National Park Service
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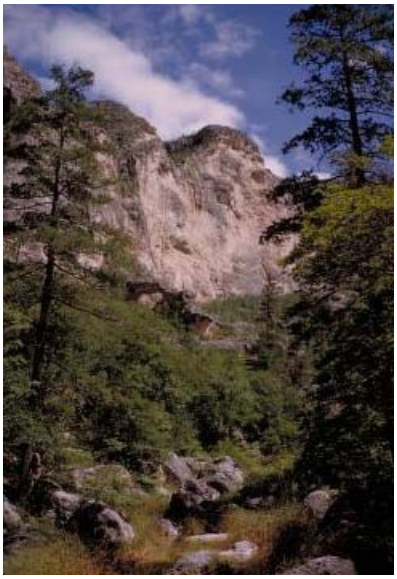
Natural Resource Program Center

Chihuahuan Desert Network Vital Signs Monitoring Plan

Natural Resource Report NPS/CHDN/NRR—2010/188



ON THE COVER
Clockwise from upper left to bottom right: Carlsbad Caverns National Park, Guadalupe Mountains National Park, Fort Davis National Historic Site, Big Bend National Park, White Sands National Monument (by Pete Mananen), Amistad National Recreation Area. NPS photos unless otherwise noted.

Chihuahuan Desert Network Vital Signs Monitoring Plan

Natural Resource Report NPS/CHDN/NRR—2010/188

National Park Service
Chihuahuan Desert Inventory and Monitoring Network
Genesis C Building
New Mexico State University
Las Cruces, NM 88003

April 2010

U.S. Department of the Interior
National Park Service
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Fort Collins, Colorado

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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 Chihuahuan Desert Network I&M program, leading the biological inventory field efforts for several years and serving as the first network program manager 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 was 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 taught us never to believe in first impressions, and to always give your colleagues and friends the benefit of the doubt. He understood the meaning of friendship. Bill is sorely missed.

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Acronyms

ac	acres
AMIS	Amistad National Recreation Area
AQRV	Air-quality-related values
BIBE	Big Bend National Park
BOD	Board of Directors
BSC	biological soil crust
CAVE	Carlsbad Caverns National Park
CC	Área de Protección de Flora y Fauna Cuatrociénegas
CESU	Cooperative Ecosystem Studies Unit
CH_4	methane
CHDN	Chihuahuan Desert Network
CO_2	carbon dioxide
CONANP	National Commission of Protected Natural Areas
DMP	Data Management Plan
DOC	dissolved organic carbon
EPA	Environmental Protection Agency
Fe	iron
FODA	Fort Davis National Historic Site
ft	feet
FTE	full-time equivalent
FY	fiscal year
GIS	geographic information systems
GMP	general management plan
GPRA	Government Performance and Results Act
GRTS	Generalized Random Tessellation Stratified
GRYN	Greater Yellowstone Network
GUMO	Guadalupe Mountains National Park
H_2S	hydrogen sulfide
ha	hectares
I&M	inventory and monitoring
IBWC	International Boundary and Water Commission
IMR	Intermountain Region
in	inches
IT	information technology
km	kilometers
m	meters
Mn	manganese
MS	Microsoft
NHS	national historic site
NM	national monument
NP	national park
NPS	National Park Service
NRA	national recreation area
O_2	oxygen
OMB	U.S. Office of Management and Budget
ONRW	Outstanding National Resource Waters
PI	principal investigator
POC	particulate organic carbon
ppm	parts per million
QA/QC	quality assurance/quality control

RIGR	Rio Grande Wild and Scenic River
RMBO	Rocky Mountain Bird Observatory
ROMN	Rocky Mountain Network
SODN	Sonoran Desert Network
SOPN	Southern Plains Network
SOPs	standard operating procedures
TBD	to be determined
TC	Technical Committee
TCEQ	Texas Commission on Environmental Quality
WASO	Washington Support Office
WHSA	White Sands National Monument
WSR	wild and scenic river

Executive Summary

Knowing the condition of natural resources in national parks is fundamental to the ability of the National Park Service (NPS) to manage park resources "unimpaired for the enjoyment of future generations." To more fully meet its mission, the NPS has implemented a strategy, funded by the Natural Resource Challenge, to programmatically institutionalize natural resource inventory and monitoring. This effort was undertaken to ensure that NPS units with significant natural resources possess the information needed for effective, science-based resource management decisionmaking. The national strategy consists of a framework with three major components: (1) completion of basic resource inventories upon which monitoring efforts can be based; (2) creation of experimental prototype monitoring programs to evaluate alternative monitoring designs and strategies; and (3) implementation of ecological monitoring in all parks with significant natural resources.

To facilitate collaboration and information sharing among parks with similar natural resource issues, and to achieve economies of scale in inventory and monitoring, the NPS organized the more than 270 parks with significant natural resources into 32 ecoregional networks. Parks within each network work together 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 park units in Texas and New Mexico: Amistad National Recreation Area (AMIS), Big Bend National Park (BIBE), Carlsbad Caverns National Park (CAVE), Fort Davis National Historic Site (FODA), Guadalupe Mountains National Park (GUMO), Rio Grande Wild & Scenic River (RIGR, managed by BIBE), and White Sands National Monument (WHSA). The CHDN monitoring program is designed to complement, not replace, existing park and other agency monitoring programs. Funding for the CHDN program supports a core, professional I&M staff who conduct the day-to-day activities of the network. The core staff collaborate with staff from the network parks and other programs and agencies to implement an integrated long-term program for monitoring high-priority vital signs.

The program is designed to ensure that monitoring addresses critical information needs of park managers and produces ecologically relevant, scientifically credible data that are accessible to park managers, planners, and other key audiences. The monitoring program will leverage its funding through collaborative partnerships with other programs, agencies, and academia. This monitoring plan is the foundation of the CHDN monitoring program. The plan is the result of a multi-year investment in program development.

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 that are accessible to managers in a timely manner. The CHDN monitoring program is being developed over four years, with specific objectives and reporting requirements for each of three planning phases. This final vital signs monitoring plan:

1. Outlines CHDN monitoring goals and the planning process used to develop the monitoring program (Chapter 1);
2. Summarizes existing information concerning park natural resources and resource management issues across the network (Chapter 1);
3. Provides a conceptual model framework for CHDN park ecosystems (Chapter 2);
4. Selects and prioritizes vital signs (Chapter 3);
5. Presents a sampling framework for aquatic and terrestrial ecosystems in parks (Chapter 4);
6. Summarizes monitoring protocols (Chapter 5);

7. Describes the network's approach to data management (Chapter 6); and
8. Provides information on program administration, operations, and funding (Chapters 8-10, respectively).

The diversity of ecosystems in CHDN parks, the geographic distribution of these parks, and differences in resource management priorities among parks are perhaps the greatest challenges facing the network. However, the vital signs selection process found that parks share a number of similar resource management issues and monitoring needs. The vital signs selection process also recognized that high-priority, park-specific needs should be addressed to the extent possible. This balance between identifying common needs and addressing park-specific issues will continue to be important as the CHDN implements long-term vital signs monitoring of parks.

This CHDN vital signs monitoring plan identifies the suite of vital signs for monitoring. To monitor these vital signs, the network will prepare and implement 10 monitoring protocols in selected parks over the next 2–3 years. When possible, the CHDN will implement protocols used by other networks to increase efficiency and facilitate evaluation across greater spatial scales. Protocols, the vital signs to which they correspond, and the parks where they will be monitored are shown in the table below.

Chihuahuan Desert Network monitoring protocols by vital sign and park.

Protocol	Vital sign(s)	AMIS	BIBE	CAVE	FODA	GUMO	RIGR	WHSA
Air Quality	Ozone Wet and Dry Deposition Visibility and Particulate Matter		X	y		X		
Climate	Basic Meteorology	X	X	X	X	X		X
Dune Dynamics	Dune Formation and Stability Dune Morphology					y		X
River Channel Morphology	River Channel Characteristics	y	X				y	
Groundwater Quantity	Groundwater Quantity	X	X	X	X	X		X
Surface Water Quality and Dynamics	Surface Water Dynamics Persistence of Springs Surface Water Quality Aquatic Invertebrates	X	X	X		X		
Invasive/Non-native Plants	Invasive/Non-native Plants	X	X	X	X	X	X	X
Landbirds	Bird Communities	X	X	X	X	X	X	X
Integrated Uplands (Soils and Vegetation)	Plant Community Composition Soil Hydrologic Function Biological Soil Crusts Soil Erosion (Wind and Water) Bare Ground		X	X	X	X		X
Landscape Patterns and Dynamics	Land Cover Land-Use Changes	X	X	X	X	X		X

y = This park will be monitored if resources permit.

Network I&M staff and their cooperators make thousands of observations each year about plant and animal populations, communities, and their environments. In essence, the purpose of data management is to ensure that an accurate and complete record of those observations is maintained in perpetuity. The CHDN Data Management Plan identifies key data resources and processes to manage inventory and monitoring data. Assuring and maintaining data integrity is fundamental to the CHDN mission and requires a considerable investment of staff time. Data management procedures follow five key steps: acquisition, verification, validation, analysis, and dissemination. In addition, storage, maintenance, and security issues apply to all stages of data flow.

Reporting is the process through which we derive information from data through analysis and interpretation for use by park managers. Vital signs reporting will include annual reports for specific protocols and projects; annual briefings to park managers; resource briefs; analysis and synthesis reports; protocol and program reviews; natural resource summary tables; scientific journal articles and book chapters, and presentations at scientific meetings; and postings to network Internet and Intranet websites and the Learning Center of the American Southwest. To promote efficient reporting, data management efforts during the summary and analysis phase will focus on automation of routine reports. Summary analysis for annual reports of vital signs monitoring studies will include graphed results and descriptive statistics (mean, standard deviation, sample size) for all of the primary variables included in the project. Five to ten-year trend reports will typically include correlation and trends analysis.

Administrative oversight for the program originates from the CHDN Board of Directors (BOD) and Technical Committee (TC). The BOD, composed of the superintendents of six parks, is charged with oversight of the network. The TC is composed of natural resource managers from each CHDN park and serves as the scientific and operational body of the network that develops recommendations on how monitoring is implemented. The CHDN program manager is supervised by the Intermountain Region I&M program manager with input from the BOD. In turn, the program manager, or his/her subordinates, supervise all I&M staff. Currently, the CHDN employs three permanent and one term employee, and two students from New Mexico State University.

Two principal sources of funding are combined to support operations of the CHDN: vital signs monitoring funds from the Natural Resource Challenge ($799,400 in FY10) and $66,700 (in FY10) for water quality monitoring from the NPS Water Resources Division. All funds are managed by the program manager under the oversight of the BOD. An annual work plan that directs expenditure of funds is developed with input from the TC and approved by the BOD. All I&M program funds must be accounted for and disclosed in an annual administrative report, reviewed by the BOD.

The CHDN will be subject to periodic reviews to ensure high program quality and accountability. This monitoring plan was approved by the Washington Support Office monitoring leader in 2010. In 2013, and every fifth year thereafter, a comprehensive review of program operations will be conducted. Peer review of monitoring protocols will be conducted by the IMR I&M program manager upon their completion and prior to implementation.

Acknowledgements

This monitoring plan could not have been completed without the commitment, hard work, and support of network staff, park staff, and external cooperators. Specifically, the CHDN would like to acknowledge the following people for developing and authoring sections of this plan: Hildy Reiser (Chapters 1, 3, 5, 7, 8, 9, 10, appendices), Steve Garman (Chapters 2, 4), Missy Powell (Chapter 11), Tom Richie (Chapter 6), James P. Ward, Jr. (Chapters 2, 4) and Kirsten Gallo (Chapters 4, 5, 8, 9, 10). Ann Lewis and Alice Wondrak Biel provided invaluable editorial assistance.

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Chapter 1: Introduction

1.1 Background

Knowing the condition and trends 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." National park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions, and for working with other agencies and the public for the benefit of park resources.

An essential tool for natural resource stewardship in the NPS is the use of monitoring. Ecological monitoring establishes reference conditions for natural resources that can be used to detect future changes and determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Monitoring results may also be used to determine what constitutes impairment and to identify the need to initiate or change management practices. Natural resource monitoring offers park-specific information needed to understand and identify changes in complex, variable, and imperfectly understood natural systems (i.e., threats from air and water pollution, climate change, and invasive/non-native species originating outside park boundaries). Monitoring provides a basis for understanding and identifying meaningful change in natural systems (Roman and Barrett 1999).

Accordingly, in 1999, the 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 augment ongoing park inventory and monitoring efforts into an ambitious, comprehensive, nationwide program. The servicewide natural resources inventory and monitoring (I&M) program was introduced to 270 parks identified as having significant natural resources. Under this program, parks were organized into 32 networks based on similar geographic and natural resource characteristics, allowing for improved efficiency and sharing of staff and resources (Fancy et al. 2009). The Chihuahuan Desert Network (CHDN) is one of those 32 networks.

