. Interactive controls are constrained by the five state factors, which determine the "constraints of place" (Dale et al. 2000).*

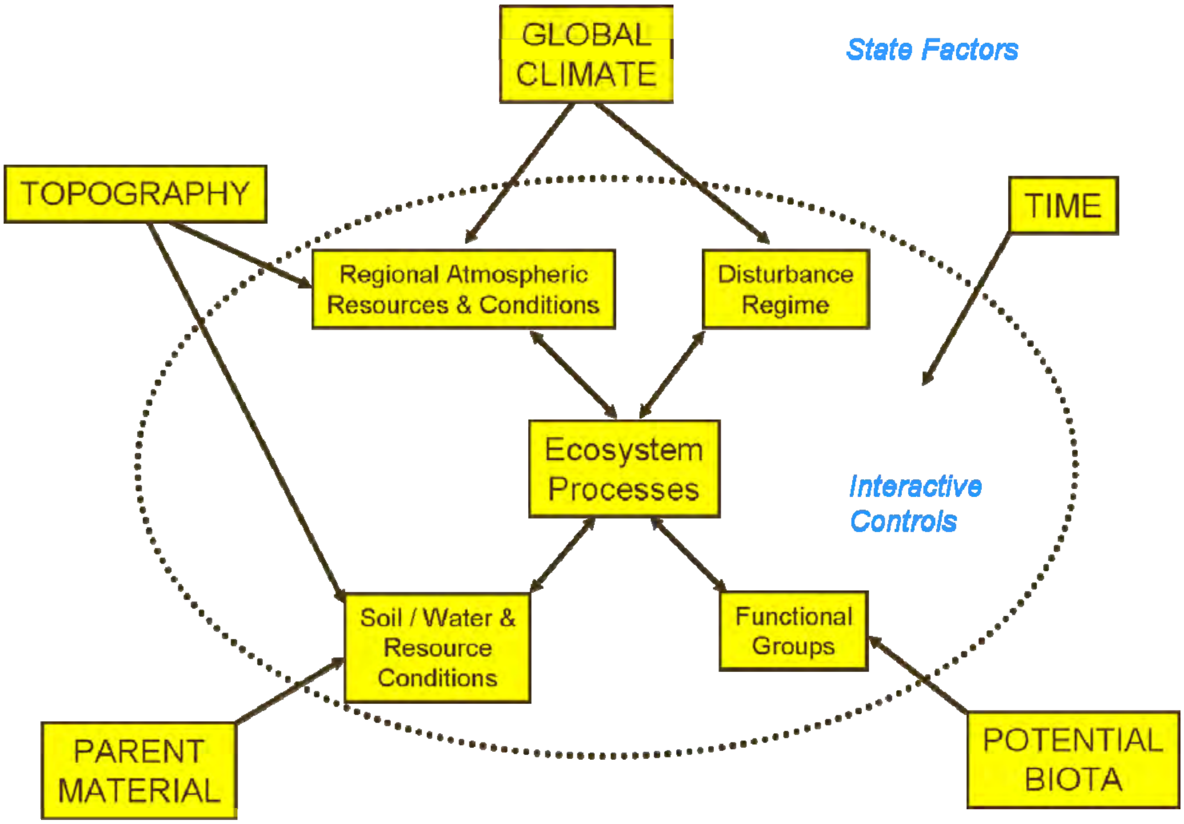

Figure 2.1. Aggregated system characterization model illustrating key ecosystem processes, characteristics and sustainability as a function of a hierarchical set of state factors and interactive controls. This model provides the theoretical foundation for more detailed, system-specific process and driver models. The oval 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). Soil, water, and air provide resources to primary producers. 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 is a component defined by 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 influenced by human management of the soil and interactions with biota (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 CO_2, 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 characteristics different from those of 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 in turn 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. If they are introduced to or lost from a system, species that affect soil-resource regimes, disturbance regimes, or functional-group structure are most likely to have profound effects on ecosystem characteristics (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).

We incorporated the underlying ideas of the Jenny-Chapin model by treating several of the state factors and interactive controls as ecosystem drivers. However, we treated two interactive controls (soil/water and biotic functional groups) as focal resources subject to influence not only by ecosystem processes but from anthropogenic forces or stressors as well. As in the Jenny-Chapin model, we portray dominant effects from state factors (or drivers and stressors) and the potential for multiple interactions among interactive controls (or focal resources).

2.4 Development of Conceptual Models for CHDN

We followed three steps to produce conceptual models for the CHDN ecosystems. First, we reviewed the models and development procedures used by other NPS I&M Program networks with similar environments. Second, we compiled and reviewed literature on the structure, function, and ecological relationships of the Chihuahuan Desert and similar ecosystems. Third, for drafting and refining the models, we collaborated with scientists and resource managers who had working knowledge of the Chihuahuan Desert ecosystems and parks.

Review of selected conceptual models and development processes used by other networks provided a basic template for structuring and presenting conceptual models for CHDN ecosystems. Select networks cited the work of Jenny (1941) and Chapin et al. (1996) as a theoretical foundation for modeling process and function of an ecosystem (see section 2.3). From that foundation, these networks usually produced a generalized or global model to characterize a particular ecosystem. These models portrayed the relationships among ecosystem drivers, stressors, and key components or focal resources. Drivers are defined as major external driving forces such as climate, hydrologic cycles, and natural disturbance events (e.g.; fire, droughts, floods) that have large scale influences on natural systems (standardized definition for NPS I&M Program, National Park Service 2003). Stressors are defined as physical, chemical, or biological perturbations to a system that are either foreign to that system or natural to the system but applied at an excessive (or deficient) level (Barrett et al. 1976:192). Focal resources are defined as 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. Our review indicated that drivers and stressors were similar among networks with ecosystems likely to be similar to those found in the CHDN parks (Table 2.1). The list of drivers and stressors from other networks with arid or semi-arid ecosystems provided an initial set of possible drivers and stressors to consider in the CHDN models. Understandably, the focal resources included in models of the other networks varied depending on the level of specificity presented in their models and the character of the network parks and ecosystems. However, vegetation and/or a broader grouping termed "biotic communities" were standard focal attributes of network ecosystem models.

Table 2.1. Ecosystem drivers and stressors identified in conceptual models of monitoring networks with ecosystems similar to those found in the Chihuahuan Desert Network.

Source	Ecosystem	Drivers	Stressors
Mau-Crimmins et al. 2005 (Sonoran Desert)	Low-Elevation	Solar/seasonal cycles Climate/weather Geologic processes Hydrologic processes Biological processes Natural fire regimes	Climate change Invasive species introductions Fire management Park operations Land use and development Human population growth Recreation use

Source	**Ecosystem**	**Drivers**	**Stressors**
Mau-Crimmins et al. 2005 (Sonoran Desert)	Mid-Elevation	Hydrologic processes Solar/seasonal cycles Climate/weather Geologic processes Biological processes Natural fire regimes Nutrient cycling	Park operations Land use and development Recreation use Border operations Climate change Soil alteration Invasive species introductions Fire management Native species declines Nutrient enrichment
Mau-Crimmins et al. 2005 (Sonoran Desert)	High-Elevation	Climate/weather Nutrient cycling Geologic processes Natural fire regimes Biological processes	Air-quality degradation Nutrient enrichment Soil alteration Climate change Fire management Native species decline Invasive species introductions Park operations Land use and development Human population growth Recreation use
O'Dell et al. 2005 (Northern Colorado Plateau)	Dryland	Regional climate Atmospheric conditions Natural disturbance	Climate change Air pollution Fire exclusion Visitor use Invasive exotic plants Livestock grazing Adjacent land use
Vankat 2004 (Southern Colorado Plateau)	Montane	Climate/weather Landform/elevation Soil system Fire and other disturbance Adjacent landscapes	Exotic species Fire exclusion Air pollution Historic livestock grazing Adjacent land use
O'Dell et al. 2005 (Northern Colorado Plateau)	Aquatic/riparian	Regional climate Atmospheric conditions Natural disturbance Upland watershed conditions Stream flow regime	Climate change Air pollution Stream flow alteration Visitor use Invasive exotics Fire Livestock grazing Alteration of upland watershed

From our review (see also Gross 2003), we crafted a simple set of guidelines for structuring the conceptual models. Accordingly, we attempted to:

- Identify key components and processes of the ecosystem: interactions between components, inputs and outputs to surrounding resources, and important ecosystem drivers 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.

- Balance complexity and simplicity in presenting conceptual models by using multiple models rather than one comprehensive complicated model to relate detail.

We chose to follow the modeling format and presentation style used by O'Dell et al. (2005). This format conveys detail of function and differences in scale by use of a hierarchy of models (Figure 2.2). The first model in the hierarchy is very general and is used to characterize an ecosystem (Figure 2.2a). The second model in the hierarchy is used to show how specific subsystems can change (Figure 2.2b). The third, more detailed, model in the hierarchy presents the perceived causes of relevant subsystem dynamics (Figure 2.2c). Lastly, we added a fourth model that shows the functional relationship between measures of one or more attributes indicated in the mechanistic model (Figure 2.2c) and a given ecological state or condition portrayed by a subsystem model (Figure 2.2d). This last level in the hierarchy provides the detail that ultimately will be needed by resource managers to connect monitoring data with early warning trigger values and thresholds to be used for guiding management decisions. For this report, we concentrated on developing and describing ecosystem characterization models. Identification and presentation of more detailed subsystem models will follow as supplements to the Phase III report. We elaborate further on each of these types of models below.

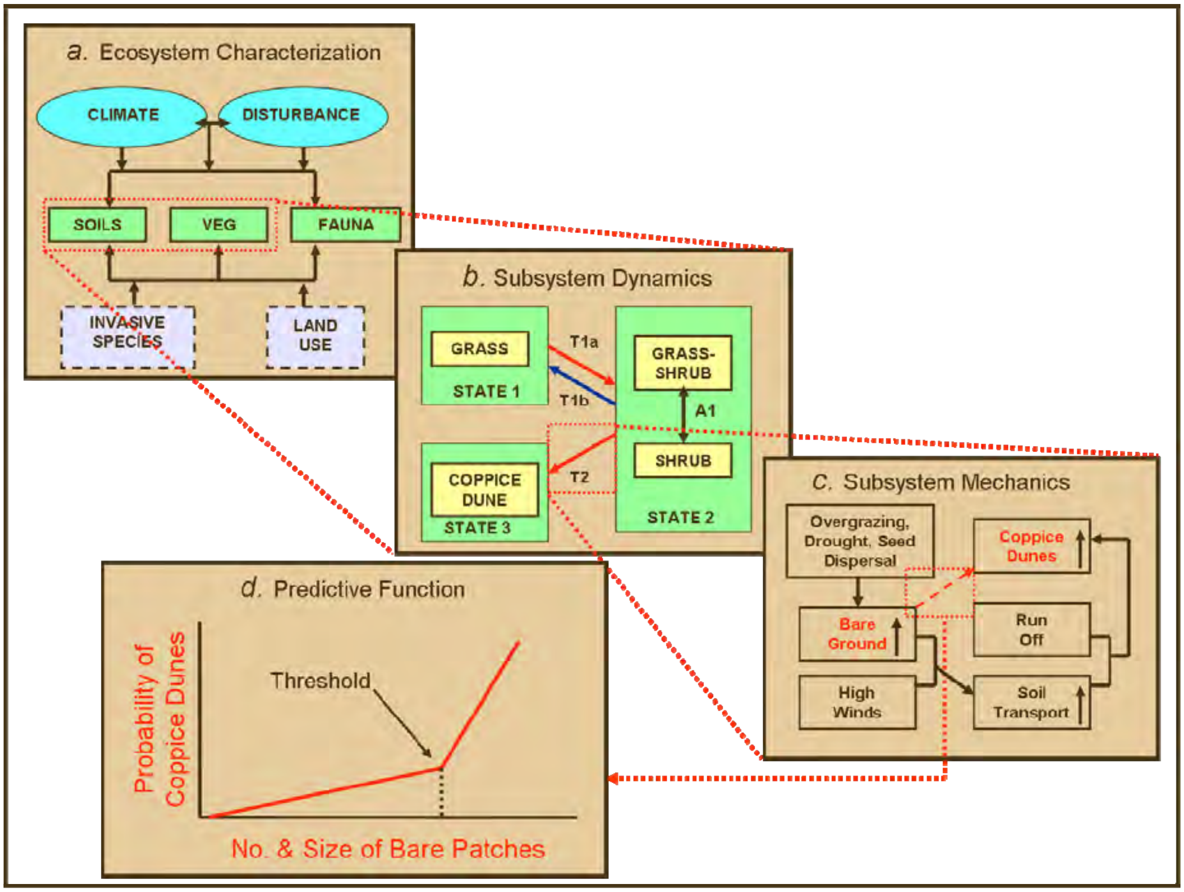

Figure 2.2. A hierarchy of conceptual models used to show functional relationships among ecosystem components and processes at multiple scales of detail. Model a) is used to characterize each ecosystem in terms of drivers, stressors and focal resources. Model b) describes changes in ecological states of focal resources, and model c) shows the mechanisms that cause the state changes. Model d) shows the expected response of a particular state change as a function of an attribute or set of attributes measured during monitoring. This figure includes generalized, hypothetical models and is used for illustrative purposes only.

2.4.1 Ecosystem Characterization Models

For each ecosystem, we developed a general descriptive model to characterize key classes of components, ecological processes, and interactions (Figure 2.2a). Each model includes a diagram augmented by a literature-based narrative. Our ecosystem characterization models describe ecosystems in terms of three fundamental components: drivers, stressors, and focal resources. Other authors have suggested categories of components that should be considered in developing these types of models (Chapin et al. 1996, Harwell et al. 1999). Chapin et al. (1996) emphasized using functional groups to convey biotic components that are functionally related to ecosystem sustainability, whereas Harwell et al. (1999) emphasized that a full range of biotic components is necessary to convey the concept of ecosystem integrity.

Our focal resources represent classes of either functional groups or single organisms that span the spectrum of biotic potential.

The objectives of ecosystem characterization models (Thomas et al. 2004) are to:

1. illustrate major subsystems and system components and their interactions;
2. indicate the driving abiotic factors that constrain the system, depict their relationships to key structural components and processes, and describe resultant ecosystem characteristics;
3. describe the predominant natural disturbances that historically influenced the system, indicate their relative importance in structuring the system, and summarize ecosystem-specific disturbance patterns (return intervals, extent, magnitude, seasonality);
4. characterize the prevalent anthropogenic stressors currently affecting the system, describe their relationships to key structural components and processes, and describe resultant ecosystem effects.

At this top level in our modeling hierarchy, the components and organization of an ecosystem can appear somewhat similar across a range of ecosystems, while the relative strength of system drivers and the nature of interactions between drivers and key components can vary from system to system. Characterization models for different systems should illuminate structural and functional similarities and differences between systems, with implications for monitoring. For example, episodic drought may be a common overriding determinant of ecosystem dynamics throughout the Chihuahuan Desert Network, 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, is much greater in the Foothills and Mountain Ecosystems. Additional differences among ecosystems can be made apparent through subsystem dynamic or mechanistic models.

2.4.2 Subsystem Dynamic Models

One important purpose of vital signs monitoring is to detect meaningful changes in the condition (structure and functioning) of park ecosystems. If conceptual models are to help guide selection of vital signs that fulfill this purpose, then these models should show how selected vital signs are related to ecosystem dynamics. That is, the models should indicate how and why ecosystems can change. To convey this next level of detail, we adopted models that show processes and causes of change in the focal resources depicted in the more general characterization models (Figure 2.2b). Accordingly, we refer to these as subsystem dynamic models.

The objectives for subsystem dynamics models (Thomas et al. 2004) are to:

1. identify the key components and interactions that historically controlled ecosystem structure and function,

2. describe ecosystem dynamics resulting from spatio-temporal variability in interactive controls,

3. illustrate key anthropogenic disruptions to system drivers,

4. provide a foundation for evaluating the range of current conditions of key structural components within the context of historic natural variability.

State-and-transition models provide a means for depicting subsystem dynamics. These models depict ecological states and pathways of change (Figure 2.2b). Information associated with state-and-transition models describes potential causes for the depicted state changes and plausible indicators of the impending changes. State-and-transition models are currently being developed for various terrestrial systems by several land management agencies or organizations (Bestelmeyer et al. 2004). State-and transition models and associated information provide hypotheses about causes of ecological change and ecological thresholds (Westoby et al. 1989, Stringham et al. 2001a, Bestelmeyer et al. 2003). They may be particularly useful to integrated monitoring programs by helping to identify attributes that have a demonstrable relationship to ecological function and to a remedial action (Herrick et al. 2006).

The basic unit of state-and-transition models is the ecological site, "a kind of land with specific physical characteristics, which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management" (Society for Range Management, Task Group on Unity in Concepts and Terminology 1995). Ecological sites are land units defined and recognized on the basis of climate, landscape position, and inherent soil properties (texture and mineralogy by depth) and are basic land units referenced for resource management and analysis by the Bureau of Land Management and the USDA Natural Resource Conservation Service. The concept is synonymous with "ecological land types" of the USDA Forest Service. Multiple states can occur at an ecological site (green shaded boxes of Figure 2.2b). Each ecological state is comprised of one or more plant communities or community phases, which are frequently named according to dominant or common plant species or growth form. Shifts in community phases can occur through time. These shifts can be reversed by climate fluctuations or through *facilitating* practices (represented by black, double-headed arrow labeled 'A1' in Figure 2.2b). States are also dynamic. They are distinguished by differences in structure and the rates of ecological processes such as erosion. The transitions among states (red arrows) are reversible (blue arrow) only through *accelerating* practices (e.g.; restoration activities such as exotic species removal/control, and/or addition of soil) that can be applied at relatively great financial expense (Thomas et al. 2004, Bestelmeyer et al. 2003).

We represented subsystem dynamics with state-and-transition models. We focused detailed description of subsystem or state-and-transition models on two focal resources, soil and vegetation. These models typically pertain to soil quality (primarily dynamic soil properties), vegetation composition/structure, and strong soil-vegetation feedbacks. In addition, soil and vegetation play strong roles in structuring other biotic components of an ecosystem. State-and-transition models can also be applied to riparian subsystems (e.g., Richter and Richter 2000; Stringham et al. 2001b). Riparian state-and-transition models would focus on vegetation, geomorphology, and hydrology/geohydrology.

Like ecosystem characterization models, subsystem dynamics models are incomplete without a literature-based narrative. Subsystem dynamic models provide a graphic view of ecological changes that can occur. The associated narratives describe how those transitions occur. Mechanistic models (Figure 2.2c) are used to illuminate the causes of ecological changes and are therefore interlinked with the transition pathways indicated in the subsystem dynamic models. For this reason, more detailed description of key transitions may be embedded in the narratives for mechanistic conceptual models (see Section 2.4.3).