Over a multi-year period, the CHDN Vital Signs Monitoring Plan was developed following specific guidance from the NPS Washington Support Office (WASO) (NPS 2006a). This plan describes the process for selection of and the plan for monitoring "vital signs" of the natural resources in Amistad National Recreation Area (AMIS); Big Bend National Park (BIBE) and Rio Grande Wild and Scenic River (RIGR), administered by BIBE; Carlsbad Caverns National Park (CAVE); Fort Davis National Historic Site (FODA); Guadalupe Mountains National Park (GUMO); and White Sands National Monument (WHSA).

"Vital signs," as defined by the 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 or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve, including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. The broad-based, scientifically sound information obtained through natural resource inventories and monitoring will have multiple applications for management decisionmaking, research, education, and promoting public understanding of park resources (Figure 1.1).

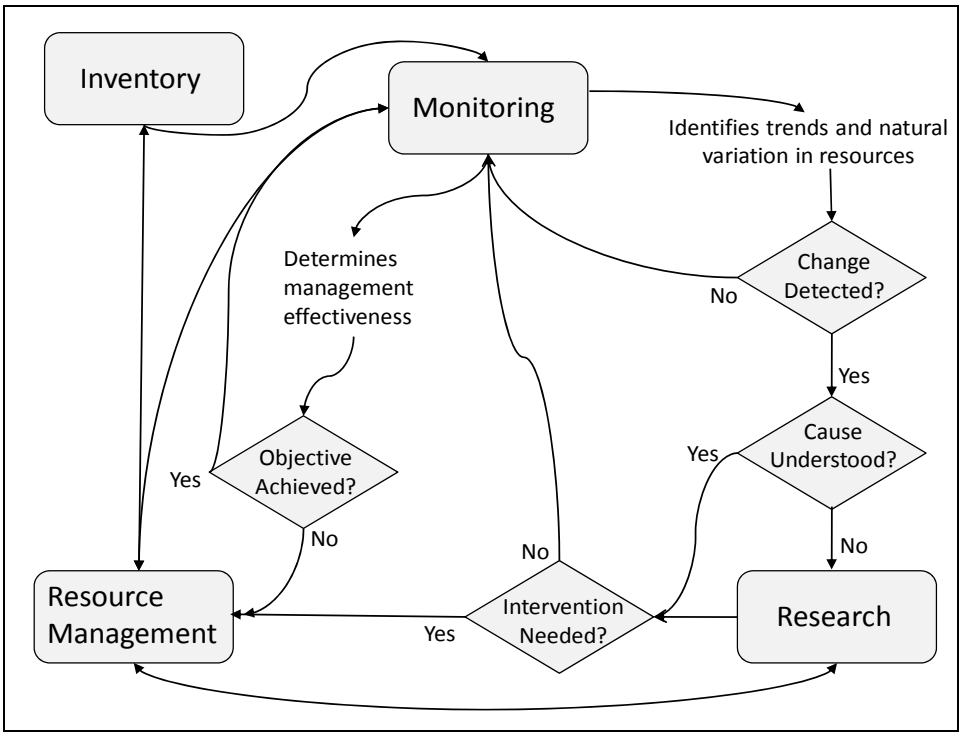

Figure 1.1. Relationships between monitoring, inventories, research, and natural resource management activities in national parks (modified from Jenkins et al. 2002).

1.2 Guidance

1.2.1 Goals of vital signs monitoring in the Chihuahuan Desert Network

The overall goal of the servicewide I&M program is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems (Fancy et al. 2009). The five NPS servicewide and CHDN vital signs monitoring goals are:

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

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

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

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

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

Clearly articulated goals and objectives help define all aspects of a program, including the choice of vital signs to be monitored. CHDN objectives will be developed for each individual vital sign.

1.2.2 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 . . . by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, 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), effectively ensuring that all park units be united into the "National Park System" by a common purpose of preservation, regardless of title or designation. Several decades later, NPS management policy reiterated the importance of this protective function of the agency to "understand, maintain, restore, and protect the inherent integrity of the natural resources" (NPS 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 (Public Law 105-391). One intent of the Act was 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." In 2001, NPS managers updated previous policy and specifically directed the NPS to inventory and monitor natural systems in efforts to inform park management decisions (NPS 2001).

The NPS Water Resources Division provides explicit guidance and funding for the water quality component of each of the 32 networks' monitoring programs. Design and implementation of water quality monitoring is fully integrated with the network vital signs monitoring design process (including staffing, planning, and design) to facilitate integration within the context of a comprehensive network monitoring program. The NPS goal is to rely on its own uniform monitoring data and use it to protect water resources. Monitoring of water quality also is supported through legislation, policy, and guidance as described above. Each I&M network is required to (1) determine priorities for impaired water and pristine water monitoring; (2) define site-specific monitoring objectives; and (3) develop water quality monitoring plans.

Additional legislation is intended not only to protect the natural resources within national parks and other federal lands, but also 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 contain natural resources that are compromised in other parts of the country. Therefore, the 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 (Appendix A).

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

1.2.3 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). Park-specific enabling legislation (see Appendix A), as well as international programs, collectively influence 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 protect and, in some cases, gives specific guidance for the direction and emphasis of resource management programs, including inventory and monitoring.

1.2.4 The Government Performance and Results Act

The Government Performance and Results Act (GPRA) is central to NPS operations, including the I&M program. The NPS has developed a national strategic plan identifying key goals to be met (NPS 2001). A list of the national GPRA goals relevant to CHDN parks is located in Table 1.2.4. 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 1.2.4. Government Performance and Results Act goals specific to CHDN parks and relevant to the monitoring plan.

Goal #	GPRA Goal	Parks with this Goal
Category 1a: Natural and cultural resources and associated values are protected, restored, and maintained in good condition and managed within their broader ecosystem context.		
1a1A	Disturbed Lands Restored	BIBE, GUMO
1a1B	Invasive/Non-native Plants	AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA
1a1D	Land Health – Riparian and Stream Areas	BIBE, CAVE, GUMO
1a1E	Land Health – Upland	BIBE, CAVE, FODA, GUMO
1a2	Threatened and Endangered Species	AMIS, CAVE, BIBE, GUMO, RIGR,
1a2B	Species of Special Management Concern	BIBE
1a2C	Invasive/Non-native Animals	AMIS, BIBE, CAVE, GUMO, RIGR, WHSA
1a3	Air Quality and Wilderness Values	BIBE, GUMO
1a4A	Water Quality (Rivers, Streams)	AMIS, BIBE, GUMO, RIGR
1a4B	Water Quality (Lakes)	AMIS
1a4C	Water Quantity (Protected and/or Restored)	BIBE, CAVE, GUMO, RIGR, WHSA
Category 1b: The NPS contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information.		
1b01	Park Natural Resource Data Sets (Inventories)	AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA
1b3A	Vital Signs Identified	AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA
1b3B	Vital Signs Monitored	AMIS, BIBE, CAVE, FODA, GUMO, RIGR, WHSA

1.3 Overview and Ecological Characteristics of the Chihuahuan Desert Network

The Chihuahuan Desert Network includes seven NPS units in New Mexico and Texas (Table 1.3, Appendix C). These park units vary in size from almost 200 ha (~500 ac) at FODA to over 300,000 ha (800,000 ac) at BIBE (Table 1.3). In this section, we provide an overview of the CHDN, briefly describe ecological factors that influence the types of resources within park boundaries, and discuss salient characteristics of each park unit.

Table 1.3. National Park System units and size in the Chihuahuan Desert Network.

Unit	State	Park code	Area	
			Hectares	Acres
Amistad National Recreation Area	TX	AMIS	23,195	57,292
Big Bend National Park	TX	BIBE	324,641	801,863
Carlsbad Caverns National Park	NM	CAVE	18,934	46,766
Fort Davis National Historic Site	TX	FODA	192	474
Guadalupe Mountains National Park	TX	GUMO	34,986	86,416
Rio Grande Wild and Scenic River*	TX	RIGR	2,091	5,164
White Sands National Monument	NM	WHSA	58,191	143,733
All CHDN park units	**2**	**7**	**462,230**	**1,141,708**

* RIGR is administered by BIBE; the portion within BIBE is 209 river km (127 river miles) long.

1.3.1 Ecoregions encompassing CHDN parks

All CHDN park units are geographic entities that can be placed at different levels of a hierarchical framework defined by ecological processes. Knowing a network or park unit's position in a broader-scale framework provides an initial step for identifying ecological factors (e.g., broad-scale drivers) that influence the nature, distribution, and quantity of park resources and their management. One classification level often used to describe I&M networks is the ecoregion. An ecoregion is a relatively homogeneous, ecologically distinctive area that has resulted from a combination of climatic, geological, landform, soil, vegetative, wildlife, water, and human factors (Environment Canada 2007). Another well-used level is the ecosystem, which is typically a smaller geographic area within an ecoregion.

The park units of the CHDN are primarily located within the northern extent of the Chihuahuan Desert Ecoregion (Figure 1.3.1). The Chihuahuan Desert Ecoregion spans approximately 70 million hectares from 1,500 km 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 1.3.1). Six of the seven CHDN park units are located in the Northern Chihuahuan Subregion of the Chihuahuan Desert Ecoregion. The exception, AMIS, is situated primarily within the Tamaulipan Thornscrub (Mezquital) Ecoregion of southern Texas and northeastern Mexico, but it is also influenced by both the Chihuahuan Desert and Edwards Plateau ecoregions (Rich et al. 2004). Bailey and others (1994) provide another classification framework, which is standardized for the entire U.S. In this framework, land units at large scales (tens-of-thousands to millions of km^2) are identified according to domains, followed by divisions and then provinces. Bailey and others (1994) place CHDN park units within the Dry Domain, two different divisions and two different provinces. In the latter case, CAVE and GUMO would be considered

part of the Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest - Alpine Meadow Province. All other park units, including AMIS, would be considered part of the Chihuahuan Semi-Desert Province. Appendix D provides further discussion about land classification and reasons for emphasizing the use of the Chihuahuan Desert Ecoregion advanced by Pronatura Noreste and others (2004) for describing CHDN and its member units.

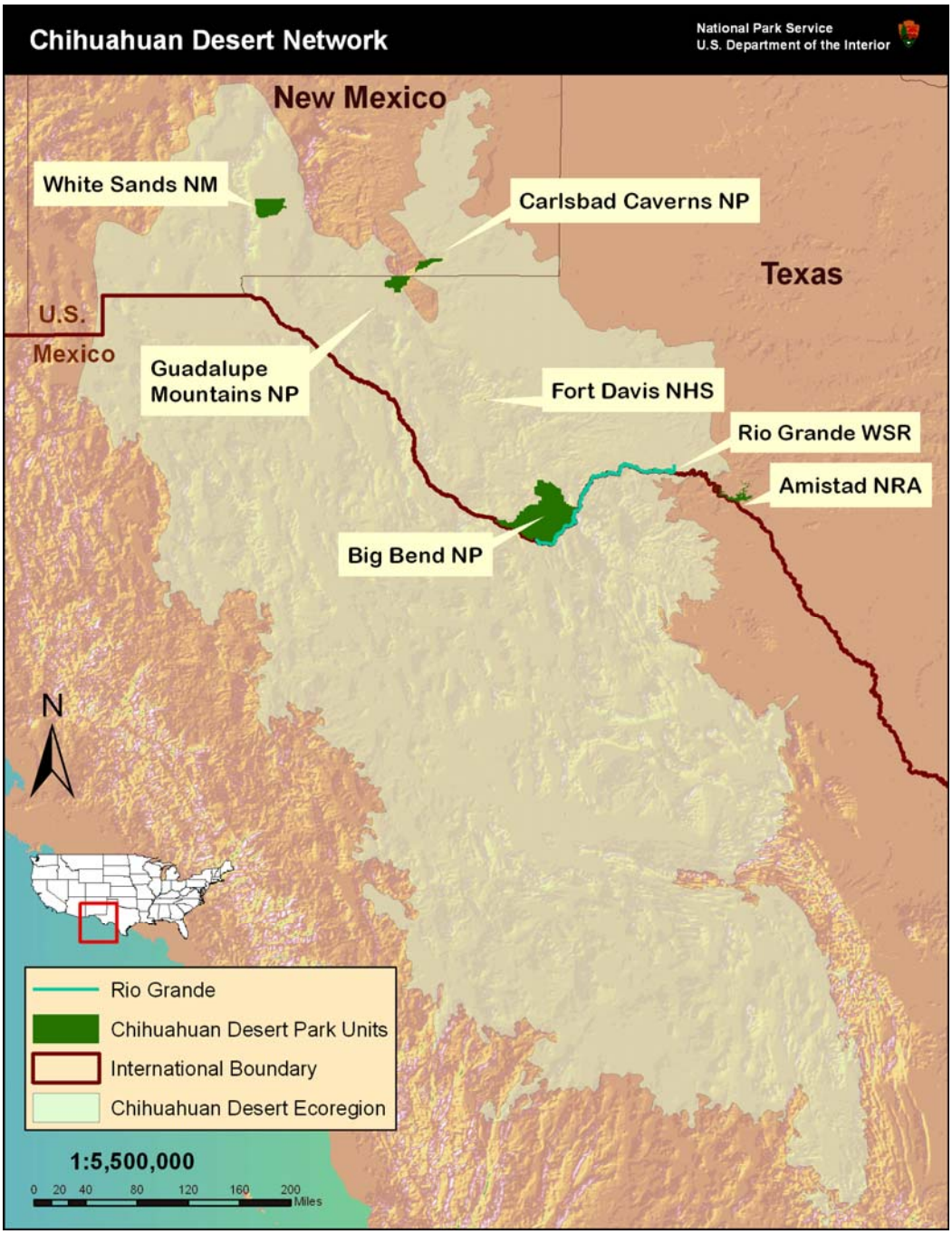

Figure 1.3.1. Location of CHDN park units within the Chihuahuan Desert Ecoregion (map produced by CHDN; ecoregion boundary from Pronatura Noreste et al. 2004).

1.3.2 Climate

Precipitation and solar radiation are two dominant inputs that drive ecological processes in all desert ecosystems. Seasonality, spatial variability, and duration of precipitation act to create pulses of water input (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 the productivity and structure of other resources in the Chihuahuan Desert Ecoregion (Whitford 2002, Schlesinger et al. 2006). Solar radiation provides the initial energy that fuels primary production of vegetation and floral microbes in the 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 also play a prominent role in this ecoregion by affecting soil transport, redistribution of nutrients, and convection, all of which affect evaporation of soil moisture and plant desiccation (Gillette and Pitchford 2004, Okin et al. 2006).

The Chihuahuan Desert is one of three "warm" deserts of North America. The term *warm* refers more to the relatively milder temperatures during winter that allow precipitation to fall as rain, rather than snow (MacMahon 2000). The term *desert* is frequently applied to semi- or fully arid lands where (1) annual precipitation (P) is usually exceeded by evapotranspiration (ET) (e.g., P/ET <0.50), (2) annual precipitation typically is <400 mm (16 in), (3) interannual variability of that precipitation ranges from 20 to 100%, and (4) ambient temperatures remain above freezing for more than six months each year (Whitford 2002). Climate within the Chihuahuan Desert Ecoregion is relatively uniform, with hot summers and cool or cold, dry winters (Schmidt 1979; Figure 1.3.2). 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. Consequently, a high percentage of Chihuahuan Desert precipitation falls in the form of monsoonal rains during the summer months (Figure 1.3.2; Appendix E). Although not as celebrated, as frequent, or as plentiful, winter rains can be a critical event for some species of plants and animals in the Chihuahuan Desert. Overall, this desert has more rainfall than other warm desert regions, with precipitation typically ranging from 150 to 500 mm (6–20 in) annually, averaging about 235 mm (10 in) (Schmidt 1979). In the Tamaulipan Thornscrub, rainfall tends to increase from west to east but, in general, that ecoregion receives larger amounts of more evenly distributed rainfall than does the Chihuahuan Desert. Some areas even approach a more humid, subtropical climate regime.

Temperatures in the Northern Subregion of the Chihuahuan Desert Ecoregion rarely exceed 25°C. The warmest months are typically June through August (Figure 1.3.2; Appendix E). However, warm fall temperatures, especially following a wet monsoon season, can promote and extend the growing season for warm-season plants.

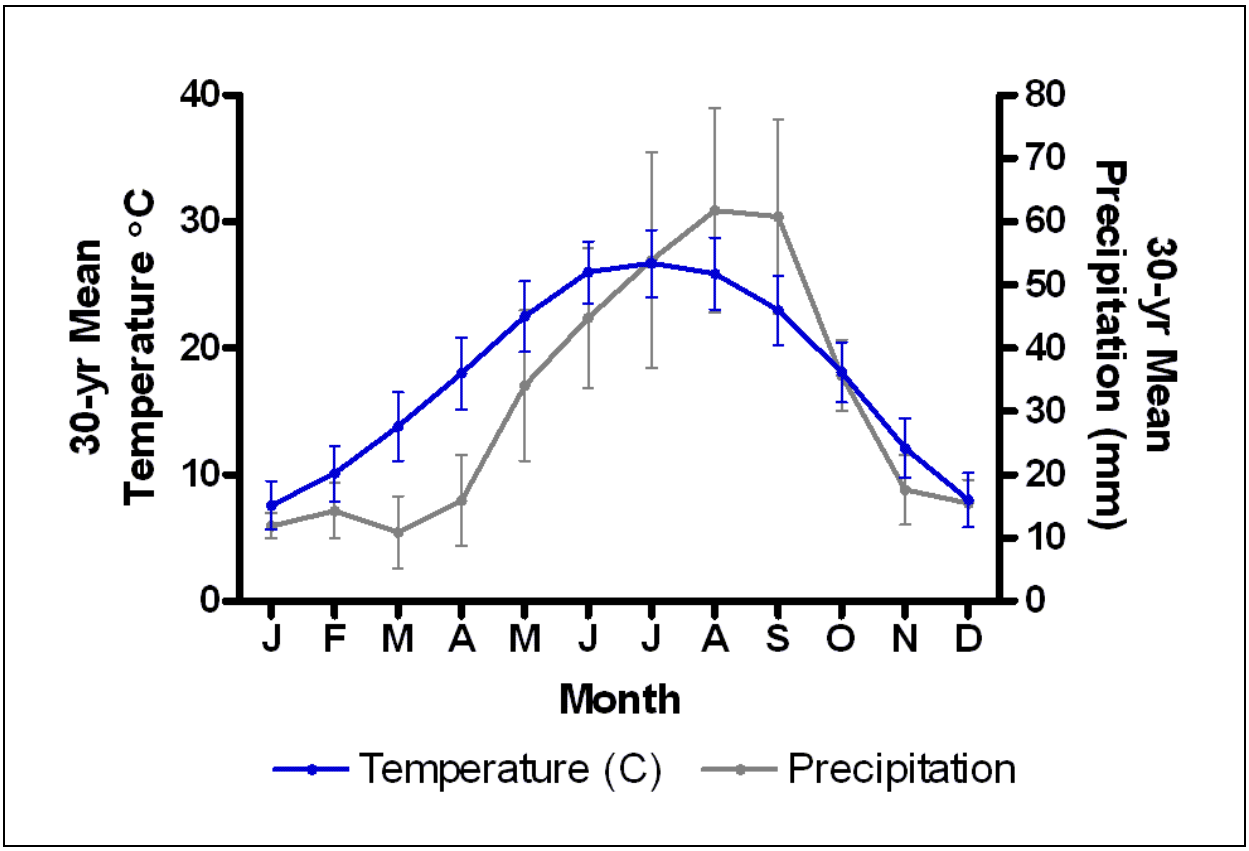

Figure 1.3.2. Walter climate diagram for CHDN park units (n = 8 stations; 2 from BIBE). Note that dry seasons occur when the precipitation line falls below the temperature line and wet seasons occur during months when the precipitation line is above the temperature line. The 95% confidence intervals for temperature indicate greater consistency among the park units than that for rainfall. Particularly variable are the summer rainfall amounts among the CHDN park units during this 30-yr period (1971–2000). A lack of winter months with temperatures less than 0°C (freezing point of water) is a primary reason why the Chihuahuan Desert is considered a warm desert.

1.3.3 Elevation, landform, and soils

Most of the Chihuahuan Desert Ecoregion lies between 900 and 1,500 m (approximately 3,000–5,000 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). In the Tamaulipan Thornscrub Ecoregion, 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).

In conjunction with climate, geologic and hydrologic properties and processes shape Chihuahuan Desert landforms. In turn, landforms create a template for a wide variety of ecological processes, including distribution, structure, and composition of resources (Wondzell et al. 1996, Monger and Bestelmeyer 2006). At a broad scale, the Chihuahuan Desert Ecoregion is formed by a series of basins and ranges. At a finer scale, bajadas and alluvial fans become apparent and provide obvious examples of the fundamental effects of landforms on desert resources. The resulting soil structure on bajadas creates an ecological site that is often dominated by creosote (Whitford 2002). Even at small scales, minor variations in landform can modify the influence of solar radiation enough to facilitate thermal heterogeneity and different microclimates for plants and animals (Whitford 2002). Such orographic effects, caused by interactions between weather and landform, topography, and aspect, have a strong influence on the distribution of resources in both ecoregions (Pronatura Noreste et al. 2004, Monger and Bestelmeyer 2006). For

example, north-facing sides of deep, reticulated canyons often provide cooler, moister conditions, which in turn provide habitat for a mixture of riparian or non-xeric plant species and rare animal species, such as the Mexican spotted owl (*Strix occidentalis lucida*; Figure 1.3.3-1). Landforms can also 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.

The availability of soil moisture and nutrients is a primary factor limiting productivity in the Chihuahuan Desert (Whitford 2002, Snyder et al. 2006). Soil characteristics, such as 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 the Chihuahuan Desert Ecoregion can strongly affect system composition and function and ultimately lead to desertification (Schlesinger et al. 1990, Gillette and Pitchford 2004).

Basin soils in the Northern Chihuahuan Desert Subregion 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, characterized by a thermic temperature regime, an aridic moisture regime, and mixed or carbonatic mineralogy (USDA NRCS 2006). Soils along the Rio Grande in the Big Bend are hyperthermic. Approximately 80% of Chihuahuan Desert Ecoregion soils are derived from limestone beds. These soils sometimes have accumulations of calcium carbonate below the surface horizons that, 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 ecoregion. These soils are shallow, very poorly developed, and may consist primarily of sand and rock (USDA NRCS 2006). Mountain ranges also include Mollisols and Entisols. Mollisols include soils with loamy texture. Montane valleys may include very deep soils with well-developed O-horizons. Many of these soils have mesic temperature regimes (USDA NRCS 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.

A notable example of soil effects on plant communities can be seen at WHSA. 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 by wind away from the lakeshore 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 1.3.3-2, Rosenblum 2006). Although some biota may be limited by gypsum soils, the shaping of unique forms tolerant of this local condition ultimately increases regional biological diversity.

Figure 1.3.3-1. Mexican spotted owl roosting in a chinquapin oak in a canyon in Guadalupe Mountains National Park. Photo by Timothy C. Mullet.

Figure 1.3.3-2. Little white whiptail lizard adapted to dunes. Photo by James Borgmeyer.

1.3.4 Water and hydrology

Water is a precious resource in any ecoregion, but all life forms in the Chihuahuan Desert Ecosystem are particularly dependent on the quantity and quality of water due to its relative scarcity and the poor quality of desert soils. The Northern Chihuahuan Desert Subregion is bisected by three predominant rivers, the Rio Grande (or Río Bravo del Norte), Conchos, and Pecos. In addition, the Rio Grande, Pecos, and Devils River empty into a large, internationally shared reservoir at AMIS, the southeastern edge of this subregion.

These waters are influenced by a number of factors, including interactions among climate, hydrology, watershed conditions (e.g., geology, landforms, and soils), vegetation, impoundments, and natural disturbance regimes. The quality of these waters is a priority management concern throughout the subregion. Water quality information has been compiled for CHDN park water bodies (Porter et al. 2009).

Free-flowing and standing water also produce a diverse array of freshwater habitats in the two ecoregions. These include large rivers, numerous seeps and springs, and smaller perennial and ephemeral streams (Table 1.3.4).

Large gains in streamflow (100–400 ft^3/s) along the lower segments of RIGR presumably are associated with springs discharging from the Edwards-Trinity (Plateau) aquifer. The Pecos River is less influenced by groundwater flows, but drawdown of the underground water will likely affect the hydrology of the majority of water bodies and smaller springs in the subregion. Combinations of periodic drought, a natural and frequent disturbance factor in the Chihuahuan Desert Ecoregion, combined with intensive use of groundwater for agriculture, has caused serious environmental degradation and loss of habitat and endemic species at Cuatrociénegas, in Coahuila, Mexico (Hendrickson et al. 2008).

Table 1.3.4. Aquatic habitat types of the Chihuahuan Desert (adopted from Dinerstein et al. 2000).

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

1.3.5 Flora and plant communities

As recently as 9,000 years ago, the Northern Chihuahuan Desert Subregion was much more mesic in climate and dominated by coniferous woodland, typically piñon pine (*Pinus* spp.) and juniper (*Juniperus* spp.; Allen et al. 1998, Van Devender 1990). Miller (1974) suggested that increasing aridity of the Chihuahuan Desert resulted in isolation, differentiation, and extinction that led to the unique biota observed 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 (Johnson 1974).

Conservation organizations, such as the World Wildlife Fund, consider the Chihuahuan Desert Ecoregion one of the most diverse deserts in the world and a critical reservoir for conserving biodiversity (Olson and Dinerstein 1998). At least 1,000 endemic plant taxa occur in the Chihuahuan Desert, an astonishing richness of biodiversity (Johnson 1974). This high desert area is a center for endemism of yuccas and cacti (Hernández and Bárcenas 1995). Of the 1,500 known species of cacti, 350 occur in the Chihuahuan Desert. 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 diversity of the Tamaulipan Thornscrub is not as high as that of the Chihuahuan Desert, but it still supports more than 600 species of plants and animals. The region is particularly rich in tree species, including two endemics, and birds (Ricketts et al. 1999).

Plant assemblages and communities can be described in many ways. In this report, we describe plant assemblages using vegetation habitat types (Table 1.3.5, Appendix D). 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 assemblages of Tamaulipan Thornscrub Habitat Type, South Texas Plains Scrubland and Edwards Plateau Scrubland, are found bordering the Reservoir Ecosystem of AMIS. These habitat types are described further, along with the names of common plant species found in each type, in Appendix D.