2.4.3 Subsystem Mechanistic Models

We used mechanistic models (Figure 2.2c) to diagram and discuss in greater detail the ecological processes governing the patterns depicted in subsystem dynamics models. Detailed mechanistic models of processes that may propel particular (undesirable) system transitions can suggest indicators. These models may also provide insight into pathways and primary or secondary effects of particular stressors (Thomas et al. 2004: Figure 17). Mechanistic models should provide the necessary level of detail to suggest specific monitoring indicators or measures and their links to an undesirable outcome (e.g., degraded ecological state). This information can provide the inputs for quantitative predictive functions, which show the relative probabilities of a transition as a function of the measured environmental conditions (e.g., climatic fluctuations) or stressors (see Section 2.4.4).

2.4.4 Predictive Functions

Vital sign trends should indicate whether change in a particular system warrants management action. Predictive functions provide a tool for interpreting monitoring data. Useful predictive functions are quantitative and indicate the change of a state or response variable as a function of the measured vital sign (or set of vital signs). Optimal functions show thresholds, those values of the monitoring measure at which the system change becomes more likely as the monitoring indicators either increase or decrease in value (Figure 2.2d). For example, in the diagram representing mechanistic change of a grass-shrub mixed or shrub dominated state (State 2 of Figure 2.2c), the increase in bare ground is suggested as an indicator of change to an undesirable, less productive state (State 3 of Figure 2.2c) of coppice dunes. Bare ground is often monitored by measuring the number and size of patches of bare soil (e.g., see Herrick et al. 2005). In this case, an optimal predictive function would be one that indicated the threshold at which the relative occurrence (or probability) of the coppice dunes increases more rapidly with increases in bare ground (Figure 2.2d). Monitoring values of bare ground below (left of) the threshold value indicate that the system is likely functioning within the range of normal variability. In addition, values in the monitoring data indicating that the amount of bare ground is at or near the threshold value provide a trigger point for management decisions. Vital signs that cannot be related to functional change in the monitored systems will be less useful at informing management decisions. Monitoring indicators that can be assigned to predictive functions that show thresholds of system change will be most valuable to the NPS I&M program. Ideally, we would choose vital signs that could provide predictive functions with thresholds of change in CHDN systems and/or those which may provide predictive power following supplemental research. A primary goal during Phase III will be to determine which vital signs might provide this key information.

For this report, we concentrated on developing and describing ecosystem characterization models. Identification and presentation of more detailed subsystem models will follow as supplements to the Phase III report.

2.4.5 Model Sources

Models and associated narratives are based on compiled literature, previously developed models, and opinions of scientists and park experts. CHDN staff and cooperators assembled citations of 1,781 papers and stored them in a searchable reference database. This database will eventually be made available on the CHDN website. We used information from these references to show and describe functional relationships in the terrestrial CHDN ecosystems. CHDN staff and cooperators also have examined a suite of ecological site descriptions developed by the Natural Resources Conservation Service (NRCS). These site-specific reports provide the sources for ecological state-and-transition models, which we can use to portray dynamics of subsystems defined by soil and vegetation resources. Dynamic models for subsystems in the Foothill and Mountain Ecosystems will follow Miller and Thomas (2004) and Vankat (2004) and, where necessary, will be modified to show processes more representative of the CHDN. In addition, we developed some of the ideas in the conceptual models in collaboration with several ecologists from the USDA Agricultural Research Service, Jornada Experimental Range (ARS-JER). Substantial progress has been made by ARS-JER researchers and cooperators in identifying dominant agents and processes that affect ecological change in the northern Chihuahuan Desert and in developing strategies for monitoring ecological conditions (Brown and Havstad 2004, Havstad et al. 2006, Herrick et al. 2006, Peters and Havstad 2006). Similarly, academicians have devoted many years of study to understanding process and function in aquatic systems of West Texas (Ground and Groeger 1994, Groeger et al. 1997, Groeger 2005). Information on stressors came primarily from opinions of park managers and scientists during scoping meetings and Vital Sign Prioritization Workshops (e.g., see Chapter 3, Appendix M). Many of the findings and perspectives provided by these groups were incorporated into the models presented in Section 2.5.

2.5 CHDN Ecosystems

Before an ecosystem can be modeled, it has to be defined. An ecosystem is "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). Various approaches have been used to classify and delineate ecosystems, including by climate, major plant association, watershed boundaries, and physiographic properties like terrain or elevation (Rowe and Barnes 1994, Rowe 1996, Bailey 1998). We used bands of elevation and basic geomorphic or hydrologic form to designate six broad ecosystem categories in the CHDN. This classification incorporates two fundamental concepts: 1) that soil, topography, and parent material form a soil-geomorphic template that can influence hydrologic flow and biotic change, and 2) that abiotic factors like precipitation and temperature, which also influence hydrologic properties and the composition and structure of biotic communities, correspond to topography (Monger and Bestelmeyer 2006). The six ecosystems were labeled: 1) Desert, 2) Foothill, 3) Mountain, 4) Reservoir, 5) River, (applied to the three major rivers; the smaller wetland types are addressed within terrestrial ecosystems) and 6) Unique (Table 2.2). The unique category includes two subsystems, caves and dune fields. Caves of Carlsbad Caverns National Park may be more appropriately considered a subsystem of the Foothill and Desert Ecosystems, and the Dune Fields of White Sands National Monument and Guadalupe Mountains National Park a subsystem of the Desert Ecosystem (Figure 2.3). However, our designation of these systems as unique was done in part to allow for the identification of unique vital signs for these specialized systems.

We estimated the area associated with each ecosystem by NPS unit to summarize the spatial extent and distribution of ecosystems within the CHDN (Table 2.2). Area for the non-specialized terrestrial systems and Amistad Reservoir were estimated from elevation bands and a comprehensive digital elevation model (60-m resolution) developed for the Chihuahuan Desert Ecoregion (Monger et al. 2005). Area below 1,370 m (4,500 ft) was considered a Desert Ecosystem, area between 1,370 to 1,981 m (4,500 to 6,500 ft) a Foothill Ecosystem, and area above 1,981 m (6,500 ft) a Mountain Ecosystem. These ecosystems were designated irrespective of vegetation type. Based on elevations provided by Amistad staff, area for Amistad Reservoir was estimated from the elevation associated with conservation water surface elevation. Area for the River Ecosystem was based on a product of an average river width (0.185 km; n = 30 segments of the Rio Grande) and total river length in each NPS unit. The spatial extent and distribution of each of these ecosystems throughout the CHDN is shown in Figure 2.3. Associated park units provided area of dune fields and linear distance of caves.

These area values indicated the vast extent (77%) of the Desert Ecosystem in the CHDN, which occurs in five of seven NPS units (Table 2.2). However, the areas also indicated that effort and resources for monitoring health and function of these ecosystems should not be allocated strictly by extent or coverage of a particular system. Such a strategy would ignore the smaller River Ecosystem, which is ecologically and economically significant to the northern Chihuahuan Desert and its inhabitants (Ward and Booker 2003). In the following sections, we describe pertinent features of each of these ecosystems and present associated characterization models.

Table 2.2. Classification and area of Chihuahuan Desert Network (CHDN) Ecosystems.

		CHDN							
Ecosystem Name		**AMIS**	**BIBE**	**CAVE**	**FODA**	**GUMO**	**RIGR**	**WHSA**	**Total and % Area (km^2)**
Desert	Arid terrestrial and non-extensive aquatic systems that occur at lower elevations (generally <1,370 m [<4,500 ft]). Major subsystem or habitat types include Chihuahuan Desert Grasslands, Chihuahuan Desert Shrublands, Tamualipan Desert Shrubland, Playa/Salt Flats, Perennial Streams, Springs/Seeps, and Intermittent/Ephemeral Streams plus associated vegetation (e.g., riparian).	47	3,041	60	0	119[a]	0	304[a]	3,571
									77.3%
Foothills	Arid/Semi-arid terrestrial and non-extensive aquatic systems that occur at mid-level elevations (1,370 to 1,981 m [4,500 to 6,500 ft]). Major subsystem or habitat types include Woodlands, Chaparral, Perennial Streams, Springs/Seeps, and Intermittent/Ephemeral Streams plus associated vegetation (e.g., riparian).	0	173	129	2	124	0	0	428
									9.3%
Mountains	Montane terrestrial and non-extensive aquatic systems that occur at upper elevations (>1,981 m [>6,500 ft]). Major subsystem or habitat types include Montane Forest, Perennial Steams, Springs/Seeps, and Intermittent/Ephemeral Streams plus associated vegetation (e.g., riparian).	0	17	0	0	99	0	0	116
									2.5%
Reservoir	Aquatic system associated with Lake Amistad, a reservoir created by a damming of the Rio Grande below the confluence of the Devil and Pecos Rivers.	182	0	0	0	0	0	0	182
									3.9%

		CHDN							
Ecosystem Name		**AMIS**	**BIBE**	**CAVE**	**FODA**	**GUMO**	**RIGR**	**WHSA**	**Total and % Area (km^2)**
River	Large river and associated aquatic systems. Includes Rio Grande and primary river confluences in or proximal to park units (e.g., Devil and Pecos Rivers). Area values only for the in-unit river lengths.	3[b]	11	0	0	0	21	0	35
									0.8%
Unique	Ecosystems that are extensive and/or different enough that components and processes defined for the other described systems are not adequate for defining function of these unique systems. These would include primarily Gypsum (or other) Dune Systems and Subterranean Cave Systems.	0	0	256[c]	0	8	0	278	286
									6.2%
						Total Area:			**4,618**

[a] Excluding the dune systems which by its elevation could also be considered in the Desert Ecosystem.

[b] Based on number of free-flowing river kilometers, not influenced by the reservoir. Numbers provided by Amistad NRA.

[c] Linear kilometers surveyed for 113 caves in Carlsbad Caverns National Park. No area estimate calculated.

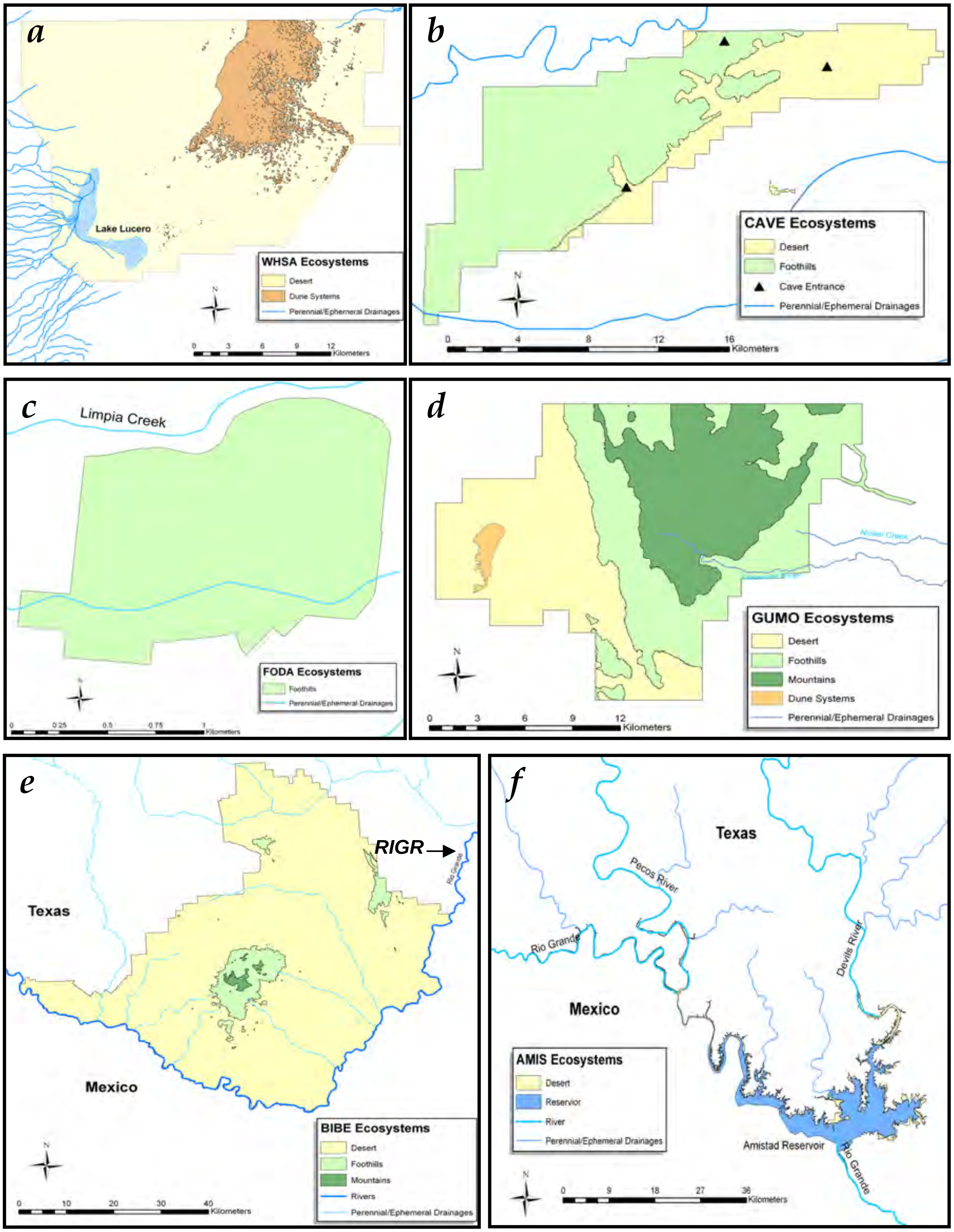

Figure 2.3. Spatial extent of ecosystems within National Park units of the Chihuhuan Desert Network. a) White Sands National Monument, b) Carlsbad Caverns National Park, c) Guadalupe Mountains National Park, d) Fort Davis National Historic Site, e) Big Bend National Park, with part of the Rio Grande Wild and Scenic River, and f) Amistad National Recreation Area (AMIS).

2.5.1 The CHDN Desert Ecosystem

We classified the Desert Ecosystem as elevations below 3,170 m (4,500 ft), which generally included basins, low lying alluvial or colluvial fans, bajadas, and some mesas. This classification also included minor aquatic systems like springs, seeps, and perennial or ephemeral streams, and playas (also ephemeral) found within this elevation range. We did not separate these aquatic systems at the ecosystem level because many of the major drivers and stressors that influence the other focal resources also influence minor aquatic systems. In addition, these aquatic systems are typically embedded in the surrounding desert soils and vegetation with connections among all of the depicted resources. Other spatially discrete features within the Desert Ecosystem include salt flats and dunes.

We estimated that the Desert Ecosystem (not including dune fields) comprised 3,571 km^2 or 77.3% of the CHDN (Table 2.2). This system occurred in five of seven CHDN park units (Figure 2.3). Eighty-five percent of the CHDN Desert Ecosystem is within Big Bend National Park (Table 2.2). Although the Rio Grande Wild and Scenic River passes through the Desert Ecosystem, no associated area was recorded for the limited 0.4 km (0.25-mile) land buffer on the US side of the river corridor. This buffer zone consists of private or state lands with only limited administrative power entrusted to Big Bend National Park.

We characterized the CHDN Desert Ecosystem by depicting relationships of focal resources to major drivers and stressors (Figure 2.4). Four groups of focal resources were included in the model. These were: 1) soils and biological soil crust;, 2) vegetation; 3) minor aquatic systems like springs, seeps, and streams; and 4) vertebrate and invertebrate fauna. Primary drivers included climate and atmospheric conditions, geomorphic and hydrologic conditions, and natural disturbance events. Six major stressors were identified: air pollution, climate change, land use adjacent to park lands, recreation and local use, invasive exotic species, and historical land use within the park lands. Key components and processes embodied by these focal resources, drivers, and stressors are discussed below along with a description of important relationships.

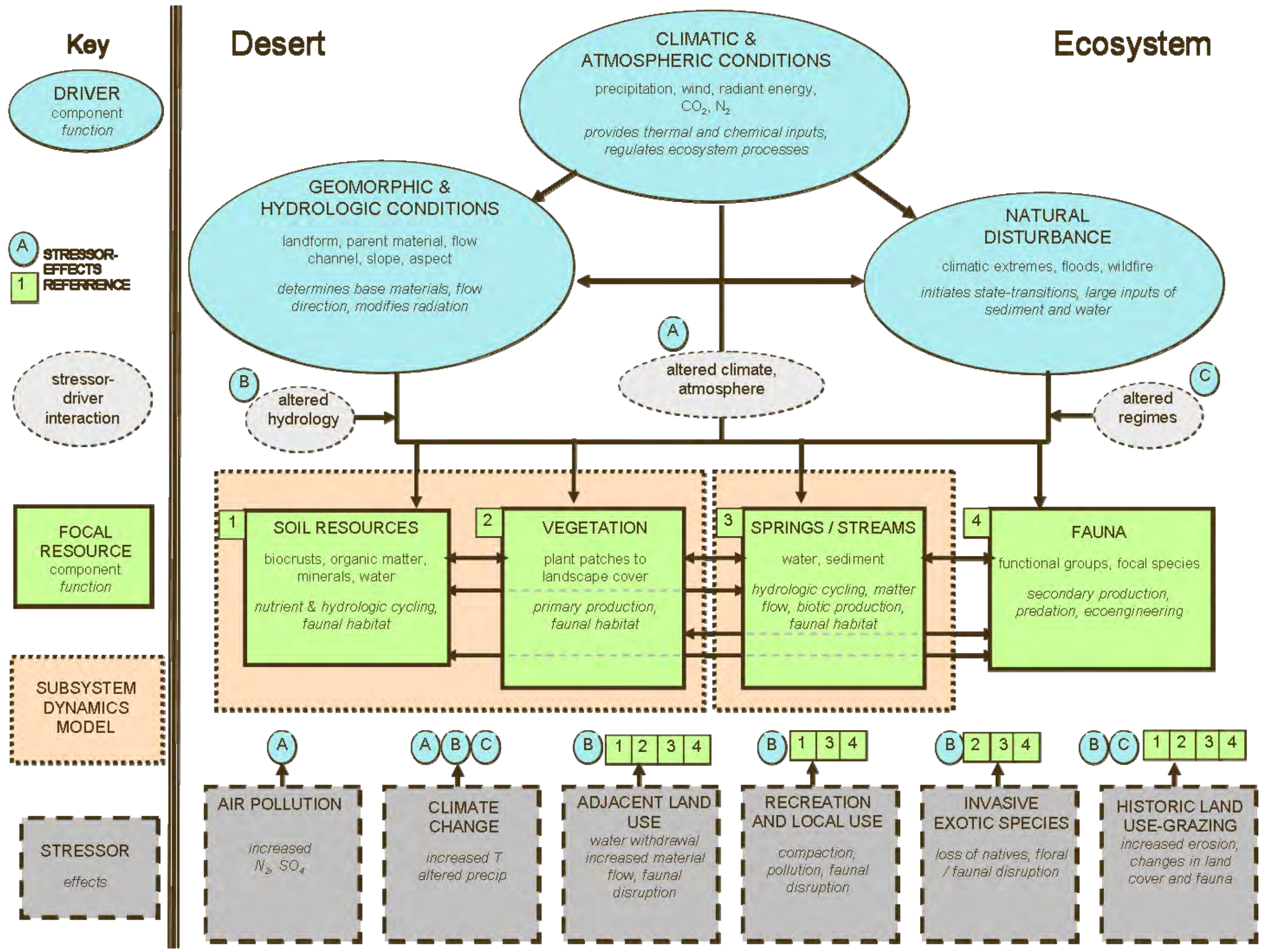

Figure 2.4. A characterization model for the CHDN Desert Ecosystem. Model symbols are described in the key on the left side of the figure. Direction of effects and interrelationships are indicated by arrows. Effects caused by interactions of major stressors and drivers are indicated by the dash-lined ovals (gray fill) and are referenced according to letters in blue circles. Focal resources influenced by stressors are referenced by numbered boxes (green fill). Effects of stressors can be envisioned by extending the arrow from a stressor to the model component indicated by the reference letter or number.