Table 1.3.5. Terrestrial habitat types of the Chihuahuan Desert Ecoregion.

I. Desert Scrub and Woodlands	II. Grasslands	III. Montane Chaparral and Montane Woodlands
A. Larrea Desert Scrub	A. Grama Grassland	A. Montane Chaparral
B. Mixed Desert Scrub	B. Sacaton Grassland	B. Juniper-Piñon Woodland
C. Yucca Woodland	C. Tobosa Grassland	C. Pine-Oak Woodland
D. Izotal (Dasylirion-Yucca-Agave)	D. Gypsum Grassland	D. Mixed-Conifer Forest
E. Prosopis Scrub	E. Lowland Riparian Marshland	E. Montane Deciduous Woodland
F. Gypsophilous Scrub		
G. Lowland Riparian Woodland		
H. Playa		

Adopted from Dinerstein and others (2000); see Appendix D for detailed descriptions of these habitat types.

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).

Currently, desert shrublands comprise half (50%) of Northern Chihuahuan Subregion landscapes. 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. Consequently, the Chihuahuan Desert is now considered synonymous with shrublands and its boundaries are determined by the contiguous distributions of creosote bush (*Larrea tridentata*) and tarbush (*Flourensia cernua*) (Dick-Peddie 1993). This change has increased the significance of remaining desert grasslands, particularly those once dominated by black grama (*Bouteloua eriopoda*). Lechuguilla is also considered a signature plant of the Northern Chihuahuan Subregion (Figure 1.3.5).

In the Tamaulipan Mezquital, trees such as acacia (*Acacia* spp.) and mesquite (*Prosopsis glandulosa*) dominate, along with other shrub species and some grasslands. Some grasslands occur within this ecoregion. The most common grasses found include curly mesquite grass (*Hilaria belangeri*), hooded finger grass (*Chloris cucullata*), grama (*Bouteloua* spp.), and muhly (*Muhlenbergia* spp).

Figure 1.3.5. Dense stand of lechuguilla and sotol at Big Bend National Park. NPS Photo

1.3.6 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. Monarch butterflies rely on the riparian vegetation to rest during their migration (Ayala et al. 1993).

The larger Río Grande system is home to native minnow, sucker, catfish, killifish, and sunfish species: two species of gar (*Lepisosteus oculatus*, *L. osseus*); and a rare sturgeon (*Scaphirhynchus platorhynchus*). Rivers draining into the interior, such as the Río Nazas, located north of Durango, Mexico, 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 1974, Minckley 1974). 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).

At least 18 species of reptiles and amphibians are endemic to the Chihuahuan Desert, including the bolson tortoise (*Gopherus flavomarginatus*) (Ricketts et al. 1999), black softshell turtle (*Trionyx ater*), Chihuahuan fringe-toed lizard (*Uma exsul*), and the little white whiptail (*Aspidoscelis gypsi*) (see Figure 1.3.3-2). The habitat ranges of several lizards are centered in the Chihuahuan Desert. Representative snakes include the Trans-Pecos rat snake (*Elaphe subocularis*), Texas blackheaded snake, (*Tantilla atriceps*), and western coachwhip (*Masticophis flagellum testaceus*).

The Chihuahuan Desert is one of few ecoregions where grizzly bears, wolves, and jaguars once were 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 (Appendix C). For example, Barbary sheep, or aoudad (*Ammotragus lervia*) and oryx, or gemsbok (*Oryx gazelle*) occur in the Northern Chihuahuan Subregion. Heteromyid rodents are considered keystone species and meso-carnivores; ringtail (*Brassariscus astutus*), skunks, and fox species are common. This desert region also is 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*).

1.3.7 Ecosystems of CHDN park units

The seven park units of the CHDN represent the most significant natural, cultural, and recreational values in the Chihuahuan Desert. Most CHDN park units were established for conservation and preservation of significant natural and geologic resources (e.g., the caverns of Carlsbad Caverns NP). The exception is FODA, which was established primarily for cultural reasons, but also contains significant natural resources. Here we first present a brief summary of the biophysical properties discussed above as they apply to each of the CHDN park units (Table 1.3.7-1). We then describe the types and spatial distribution of ecosystems found in each CHDN park unit. Knowledge of ecosystem properties and function is the cornerstone of natural resource management and a requisite to designing a reliable monitoring program. Additional information about each CHDN unit, including resource and management concerns, can be found in Appendix C. Information about functional relationships among ecosystem components is presented in Chapter 2.

We identified six ecosystems for describing CHDN park units: (1) Desert (<1,370 m/4,500 ft elevation), (2) Foothill (1,370–1,981 m/4,500–6,500 ft elevation), (3) Montane (>1,981 m/6,500 ft elevation), (4) Reservoir, (5) River (applied to the three major rivers; the smaller wetland types are addressed within terrestrial ecosystems), and (6) Unique (Table 1.3.7-2). These ecosystems were designated irrespective of vegetation type. The Unique category includes two subsystems, caves and dune fields. Caves of Carlsbad Caverns NP may be more appropriately considered a subsystem of the Foothill and Desert Ecosystems, and the Dune Fields of WHSA and GUMO a subsystem of the Desert Ecosystem. However, our designation of these systems as unique was done in part to allow for the identification of vital signs unique to these specialized systems. Our classification embodies 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, such as precipitation and temperature, which also influence hydrologic properties and the composition and structure of biotic communities, correspond to topography (Monger and Bestelmeyer 2006).

To summarize the spatial extent and distribution of CHDN ecosystems, we estimated the area associated with each ecosystem by NPS unit (Table 1.3.7-2). Areas 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). Based on elevations provided by AMIS staff, area for Amistad Reservoir was estimated from the elevation associated with conservation water surface elevation (340 m [1117 ft]). Area for the River Ecosystem was based on a product of an average river width (0.185 km [0.12 mi]; $n = 30$ 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 are shown in Figure 1.3.7. The administrating park units provided area of dune fields and linear distance of caves.

Table 1.3.7-1. Biophysical summary of Chihuahuan Desert Network parks.

Park unit	Precip. (mm)[1]	Temperature (°C)[2]	Elevation Range (m)	Aquatic habitats[3]	Terrestrial habitats[4]	Species richness[5] Number of species (Species/km^2)	
						Plants	Vertebrates
AMIS	475 (0–364)	20.6 (0–39.6)	282–364	IIB, III, IVC, VIII	IB, IE, IG	691 (2.98)	323 (0.39)
BIBE	245/479 (0–268)	16.5/21.9 (-2.0–43.8)	548–2,387	IB, IIB, III, IVC, VABC	IA, IB,ID, IE,IG, IIA, IIB, IIC, IIE, IIIA, IIIB, IIIC	1,321 (0.40)	598 (0.18)
CAVE	406 (0–423)	16.5 (-3.7–36.7)	1,096–1,992	IIB, VB, VIII	IA, IB, IC, ID, IE, IIB, IIE, IIIB	929 (4.90)	483 (2.55)
FODA	397 (0–226)	15.9 (-4.7–36.7)	1,487–1,622	VC	IB, IIA, IIIA	368 (191.67)	165 (85.94)
GUMO (near HQ)	392 (0–197)	(-4.3–33.7)	1,105–2,667	IIB, IVA, IVC, VA, VB, VC, VIB	IA, IB, ID,IE, IF, IG, IH, IIA,IIB, IID IIIA, IIIC, IIID, IIIE	985 (2.82)	366 (1.05)
RIGR	367 (0–217)	20.3 (-4.1–39.9)	360–616	IB, III,	IB, ID, IE, IG, IIIA, IIIB	-----	-----
WHSA	258 (0–245)	15.0 (-9.9–38.7)	1,185–1,290	VC	IA, IB, IF, IH, IIB, IID	265 (0.46)	254 (0.44)

[1]Thirty-year, 1971–2000, mean values for total annual precipitation and (monthly minimums–maximums). Given its expansive area, two stations from BIBE are reported: Castolon andChisos Basin.

[2] Thirty-year, 1971–2000, mean values for the annual temperature and (monthly minimums–maximums). Given its expansive area, two stations from BIBE are reported: Castolon and Chisos Basin.

[3]See Table 1.3.4 for description of aquatic habitat type identifiers.

[4] See Table 1.3.5 for description of terrestrial habitat identifiers. See Appendix D for detailed habitat descriptions.

[5] See Table 1.3 for park areas and C.7-1 for number of species used to generate species richness/km^2.

These area values indicated the vast extent (77%) of the Desert Ecosystem in the CHDN, occurring in five of seven NPS units (Table 1.3.7-2). 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). Figures 1.3.7B and 1.3.7E show the variety of ecosystems occurring within BIBE and GUMO. These two park units also have the greatest number of plant and animal species listed in Table 1.3.7-1.

Table 1.3.7-2. Classification, area, and distribution of ecosystems within CHDN national parks. Classifications were based on broad elevation and landform.

Ecosystem	Description	Area (km^2)							
		AMIS	BIBE	CAVE	FODA	GUMO	RIGR	WHSA	Total (% of CHDN)
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, Tamaulipan 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%)
Foothill	Arid/Semi-arid terrestrial and non-extensive aquatic systems that occur at mid-level elevations, 1,370–1,981 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%)
Montane	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 damming the Rio Grande below the confluence of the Devils and Pecos Rivers.	182	0	0	0	0	0	0	182 (3.9%)
River	Large river and associated aquatic systems. Includes Rio Grande and primary river confluences in or proximal to park units (e.g., Devils 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 CHDN area			**4,618 km^2**

[a] Excluding the dune systems, which, by elevation, also could 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.

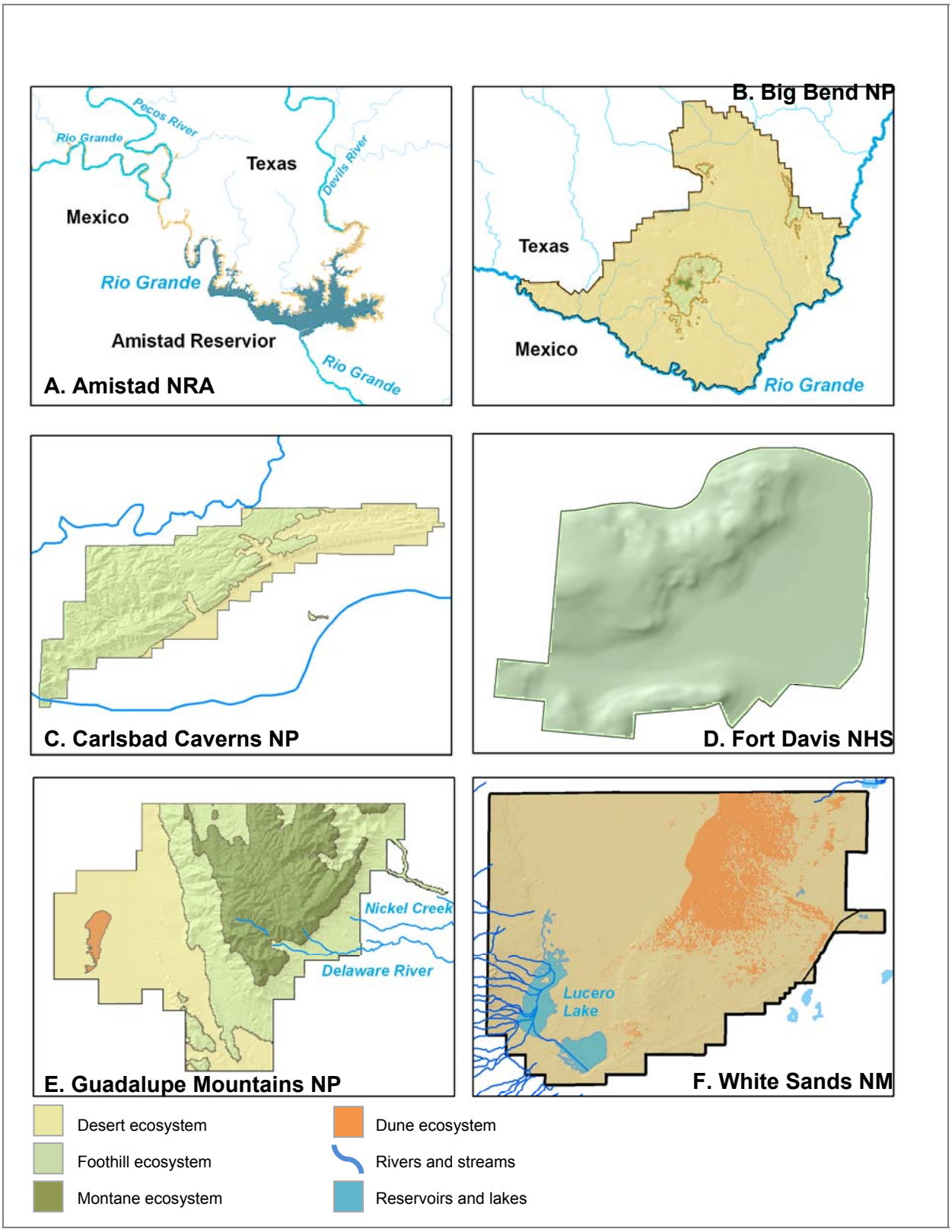

Figure 1.3.7A–F. Ecosystems of Chihuahuan Desert Network parks.