2.5.1.1 Focal Resources of the Desert Ecosystem

We portrayed the CHDN Desert Ecosystem with four fundamental focal resources: soils, vegetation, minor aquatic systems, and fauna (Figure 2.4). These resources provide many potential attributes for monitoring because change in their constituent components is often largely in response to drivers and stressors. Interactions within and among these four resource groups also shape the spatial and temporal distribution of biota and increase system complexity and variability. Arriving at effective monitoring attributes requires an understanding of these interactions. A useful first step is to identify and describe the resource components that play prominent roles in the processes and function of this desert system.

Soils

As in most terrestrial ecosystems, productivity in this Desert Ecosystem is rooted in its soils. The availability of soil moisture and nutrients is a primary factor limiting productivity in the Chihuahuan Desert (Whitford 2002, Snyder et al. 2006). Characteristics of soil, like stability, texture, structure, and associated biota, also directly influence plant composition, distribution, and growth (Macmahon and Wagner 1985, Whitford 1996, Huenneke and Schlesinger 2006). Direct and indirect effects on plant communities then influence the distribution and abundance of many vertebrate and invertebrate species (Whitford and Bestelmeyer 2006). Similarly, ecosystem resilience and function are related in large part to soil quality, integrity, and stability (Karlen et al. 1997, McAuliffe 2003). Loss and redistribution of soil resources in this Desert Ecosystem can strongly affect system composition and function and ultimately lead to desertification (Schlesinger et al. 1990, Gillette and Pitchford 2004). Measures describing soil quality and stability are practical attributes for monitoring function in the Desert Ecosystem (Havstad and Herrick 2003).

Soils of the Desert Ecosystem are typically Aridisols. Predominant soil types include Torriorthents, Calciorthids, and Haplagids. Most are moderately deep to very deep, well drained soils of loamy or clayey texture and are characterized by a thermic temperature regime, an aridic moisture regime, and mixed or carbonatic mineraology (USDA Natural Resources Conservation Service 2006). Soils along the Rio Grande in the Big Bend are hyperthermic. Approximately 80% of Chihuahuan Desert Ecoregion has soils derived from limestone beds. These soils sometimes have accumulations of calcium carbonate below the surface horizons, which when compacted form a layer often referred to as caliche. Very shallow or compacted soil layers that are lime-rich can provide favorable substrates for cacti while creating less favorable environments for other plant species (Dick-Peddie 1993). Entisols are also found in some parts of this ecosystem. These soils are shallow, are very poorly developed, and may consist primarily of sand and rock (USDA Resources Conservation Service 2006).

A notable example of soil effects on plant communities can be seen at White Sands National Monument. Here a substantial amount of soil is created from water-leached dolomite, which collects, evaporates, and forms gypsum crystals in a large playa lake bed (Kiver and Harris 1999). These crystals eventually weather and are then transported away by wind from the lake shore to form gypsum dunes (Langford 2003). The chemical composition, coarse structure, and instability of these soils often preclude development of diverse plant communities. Plants that do manage to thrive in these soils have a high tolerance of gypsum (Dick-Peddie 1993), and many of the invertebrate and vertebrate species have adapted a pale or white coloration that matches the soil color (Figure 1.14, Appendix A, Rosenblum 2006). Although some biota may be limited by the gypsum soils, the shaping of unique forms tolerant of this local condition ultimately increases regional biological diversity.

Because the soil organic horizon is usually limited, the formation and presence of biological soil crusts, also called cryptogams, can provide important functions to the Desert Ecosystem. Biological soil crusts are microbial communities consisting of fungi, algae, cyanobacteria, and their symbiotic lichens (Belnap and Lange 2001). Well-developed crusts can facilitate growth of desert mosses and other higher plant forms by providing organic matter that retains moisture for germination, growth, and survival. Cyanobacteria in the soil biotic crusts fix atmospheric nitrogen gas into amino acids. This process enriches the soil over time, further facilitating plant growth and soil stabilization. Given their susceptibility to loss from air pollution, trampling, or mechanized forms of disturbance, the presence and distribution of biological crusts may provide a function-related attribute for monitoring.

Vegetation

Primary production is the conversion of solar energy, along with nutrients and water from the soil, into plant biomass. This process is fundamental to all ecosystems and provides the material base for energetic flow in the system. Structure and composition of plant communities affect runoff and soil stability (Gillette and Prichard 2004, Abrahams et al. 2006) and provide habitat for fauna (Naranjo and Raitt 1993, Jorgensen et al. 2000, Gutzwiller and Barrow 2002, Menke 2003). Shrub and grass growth forms are the main primary producers in the Desert Ecosystem (Huenneke and Schlesinger 2006). Succulents, like cacti and agaves, are another defining plant growth form of this ecosystem. Trees are often absent. Despite the lack of trees, plant communities within the CHDN Desert Ecosystem make it one of the most biologically rich of any desert system.

Plant communities can be described any number of ways. In this report, we describe associations of plants using vegetation habitat types (Section 1.2,

Appendix H). Habitat types and subtypes of this ecosystem include *Larrea* Desert Scrub, Mixed Desert Scrub, Chihuahuan Sandy Plains Semi-Desert Grassland, Chihuahuan-Sonoran Desert Bottomland and Swale Grassland, Chihuahuan Gypsophilous Grassland and Steppe, Chihuahuan Succulent Desert Scrub, Chihuahuan Mixed Desert and Thorn Scrub, *Yucca* Woodland, Gypsophilous Scrub, Desert Wash/Riparian Woodland and Shrubland, Desert Riparian Woodland and Shrubland, Desert Riparian Mesquite Bosque, Lowland Riparian Marshland, and Playa. Two associations of Tamaulipan Thornscrub Habitat Type, South Texas Plains Scrubland and Edwards Plateau Scrubland, are found bordering the Reservoir Ecosystem of Amistad National Recreation Area and are included in this Desert Ecosystem (see also Appendix A). These habitat types are described further, along with the names of common plant species found in each type, in Appendix H.

Diversity within (alpha diversity) and among (beta diversity) Chihuahuan Desert habitat types is influenced by a number of factors including landform, soil condition, climate, elevation, topography, land use, and faunal interactions (Guo 1998, Peters and Gibbens 2006). During the last century, woody shrubs have intruded and expanded into areas of this ecosystem once dominated by or occupied by grasses (Peters and Gibbens 2006). The causes of this shift are equally diverse and complex, involving historical fauna and land use, human and animal forms of plant seed dispersal, excessive herbivory, extended drought, increased atmospheric carbon dioxide, fire, redistribution and heterogeneity of soil resources, and physiological adaptations of plants (Cole and Monger 1994, Fredrickson et al. 2006, Housman et al. 2006, Peters et al. 2006, Peters and Havstad 2006).

Minor Aquatic Resources

Springs, seeps, and ephemeral and perennial streams are rare but functionally important elements of the Desert Ecosystem. These limited aquatic resources provide specialized habitats and life-sustaining resources for plants and animals and can greatly augment local biodiversity. Because they are isolated, desert springs are often sites of speciation or endemism (Hubbs et al. 2002, Collyer et al. 2005, Wallace et al. 2005). The most common form of this resource occurs as ephemeral arroyos and draws, which cross the desert basins of CHDN park units (Appendix I). Periodic (flash) flood events can occur during the summer monsoonal rains. These events are likely a primary source of long-range material transport and ground water recharge within the Desert Ecosystem (Whitford 2002, Snyder et al. 2006). The minor aquatic systems are functionally related to groundwater levels (e.g., see Stevens and Springer 2004). In addition, riparian vegetation is limited to drainage systems with more persistent or predictable water sources at or nearer the surface than in surrounding lands. Water flow and riparian environments are also common avenues for spread of invasive plant species like salt cedar (*Tamarix* spp.), which has found its way into several CHDN park units (Appendix B).

Fauna

A wide variety of invertebrates and vertebrates is found in this ecosystem (e.g., see Appendix A; Whitford and Bestelmeyer 2006). Both broad faunal groups function to transfer minor amounts of energy (usually <10% of net primary production, Whitford and Bestelmeyer 2006) and, more importantly, to regulate system processes via ecological feedbacks (Chew 1974). In addition, many vertebrate species appeal to the public in national parks. Particular functional groups of organisms, keystone species, or species with special status may be suitable for monitoring patterns of change in the desert ecosystem. However, given the many functional effects organisms have and the variability in their population responses to drivers and stressors, it is unlikely that monitoring a single faunal attribute will precisely predict change in system function.

In general, feedbacks of fauna on Desert Ecosystem processes affect the heterogeneity of resources over space and through time (Whitford and Bestelmeyer 2006). Key functional groups of fauna, their particular environmental associations, and their roles in regulating ecosystem processes (Table 2.3) have recently been summarized by Whitford and Bestelmeyer (2006). These groups of organisms play prominent roles in shaping the distribution and availability of limited resources. Other focal species that may require monitoring because of their conservation status are listed in Appendix A.

Kangaroo rats (*Dipodomys* spp.) and subterranean termites have been identified as keystone groups for the Desert Ecosystem (Nash and Whitford 1995, Kerley et al. 1997, Fields et al. 1999, Krogh et al. 2002, Whitford and Bestelmeyer 2006). Banner-tail kangaroo rats (*D. spectabilis*) are desert grassland specialists absent from areas with >20% shrub cover (Krogh et al. 2002). Burrowing activity by this rodent species can positively influence establishment of black grama grass in patches otherwise dominated by a competing species, blue grama (*B. gracilis*), and increase plant diversity by facilitating establishment of forbs, shrubs, and succulents (Fields et al. 1999). Medium-sized kangaroo rats (*D. merriami* and *D. ordii*) can promote change in local vegetation composition by harvesting flowering tillers of tall tussock grasses (Kerley et al. 1997). This action can result in reduced reproduction and eventually density of these tussock grass species over decades (Brown and Heske 1990). Seed caches and foraging pits of kangaroo rats can also have a positive influence on germination and redistribution of nutrients (Whitford 2002). Kangaroo rats also comprise part of the food resources used by a diverse assemblage of predators.

Subterranean termites affect nutrient cycles and soil moisture. For example, termites can process 3-50% of leaf litter in this Desert Ecosystem (Whitford and Bestelmeyer 2006: Table 12-1). Because little of this material is returned to the pool of soil organic matter, nitrogen mineralization is slowed, reducing the amount of nitrogen available to plants. However, through predation by termites, several nutrients, including nitrogen, phosphorous, and sulfur, can be returned to the nutrient cycle (Whitford and Bestelmeyer 2006). In addition, the materials used in sheeting of potential food plants are enriched in calcium and potassium. Soil porosity and water infiltration are increased by gallery development and expansion. Thus, the combined influences of termites on soil nutrient cycling and water infiltration affect resource distribution, which ultimately affects composition and productivity of vegetation communities.

Predation and competition are key processes that shape desert fauna. These interactions are often coupled with responses to productivity of other focal resources in the system, such as soil and vegetation. Predation and competition are often complex and may act to increase resource variability, promote community stability, or enhance biological diversity (Shachak et al. 2005).

Table 2.3. Functional groups of fauna and their ecological relationships and roles in the Desert Ecosystem (from Whitford and Bestelmeyer 2006: Table 12-2).

Faunal Functional Group	Effect of Ecosystem Structure	Feedbacks to Ecosystem
Microarthropods	Ubiquitous in litter	Regulate fungi and availability of N to plants; control nematode predation on bacteria, which mediates decomposition rates
Macro-detritivores	Species sort among grasslands and shrublands	Decomposition of litter
Phyotphagous insects	Specialized to shrubs	Frass locally alters nutrient availability
Termites	Ubiquitous except in inundated areas	Rapid breakdown of roots, litter, and dung; reduce soil C and N mineralization rates; N fixation via hindgut symbionts; increase macroporosity and water infiltration
Ants	Additional species in shrublands	Granivory effects on plant reproduction; nutrient concentration in nests and soil patches; bioturbation and vertical redistribution in soils; food for specialist predators like horned lizards
Anurans	Positively affected by water redistribution	Redistribute aggregated nutrients to surrounding watershed via storage in their bodies and dispersal
Lizards	Increased density/richness in shrublands	Consumption of ants and termites
Birds	Increased density/richness in shrublands	Redistribute grass seeds (natives and exotics)
Rodents and lagomorphs	Increased density in shrublands	Graminivory, herbivory reduce grass reproduction; foraging pits favor seed germination for some grasses

2.5.1.2 Drivers of the Desert Ecosystem

Structure, composition and productivity of the four focal resources are fundamentally driven by climate, geology, and hydrology, while spatial heterogeneity of these resources is shaped by natural disturbances (Whitford 2002). Accordingly, we characterized the CHDN Desert Ecosystem using three classes of drivers: 1) climate and atmospheric conditions, 2) geomorphic and hydrologic conditions, and 3) natural disturbance (Figure 2.4). The Desert Ecosystem is characterized by low precipitation and low net primary productivity but high plant diversity. Net primary productivity of this desert system is limited primarily by water and nutrient availability (Whitford 2002). These drivers act in several ways to influence available water and nutrients, which in turn directly define species assemblages and associated interactions. Some key effects and interactions of these three drivers are explained below.

Climate and Atmospheric Conditions

Precipitation and solar radiation are two dominant inputs that drive the Desert Ecosystem. Seasonality, spatial variability, and duration of precipitation act to create pulses of water input (Appendix G; Snyder and Tartowski 2006). When combined with the effects of evaporation, these pulses have a strong influence on the distribution of soil resources that determine productivity and structure of other focal resources in this ecosystem (Whitford 2002, Schlesinger et al. 2006). Solar radiation provides the initial energy that fuels primary production of vegetation and floral microbes in the minor aquatic systems and directly affects behavior and energy budgets of animals. Consequently, many plant and animal species have adapted special features to persist under conditions of low water availability and high solar radiation influx (Whitford 2002). In addition, chemical composition of rainfall and atmospheric nitrogen and carbon affect metabolic processes of soil microbes and plants (Schlesinger et al. 2006). Eolian (wind) processes can play a prominent role in the Desert Ecosystem by affecting soil transport, redistribution of nutrients, and convection, which affects evaporation of soil moisture and plant desiccation (Gillette and Pitchford 2006, Okin et al. 2006). Large, rapid pulses of rainfall can cause flooding, disrupt normal hydrological cycles, and create temporary resources like playa lakes. Lightning can ignite community-changing fires. Over the long-term, climate driven processes interact with geologic materials and land forms to form or change desert soils (Monger and Bestelmeyer 2006).

Geomorphic and Hydrologic Conditions

Ecological processes and system function are based on geology and hydrology. In conjunction with climate, both drivers shape land forms. Land forms in turn create a template for a wide variety of ecological processes, including distribution, structure, and composition of desert resources (Wondzell et al. 1996, Monger and Bestelmeyer 2006). Bajadas and alluvial fans are common land forms throughout the Desert Ecosystem and provide obvious examples of the fundamental effects of these two drivers. The resulting soil structure on bajadas creates an ecological site that is often dominated by creosote (Whitford 2002). Compared to Foothill and Mountain Ecosystems, topography is less developed in the Desert Ecosystem. Nonetheless, solar radiation can be modified enough by even minor variations in landform to facilitate thermal heterogeneity and different microclimates for plants and animals (Whitford 2002). Similarly, both of these drivers can affect the magnitude of natural disturbances. For example, slope and channel characteristics influence rates of water flow during precipitation (Simmers 2003). Given the same rate of rainfall, a steep, narrow arroyo with exposed bedrock will transport water faster and further than a gently sloped channel with a sandy bottom.

Natural Disturbance

Prolonged drought, excessive rainfall, and extreme temperatures can change structure and composition of focal resources. Extended dry periods, particularly when coupled with hot dry winds, can cause mass mortality of perennial grasses. This creates more and larger bare patches vulnerable to erosion. At some northern Chihuahuan Desert sites, prolonged drought during the 1950s has had a lasting effect on regeneration of black grama grasslands (Peters et al. 2006). Prolonged or rapid rainfall that cannot be absorbed by the soil can result in flooding that redistributes resources throughout the Desert Ecosystem and recharges aquifers and aquatic systems. Through biotic interaction with species like spadefoot toads (*Scaphiopus* spp.), recharged playa beds can become oases of available nutrients and local redistribution (Whitford 2002). Lightning ignites natural fires that can cause extensive heterogeneity in landscapes, facilitate mineralization, and transport nutrients into the atmosphere. Historically, fire is thought to have played a vital role in maintaining desert grasslands and inhibiting the incursion of shrub dominated associations (McPherson 2003). However, the role of fire in shrub dominated communities of the Desert Ecosystem is variable, not fully understood, and likely less influential than soil integrity and seed dispersal (Dick-Peddie 1993, Drewa and Havstad 2001, Valone 2003).

2.5.1.3 Stressors of the Desert Ecosystem

The stressors of this ecosystem include air pollution, climate change, adjacent land use, recreation and local use, invasive exotic species, and historic land use – grazing (Figure 2.4). These stressors were identified by park-based scoping meetings and conceptual modeling (Table 1.11 and Table 1.12).

Air Pollution

Air pollution in the desert ecosystem is the result of several factors, including coal-burning power plants, oil and gas developments (which increase airborne nitrates and sulfates), industrial point and non-point sources from Mexico, and particulate matter. Declines in air quality likely reduce visitor experience by impairing scenic vistas, changing soil chemistry, and ultimately altering species composition. Additionally, if conditions exist to produce acid rain, especially from industrial development across the border, pictographs and water quality will also be affected.

Climate Change

Climate change is potentially a very important stressor that may interact with all three drivers of the system. Most park units, with the exception of White Sands National Monument, were concerned about climate change. Global warming in particular was viewed as a likely future threat to the integrity of park ecosystems. Potential management concerns included altered plant distribution and populations; reduced landscape connectivity, affecting the movement of animals and increasing local extinction events; changes to disease and insect outbreaks; and alterations to natural disturbance regimes (i.e., fire, flood). However, the greatest concern of park staff was that dramatic changes in precipitation patterns would alter entire terrestrial, subterranean, and aquatic ecosystems.

Adjacent Land Use

Adjacent land use is most often associated with agricultural and urban development and encroachment outside the immediate park boundaries. Additional land use changes of concern to parks are mining for bentonite and humates outside Big Bend National Park; oil and gas development, especially around Carlsbad Caverns National Park; wind farm developments and exotic species game farms (which could enhance the presence of such diseases as chronic wasting disease) near Guadalupe Mountains National Park; and groundwater pumping and mining at all parks. At current and anticipated scales, these threats could lead to conversion of native plant communities to non-native states, regional-scale habitat fragmentation, viewshed changes, degradation of wilderness character, impact to night skies, wildlife mortality (from wind farms, especially of bats and raptors), impacts to water quality, and reduction in water quantity (from groundwater withdrawals and diversions of surface water flows).