1.4 Park Natural Resources Issues and Management Concerns

CHDN parks share similar natural resources, threats, issues, and management priorities. In order to narrow the focus, ensure relevance to several network parks, and increase efficiencies in the planning process, priorities were established among focal resources and resource concerns. Network staff used many tools to identify important management issues and other common priorities, including reviews of park management plans (i.e., General Management Plans, Resource Management Plans), reviews of state conservation strategies, interviews with park staff and outside cooperators, park-based vital signs scoping workshops, Technical Committee meetings, and direct observation. The following section provides a summary of methods that helped the CHDN with vital signs planning and ecological model development.

1.4.1 Issues identified in park interviews and network scoping

Personal interviews with superintendents, division chiefs, park natural resource staff, other park staff, and other NPS staff who provide services to multiple parks (e.g., Exotic Plant Management Team program manager, regional fire ecologist) were conducted during the fall of 2004 (Appendix G). The responses compiled from this questionnaire were kept anonymous, and served to identify initial management issues, threats to park resources, and areas in need of monitoring. These responses also provided a starting point for discussions at park-based vital signs scoping workshops held from December 2004 through April 2005 to create park-specific lists of issues, threats, and potential vital signs (Appendix G). High-priority issues identified in this early stage included air quality degradation; impacts of climate change to water quantity and plant communities; impacts of soil erosion to natural plant communities; impacts of invasive/non-native plant species and groundwater withdrawal on persistence of springs and seeps; impacts to water quality; impacts to riparian and grassland bird communities; and understanding land-cover, land-pattern, and land-use changes over time and their impacts to habitat quality, connectivity, and fragmentation. Summary results are provided in Table 1.4.1.

Table 1.4.1. Relative importance of Chihuahuan Desert Network ecosystem stressors (from the CHDN park-level vital signs scoping workshops, 2004–2005).

Stressor	AMIS	BIBE	CAVE	FODA	GUMO	WHSA	Overall
Groundwater Quantity Depletion	L	H	H	M	H	H	H
Invasive/Non-native Plant Species	M	H	M	L	H	H	H
Water Quality Degradation	H	H	M	L	H	L	H/M
Climate Change	L	H	M	M	M	M	M
Altered Disturbance Regimes	M	H	M	M	H	L	M
Historic/Contemporary Livestock Grazing	H	H	L	M	M	L	M
Air Quality Degradation	L	H	M	L	H	M	M
Land-use Change	M	H	M	-	M	M	M
Recreation	M	M	M	L	M	-	M
Soil Alteration	-	H	L	L	M	M	M
Resource Extraction	L	M	H	L	H	L	M/L

L = low importance; M = moderate importance; H = high importance

1.4.2 General management plans and resource stewardship strategies

The CHDN parks have either recently completed their General Management Plans (GMP) (e.g., BIBE completed in 2004, GUMO completed 2008) or have not yet begun the process of updating their GMPs (e.g., CAVE, WHSA). This process takes 3–5 years, or longer, to define how the park will be managed for the following 15–20 years. Each park describes its desired future conditions, then develops a plan for achieving those conditions through management of visitor use, facilities, and resource protection through a variety of alternatives. Public comment and scoping helps ensure the park's vision is consistent with the vision of its users and, through an iterative process, the GMP is developed.

Some parks underwent the GMP process during the development and/or finalization of the CHDN vital signs monitoring plan. In those cases, it was useful for park managers to be thinking about what might be occurring in their parks two decades in the future as they considered how park resources may be affected over the long term. Using the information collected during the vital signs planning process and implementation should assist park managers not only in determining the ecosystem health of their parks, but also in deciding how to manage toward the desired future conditions stated within their GMPs.

1.4.3 State comprehensive wildlife conservation strategy

As the number of species listed under the Endangered Species Act has steadily increased, along with the costs involved with saving imperiled species, it has become clear that a more comprehensive approach to wildlife conservation is necessary. The U.S. Congress helped to address this need by creating the State Wildlife Grants Program in 2002. Under this national effort, with all U.S. states and territories participating, each entity created a long-range strategy for managing all fish and wildlife under its jurisdiction. These strategies were submitted to the U.S. Fish and Wildlife Service by October 1, 2005. The objectives of the program are to identify species (and their habitats) of greatest conservation need and to develop and implement high-priority conservation actions to abate problems for those species and habitats. These steps will save millions of tax dollars by preventing declines before species become imperiled. The State Wildlife Grants Program encourages partnerships and cooperation through a fund-matching requirement.

The states of New Mexico and Texas both completed their conservation strategies for the program (NMGF 2005; Bender et al. 2005), and the National Park Service and the CHDN are participating in implementation strategy meetings for these plans. Materials from the strategy documents were used in developing habitat descriptions to affirm the linkages in CHDN's ecosystem characterization models. The CHDN hopes to actively collaborate with these efforts so that regional trends may be better evaluated in the future.

1.4.4 Vital signs monitoring in Mexico

Taking advantage of the synergy that was generated from a sister-park meeting held at Grand Canyon National Park, Arizona, in February 2008, and through funding from a Sister Parks Program grant to WHSA (summer 2008), the National Commission of Protected Natural Areas (CONANP); WHSA and its Sister Park, Área de Protección de Flora y Fauna Cuatrociénegas (CC); and the CHDN began a partnership to explore monitoring of vital signs common to both parks. In a three-day workshop held in early September 2008, representatives from two Mexican parks; the northeastern regional director for CONANP; staff from WHSA, CHDN, and the Western National Parks Association; and university researchers met to discuss similar park management issues, assist CC in developing interpretive and other educational programs that promote community and visitor support for resource conservation and protection, and share components of the CHDN I&M program (i.e., utilizing protocols, research and inventory methodologies) with CC. CONANP expressed interest in adopting the protocols of CHDN and other I&M networks, systemwide.

1.5 Designing an Integrated Monitoring Program for the Chihuahuan Desert Network

Each network is required to design an integrated monitoring program that addresses the five broad, servicewide monitoring goals listed in Section 1.2.1, and is tailored to the high-priority monitoring needs and partnership opportunities for the parks in that network. Working from the servicewide goals, the CHDN has developed a set of monitoring objectives for each of its high-priority vital signs, grouped into the following conceptual categories (Figure 1.5; Woodley 1993):

1. ***Threat-specific Monitoring.*** Conducted when sufficient understanding exists between potential effects and responses by park resources (known effects), monitoring of system drivers, stressors, and affected park resources.

2. ***Focal Resource Monitoring.*** Monitors a set of focal resources (including ecological processes) to address both known and unknown effects of system drivers and stressors on park resources.

3. ***Ecosystem Status Monitoring.*** Monitors key properties and processes of ecosystem status and integrity to improve long-term understanding and potential early warning of undesirable changes in park resources.

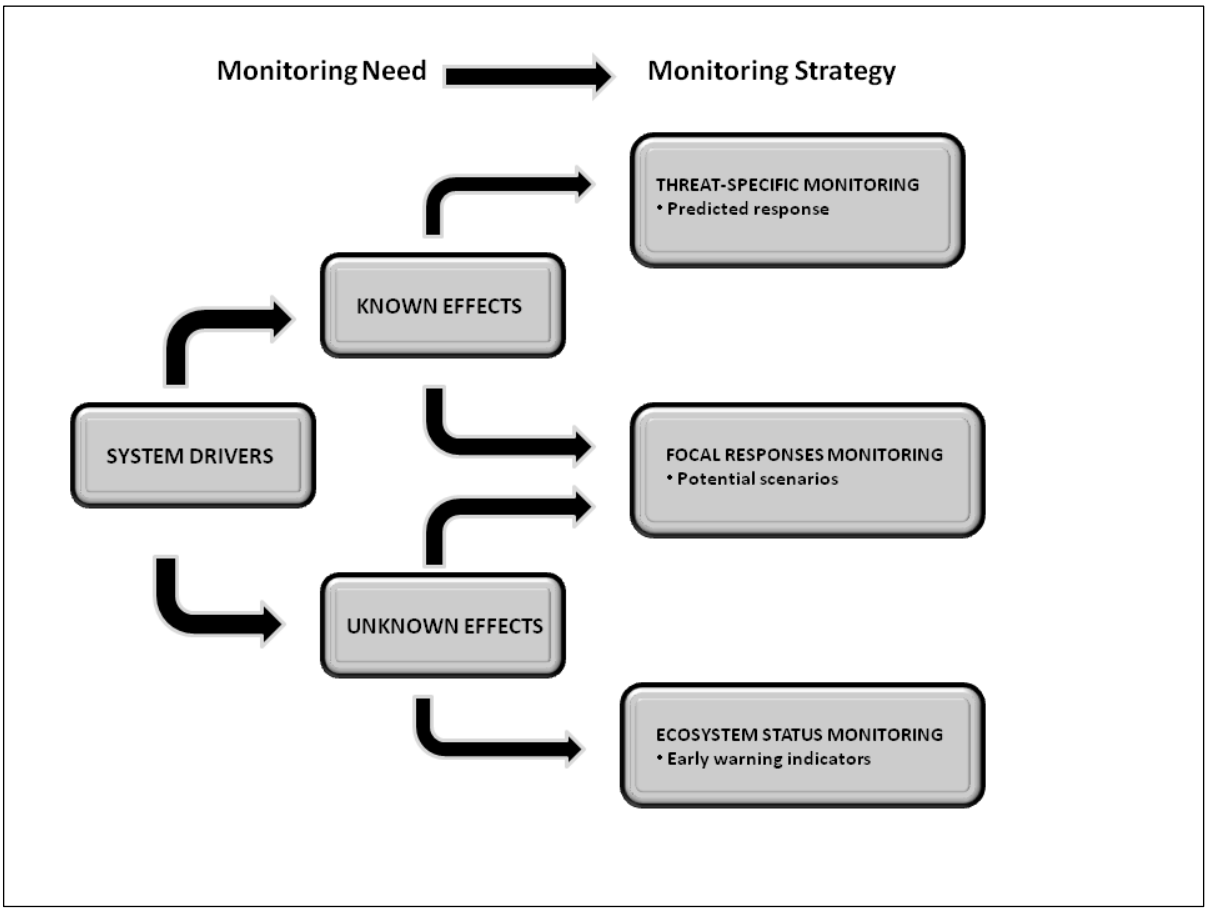

Figure 1.5. The conceptual framework for categorizing CHDN vital signs (adapted from Woodley 1993).

These categories provide a useful framework for organizing not only the selected vital signs, but also the thinking by which these vital signs were selected. The intent has been to ensure that at least some vital signs are selected from each category to ensure program integration, so that when taken together, the CHDN program whole is greater than the sum of its parts. This approach is necessary because practical constraints, such as budgets and staff size, prevent the selection of all important vital signs. Selecting vital signs from each of these categories helps ensure a balanced, integrated program that can address the status and long-term trends of ecological phenomena across a range of temporal and spatial scales, and for which effects are both known and unknown.

1.5.1 CHDN approach to vital signs monitoring

The basic approach to designing a monitoring program should follow five steps:

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

These steps were incorporated into a three-phase planning and design process established for the CHDN monitoring program. Phase 1 of the process involved defining goals and objectives; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and completing other background work as a prelude to the selection of ecological indicators (NPS 2006b). Much of this background information is documented in this chapter and appendix reports (Appendices C–H). Conceptual models are discussed in Chapter 2.

Phase 2 of the planning and design effort involved prioritizing and selecting a core set of vital signs and developing specific monitoring objectives for each vital sign that will be included in the network's initial monitoring program. The process is documented in Chapter 3 and Appendix I.

Phase 3 entailed the detailed design work needed to implement monitoring, including outlining strategies for vital signs implementation and relationships with existing programs, outlining sampling design issues (Chapter 4), and developing specific monitoring objectives for the 10 protocols CHDN will be implementing (see Chapter 5, Table 5.1 and Appendix J). These monitoring objectives will be refined as protocol development progresses. Phase 3 also included a plan for data management (Chapter 6 and Appendix K); details on the type of analyses and content of various products of the monitoring effort, such as reports and websites (Chapter 7); and the administrative structure (Chapter 8). Chapter 9 outlines the anticipated schedule of protocol development and monitoring activities planned for the five years following plan approval. The budget is shown in Chapter 10.

The CHDN recognizes the NPS I&M program as a unique opportunity to advance understanding of the ecosystems that encompass CHDN parks. The CHDN is committed to being an active partner with state and federal agencies, academic institutions, and other organizations involved with monitoring in the Chihuahuan Desert, as well as actively pursuing coordination and partnerships with Mexico. The network also is committed to establishing the foundation for a monitoring program that will last in perpetuity.

1.6 Summary of Current Monitoring Within and Surrounding the Network

An understanding of current and past monitoring activities in and around network parks is an important foundation for development of the CHDN vital signs monitoring program. Such information allows the network to identify where monitoring is adequate, might need to be expanded (or abandoned), or where additional inventory, monitoring, or protocol development is needed.

Thorough analysis of current and past monitoring projects and data (Table 1.6) could serve as the basis for long-term monitoring in parks related to high-priority CHDN vital signs. However, the small staff of CHDN parks has limited the amount of natural resource monitoring currently occurring in those parks. Several parks participate in annual breeding bird surveys or National Audubon Society Christmas bird counts, but few conduct any formal resource monitoring and, with the exception of monitoring for some threatened and endangered bird species, none of these monitoring projects is conducted with peer-reviewed protocols that include a statistically sound sampling strategy.

Table 1.6. Record of historic (H, >5 years ago) or current (C) monitoring data for CHDN parks.

Category	CHDN parks					
	AMIS	BIBE	CAVE	FODA	GUMO	WHSA
Air quality-Ozone		C	C		C	
Air quality-Wet and dry deposition		C			C	
Air quality-Visibility and particulates		C			C	
Climate-Basic meteorology	C	C	C	C	C	C
Cave resources[1]			C			
Groundwater dynamics	H	H	H	H	C	C
Surface water dynamics	C	C	H			
Surface water quality	C	C	H		C	
Springs/seeps		C	H		H	
Invasive/Non-native plants		C			C	C
Vegetation change		H,C	H		H	
Bird communities	H[2]	C[3]	C[3,4]		C[3]	
Fish communities	C	C				
Species-at-risk	C[5]	H[6],C[7]	H[8]		C[9]	H[10]
Fire and fuel dynamics		H,C	C		H,C	

[1]Cave resources (water, microbial, climate)
[2]MAP Station (2000–2004)
[3]Christmas Bird Counts
[4]Cave swallows (1980–2009)
[5]Interior least terns (1986–2009)
[6]Peregrine falcon (1976–2003)
[7]Black-capped vireo (1987–2009); Chiso's hedgehog cactus (1996–2009)
[8]Bell's Vireo
[9]Mexican spotted owl
[10]White Sands pupfish

The lack of past long-term monitoring activities in network parks serves to reinforce the importance of the I&M program to this group of parks. Natural resource information upon which resource managers can base sound decisions upon is extremely limited.

1.6.1 Air quality monitoring

Air pollution damages resources and values that national parks are mandated to protect. Under the Clean Air Act and GPRA mandate, managers of Class I parks have a special responsibility to monitor and protect air quality and related resources from the adverse effects of air pollution, and to provide recommendations to protect park natural and cultural resources. At the network level, monitoring air quality conditions and understanding their interactions with physical and biological components of the ecosystem is vitally important to effectively evaluating the effects of these hazards on ecosystem health.

In the CHDN, climate and air quality data are monitored at a variety of stations in six park units (Table 1.6.1, Appendices E and H). BIBE, CAVE, and GUMO are Class I air quality areas, receiving the highest protection under the Clean Air Act. The other park units are Class II air quality areas, which also receive protection under the 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. Research has found a rapid, major decrease in soil pH in BIBE grasslands. Studies were initiated in 2003 to assess the impacts of atmospheric nitrogen deposition and climate change on desert ecosystems in the park.

The NPS has summarized five-year averages of annual ozone values from 1995 to 1999 (NPS-ARD 2004). Two CHDN parks (AMIS and CAVE) are considered at moderate risk from ozone. These two parks exceeded the ozone standard with values of 0.8 ppm, levels that could damage foliage. Even though AMIS 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 CAVE, but 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 do occur at other network parks. These plants include ponderosa pine (*Pinus ponderosa*) and skunkbush at BIBE and GUMO, and Southwestern chokecherry (*Prunus serotina*) and skunkbush at BIBE, FODA, and GUMO (NPS-ARD 2004).

Types of monitoring at BIBE and GUMO include ozone monitoring through the NPS Gaseous Pollutant Monitoring Network, wet deposition monitoring of atmospheric pollutants by the National Atmospheric Deposition Program (NADP), dry deposition monitoring of atmospheric pollutants by the Clean Air Status and Trends Network (CASTNet), and visibility monitoring through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. CAVE has a temporary station set up to monitor ozone only. All of the parks, except RIGR, have one or more climate monitoring stations (see Appendix E).

Air-quality-related values (AQRV) are resources that may be adversely affected by a change in air quality. The resource can include visibility of a specific scenic, cultural, physical, biological, ecological, or recreational resource. Table 1.6.1 identifies natural resource AQRVs of each CHDN park. As new information is developed for the network, it will be added to the NPS Air Resources Division's Air Resources Information System website, http://www2.nature.nps.gov/air/permits/aris/networks/index.cfm.

Table 1.6.1. Air quality-related values (AQRV) of Chihuahuan Desert Network parks.

Park	Visibility[1]	Vegetation[2]	Surface Waters[3]	Soils[4]	Fish and wildlife[5]	Night skies[6]
AMIS	✓	✓	Unknown	Unknown	✓	✓
BIBE	✓	✓	✓	✓	✓	✓
CAVE	✓	✓	✓	Some soils may be sensitive to eutrophication	✓	✓
FODA	✓	✓	No	Unknown	✓	✓
GUMO	✓	✓	✓	✓	✓	✓
RIGR	✓	Unknown	Unknown	Unknown	✓*	✓
WHSA	✓	✓	✓	✓	Unknown	✓

Data from http://www.nature.nps.gov/air/permits/aris/index.cfm.

✓ – AQRV is known to be, or likely to be, sensitive to air pollution.

No – indicates that the source is not sensitive to air pollution.

Unknown – indicates insufficient park-specific information to determine if resource is sensitive for the park.

* Fish consumption advisories have been issued by the state for the park due to unsafe levels of one or more toxics.

[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://www.nature.nps.gov/air/Permits/ARIS/docs/Ozone_Sensitive_ByPark_3600.pdf).

[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.

1.6.2 Water resources monitoring

A review of water resources in individual network parks, baseline water-quality inventory data and analysis, clean water action plans, water quality standards for Texas and New Mexico, and water monitoring projects in the CHDN is provided in Appendix F. Several recent reports that discussed and analyzed surface and groundwater status and trends in the CHDN (Reid and Reiser 2005, Huff et al. 2006, Porter et al. 2009) are summarized in Appendix F. Surface water quality and quantity in Amistad International Reservoir, an impoundment of the Rio Grande near Del Rio, Texas, are monitored extensively by the International Boundary and Water Commission (IBWC) (http://www.ibwc.state.gov) and the Texas Commission on Environmental Quality (TCEQ) (http://tceq.state.tx.us) because of its importance as a regional source of water for the United States and Mexico. The surface water quality and flow rates of the Rio Grande are also monitored by IBWC and TCEQ. The CHDN will periodically review TCEQ 303(d) listings to determine the current regulatory status of Amistad International Reservoir and upstream segments of the Rio Grande; however, the reservoir itself will not be directly sampled by the CHDN network, nor addressed in the conceptual models presented in Chapter 2.

Under Section 305(b) of the Clean Water Act, each state is required to conduct water quality surveys to determine the overall health of the waters of the state, including whether or not designated uses are being met, and report to the Environmental Protection Agency (EPA) every two years. When impaired water bodies are identified, they are included in 303(d) priority lists in order to limit discharges of specific contaminants to that water body. A portion of Rio Grande Segment 2307, upstream from BIBE, is listed as an impaired water body under Section 303(d) of the Clean Water Act because of excessive fecal-indicator bacteria levels. Rio Grande Segment 2306, located just above Lake Amistad, will be listed in 2010 for impaired excessive sulfate concentrations and total dissolved solids. Although no other CHDN surface waters were are on the 303(d) list as of March 2010, the Rio Grande adjacent to BIBE and throughout the wild and scenic river (RIGR) segment has been designated by TCEQ as Special Concern because of excessive algae (chlorophyll *a*) and nutrient concentrations (total phosphorus) in Segment 2306 above Amistad Reservoir, and nitrate concentrations in the reservoir (TCEQ Segment 2305).

A 196-mile segment of the Rio Grande, from Mariscal Canyon to the Terrell–Val Verde county line, was designated as a wild and scenic river by the U.S. Congress in 1978. U.S. rivers with this designation are to be preserved in their free-flowing condition, and their associated ecosystems are to be actively protected in their natural state. Some states have developed lists of Outstanding National Resource Waters (ONRW) under EPA guidance. There are no official ONRWs in the CHDN; however, several streams and other surface-water bodies (including springs) appear to be of outstanding quality and are critically important to their respective parks: Devils River (AMIS), Langford Hot Springs Complex (BIBE), River Mile 832-808 (BIBE and RIGR), Rattlesnake Springs (CAVE), McKittrick Creek (GUMO), and Lake Lucero playa (WHSA). These surface waters are located in areas of little or no human habitation, industrial development, or agricultural practices where the drainage basins are relatively undisturbed by human activities.

Chapter 2: Conceptual Models

2.1 Conceptual Models

Conceptual models of ecological systems are "caricatures of nature" (Holling et al. 2002) designed to describe and communicate ideas about how nature works. Conceptual models provide a way to organize current understanding of ecosystem structure and processes and explore hypothesized linkages among system components. Conceptual models also improve communication among scientists from different disciplines, between scientists and managers, and between managers and the public.

Key Terms

Degradation – reduction in the capacity of an ecosystem to perform natural functions (e.g., maintenance of native biota).

Disturbance – discrete event that changes ecosystem conditions. Natural disturbances are within the range of natural variability.

Driver – external forces exerting control on an ecosystem (e.g., weather).

Stressors – human activities, or natural events outside the range of natural variability, that alter ecological integrity.

Conceptual models are essential to the design of credible and effective ecological monitoring programs. Ecological systems are highly integrative and complex, and their response to novel environmental or biotic conditions is often poorly understood. When used to inform long-term monitoring, the intent of conceptual models is not to represent the full complexity of a system, but rather to use current knowledge to identify a limited set of integrative elements that provide information on multiple aspects of ecosystem condition (Noon 2003). Moreover, conceptual models motivate hypotheses regarding consequences of natural and anthropogenic processes on system structure and function. Conceptualizing the external processes that influence ecosystems (i.e., drivers), the key products of human activities or natural events that alter ecosystem integrity (i.e., stressors), and likely pathways of degradation and attendant changes in system structure and function aids in identifying key system indicators or vital signs. Concentrating monitoring efforts on these vital signs ensures the collection of information useful for understanding ecological condition and change, and for informing park management decisions.

2.2 Conceptual Model Approach

The CHDN adopted a modified version of the interactive-control model (Chapin et al. 1996, Jenny 1941) as the overarching framework for conceptual model development (Figure 2.2-1). This model, also known as the Jenny-Chapin model, defines state factors and interactive controls central to the structure and function of sustainable ecosystems. Jenny (1980, 1941) proposed that soil and ecosystem processes are determined by five state factors: global climate, potential biota, relief (topography), parent material, and time since disturbance (Figure 2.2-2A). Chapin and others (1996) extended this framework to define a set of four interactive controls regulated by the five state factors. These interactive controls (regional climate, soil resources, major functional groups of organisms, and disturbance regime) govern and respond to ecosystem attributes (Figure 2.2-2B). Including hydrologic resources as an interactive control, the Jenny-Chapin model can be applied to aquatic as well as terrestrial ecosystems (Chapin et al. 1996). Regional climate and disturbance regimes are external to the system and are categorized as drivers of ecosystem structure and function. Soil and hydrologic resources, and functional groups, encompass system states and processes that influence overall system structure and function. Functional groups pertain to species or species assemblages likely to have profound effects on ecosystem characteristics following their introduction or loss from a system (Chapin et al. 1997, Vitousek 1990).