Recreation

Recreation activities affect park natural environments in many ways. Waste management and backcountry waste disposal (of garbage, human waste, toilet paper, and fishing line) and the subsequent impacts to water quality were a primary concern. Park staff also identified as threats the release of unwanted pets, especially cats, on park lands and the introduction of non-native exotic species. Introduced animals and feeding of wildlife by visitors can alter native wildlife movement, impact natural behavior, and increase the chances of injury from wildlife. Social trails, especially in fragile or sensitive habitats, can lead to compaction and soil erosion that may affect water quality, water infiltration rates, or biological soil crusts.

Invasive Exotic Species

Invasive species represent a potential loss of biodiversity and ecosystem change and degradation. The list of non-native animal and plant species affecting CHDN park units is extensive (Appendices B and C). NPS mowing and maintenance practices, visitors, and adjacent land practices increase the risk of continued and new invasions. These invasions cause displacement or extermination of native species through disease, competition, and predation, thereby changing vegetation and animal communities. Exotics impact water quantity and affect fire regimes. Even subterranean cave systems are not immune from exotics; e.g., when algae in the caves degrade speolothems.

Historic Land Use - Grazing

Historic grazing practices contributed to the transformation of desert grasslands to desert shrublands in Desert Ecosystems. The majority of CHDN desert grasslands were severely overgrazed prior to the transfer of these areas to the National Park Service (Wondzell and Ludwig 1995). However, it is difficult to separate conversion due to changes in global climate patterns (end of the 'little ice age', ca. 1900) and the rapid increase in domestic livestock across the Southwest and the Trans-Pecos regions (Neilson 1986). If CHDN considers monitoring such focal resources as grass cover, it will be important that we also attempt to identify the abiotic and biotic factors that regulate the response of desert grassland and shrubland species to climate change.

2.5.2 The CHDN Foothill Ecosystem

We classified the Foothill Ecosystem as occurring at elevations between 3,170 m and 1981 m (4,500–6,500 ft), which generally include piedmonts, foothills, some mesas, and canyons. Land forms in this ecosystem are often connected to those from the Mountain Ecosystem. Thus, the Foothill Ecosystem is often an area of transition between a higher montane environment and a lower desert environment. As with the Desert Ecosystem, minor aquatic systems like springs, seeps, and perennial or ephemeral streams were included as subsystem elements. Likewise, some openings extend from this ecosystem into the caves of Carlsbad Caverns National Park (Fig 2.3*b*).

We estimated that the Foothill Ecosystem comprised 428 km^2 or 9.3% of the CHDN. This ecosystem occurs at four of seven CHDN park units (Table 2.2). The limited area (2 km^2) associated with Fort Davis National Historic Site is entirely comprised by the Foothill Ecosystem. Big Bend National Park has the greatest area associated with this ecosystem (173 km^2). However, substantial area of the Foothill Ecosystem is also found in Carlsbad Caverns (129 km^2) and Guadalupe Mountains (124 km^2) National Parks (Figure 2.3).

The same four groups of focal resources; soils and biological soil crusts; vegetation; minor aquatic systems like springs, seeps, and streams, and fauna (vertebrate and invertebrate) were included in the model. However, the characteristics of soils and organisms portrayed by these resource groups often differ from those found in the Desert Ecosystem. Primary drivers also included climate and atmospheric conditions, geomorphic and hydrologic conditions, and natural disturbance events. Likewise, the same six stressors, air pollution, climate change, land use adjacent to park lands, recreation and local use, invasive exotic species, and historical land use within the park lands, were identified. Notably, fire suppression was identified as a historical land practice and considered a greater form of stress in the Foothill Ecosystem than in the Desert Ecosystem.

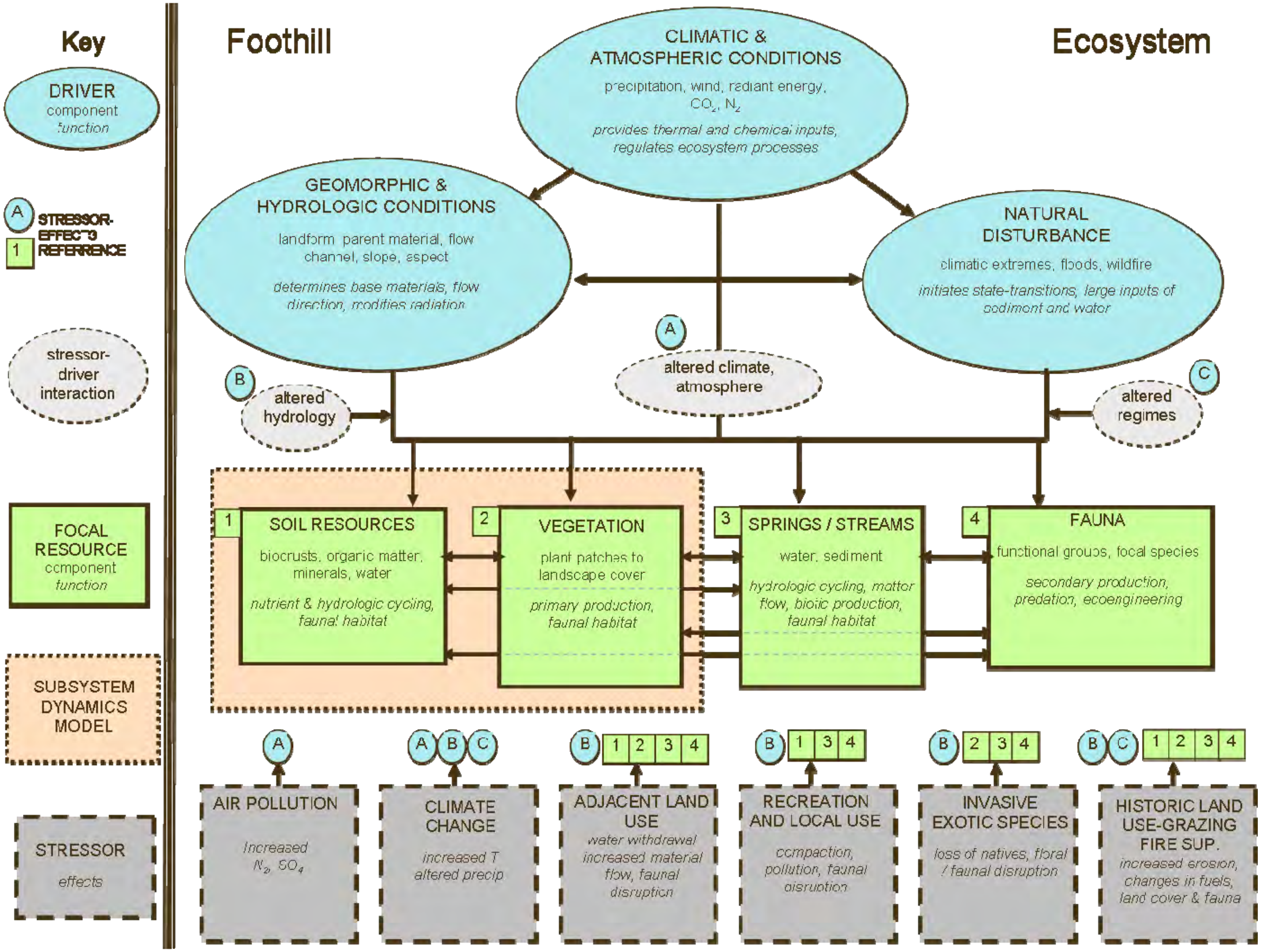

Figure 2.5. Characterization model for CHDN Foothill Ecosystem.

2.5.2.1 Focal Resources of the Foothill Ecosystem

Soils

The dominant soil orders in the Foothills Ecosystem are Aridisols, Entisols, and Mollisols. Most of the soils are Argids, Calcids, Ustolls, or Orthents. These soils are usually well drained, are moderately coarse to moderately fine in texture, and are characterized by a mesic soil temperature regime, an ustic or aridic soil moisture regime, and carbonatic or mixed mineralogy. Generally, the moisture regime is aridic bordering on ustic, but areas of pinyon-juniper woodland and savannah at the higher elevations have an ustic regime bordering on an aridic regime (USDA Natural Resources Conservation Service 2006).

Vegetation

As in the Desert Ecosystem, vegetation of the Foothill Ecosystem fulfills similar ecological roles. This focal resource provides the primary source of production, stabilizes soils, and provides food and cover for other organisms. However, species of plant communities differ substantially from the Desert Ecosystem as a function of differences in soil properties and climate. Orographic effects from topography and elevation provide additional stratification of local environments (microhabitats) that can enhance beta-diversity. Cacti, yucca, and agave plant forms are present, and shrub forms may also dominate some plant communities as in the Desert Ecosystem. Large expanses of grassland are atypical, except on high mesas, and trees are much more common in the Foothill Ecosystem. Common habitat types (Appendix H) of this ecosystem include, Chihuahuan Mixed Desert and Thorn Scrub, Izotal, Chihuahuan Mesquite Upland Scrub, upland extensions of Desert Wash/Riparian Woodland and Shrubland, upland extensions of Grama Grassland, Coahuilan Chaparral, Southern Rocky Mountain Juniper Woodland and Savanna, Madrean Pinyon-juniper Woodland, and lower reaches of Pine-oak Woodland.

Minor Aquatic Systems

Similar to the Desert Ecosystem, minor aquatic systems such as springs, seeps, ephemeral streams, and perennial streams also occur in the Foothill Ecosystem. However, arroyos and dry washes are less common. Open to steep-walled canyons may form narrow but distinct riparian corridors, which result in stronger gradients of environmental differences from surrounding terrain than are found in desert arroyos and washes. The cooler, moister conditions, and in some cases differences in soil quality, of foothill canyons and draws can lead to plant-rich microcosms. In some cases, these southwestern riparian areas form stringers of closed canopy woodlands with developed understories of herbs and shrubs (Baker et al. 2004). These areas can provide refugia for some organisms during dry years. Springs and seeps also provide localized spots of diversity and may be associated with canyons and riparian systems. Riparian corridors of the Foothill Ecosystem are primary routes of biotic transition and material flow (e.g., water and sediments) between the upper elevations and desert basin.

Fauna

The Foothill Ecosystem includes species that are not as adapted for life in arid conditions and species that may only be transitory through the Desert Ecosystem. Bird communities can be particularly diverse in riparian or canyon habitats of the Foothill Ecosystem. The structure, composition, and microclimate of the riparian vegetation provide suitable nesting and foraging conditions for a number of bird species (Mills et al. 1991, Bryant and Karges 2001), including some threatened or endangered species like Mexican spotted owls (*Strix occidentalis lucida*, Ward et al. 1995). Mast is periodically abundant in many of the woodland types. Habitats of this ecosystem also provide important wintering areas for a number of mammals that migrate to lower elevations or to birds migrating latitudinally in spring or fall (Skagen et al. 2005). A key shift in small mammal communities can be seen in the loss of heteromyid rodents with elevation, accompanied by a gain in cricetid rodents (Jorgensen et al. 1998). Strong keystone roles by species in the Foothill Ecosystem have not been identified. However, two avian species and a mammal species may play key roles in shaping foothill environments. Pinyon and scrub jays (*Gymnorhinus cyanocephalus* and *Aphelocoma coerulescens*, respectively) and collared peccaries (*Tayassu tajacu*) may aid in the dispersal of mast-bearing plant species and cacti, and in the case of rooting by collared peccaries, facilitate microenvironments for plants, insects, and small mammals. Caching of pinyon nuts or juniper berries by jays also likely provides food sources for several rodents (Christensen and Whitham 1993, Stotz and Balda 1995, Vander Wall 1997). In general, the interfaces between the Foothill and other ecosystems provide transitions zones that increase local biotic diversity.

2.5.2.2 Drivers of the Foothill Ecosystem

Focal resources of the Foothill Ecosystem are shaped by the same three categories of drivers described for the Desert Ecosystem. These include climate and atmospheric conditions, geomorphic and hydrologic conditions, and natural disturbance (Figure 2.5). The nature and magnitude of influence by these drivers on elements of the Foothill Ecosystem may differ from the Desert Ecosystem as a function of topography and climate variation associated with higher elevation. Upper elevations receive more precipitation and cooler temperatures. Surface water channels can be more incised, narrower, and have steeper gradient than arroyos and washes of the desert basins. This can create faster flow and greater sediment loading during rain events. Similarly, steeper slopes have greater erosion potential. In addition, a normal regime of fire, a natural disturbance agent, has been altered during the past century in the Foothill Ecosystem. Consequently, fuel loads have increased significantly with climate change, historically heavy live-stock grazing, and fire suppression. These events have established conditions that may spark more frequent stand-replacing fires than would otherwise occur in this ecosystem. Stand replacing fires in riparian woodlands, which are limited in area but critical resources for many organisms, could have a major influence on local biological diversity.

2.5.2.3 Stressors of the Foothill Ecosystem

The stressors of the Foothill Ecosystem (Figure 2.5) are the same broad categories of stressors identified for the Desert Ecosystem. These include air pollution, climate change, adjacent land use, recreation and local use, invasive exotic species, and historic land use. The magnitude of effects of air pollution and climate change may vary with higher elevation and or vegetation/soil differences found in the Foothill Ecosystem, but differences of effects among these two ecosystems are unknown. Adjacent land use effects on lowering water tables or quality (of surface and ground waters) is a potent threat for the Foothills Ecosystem, particularly for two CHDN units. Fort Davis National Historic Site is tucked in a growing urban interface with increased water demands. Carlsbad Caverns National Park is near natural gas and oil fields that are increasingly being exploited. Local recreation, particularly around minor aquatic systems, poses a threat to the Foothill Ecosystem when water quality and biotic communities are disrupted repeatedly by human pollution or activities. Increased human visitation may also exacerbate effects of low water tables created from adjacent land use. Exotic, invasive species are also a potential threat to the Foothills Ecosystem. For example, feral hogs (*Sus scrofa*) in the Davis Mountains can have drastic effects on the structure of riparian vegetation and springs and limit resources for collared peccaries. Trespass cattle are another example of exotics in the Foothills Ecosystem. Historic land use stressors in this ecosystem include extensive grazing by livestock and fire suppression. Both agents can change trajectories of vegetation distribution and structure at various scales on a landscape. As with many agents that influence vegetation, small scale events and disturbances add to spatial heterogeneity and biotic diversity. Large scale events may lead to extensive homogeneity in conditions. Current vegetative conditions in some portions of the Foothill Ecosystem have been shaped by extensive historical grazing and fire suppression.

2.5.3 The CHDN Mountain Ecosystem

We classified the Mountain Ecosystem as occurring at elevations above 1981 m (6,500 ft), which included steep-sloped terrain and intermittent valleys or canyons. Land forms in this ecosystem are often connected to those at lower elevations that we classified as Foothill Ecosystems. As with the Desert and Foothill Ecosystem, minor aquatic systems like springs, seeps, and perennial or ephemeral streams were included as subsystem elements in the Mountain Ecosystem.

We estimated that the Mountain Ecosystem comprised 116 km^2 or 2.5% of the CHDN. This ecosystem occurs at two of seven CHDN park units (Table 2.2). Most area associated with the Mountain Ecosystem (99 km^2) is in Guadalupe Mountains National Park (Figure 2.3d). Big Bend National Park has limited amounts of this ecosystem (17 km^2) located in the Chisos Mountains (Figure 2.3e).

We characterized the CHDN Mountain Ecosystem by depicting relationships of focal resources to major drivers and stressors as shown for the Desert and Foothill Ecosystems (Figure 2.6). As in the other two ecosystems, four groups of focal resources: soils, vegetation, minor aquatic systems like springs, seeps, and streams, and vertebrate and invertebrate fauna, were included in the model. Biological crusts were not considered an integral feature of soils in the Mountain Ecosystem. The same three primary drivers, climate and atmospheric conditions, geomorphic and hydrologic conditions, and natural disturbance events, were included. However, the interaction of climate and the geomorphic drivers create a suite of orographic effects that are stronger in this ecosystem than in the Foothill and Desert Ecosystem. Only five major stressors were identified in characterizing the Mountain Ecosystem. These were air pollution, climate change, recreation and local use, invasive exotic species, and historical land use within the park lands. Land adjacent to park lands was not considered a major stressor because most of the area associated with the Mountain Ecosystem is enveloped within the park and likely buffered from this stressor. As in the Foothill Ecosystem, fire suppression was identified as a historical land use and considered a greater form of stress than in the Desert Ecosystem.

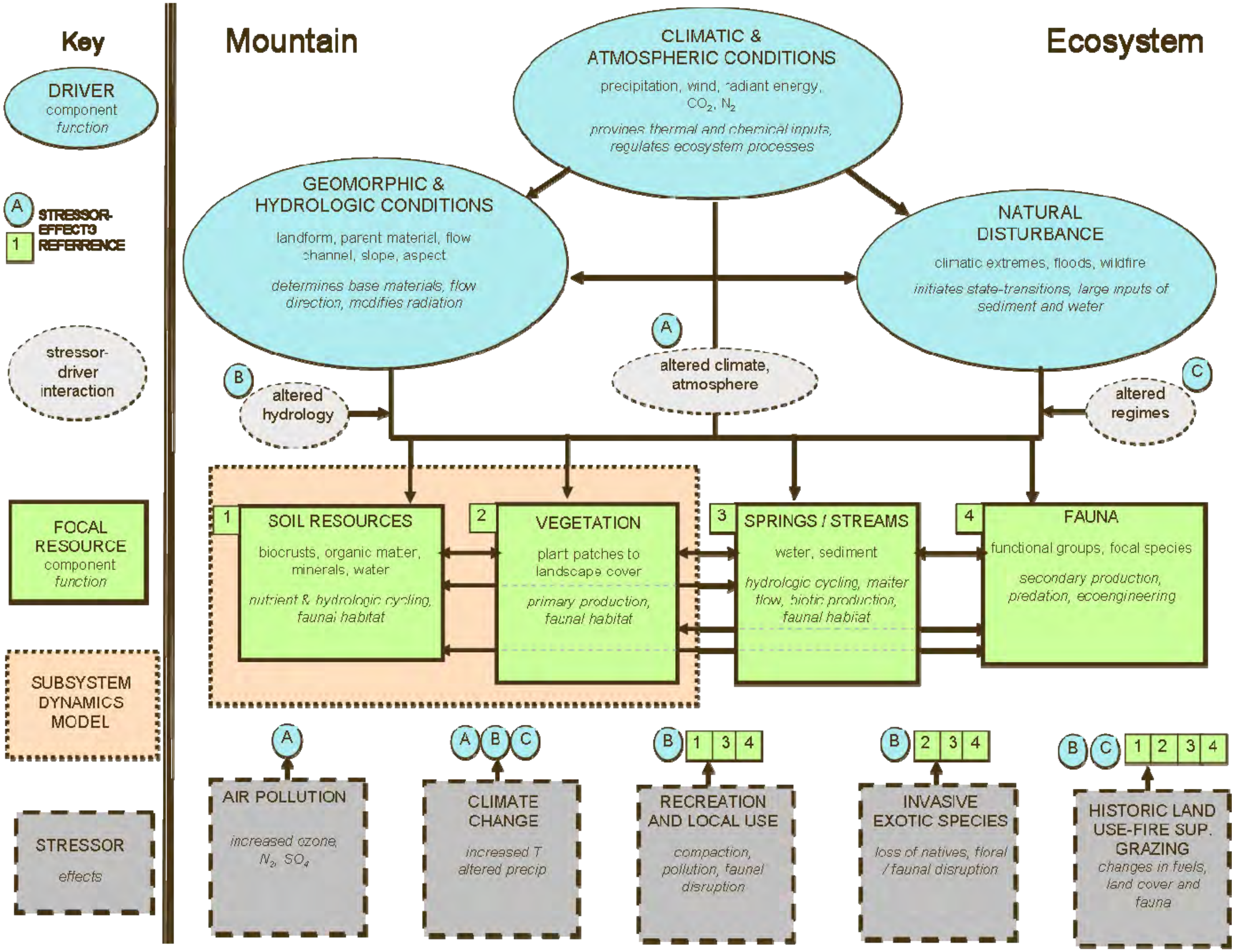

Figure 2.6. Characterization model for the CHDN Mountain Ecosystem.

2.5.3.1 Focal Resources of the Mountain Ecosystem

Soils

Soil orders of the Mountain Ecosystem are primarily Mollisols and Entisols. Mollisols include soils with loamy texture. Valleys of the Mountain Ecosystem may include very deep soils with well developed O-horizons. Many of these soils have mesic temperature regimes (USDA Natural Resources Conservation Service 2006). Entisols include shallow soils over bedrock. Some Haplustolls (Brewster series) and Argiustolls (Mainstay series) may be found in colluvium underlain by igneous rock on hills and mountains.

Vegetation

In the Mountain Ecosystem, plant communities show a general shift from shrub or succulent and sometimes grass dominated communities in the Desert and Foothill Ecosystems to tree dominated communities. In particular, the presence and diversity of trees is a distinguishing character for this ecosystem. Trees affect productivity and diversity of plant communities more than in the other terrestrial CHDN ecosystems. For example, increases in vertical structure result in greater plant biomass, while heterogeneity of tree canopy influences understory plant diversity and productivity to a greater extent than in open canopy communities of lower elevations. Trees and their products also provide for different faunal niches. Plant communities of the Mountain Ecosystem (Appendix H) include upland extensions of Pine-oak Woodland, Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland, Rocky Mountain Montane Mesic Mixed Conifer Forest and Woodland, and Montane Deciduous Woodland.

Minor Aquatic Systems

The Mountain Ecosystem also includes springs, seeps, ephemeral streams, and perennial streams. Because higher elevations experience cooler temperatures and more precipitation, water is often available longer in these systems than in the Desert and Foothill Ecosystems. Streams and springs of the Mountain Ecosystem are frequently the headwaters for aquatic systems at lower elevations. The health of these aquatic systems is often linked to the health of upland sources. Riparian vegetation is less diverse at higher elevations in the Mountain Ecosystem and increases as riparian corridors descend into the Foothill Ecosystem. Precipitous and narrow canyons characterize these corridors at their headwaters. These same corridors often deepen and widen as they pass through the limestone base. Mountain springs and seeps are isolated and may provide habitat for rare and endemic plants or animals.

Fauna

Many species of this ecosystem are seasonal visitors, using resources for breeding during temperate warm months and migrating to other latitudes or altitudes during non-breeding periods. For example, larger mammals and many passerine bird species found in the Foothill Ecoystem can also be found in the Mountain Ecosystem. Some species, however, are resident. Black bears (*Ursus americanus*) in Big Bend National Park are residents of the Chisos Mountains and, although they also use some habitat types of the lower Foothills Ecosystem, this population is extremely isolated (Onorato et al. 2004). Because of geographic isolation, resident species of the Mountain Ecosystem, particularly those with limited reproductive rates or dispersal abilities, are vulnerable to extirpation. In addition to black bears, other examples include Mogollon voles (*Microtus mogollonensis*) and Mexican woodrats (*Neotoma mexicana*) (Sullivan et al. 1994). Dynamics of isolated populations can be indicators of local (resource conditions) or regional (dispersal and recruitment) processes. If a species' population is so isolated that the only source of recruitment is local reproduction, then this population can be an indicator of an ecosystem's ability to support that population. Keystone species of the Mountain Ecosystem have not been identified. However, montane environments often provide key or additional habitats for large carnivores, which in turn can limit effects of herbivores on vegetation (Schmitz et al. 2000, White et al. 2003). Montane fauna add substantially to biotic diversity of Big Bend and Guadalupe Mountain National Parks (see species lists of Appendix A) and the West Texas.

2.5.3.2 Drivers of the Mountain Ecosystem

Although this ecosystem is limited to two CHDN park units, the higher montane elevations of areas capture and contribute substantially to the water balance of lower watersheds and ecosystems. Steep slopes, rugged terrain, and high elevations have stronger orographic effects than in the Desert or Foothill Ecosystems. Ambient temperatures are generally cooler than at the lower elevations. Temperatures vary inversely with elevation and widely according to land form, aspect, and habitat type. Temperatures below 0^{o} C are not uncommon during the winter, leading to shorter growing seasons for many plant species and providing for more rapid weathering of parent materials. Precipitation also varies directly with elevation, and this ecosystem receives more input from precipitation per unit of area than those systems at lower elevations. More precipitation facilitates greater density of woody biomass than in other CHDN ecosystems. Spatial and temporal variation in temperature, precipitation, and, to some extent, soil conditions create a number of microhabitats, which are ultimately reflected in the vegetation of this ecosystem. Steep gradients and increased rates of mineralization and precipitation facilitate transport of materials to Foothill and Desert Ecosystems.

2.5.3.3 Stressors of the Mountain Ecosystem

We depict one less stressor for the Mountain Ecosystem than for the Desert and Foothill Ecosystems (Figure 2.6). The montane environments of

Guadalupe Mountains and Big Bend National Parks are not likely to be affected by water withdrawal or water pollution from land use outside of park boundaries, due to distance from adjacent lands and buffering by other ecosystems within these parks. Ozone is an air pollutant that will have its greatest influence at higher elevations and is therefore emphasized for the Mountain Ecosystem. Ozone affects the wave length and intensity of solar radiation that passes through the atmosphere. The amount of ozone or of select response variables may provide a useful monitoring attribute for this ecosystem. Disturbance and pollution from recreation in minor aquatic systems are also localized stressors, particularly for those aquatic systems near hiking trails or popular campsites. Invasive and exotic species are probable but not as likely in the Mountain Ecosystem. Many exotic species found in the CHDN ecosystems established themselves near water courses and roads or as a result of alluvial transport or seed dispersal by trespassing livestock. All of these vector routes typically occur away from montane areas. As in the Foothill system, grazing, fire suppression, and heavy fuel loadings are historical processes that now pose a threat to the health of the Mountain Ecosystem. Although the higher elevations of this system provide more mesic conditions, abundant wood biomass per unit of area is also exceptionally dense in many conifer stands. Dry, windy springs preceded by dry winters create conditions for rapidly spreading, high severity fires, which can burn hot enough to denature soil and change plant species composition for ecologically long time spans.

2.5.4 The CHDN Reservoir Ecosystem

We classified the Reservoir Ecosystem of International Lake Amistad as elevations below 341 m (1118 ft), which delineated the reservoir water surface elevation at full conservation pool. The Reservoir Ecosystem also includes the environments created by the confluence of three major rivers into Lake Amistad: the Rio Grande, Pecos, and Devils Rivers (Figure 2.3f). Using the above elevation limit, we estimated that the Reservoir Ecosystem covered 178 km^2 of area or 4.2% of the total area for CHDN park units (Table 2.2).

International Lake Amistad is a reservoir divided by the boundary of Coahuila, Mexico and Texas, USA. It has the largest drainage basin of any major reservoir in Texas (323,643 km^2), with the exception of Lake Falcon, another Rio Grande reservoir found downstream (Ground and Groeger 1994). At its conservation elevation of 340.5 m above sea level, the reservoir has a mean depth of 16.5 m. The Rio Grande, Pecos River, and Devils River account for 68%, 13%, and 19%, respectively, of the long-term median surface water inflows to the reservoir (Groeger et al. in press). The three rivers differ greatly in sediment load and water chemistry (Table 2.4). The Rio Grande is very turbid, and the Pecos River is much more saline. The reservoir has been thoroughly described by Purchase et al. (2001).

Table 2.4. Conductance and turbidity of three rivers feeding the Reservoir Ecosystem of Lake Amistad.

River	Specific Conductance (µS/cm)	Turbidity (NTU)
Rio Grande	1155	90
Pecos River	3120	1.5
Devils River	384	1.4

A reservoir, while a discrete ecosystem unto itself, is also part of the larger river ecosystem. Key processes will include input to, transformation of, and output of critical chemical elements and compounds; including nutrients, major ions, pollutants, and reduced carbon compounds; that drive aquatic food webs. Reservoirs tend to be efficient traps of particles or particle reactive compounds such as nutrients, heavy metals, and hydrophobic organic pollutants. Therefore, major loading of these substances to the reservoir sediments tends to occur, and many of these chemical compounds will be "permanently" lost (over ecological, but not geological time scales) to the reservoir and downstream river ecosystems. With the very high rates of sedimentation found in this reservoir (Purchase et al. 2001), many of these substances may be buried quite quickly relative to a natural lake.

We characterized the CHDN Reservoir Ecosystem by depicting relationships of focal resources to major drivers and stressors (Figure 2.7). Four groups of focal resources were included in the model: 1) water column, 2) sediment, 3) littoral and inundated riparian zone, and 4) vertebrate and invertebrate fauna. Primary drivers included climate and atmospheric conditions, watershed conditions, hydrology, and natural disturbance events. Six major stressors were identified, including air pollution, climate change, water pollution and eutrophication, altered hydrologic budget, invasive exotic species, and watershed degradation. Key components and processes embodied by these focal resources, drivers, and stressors are discussed below, along with a description of important relationships.

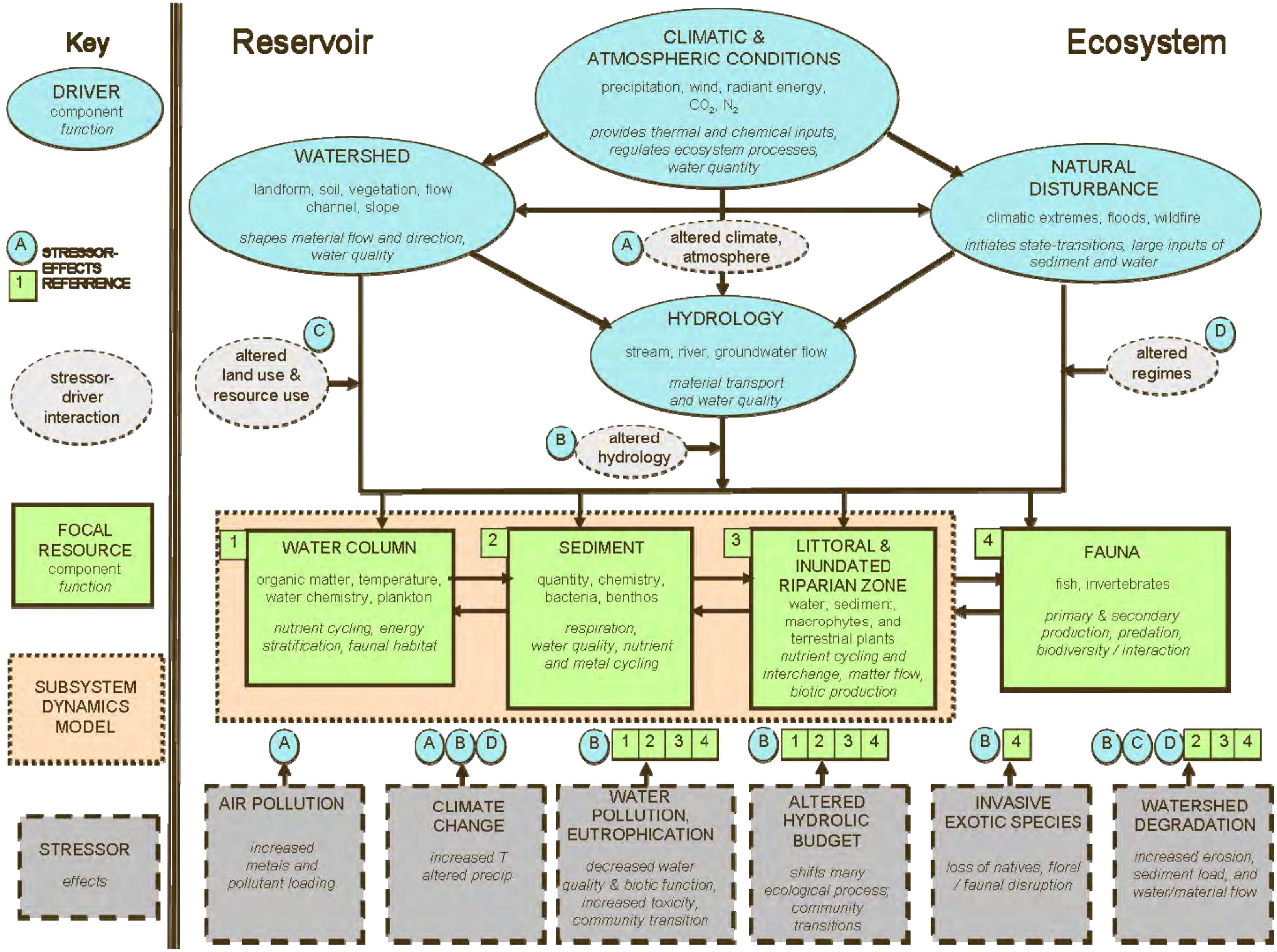

Figure 2.7. Characterization model for the CHDN Reservoir Ecosystem of Lake Amistad National Recreation Area, Texas.

2.5.4.1 Focal Resources of the Reservoir Ecosystem

The first three focal resources for the Reservoir Ecosystem (water column, sediments, and littoral and inundated riparian zone) have definite spatial distributions, while fauna tend to be quite mobile (Figure 2.7).

Water Column

The water column consists of the complete body of water that fills the reservoir basin and various physical, chemical, and biological components and characteristics of the water that will compose and define its general water quality. Biological components would include the plankton community (bacterio-, phyto-, and zooplankton). Chemical aspects would include the: 1) dissolved chemical species (electrolytes and non-electrolytes), including the major ions (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, SO_4^{-2}, HCO_3^{-}, and Cl^{-}), nutrients, microelements, and a complex soup of natural and anthropogenic organics; and 2) suspended particulates (e.g., clays and other clastics, $CaCO_3$, and organics), and 3) gasses (O_2, CO_2, H_2S, CH_4). The physical aspects include: 1) the light environment (light penetration into the water column, influenced primarily by particulates and "colored" organic molecules), 2) temperature, 3) placement of static and mobile layers of different density formed by classic seasonal stratification patterns and inflows of rivers of very different density, and 4) mixing due to winds and inflow and outflow dynamics.

An important process within the Reservoir Ecosystem is the primary production of phytoplankton, periphyton, and macrophyte communities. Primary production drives the aquatic food webs of the reservoir. Phytoplankton and periphyton production are driven by nutrient availability in the water column, and production by macrophytes is mostly affected by nutrient availability in sediments. In the down-lake, lacustrine zone of this reservoir, the water column usually has low phytoplankton biomass (chlorophyll a) and nutrients, andit functions like an oligotrophic ecosystem (Groeger et al. unpublished data). In uplake regions, in both the Rio Grande and Devils River arms, productivity seems to be much higher, reflective of transitional-zone productivity commonly found in reservoir ecosystems.

Sediments

The sediments component is created as particulates "rain out" of the water column of the reservoir down to the bottom. Due to the large drainage basin and very turbid nature of the Rio Grande, Amistad has high rates of sediment formati. Sediments contain a high concentrations of bacteria and other decomposers and tend to be a hot spot of reservoir metabolism. Sediments found in deeper waters tend to become isolated from atmospheric gas exchange and therefore often become anoxic during periods of stratification. This results in low to very low redox conditions and the transport of nutrients and toxic materials (e.g., H_2S, CH_4, Fe, Mn, some heavy metals) into the overlying water column. The sediments also accumulate many pollutants that tend to be largely insoluble in water, such as the heavy metals and hydrophobic organic compounds

Littoral and Inundated Riparian Zone

This zone includes shallow water areas or inundated terrestrial vegetation. A classic littoral zone with macrophytes forms in the littoral areas. Inundated terrestrial vegetation consists of vegetation killed in the initial flooding of the reservoir or smaller vegetation that was on the riparian fringe and lateral canyons when the water elevation was below the conservation level. These areas are extremely productive and provide excellent faunal habitat because they provide cover (e.g., for young and small fish from predators) and high invertebrate biomass. As the reservoir refilled in 2003 and 2004 after 10 years of drought, vast areas of new, energy-rich habitat formed, providing a boom in the sport fishery. This wax and wane of potential littoral habitat is much better developed on the Rio Grande side of the reservoir, as compared to the Devils River side.

Fauna

Reservoir fauna include predominantly fish and invertebrates, other than the zooplankton and benthos associated with deep water sediments. Many fish species are non-native to the Rio Grande and tributaries but are valued as a sports fishery (Appendix A).

2.5.4.2 Drivers of the Reservoir Ecosystem

The drivers of this ecosystem include climatic and atmospheric conditions, watershed condition, natural disturbance, and hydrology (Figure 2.7). While these drivers are not mutually exclusive, they all represent important controlling forces on this reservoir.

Climatic and atmospheric conditions will drive temporal cycles, including diel and seasonal cycles, particularly through the daily and seasonal variation in solar energy. Precipitation also tends to follow a seasonal pattern, often with summer rains associated with the "Mexican monsoon." Solar input and movement of air masses drive wind, which mixes the reservoir. The movement of air masses from different continental areas is also important in transporting air of different density, moisture content, and ionic composition over the watershed and reservoir. The combination of climate and watershed geology (watershed condition) will be the prime determinants of natural variability in reservoir water quality (Gibbs 1970).

Watershed condition, including surface geology, physiography, and topography, in combination with climatic and atmospheric conditions and natural disturbance, determine transport of particulates and dissolved weathering products to the reservoir. Watershed conditions are greatly influenced by processes that occur in terrestrial ecosystems near the reservoir and also in distant uplands. The latter systems can influence sediment loads and nutrient content of water inputs. Thus, the functional health of the Reservoir Ecosystem is also linked to the health and condition of other terrestrial and river ecosystems within its watershed.

The natural disturbance driver will define the variability of reservoir conditions over monthly, annual, and decadal spans. Disturbances will include hurricanes, drought cycles, and wet years associated with large climatic phenomena (e.g., El Nino). The volume of the reservoir at any time reflects past natural disturbances (or lack thereof) over the previous decade. Groeger and Bass (2005) found that flow of the Guadalupe River, which occurs further east on the Edwards Plateau, was among the most variable in the United States as a consequence of these factors.