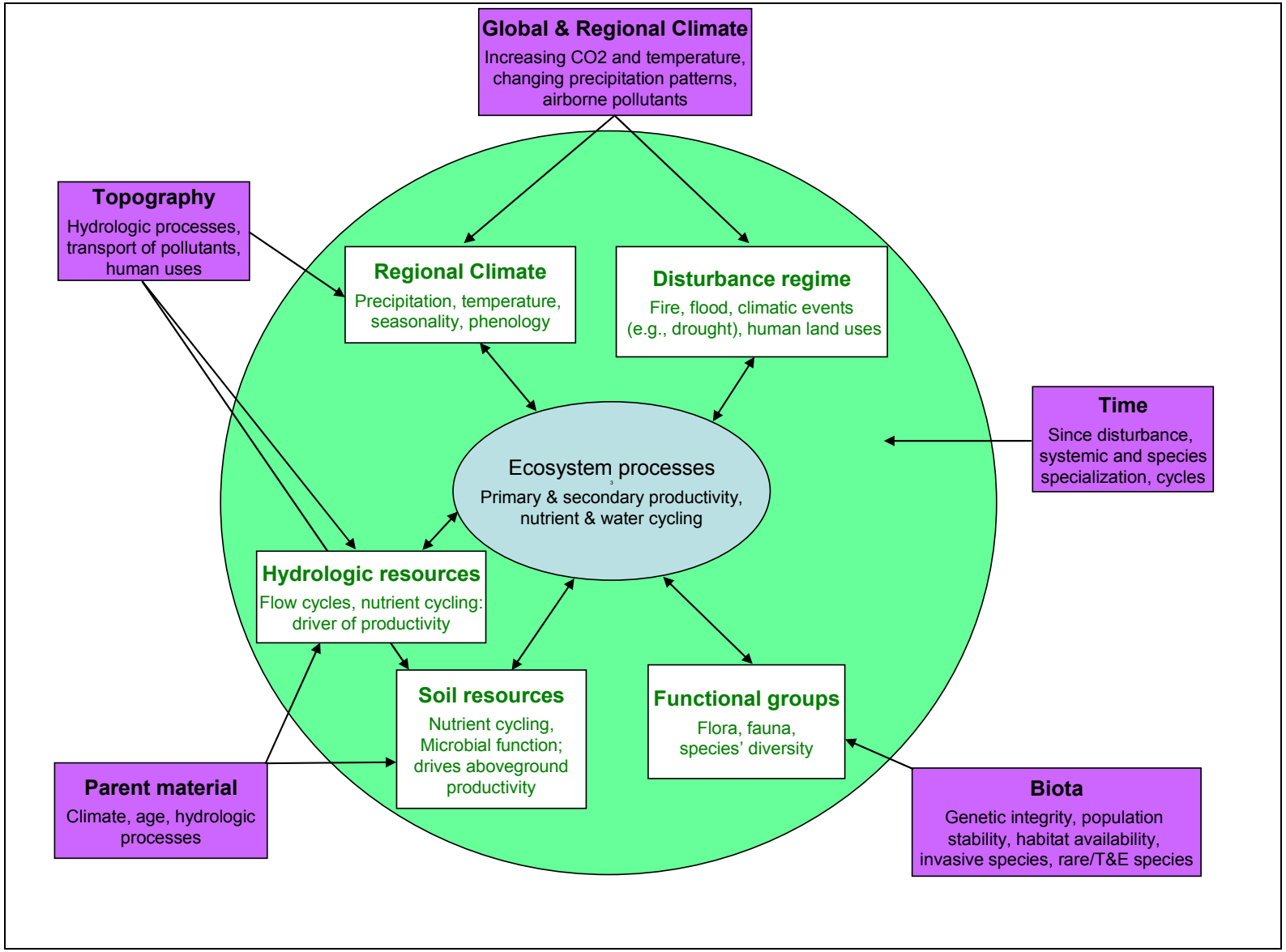

Figure 2.2-1. Illustration of the Jenny-Chapin model, showing relationships among state factors, interactive controls, and ecosystem processes (modified from Figure 2.1.1 in Britten et al. 2007).

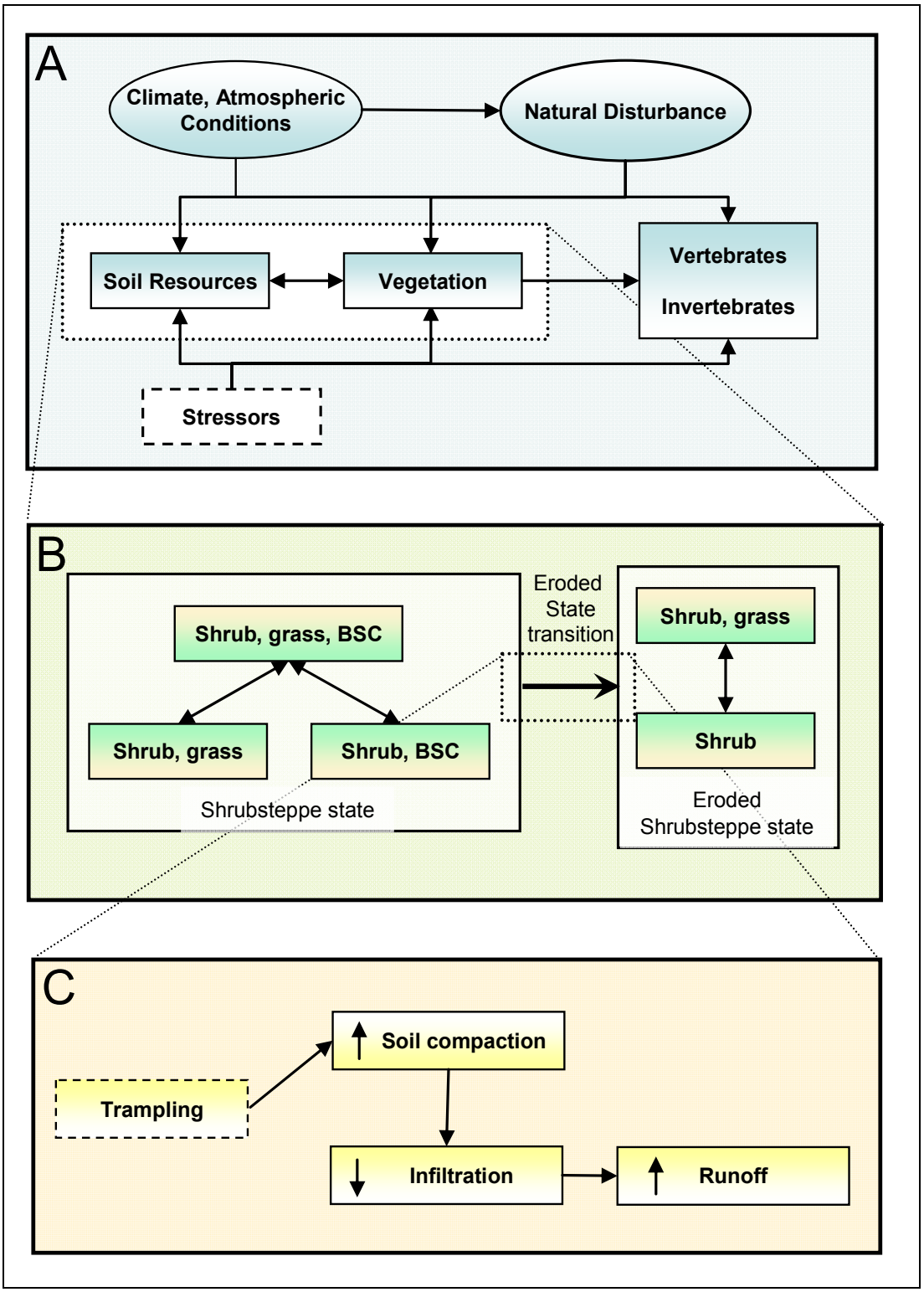

Figure 2.2-2. Illustration of the hierarchical conceptual model scheme used to identify vital signs for monitoring (O'Dell et al. 2005). A – ecosystem characterization model showing drivers (ovals), functional components (rectangles), and stressors (dashed rectangles), B – ecosystem dynamics model using a state and transition framework, C – mechanistic model illustrating the degradational pathway of a stressor (e.g., trampling).

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 an ecosystem with different characteristics than the original system (Chapin et al. 1996). For example, major changes in soil resources can greatly affect productivity, recruitment, and competitive relations of plants, and result in substantive changes in the structure and function of plant communities and higher trophic levels.

Using the Jenny-Chapin model as a central theme (Figure 2.2-1), a nested hierarchy of conceptual models (Figure 2.2-2) was used to identify specific drivers and stressors, plausible stressor-induced degradation pathways and ecosystem responses, and measures and vital signs indicative of the domain of natural conditions and transition to degraded conditions.

The nested hierarchy consists of three general types of conceptual models:

- **Ecosystem Characterization Models** (Figure 2.2-2A) are generalized models that include a list of state variables and forcing functions important to the ecosystem and the focal problem, and also illustrate processes connecting components (Jorgensen 1986). These models provide a framework for organizing information from discussion and literature review around the five interactive controls.

- **Ecosystem Dynamics Models** (Figure 2.2-2B) present hypotheses about ecosystem dynamics; that is, how and why ecosystems change as a consequence of interacting natural and human factors. State-and-transition models are used to depict system dynamics and pose hypotheses about ecological thresholds, transitions among states, and the effect of management activities on state transitions (Bestelmeyer et al. 2003, Jackson et al. 2002, Stringham et al. 2001). Models are developed for broad functional groupings of ecosystems, with eventual development of site-specific models of selected systems.

- **Mechanistic Model** (Figure 2.2-2C) provide details about the actual ecological processes responsible for patterns depicted in the dynamic models. These models provide insight into pathways and primary and secondary effects of particular stressors, highlight potential monitoring attributes or measures, and illustrate the linkage of these attributes in the context of the broader ecosystem. Models are developed for single or multiple combinations of stressors.

2.3 Summary of Conceptual Models for Six Chihuahuan Desert Network Ecosystems

Ecosystem characterization models and narratives for each CHDN system are provided below to illustrate interactive controls (drivers, soil/water resources, functional groups). Stressors and key degradational processes are also included in these models, and potential ecosystem measures to characterize degraded system conditions are listed at the end of each section. Published hierarchical conceptual models for related systems guided the identification of interactive controls, stressors, and degradation pathways for the Desert Ecosystem (Miller 2005), Montane Ecosystem (Thomas et al. 2006: Appendix I), and the riparian component of River Ecosystems (O'Dell et al. 2005: Appendix J). For other CHDN ecosystems, only ecosystem characterization models were developed. For all ecosystems, details of system dynamics were acquired from literature review and expert opinion. Chapter 3 describes how conceptual models were used in the selection of CHDN vital signs.

2.3.1 Desert Ecosystem

The Desert Ecosystem occurs below 1,370 m (4,500 ft) in elevation, and includes basins, low-lying alluvial or colluvial fans, bajadas, and mesas. About 77% of the CHDN is classified as desert, and this ecosystem occurs in five of the seven CHDN parks. The Desert Ecosystem is characterized by low

precipitation, nutrient availability, and net primary productivity, but high plant diversity (Whitford 2002). Vegetation consists of sparse cover of shrub and desert grasslands, and biological soil crust. Salt flats and dunes also are discrete features within this system. Although limited in extent, springs, seeps, perennial and ephemeral streams, and playas (also ephemeral) occur within the desert system. These aquatic systems were not treated separately because they are embedded in the surrounding desert soils and vegetation with connections among all systems. The ecosystem characterization model for the Desert Ecosystem is shown in Figure 2.3.1, and discussed below.

Regional climatic and atmospheric conditions are key drivers of the desert system. Precipitation regulates water-limited ecological processes, such as primary production, nutrient cycling, and plant reproduction (Noy-Meir 1973, Comstock and Ehleringer 1992, Whitford 2002). Interactions among seasonality, spatial variability, and duration of precipitation events create pulses of water input (Appendix F; Snyder and Tartowski 2006) and determine ecosystem response to precipitation. Seasonality influences the partitioning of precipitation among evaporation, transpiration, runoff, drainage, and soil-water storage, and is a determinant of vegetative lifeform dominance (Comstock and Ehleringer 1992). Small precipitation events drive soil-surface processes, such as nutrient mineralization and volatilization, with larger events initiating seed germination and soil-water recharge (Ehleringer et al. 2000). Precipitation intensity, in combination with soil characteristics and soil-surface features, determine infiltration and runoff levels (Whitford 2002, Breshears et al. 2003). Orographic effects, rain-shadows, and seasonal storm features determine spatial pattern of precipitation, which can be highly variable in summer months. In addition, chemical composition of rainfall, and atmospheric nitrogen and carbon, affect metabolic processes of soil microbes and plants (Schlesinger et al. 2006). Large, rapid pulses of rainfall can cause flooding and create temporary resources, such as playa lakes. The temperature regime, driven by solar insolation, results in evaporative loss and water-stress in plants during summer months, and imposes limitations to productivity. Desert plant and animal species have adapted special features to persist under conditions of low water availability and high solar radiation influx (Whitford 2002). Over the long term, climate-driven processes interact with geologic materials and landforms to form or change desert soils (Monger and Bestelmeyer 2006).

Eolian (wind) processes also play a prominent role in the Desert Ecosystem. Winds modify the energy and water balances of plants and soils (Gillette and Pitchford 2004, Okin et al. 2006), and redistribute soils and nutrients.

Ecological processes of the desert system are mediated by geology and hydrology. Landforms resulting from geologic processes create a template influencing the structure and composition of desert resources (Wondzell et al. 1996, Monger and Bestelmeyer 2006). Bajadas and alluvial fans are common landforms throughout the Desert Ecosystem, and the parent materials that create these landforms mediate soil properties and, subsequently, associated vegetative communities (Whitford 2002). The topography of desert systems is relatively flat, but minor variations are sufficient to create different microclimates for plants and animals (Whitford 2002). Slope and channel characteristics influence rates of water flow during precipitation (Simmers 2003).