The hydrology driver includes river flow and groundwater input to the reservoir. These water sources maintain the volume of the reservoir and ultimately supply downstream flows. This reservoir is on the Edwards Plateau. Consequently, groundwater inflows from the associated Edwards-Trinity Aquifer (entering either into the reservoir or the rivers nearing the reservoir) are very important in maintaining volume and quality of the reservoirs waters (Jeff Bennett, NPS Big Bend, personal communication; Groeger et al. manuscript in preparation). While flows tend to be quite variable (see above), groundwater inputs tend to buffer this variability, particularly during drier periods.

2.5.4.3 Stressors of the Reservoir Ecosystem

The stressors of this ecosystem include air pollution, climate change, water pollution and eutrophication, altered hydrologic budget, invasive exotic species, and watershed degradation (Figure 2.7). Air pollution will increase airborne loading of heavy metals, other combustion byproducts, and volatile organic pollutants to the watershed and reservoir. Air pollution may also influence incident light striking the reservoir and affect weather patterns. Climate change is potentially a very important stressor that may interact with all four drivers of the system. Increasing air temperatures may have their greatest direct influence by causing a warmer water column during the winter. This results in a warmer hypolimnion during the summer and an extended period of anoxia in this layer. Warmer winters at Canyon Reservoir, directly to the east on the Edwards Plateau, have caused a warmer hypolimnion during the summer (Groeger and Bass 2005). Increasing atmospheric temperatures will speed the precipitation and evaporation components of the global hydrological budget. Global atmospheric circulation models suggest this could result in either a drier or wetter climate in central Texas in the future (see Groeger and Bass 2005 and references therein). Such climate changes would impact all aspects of the local hydrologic budget. They are widely predicted to increase the variability of weather events such as droughts and hurricanes and play a key role in altering the hydrologic budget of Lake Amistad. The very high natural variability in this ecosystem may make the effects of climate change very hard to detect in the short run.

Pollutants and nutrients from upriver and the atmosphere represent threats to the quality of reservoir water (water pollution and eutrophication stressor). Eutrophication, or increased productivity due to increased nutrient loading, will pressure the system through increased organic matter loading to the sediments, thus resulting in a higher oxygen demand and earlier and more intense anoxia in the deeper waters. Eutrophication also detracts from water clarity within the reservoir. Lake Amistad is one of the clearest reservoirs in Texas (Groeger et al. [unpublished data] have recorded Secchi disk readings > 14 m); clarity thus represents an important aesthetic quality of the reservoir. Water clarity is a truly sensitive characteristic that can degrade rapidly and early during eutrophication. Another form of water pollution that threatens the reservoir is salinization. Likely sources of salinization would be irrigation, oil field activity, and upstream reservoir releases of salty water.

The hydrologic budget in this system is most disrupted when water received from its upstream sources is less than water lost from the reservoir. This net loss of water effectively shrinks the ecosystem. A resulting decrease in water level and area can disrupt and eventually minimize function of the littoral and inundated riparian zone, shift turbidity fronts further toward the dam, and eliminate access to boaters at the head of the reservoir. Extremely low reservoir levels likely compromise the aesthetic appeal of the park.

Invasive exotic species present a potential loss of biodiversity and add a stress that can change and degrade this ecosystem. Two examples include *Hydrilla* spp. (an invasive rooted submergent macrophyte) and *Prymnesium parvum*, a toxic, brackish water phytoplankter responsible for massive fish kills.

Watershed degradation would include changes in land use, such as increased agricultural use, increased oil and gas activities, and urban growth. These types of stresses are directly tied to changes in the chemical and physical qualities of the receiving waters. Changes in water demands down river can also affect reservoir level, which in turn can cause a number of changes in this ecosystem.

2.5.5 The CHDN River Ecosystem

–in progress–

by Dr. Al Groeger, Texas State University – San Marco, Texas

2.5.6 The CHDN Unique Ecosystems

–in progress–

Dune Ecosystem: by Dr. Richard Langford, University of Texas – El Paso, Texas

Cave Ecosystem: by Dr. Penny Boston, New Mexico Institute of Mines and Technology, Socorro, New Mexico,

Dr. Diana Northup, University of New Mexico, Albuquerque, New Mexico, and Dr. Hazel Barton, Northern Kentucky University, Highland Heights, Kentucky

2.6 Using Conceptual Models to Identify Vital Signs

In general, the conceptual models depict state variables and functions that are important to the ecosystem, and they also show how these components are connected by means of processes.

In many of the NPS I&M networks, development of conceptual models was initiated in Phase I. Workshops were held by some networks to develop their conceptual models, while others contracted model development to independent experts. Formulating models in advance of vital sign selection allowed reference to the models at subsequent workshops designed to prioritize and select monitoring vital signs. Because of limited funds and time for developing conceptual models, the CHDN has followed a parallel process, whereby models were developed quasi-independently from the vital sign listing process (see Figure 3.1). Consequently, the conceptual models can be used to provide a check on the vital signs selected through the delphi (expert opinion-consensus) method used at the vital signs prioritization workshop (see Chapter 3 for additional detail). Our parallel approach provided a means for identifying 1) vital signs that may have been missed, and 2) additional or verified scientific justification for selected vital signs.

A fundamental purpose of the most detailed models (mechanistic and predictive functions) will be to guide refinement of the list of vital signs described in Chapter 3. Not all priority vital signs can be monitored because of limits on technology, funds, or logistics. Vital signs that can be sampled effectively and efficiently and have a known function that provides trigger points or thresholds will provide greater information and may be more suitable for monitoring. Thus, identifying detailed models that exist for particular vital signs provides additional means for ranking monitoring attributes. During Phase III, CHDN will continue to identify more detailed models of subsystem dynamics (e.g., state and transition models), associated models of transition mechanisms, and predictive functions and use the results to refine the list of vital signs identified in Phase II (see Section 3.3). We will then develop sampling designs and protocols for those vital signs that have known relationships to pertinent subsystems dynamics and that have reliable predictive power.

2.7 Summary

Conceptual modeling provides a valuable tool for identifying the important components of an ecosystem, the interactions among those components, and how drivers and stressors impact the ecosystem. Conceptual models are also useful for communicating how vital signs are related to ecological components and processes. In this chapter, we described a hierarchy of conceptual models to fulfill these purposes. The most general (first level) model in the hierarchy can be used to characterize an ecosystem in terms of ecological drivers, stressors, and focal resources. These models are useful for showing the general links between prioritized vital signs and ecosystem components. Dynamics of subsystems comprised of key focal resources can be modeled and described to show more detail about key changes of ecological states and causes of those changes. Even greater detail can emanate from the subsystem dynamics models by constructing mechanistic models from the information associated with transition causes. Finally, predictive functions should be developed to indicate the quantitative relationships between a potential monitoring indicator (or its measures) identified in the mechanistic model and the probability of change to an undesirable ecological state. Finally, predictive functions provide a means for interpreting monitoring data by identifying trigger points or values at which ecological thresholds will be crossed. In addition, conceptual modeling provides these benefits:

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

In this Chapter, we also identified and described six ecosystems. These included the Desert, Foothill, Mountain, Reservoir, River, and Unique (caves and dune fields) Ecosystems. We characterized key components and processes for one aquatic and three terrestrial ecosystems using conceptual models developed from literature reviews and initiated conceptual models for the other systems. The ecosystem characterization models provided a template used in Chapter 3 for examining the distribution of prioritized vital signs among ecological drivers, stressors, and focal resources.

As we move into Phase III, the remaining ecosystem characterization and more detailed subsystem models will be sought and developed from existing sources. This process will help to refine the CHDN list of vital signs to those which are most rich in information regarding ecosystem function, process, and change. Our ultimate goal in producing conceptual models will be to identify those vital signs that have strong predictive value for providing early warning of important ecological change.

3 Vital Signs

The term vital sign is defined by this program as "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". In this chapter, we describe the vital signs for the Chihuahuan Desert Network and the process used to identify, rank, and select these vital signs.

The Chihuahuan Desert Network has identified 38 high-priority vital signs that represent an ecosystem approach to our monitoring program. Out of the high-priority vital signs, five vital signs relate to air and climate, 15 relate to biological integrity, five relate to geology and soils, six relate to ecosystem pattern and process, and seven relate to water. The network developed this list through a process of meetings and ranking exercises. We will continue to use this list in the Phase III process to develop monitoring protocols and, eventually, to implement monitoring in the next three to four years.

3.1 Process for Choosing and Prioritizing Vital Signs

The process of choosing vital signs and assigning priorities to them has been ongoing within the Chihuahuan Desert Network since the fall of 2004. This multifaceted process involved interviews, park-based scoping meetings, ranking exercises, topic-specific workshops, a vital signs prioritization workshop, and Technical Committee and Board of Directors vital signs review meetings. Over the last two years we have identified potential vital signs, focused the vital signs list, and placed it within the characterization conceptual models for ecosystems developed to date. Figure 3.1 and Table 3.1 summarize the major steps in the CHDN process for selecting vital signs.

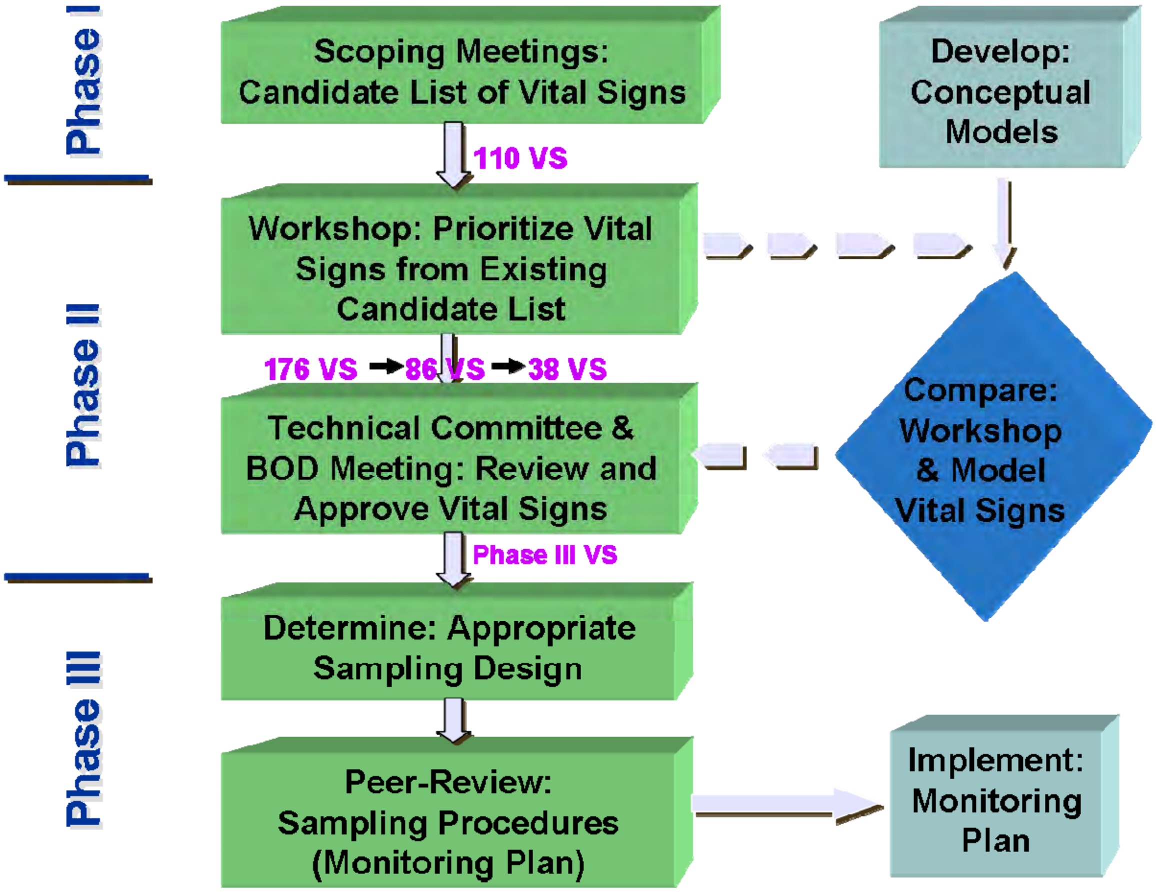

Figure 3.1. Schematic diagram of the process used by the Chihuahuan Desert Network in the development of its vital signs monitoring plan. Conceptual models being developed were used to suggest potential vital signs and convey the relationship of vital signs to ecological processes and predominant ecosystem components. The list of vital signs nominated through the workshop approach was also compared with that indicated by the conceptual models. Greater confidence will ultimately be placed in vital signs nominated by both approaches.

To initiate discussion of vital signs, we held park-level scoping meetings during the winter and spring of 2005 at each park unit within the network (Chapter 1, Section 1.3). The purposes of those meetings were to present the Vital Signs Program to all interested park staff and to receive staff input on potential vital signs for the park and network. Potential stressors, management concerns and issues, potential vital signs, and monitoring questions were identified, and information was captured directly into an Access database (Screenshot Database View). All scoping meeting data were captured in an MS Access database adapted from the Mojave Desert Network. Based on those sessions, CHDN staff developed a long list of potential vital signs. The CHDN data manager designed an on-line web-based application that allowed park resources staff and superintendents to score 145 non-unique vital signs on-line (Appendix N). This list included duplications. This park-specific list of potential vital signs was the first major milestone in the vital signs identification, prioritization and selection process.

Table 3.1. Summary of the processes used in the Chihuahuan Desert Network to identify and prioritize vital signs.

Step	Event	Vital Signs Milestone	Product
Oct. 2004	Interviews with park staff	Identified issues, management concerns, wish list of monitoring needs.	See Appendix L
Dec. 2004-Mar. 2005	Scoping meetings at each park	"Laundry list" of potential vital signs generated by brainstorming at each park.	
Jun. 2005	Intranet web-based ranking of 145 non-unique vital signs by park resources staff & superintendents	Produced candidate list of vital signs to move forward in the prioritization & selection process.	See Appendix N
Oct. 2005	Water Quality & Water Resources Workshop	Further refined water resources related vital signs of interest.	See Appendix P, Table P.1
Jun. 2006	Chihuahuan Desert Network Prioritization Workshop	Breakout Groups (park staff & invited experts) for Animals, Aquatic Resources & Water Quality, Plants & Soils, Landscape, and Unique Systems (Subterranean Caves & Dunes) reviewed and scored 97 unique vital signs from Phase I.	See Appendix P, Table P.3
Jul. 2006	Review of Cave Ecosystem vital signs by additional outside experts	Due to scheduling conflicts from other key outside experts with the June workshop, it was felt vital signs relevant to the Cave Ecosystems would benefit from an additional review.	Concurrence on submitted list, and no new vital signs suggested.
Jul. 2006	Technical Committee provides management significance scores for new and renamed vital signs from Prioritization Workshop	Management significance scores allowed the new vital signs to be fully scored and ranked; 176 "vital signs" coming out of Prioritization Workshop pared down to 86, and further reduced to 36 high priority vital signs among the seven CHDN ecosystems.	See Appendix P, Table P.5
Jul. 2006	High priority vital signs assessed in context of terrestrial ecosystem characterization models	List of 86 vital signs further reduced to 36 high priority vital signs among the seven CHDN ecosystems. Vital signs relationship to ecosystem function depicted within context of conceptual models.	See Table 3.2; Figures 3.5, 3.6 & 3.7
Aug. 2006	Technical Committee meets to review 36 high priority vital signs, prioritization and selection process and make recommendations to the Board of Directors.	Vital sign prioritization selection process was enthusiastically & unanimously supported by the Technical Committee, as were the 36 high priority vital signs.	High priority vital signs list accepted

Step	Event	Vital Signs Milestone	Product
Aug. 2006*	Board of Directors convened to discuss Technical Committee recommendations & the vital signs prioritization & selection process.	Board of Directors unanimously approved the high priority vital signs, and the Technical Committee recommendations.	High priority vital signs move forward in monitoring plan development
* Late in the conceptual modeling process, and based on comments from Big Bend National Park's new interim superintendent, two additional vital signs were added after the Aug. 2006 BOD meeting. Both vital signs, however, were reviewed by the Technical Committee and approved by the CHDN BOD at their October 2006 meeting.			

The next major stage of vital signs refinement was a Prioritization Workshop held in June 2006 (Appendix P). Invited experts and park staff, including the Technical Committee, were assigned to one of five breakout groups: Animals, Aquatic Resources and Water Quality, Landscape, Plants and Soils, and Unique Systems (Caves & Dunes). Prior to the workshop, CHDN staff provided participants with the list of vital signs relevant to their particular group and asked them to assemble literature that supported the choice of their top five vital signs. Ninety-seven unique vital signs from the park-based scoping meetings were evaluated by ecosystem, based on justification source and ecological significance score (Table P. 1 in Appendix P). In addition, potential measures and potential partners were identified (Figure 3.2). The third scoring criterion, management significance, was provided by park staff before the prioritization workshop. New vital signs were also generated by the breakout groups during the two-day vital signs prioritization workshop. These new vital signs were existing vital signs that breakout groups renamed, vital signs that resulted from combining or splitting existing vital signs, or newly developed vital signs (Figure 3.3). Following the workshop, the Technical Committee scored all new vital signs for management significance.

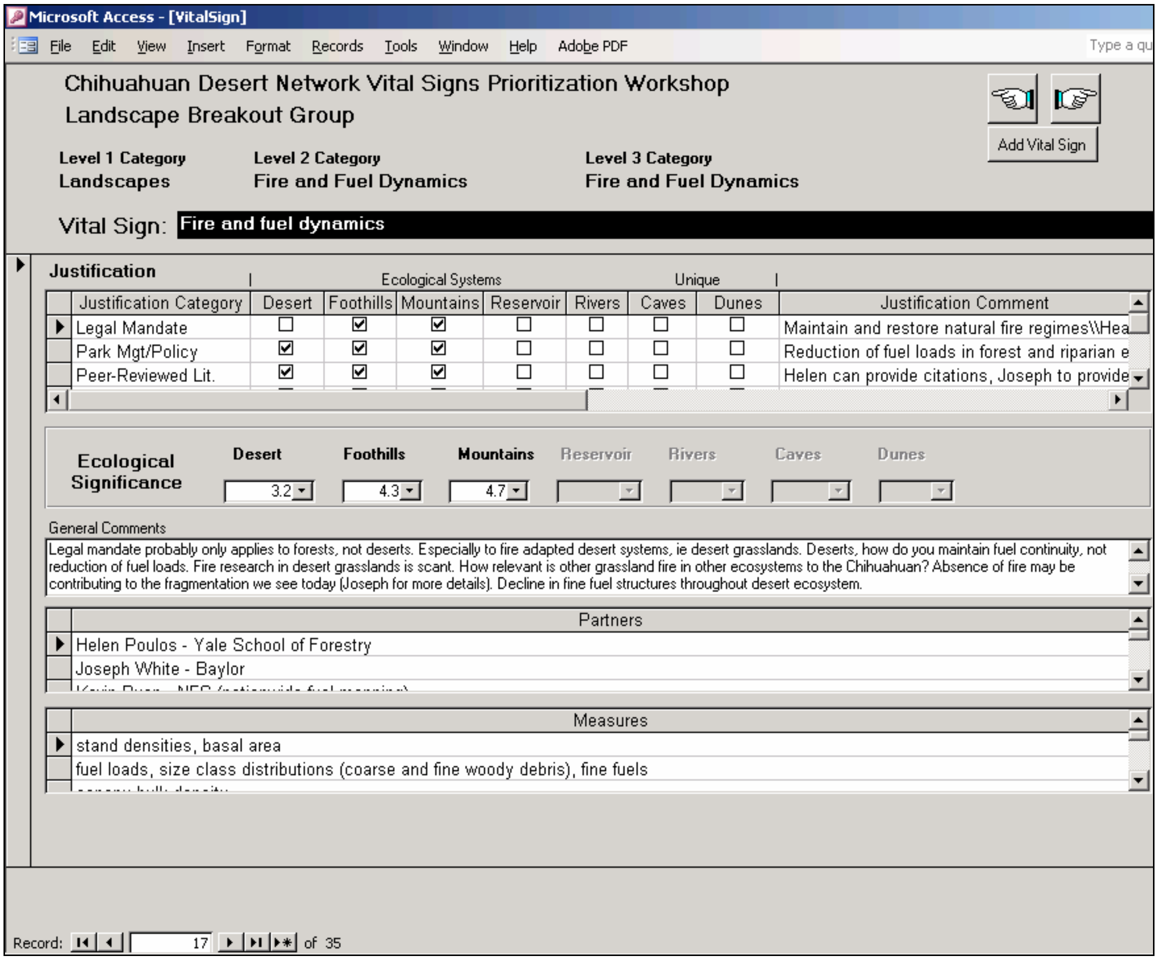

Figure 3.2. Completed datasheet from the Landscape breakout group for one of the 97 original vital signs.

After the Vital Signs Prioritization Workshop, CHDN staff evaluated existing and new vital signs from the five breakout groups. This list included a number of duplicate vital signs relevant to more than one breakout group. In some cases we decided to average scores across two or more vital signs that the breakout groups had combined. The same CHDN staff performed additional analysis of the vital signs generated by the workshop and reduced the lists generated by the workgroups to a more integrated and defined set of 86 unique candidate vital signs that were fully scored and ranked (Table P.5 in Appendix P). The breakout groups' disposition, management significance score, vital sign identification number, and CHDN final comments were also captured in an Access database (Figure 3.3). Each workgroup documented its decisions in a separate database (Landscape Vital Signs Database, Plant Vital Signs Database, Animal Vital Signs Database, Aquatic Vital Signs Database, Caves/Dunes Vital Signs Database). We then separated the scored vital signs by ecosystem and generated rank score diagrams (Tables P.6-P.12 in Appendix P). Based on scores and diagrams, we identified high priority vital signs from each ecosystem, which resulted in a list of 36 high priority vital signs (Table 3.2, Figure 3.4). Table 3.3 shows the measures for each high priority vital sign.

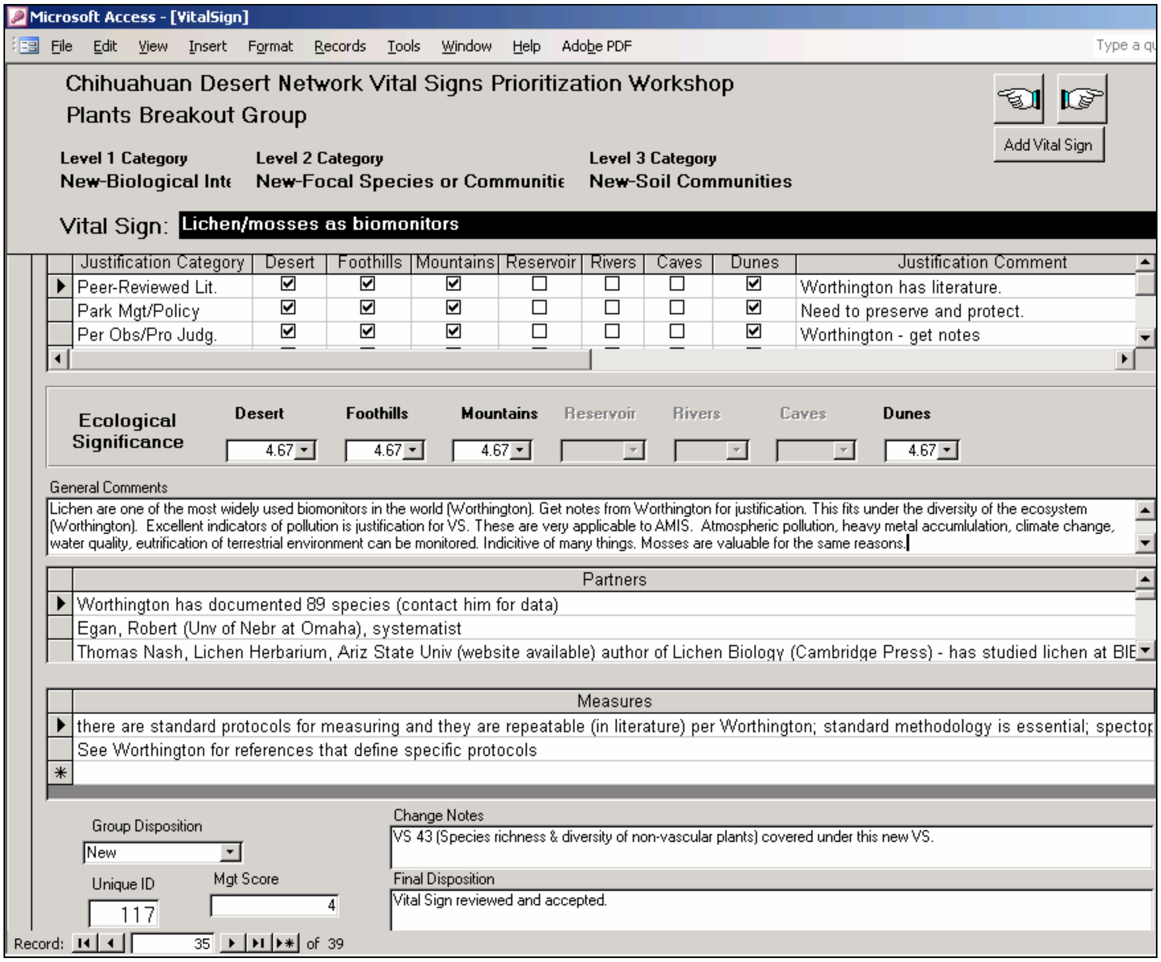

Figure 3.3. Datasheet from the Plants and Soils breakout group, showing group disposition, change notes, and final disposition for a newly developed vital sign.

In the next stage of vital sign validation, we stepped aside from the vital signs to give further thought to the overall conceptual framework for the monitoring program. The developers of the general ecosystem characterization models (see Chapter 2) viewed the high priority vital signs in the context of the models. This process, led us to identify an additional vital sign (Distribution and abundance of heteromyid rodents).

The model developers associated relevant indicators with the models as Drivers, Focal Resources (soils, vegetation, springs and seeps, fauna), and/or Stressors. Using an ecosystem perspective, we then fit the vital signs into the models. The ecosystem approach helped affirm how our conceptual models serve to maintain an encompassing view of network ecosystems. Of the high priority vital signs, eight vital signs relate to drivers, 22 relate to model attributes (focal resources), 11 relate to stressors, and three relate to two of the above (Table 3.4).

The CHDN Technical Committee met in August 2006 to discuss the vital signs process, conceptual models, candidate list of high priority vital signs, and vital signs to be retained into the next phase. No additional vital signs from the set of 86 were brought forward for inclusion in the high priority list. Representatives from Big Bend National Park and Guadalupe Mountains National Park were surprised that two vital signs, Night Sky and Soundscapes, had scored so low. The Technical Committee discussed including these vital signs in a final list but decided that existing vital signs on the list (land use changes within the Chihuahaun Desert, and landscape fragmentation) could provide an indirect measure of these vital signs. The committee decided the issue could be revisited by CHDN staff, the Technical Committee, and Board of Directors if detailed dynamic or mechanistic models supported the inclusion of Night Sky or Soundscapes.

Figure 3.4 Photo of mosses in desert ecosystem (VS 126).

The Technical Committee (TC) developed a set of five recommendations:

1. The Board of Directors should approve the list of 36 high priority vital signs identified across the seven prevalent ecosystems found among the CHDN parks.
2. The list was useful, comprehensive, and a valid representation of vital signs. It should provide monitoring information on ecological function and health to the parks, with the goal of improving decision-making and management of park resources.
3. The list was the result of a collaborative effort, with all parks working together, and it included input from outside subject matter experts. The Technical Committee did not recommend paring the list down,

except to remove any remaining redundancy by further combining vital signs.

4. The set of vital signs applicable to the greater number of ecosystems should provide the greatest value to the network parks.
5. The final set of vital signs should be in the 15-20 range (based on other networks with arid or semi-arid ecosystems); protocols, further cost analysis, and development or refinement of submodels should drive decisions on the size of the final list.

The Technical Committee agreed that, given budgetary constraints, potentially only a small subset of vital signs (5-10 range) could realistically be monitored over the long-term. Nevertheless, the Technical Committee did not want to constrain the final list of vital signs. They expressed that a spirit of cooperation with park resource staff and members of the scientific community, along with any additional conceptual modeling and scientific literature, should determine final vital signs for monitoring. (After the October 2006 meeting, two additional vital signs, Distribution and abundance of heteromyid rodents, and Geomorphology of river channels, were reviewed and approved.)

Two days after the Technical Committee met, the Board of Directors met via conference call. Most Technical Committee members were also present. A face-to face meeting was also conducted with the one Board of Director member who was unable to attend the conference call (Superintendent of Guadalupe Mountains National Park and in-coming Board of Director Chair). The vital signs prioritization and selection process was recapped, an update on the conceptual modeling process was provided, and Technical Committee recommendations were presented and discussed. The list of 86 vital signs and the subset of high priority vital signs were also reviewed and discussed.

The Board of Directors expressed confidence in the process. They felt the high priority list was comprehensive and strongly reflected indicators that should assist them and their staff in resource management. They unanimously concurred with the Technical Committee's recommendations and voted to adopt the list of 36 high priority vital signs. (After the October 2006 meeting, two additional vital signs, Distribution and abundance of heteromyid rodents, and Geomorphology of river channels, were reviewed and approved. This brings the total number of high priority vital signs to 38.)

Table 3.2. List of high priority vital signs for the Chihuahuan Desert Network by ecosystem

Level 1	Level 2	Vital Sign	Ecosystem						
			Desert	Foothills	Mountains	Reservoir	River	Caves	Dunes
Air and Climate	Air Quality	123 Atmospheric wet/dry deposition	X	X	X	X	X	X	
		3 Ozone			X				
		120 Particulate matter	X	X	X	X	X	X	X
		116 Visibility	X	X	X	X	X		X
	Weather and Climate	7 General meteorological conditions	X	X	X	X	X	X	X
Geology and Soils	Geomorphology	55 Dune formation and stability							X
		56 Dune reactivation							X
		54 Geomorphology of river channels				X	X		
	Soil Quality	80 Nutrient levels				X			
		137 Soil erosion (wind and water)	X	X	X				
Water	Hydrology	84-86 Groundwater dynamics	X	X	X	X	X	X	X
		105 Lake elevation for Amistad Reservoir				X			
		103 Persistence of springs & seeps	X	X	X	X	X	X	X
		139 Surface water dynamics	X	X	X	X	X		
		129 Watershed hydrology	X	X	X	X	X	X	X
	Water Quality	115 Sediment quality	X	X	X	X	X		
		122 Water quality (surface and groundwater)	X	X	X	X	X	X	X

Level 1	Level 2	Vital Sign	Ecosystem						
			Desert	Foothills	Mountains	Reservoir	River	Caves	Dunes
Biological Integrity	At-risk Biota	10 Distribution & relative abundance of animal species of concern	X	X	X	X	X	X	X
	Focal Species or Communities	35 Biological soil crusts	X	X	X				
		28 Bird communities	X	X	X	X	X		X
		132 Invertebrates in aquatic systems	X	X	X	X	X		X
		126 Lichen/mosses as biomonitors	X	X	X				X
		114 Microbial biofilm formation						X	
		130 Native and non-native fish in aquatic systems	X		X	X	X		
		111 Plant Phenology	X	X					X
		119 Plant community composition	X	X	X	X	X		X
		24 Relative abundance of bats	X	X	X	X	X	X	X
		118 Richness and diversity of terrestrial insects, esp. endemics	X						
		141 Distribution and abundance of heteromyid rodents	X						
	Invasive Species	110 Distribution & abundance of invasive/non-native plants	X	X	X	X	X	X	X
		112 Distribution of non-native animals	X	X	X	X	X		X
Landscapes	Extreme Disturbance Events	75 Distribution & characterization of extreme disturbance events	X	X	X	X	X	X	X
	Fire and Fuel Dynamics	76 Fire and fuel dynamics		X	X				
	Landscape Dynamics	135 Bare ground	X	X	X				X
		108 Land use changes within Chihuahuan Desert	X	X	X	X	X	X	X
		78 Landscape dynamics	X	X	X	X	X		X
		107 Landscape fragmentation and connectivity	X	X	X	X	X		X
		79 Vegetation patch dynamics (microscale)	X	X	X				X

Table 3.3. Measures for the high priority vital signs.

VS ID	Vital Sign Name	Measures
84-86	Groundwater dynamics	aquifer properties, flow (groundwater and spring) amounts and routes, rates, water level, inputs for groundwater models, interaction with surface water
129	Watershed hydrology	aquifer characterization properties, channel characteristics, hydrologic mapping, sedimentation, mass balance, water chemistry, vegetation interception and soil stability
56	Dune reactivation	mapping
122	Water quality (surface and groundwater)	endocrine disruptors, *E. coli*, pathogens, contaminants of emerging concern, isotopes, nutrient loading and budgeting, variables in EPA, NASQAN, and TECQ protocols
112	Distribution of non-native animals	distribution and abundance, diet, presence/absence
78	Landscape dynamics	fractional cover within map units, leaf area index, mapped vegetation classes with appropriate attribute data (like tree ages/size classes), remote sensing data parameters (biomass indices, brightness indices, SAVI, NDVI, EVI)
114	Microbial biofilm formation	presence/absence, other measures as dictated by qualified microbiologist
110	Distribution and abundance of invasive/non-native plants	presence and spread, see variables in PDA data, inputs for predictive models of spread
55	Dune formation and stability	mapping of spatial extent (dune margins)
126	Lichen/mosses as biomonitors	variables in protocols defined by Worthington
111	Phenology (leaf out/drop, flowering)/tree growth bands	above ground NPP measures, radial/incremental growth patterns, remote sensing variables that detect seasonal change like AVHRR
105	Lake elevation for Amistad Reservoir - AMIS only	elevation of water level
7	General meterological conditions	precipitation, wind, RH, T, snow pack, soil moisture, adiabatic lapse rates, solar radiation, short wave radiation
75	Distribution and characterization of extreme disturbance events	timing and extent (maps) of extreme events-floods, fire, defoliation, insect/pathogen outbreaks
28	Bird communities	vital rates of common species with environmental covariates, abundance, species diversity stratified by habitat, winter surveys in grassland
115	Sediment quality	concentration, loads, size distribution, chemical composition including toxic screening, redox potential
79	Vegetation patch dynamics (microscale)	gap dynamics and spatial (mapped) patterns especially at ecotones
116	Visibility	fine particles in air and light scattering and/or absorption
24	Relative abundance of bats	relative abundance and species diversity

VS ID	Vital Sign Name	Measures
108	Land use changes within Chihuahuan Desert	changes in developed areas, increasing exurban areas, human population growth, oil and gas fields/pads, agricultural lands
107	Landscape fragmentation and connectivity	road density and pattern, indices of landscape pattern like contiguity and connectivity
139	Surface water dynamics	hydroperiods, flow rates, and quantity, gauge height, stage/discharge relation, discharge, continuous and intermittent record, variables for TNC hydrologic assessment, watershed condition measures
119	Plant community composition	dominance and importance values
132	Invertebrates in aquatic systems	diversity, species richness, occurrence, observed/expected, variables in EPA, TCEQ, and NAWQA protocols
135	Bare ground	change in size and mapped distribution, rate of increase
10	Distribution and relative abundance of animal species of concern	abundance, distribution, movement, gene flow, viability
103	Persistence of springs and seeps	occurrence, persistence, discharge, change in local vegetation
123	Atmospheric wet/dry deposition	concentrations and depositions of pollutants, rainfall
120	Particulate matter	
130	Native and non-native fish in aquatic systems	variables in standard protocols (RBP, IBI), selected metrics (richness, diversity, occurrence, etc.)
76	Fire and fuel dynamics	variables in standard protocols, remote sensing variables (NBI, fire regime parameters), inputs for fire models, fire effects, area and perimeter mapping, canopy bulk density, fire return interval, fire intensity, fire severity, fuel loads, size class distributions (coarse and fine woody debris), fine fuels, stand densities, basal area
137	Soil erosion (wind and water)	see variables in baseline data of NRCS, BSNE, inputs for erosion models, remote sensing data and spatial measures, wind erosion monitoring devices, amount of silt in traps
35	Biological soil crusts	form, cover and composition by structural group
80	Nutrient levels	nitrogen, phosphorus, potassium, pH responsible for plant nutrient uptake
3	Ozone	ozone concentrations in air
118	Richness and diversity of terrestrial insects, esp. endemics	presence/absence by habitat
54	Geomorphology of river channels	remote sensing data--change detection, spatial indices (shape, tortuosity)
141	Distribution and abundance of heteromyid rodents	occurrence or abundance, species diversity stratified by habitat

Table 3.4. The interrelationships among the high priority vital signs for monitoring ecosystem health and function in National Park units of the Chihuahuan Desert Network.

Unique Name	Applicable Ecosystems*	Conceptual Model Function	Component Name
Groundwater dynamics	DE, FT, MT, RS, RV, CV, DU	Driver	Geomorphology/Hydro
Watershed hydrology	DE, FT, MT, RS, RV, CV, DU	Driver	Geomorphology/Hydro
Dune reactivation	DU	*Driver, Focal Resource*	*Geomorphology/Hydro, Dunes*
Water quality (surface and groundwater)	DE, FT, MT, RS, RV, CV, DU	Driver	Geomorphology/Hydro
Distribution of non-native animals	DE, FT, MT, RS, RV	Stressor	Invasive Species
Landscape dynamics	DE, FT, MT, RS, RV, DU	Focal Resource	Vegetation
Microbial biofilm formation	CV	*Focal Resource*	*Cave Structures*
Distribution and abundance of invasive/non-native plants	DE, FT, MT, RS, RV, DU	Stressor	Invasive Species
Dune formation and stability	DU	*Focal Resource*	*Dunes*
Lichen/mosses as biomonitors	DE, FT, MT, DU	Focal Resource	Vegetation
Phenology	DE, FT, DU	Focal Resource	Vegetation
Lake elevation for Amistad Reservoir	RS	Focal Resource	Reservoir
General meterological conditions	DE, FT, MT, RS, RV, CV, DU	Driver, Stressor	Climate/Atmospheric, Climate Change
Distribution and characterization of extreme disturbance events	DE, FT, MT, RS, RV, CV, DU	Driver	Natural Disturbance
Bird communities	DE, FT, MT, RS, RV, DU	Focal Resource	Fauna
Sediment quality	DE, FT, MT, RS, RV	Focal Resource	Soil, Springs/Streams
Vegetation patch dynamics (microscale)	DE, FT, MT, DU	Focal Resource	Vegetation
Visibility	DE, FT, MT, RS, RV, DU	Stressor	Air Pollution
Relative abundance of bats	DE, FT, MT, RS, RV, CV, DU	Focal Resource	Fauna
Land use changes within Chihuahuan Desert	DE, FT, MT, RS, RV, CV, DU	Stressor	Adjacent Land Use
Landscape fragmentation and connectivity	DE, FT, MT, RS, RV, DU	Stressor	Adjacent Land Use
Surface water dynamics	DE, FT, MT, RS, RV,	Driver	Geomorphology/Hydro
Plant community composition	DE, FT, MT, RS, RV, DU	Focal Resource	Vegetation
Invertebrates in aquatic systems	DE, FT, MT, RS, RV, DU	Focal Resource	Springs/Streams, Fauna
Bare ground	DE, FT, MT, DU	Focal Resource	Soil, Vegetation
Distribution and relative abundance of animal species of concern	DE, FT, MT, RS, RV, CV, DU	Focal Resource	Fauna
Persistence of springs and seeps	DE, FT, MT, RS, RV, CV, DU	Focal Resource	Springs/Streams
Atmospheric wet/dry deposition	DE, FT, MT, RS, RV, CV,	Stressor	Air Pollution

Unique Name	Applicable Ecosystems*	Conceptual Model Function	Component Name
Particulate matter	DE, FT, MT, RS, RV, CV, DU	Stressor	Air Pollution
Native and non-native fish in aquatic systems	DE, MT, RS, RV	Focal Resource, Stressor	Fauna
Fire and fuel dynamics	FT, MT	Stressor	Historic Land Use-Fire Suppression
Soil erosion (wind and water)	DE, FT, MT	Focal Resource	Soil
Biological soil crusts	DE, FT, MT	Focal Resource	Soil
Nutrient levels	RS	Focal Resource	Soils
Ozone	MT	Stressor	Air Pollution
Richness and diversity of terrestrial insects, esp. endemics	DE	Focal Resource	Fauna
Geomorphology of river channel	RS, RV	Driver	Watershed
Distribution and abundance of heteromyid rodents	DE	Focal Resource	Fauna
*Ecosystem abbreviations: DE=Desert, FT=Foothill, MT=Mountain, RS=Reservoir, RV=River, DU=Dune, CV=Cave			
Italicized = not confirmed in ecosystem models.			

3.2 Proposed High Priority Vital Signs

The high priority vital signs list for the Chihuahuan Desert Network includes 38 vital signs (Table 3.2). These include five vital signs related to air and climate, 15 related to biological integrity, five related to geology and soils, six related to ecosystem pattern and processes, and seven related to water. These vital signs were derived using the process described in the previous section.

Herrick et al. (1995) have also developed a suite of indicators that may be meaningful for monitoring the health of arid and semiarid ecosystems (Table 3.5). Their indicators:

1. reflected the status of a critical ecosystem process or an economic-social value,
2. were unambiguous (i.e., the trajectory of the measure is unidirectional in response to ecosystem stressors of increasing intensity),
3. were applicable to the range of ecosystems encountered in the arid and semiarid landscapes, and
4. were readily and inexpensively measured.

Whitford (2002) described several indicators that were useful in monitoring programs specific to Chihuahuan Desert rangelands: average size of bare patches, cover of long-lived grasses, a palatability index, and a soil surface stability index. Other indicators which may prove useful for assessing rangeland health include: cover of invasive species and cover of increaser species (native plant species that rapidly spread into stressed environments).

Table 3.5 . Indicators useful in assessing or monitoring the condition of arid and semiarid ecosystems (from Herrick et al. 1995).

Ecosystem Function or Process	Indicator
Soil stability and watershed function	1. Total vegetation cover and average height of vegetation
	2. Size of unvegetated patches
	3. Spatial distribution and orientation of unvegetated patches
	4. Surface stability
	5. Cryptogamic crust cover
	6. Litter and rock cover
	7. Infiltration capacity
	8. Size and spatial distribution of litter patches
	9. Penetration resistance (compaction)
	10. Root density and depth based on species composition
	11. Soil disturbance by animals
	12. Predictability of annual plants
	13. Ratio of long-lived to short-lived grasses
	14. Ratio of seed-reproducing grasses/vegetative-reproducing grasses
Productivity (energy flow)	Indicator 1
	15. Rainfall use efficiency
	16. C3/C4 plant cover ratio vs. rainfall seasonality
Animal production (including wildlife)	17. Palatability index for each animal species
	18. Forage value index
Nutrient cycling	Indicators 1, 2, 3, 8, 12, 14

3.3 Relationship of the High Priority Vital Signs to Conceptual Models and Justifications

We linked each high-priority vital sign to our general characterization models for the three terrestrial ecosystems (Figures 3.5, 3.6, 3.7). These signs include eight vital signs related to drivers, 22 related to model attributes (focal resources), and nine related to stressors. Two vital signs, Biological Soil Crusts (VS 35) and Terrestrial Insects (VS 118, Figure 3.8), were not among the top-ranked vital signs to come out of the prioritization workshop but we included them due to the level of justification support (from the characterization models and peer-reviewed literature).

In the mountain ecosystem model, another vital sign, Ozone (VS 3), is added as a potential indicator of air pollution and interacts with climate and atmospheric conditions. Two plants identified as sensitive to ozone, ponderosa pine and skunkbush, are found at Big Bend National Park and Guadalupe Mountains National Park (Appendix K). Both parks have Mountain Ecosystems.

The Technical Committee will use Figures 3.5, 3.6 and 3.7 as a basis for further vital signs discussion. During the fall of FY07, we will: 1) complete work on the other characterization ecosystem models; 2) identify existing subsystem dynamic and mechanistic models which will assist in refining the list of high- priority vital signs; and 3) identify the vital signs that would provide the most information about our resource protection concerns and ecosystems. Once we complete this exercise for each vital sign, we will then determine any further feasibility evaluations (cost and logistics of measures) needed for protocol development and sample design. We will emphasize vital signs that provide information to as many model elements (drivers, focal resources, stressors) as possible (Figure 3.9).

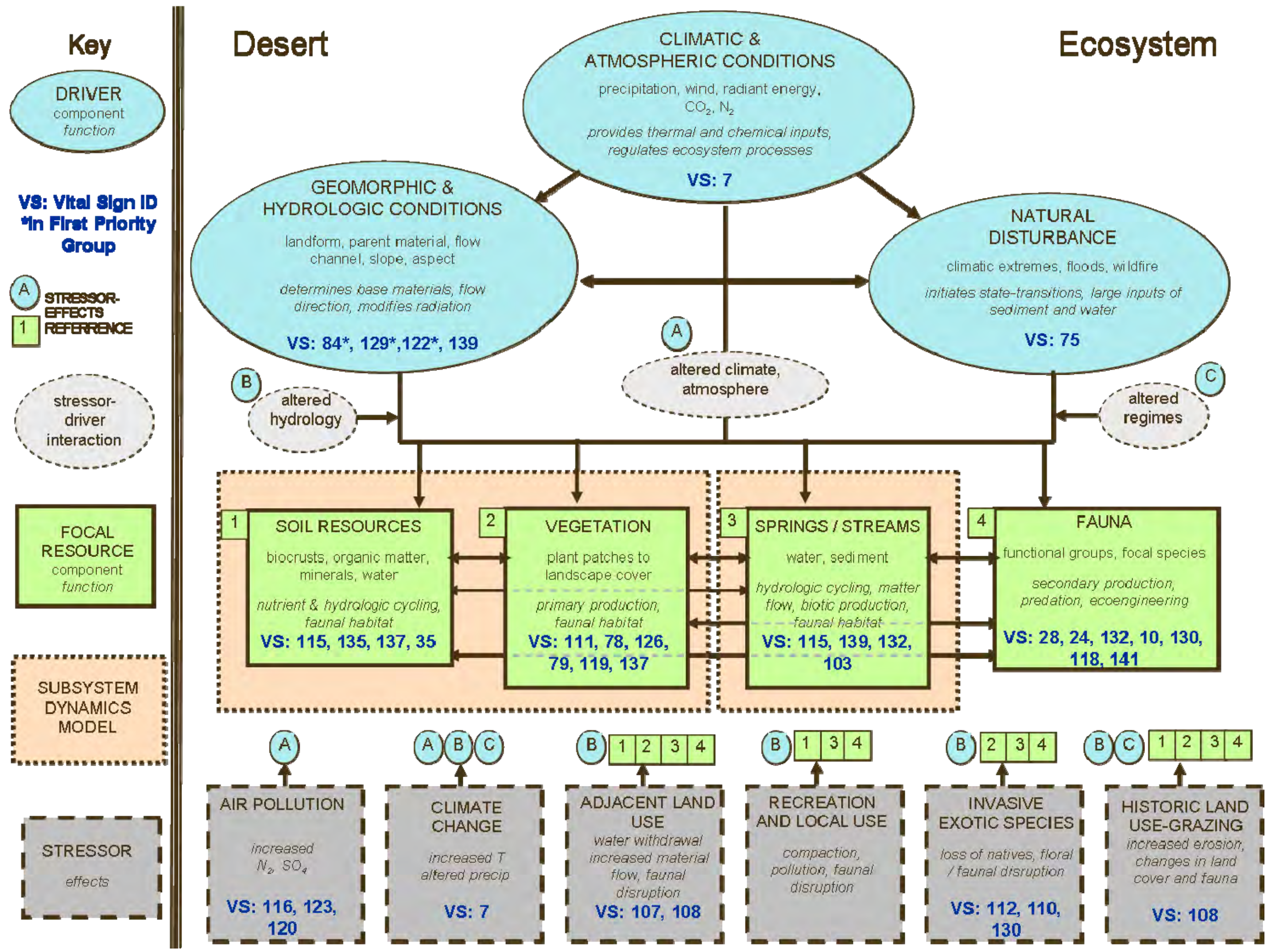

Figure 3.5. High priority vital signs of the Chihuahaun Desert Network in relation to the Desert Ecosystem Characterization Model as described in Chapter 2: Figure 2.4. Vital signs are associated with the relevant ecosystem components. For example, monitoring VS 108 (Land use changes in the Chihuahuan Desert) could provide information relevant to focal resources (i.e., changes to hydrologic cycling, landscape scale cover, and faunal populations), as well as the stressor-driver interaction of altered hydrology.

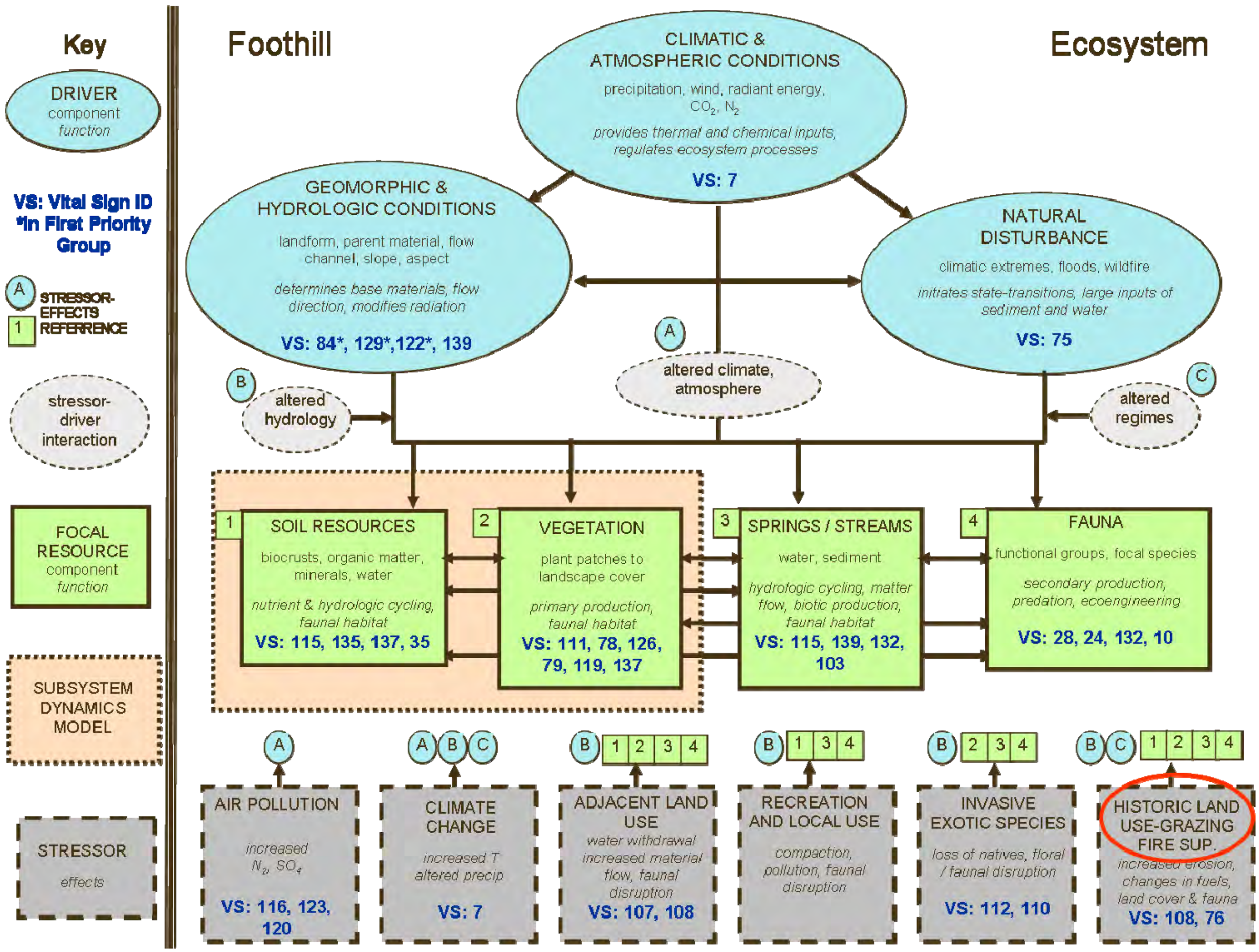

Figure 3.6. High priority vital signs of the Chihuahuan Desert Network in relation to the Foothills Ecosystem Characterization Model as described in Chapter 2: Figure 2.5. Vital signs are associated with the relevant ecosystem components. In the foothills characterization model, fire suppression is added to the stressor "Historic Land Use." Fire and fuel dynamics may therefore be an important vital sign for monitoring.

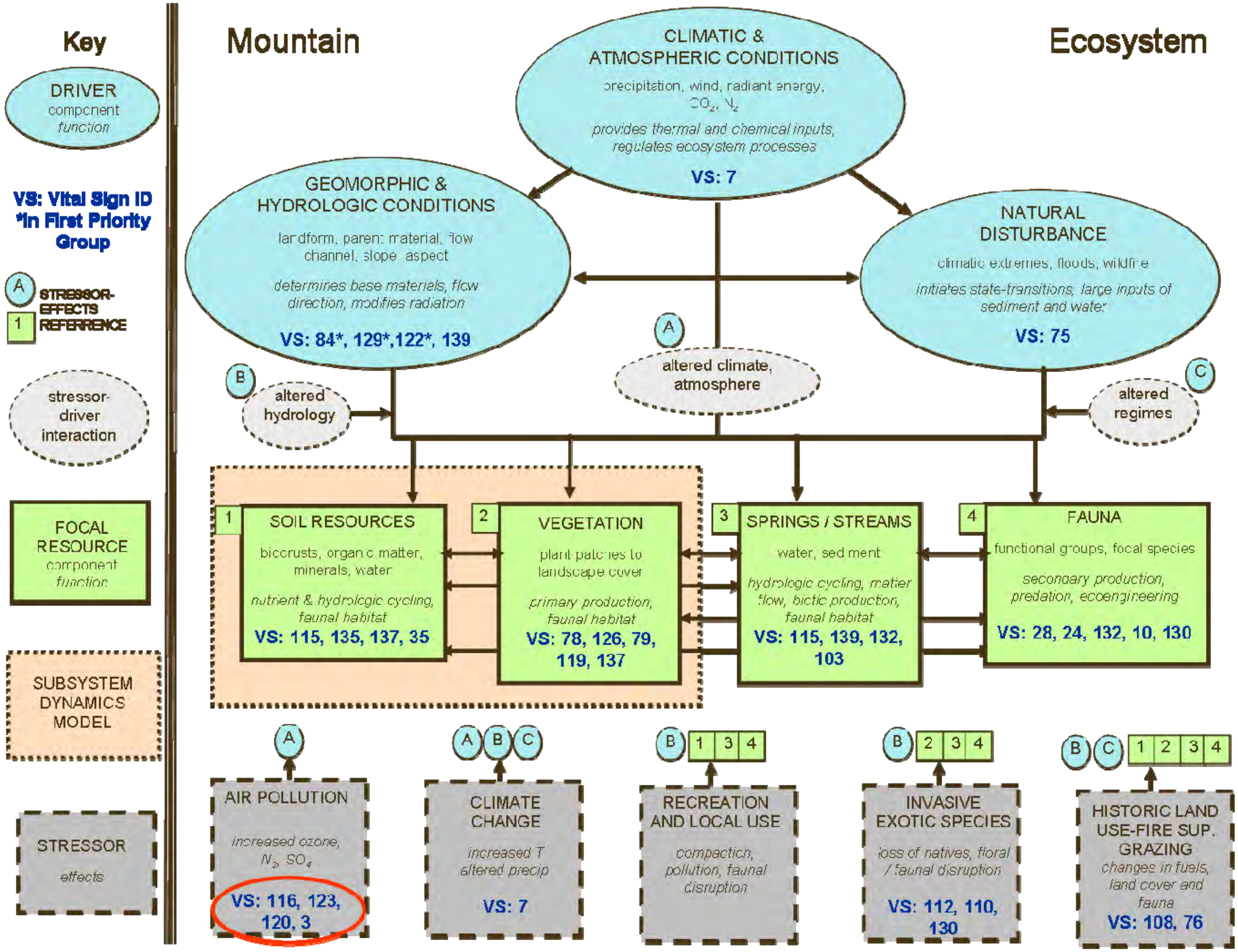

Figure 3.7. High priority vital signs of the Chihuahuan Desert Network in relation to the Mountains Ecosystem Characterization Model as described in Chapter 2: Figure 2.6. Vital signs are associated with the relevant ecosystem components. Note the addition of VS 3-Ozone as an air pollutant (stressor) of the Mountain Ecosystem.

Figure 3.8 Photo of termite swarm (VS 118).

Figure 3.9 Photo of landscape fragmentation (VS 107). Encroaching development impacts the geomorphic and hydrologic conditions of the area to cause altered hydrology, a stressor-driver interaction).

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