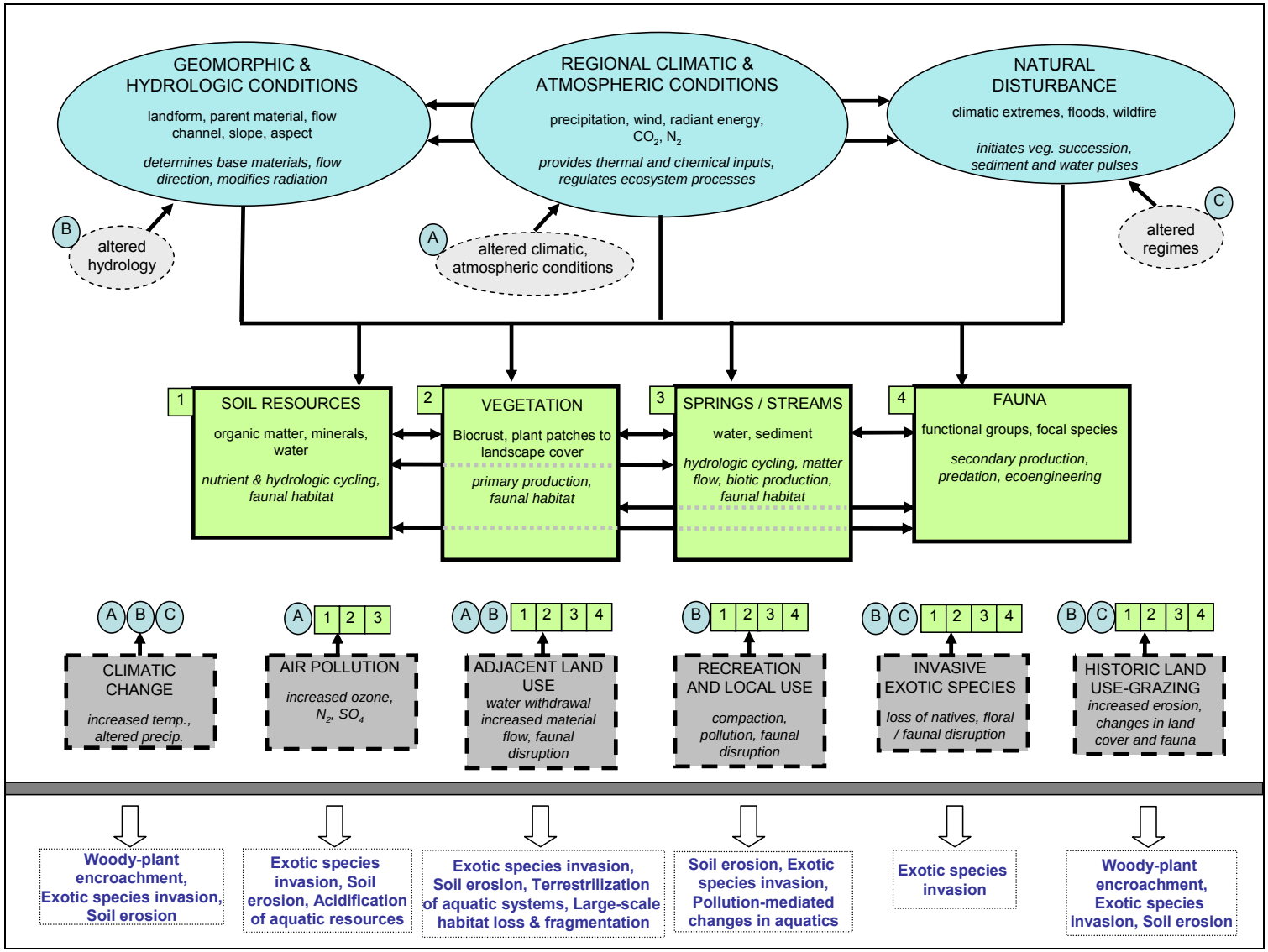

Figure 2.3.1. Ecosystem characterization model for the CHDN Desert Ecosystem. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2.3.1). Text for interactive controls indicates components or structure followed by function. Text for stressors indicates proximate effects.

Natural disturbances include extreme climatic events, flooding, and wildfire. Extended dry periods, particularly when coupled with hot, dry winds, can cause mass mortality of perennial grasses. With the loss of perennial cover, sites are more vulnerable to soil erosion by wind and water. In certain regions of the CHDN, current vegetation composition can be attributed to drought-induced die-off events more than 50 years ago (Peters et al. 2006). Periodic flash-flood events can occur during summer monsoonal rains, and are a primary source of long-range material transport and groundwater recharge within the Desert Ecosystem (Whitford 2002, Snyder et al. 2006). Through biotic interaction with species, such as 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 1995). The role of fire in shrub dominated communities of the Desert Ecosystem is variable and likely less influential than soil integrity and seed dispersal (Dick-Peddie 1993, Drewa and Havstad 2001, Valone 2003).

Soil resources mediate the productivity and function of desert systems. The availability of soil moisture and nutrients is a primary factor limiting productivity in the Chihuahuan Desert (Whitford 2002, Snyder et al. 2006). Soil stability, texture, and structure influence mineralization, soil water-holding capacity, soil biota composition, and rooting depth, all of which influence plant composition, distribution, and growth (MacMahon and Wagner 1985, Whitford 1996, Huenneke and Schlesinger 2006). The resilience of a site is largely related to soil properties (Karlen et al. 1997, McAuliffe 2003). 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). At White Sands NM, soil created from water-leached dolomite forms gypsum crystals in a large playa lake bed (Kiver and Harris 1999) and eventually forms gypsum dunes (Langford 2003). Plants adapted to these soils are limited and have a high tolerance of gypsum (Dick-Peddie 1993). Loss and redistribution of soil resources can ultimately lead to desertification (Schlesinger et al. 1990, Gillette and Pitchford 2004).

Vegetation provides energy for higher trophic levels, and the above-ground structure of vascular plants protects soils from erosive rain drops, wind, and overland water flow, and enhances the retention of soil resources (Gillette and Prichard 2004, Abrahams et al. 2006). Plants also modify the physical environment through shading and litter deposition. Vegetation is a key component of fauna habitat (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, such as cacti and agaves, are another defining plant growth form of this ecosystem. Although trees are often absent, CHDN plant communities are among the most diverse of any desert system.

Biological soil crust (BSC)—microbial communities consisting of fungi, algae, cyanobacteria, lichens, and moss (Belnap and Lange 2001)—contribute to site potential and productivity. Well-developed crusts directly influence soil stability and facilitate growth of desert mosses. Mosses provide organic matter and enhance moisture retention, which facilitates germination, growth, and survival of vascular plant species. Nitrogen fixation by cyanobacteria is an important ecosystem function of BSC, which is highly susceptible to air pollution and trampling. Recolonization of disturbed sites may require from decades to centuries.

Springs, seeps, and ephemeral and perennial streams are rare but functionally important elements of the Desert Ecosystem. These systems 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 F). These 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 the spread of invasive plant species, such as salt cedar (*Tamarix* spp.).

A wide variety of invertebrates and vertebrates is found in this ecosystem (e.g., see Appendix C, Whitford and Bestelmeyer 2006). Both 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). Key functional groups of fauna, their particular environmental associations, and their roles in regulating ecosystem processes have recently been summarized by Whitford and Bestelmeyer (2006: Table 12-2). Kangaroo rats (*Dipodomys* spp.) and subterranean termites are notable keystone groups (Nash and Whitford 1995, Kerley et al. 1997, Fields et al. 1999, Krogh et al. 2002, Whitford and Bestelmeyer 2006). Burrowing activity, harvesting of flowers, and seed caching by species of kangaroo rats influence establishment of native herbaceous plants (Fields et al. 1999), changes in local vegetation composition (Kerley et al. 1997, Brown and Heske 1990), and redistribution of nutrients (Whitford 2002). Kangaroo rats also are an important food resource for a diverse assemblage of predators. Subterranean termites can process 3–50% of leaf litter (Whitford and Bestelmeyer 2006: Table 12-1), returning several nutrients, including nitrogen, phosphorous, and sulfur, to the available nutrient pool (Whitford and Bestelmeyer 2006). Soil porosity and water infiltration are increased by gallery development and expansion. Nutrient cycling and water infiltration ultimately affects composition and productivity of vegetation communities. Fauna contribute to biological diversity, and some species are of special conservation concern (Appendix C).

Increasing levels of atmospheric CO_2, increasing soil and air temperatures, and altered precipitation patterns are likely to affect physiological processes and competitive relations of vascular plants, nutrient cycles, hydrologic processes, and natural disturbance regimes. All of these can greatly alter the structure and functioning of dryland ecosystems (e.g., Alward et al. 1999, Ehleringer et al. 2000, Smith et al. 2000, Weltzin et al. 2003) and the sensitivity of these systems to other anthropogenic stressors. Increases in CO_2 from local and global sources enhance growth rates of C3 shrubs over native grasses, and of C3 exotic annual grasses. Increase in shrub cover decreases herbaceous cover due to light competition, with a concomitant increase in bare ground between shrub canopies. Higher exposure of bare ground increases the risk of wind and water erosion of soil, and subsequent loss of site potential and biotic integrity. Expansion of woody shrubs impacts animal species associated with herbaceous plant communities. Warming and lower precipitation trends predicted for dryland systems are likely to increase evapo-transpiration and offset temperature-driven increases in plant production (Saleska et al. 1999).

Sources of air pollutants, such as particulates, tropospheric ozone, and nitrogen deposition, include coal-burning power plants, oil and gas developments (which increase airborne nitrates and sulfates), and industrial point and non-point sources from Mexico. Nitrogen deposition increases the susceptibility of a site to exotic plant invasion (Asner et al. 1997, Galloway et al. 2003, Fenn et al. 2003). Nitrogen deposition in the form of acid rain has the potential to impact water quality and degrade cultural features, such as pictographs. Ozone formed from nitrogen emissions poses a risk to human health, and particulates impact visitor experience by impairing scenic vistas.

Adjacent land use consists of agricultural and urban development, groundwater pumping, energy and mineral development, and ranching of exotic species. These activities affect park lands directly through the deposition of atmospheric pollutants, by increasing invasion by exotic plants and animals, and by altering hydrological regimes of waters that originate outside the park. Altered hydrologic regimes can decrease plant cover and increase frequency and extent of soil erosion. Land-use practices increase the risk of mortality to park wildlife that range onto adjacent lands, and potentially impact migration and

dispersal abilities of species. Loss of regional connectivity of species habitat leads to insularization of park lands.

Recreation activities affect park conditions in many ways. Waste management and backcountry human-waste disposal can impact water quality. The release of unwanted pets and introduction of non-native plants are also potential threats. Social trailing, especially in fragile or sensitive habitats, leads to compaction of vegetation, BSC, and soils, with subsequent impacts to water quality, soil stability, soil-water infiltration rates, and overall site potential.

Invasive/non-native species can replace native species, leading to loss of biodiversity, and affect ecosystem change and degradation. The list of non-native animal and plant species affecting CHDN park units is extensive (Appendices C and D). NPS mowing and maintenance practices, visitor use, and adjacent land practices increase the risk of exotic species invasion. These invasions can displace native species through disease, competition, and predation, thereby changing vegetation and animal communities. Exotic plants impact water quantity and affect fire regimes by increasing fuel loadings and, ultimately, fire frequency. Subterranean cave systems are especially sensitive to the introduction of exotic plants.

Historical grazing is considered a stressor given its impact on desert systems. 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). Conversion of grasslands to shrublands is attributed to the removal of palatable native grasses, and to trampling of soils and vegetation. The reduction of grasses promoted an increase in shrub density, and soil disturbance led to the establishment of exotic invasive plants. Loss of herbaceous cover due to shading by shrubs increases amount of bare ground and soil erosion potential. Historical grazing alone, however, may not be responsible for this conversion, given the coincidence of global climate patterns (e.g., end of the Little Ice Age, ca. 1900) and the rapid increase in domestic livestock across the Southwest and Trans-Pecos regions (Neilson 1986). Also, causes of the shift of grasslands to shrublands are complex (Peters and Gibbens 2006), and involve multiple historical and ecological factors (Cole and Monger 1994, Fredrickson et al. 2006, Housman et al. 2006, Peters et al. 2006, Peters and Havstad 2006). Monitoring to determine continued shrubland conversion and areas with trespass grazing is important to inform management of this important resource change.

Seven key degradation processes are predicted (Figure 2.3.1, Table 2.3.1). These processes can lead to conditions beyond the naturally variability of desert systems, and have important implications to ecosystem sustainability. Potential measures that would provide early warning of system degradation are listed for each process.

Table 2.3.1. Key degradation processes in the Desert Ecosystem, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation process	Stressors	Ecological effects	Potential measures
Woody-plant encroachment	The reduction of perennial grasses from grazing, CO_2 enrichment under climatic change	Altered soil-hydrologic and nutrient cycling and habitat structure, loss of herbaceous communities and associated animal species, increased soil exposure and erosion	Vegetative composition and structure, occurrence of trespass grazing, climatic-atmospheric elements, abundance of grassland-associated animal species
Exotic species invasion	Recreation and local use, adjacent land-use activities, climatic and atmospheric changes	Plants: Altered nutrient dynamics, soil-water dynamics, major shift in functional-group structure Animals: Loss of native fauna	Vegetative composition and structure, adjacent land-use activities, climatic and atmospheric elements, abundance of exotic animal species
Soil erosion and redistribution	Trampling by visitors and trespass grazing, air pollution, climatic change, dewatering of surface and groundwater by adjacent land-use activities	Erosion and loss of soil function due to reduction of biological soil crusts, soil compaction, soil-surface roughness, soil-aggregate stability, and water infiltration; decreased N fixation; changes in vegetative composition and structure	Depth, structure, and stability of soils; biological soil crust cover and distribution; vegetative composition, structure, and pattern; climatic and atmospheric elements, adjacent land-use activities; trespass grazing frequency and severity
Acidification of aquatic resources	Acid rain (atmospheric nitrogen)	Loss of native aquatic biota	Water chemistry, aquatic biota structure and composition, atmospheric elements
Large-scale habitat loss & fragmentation	Adjacent land-use activities	Regional-scale habitat loss, reduced connectivity of metapopulations, reduced ingress and egress potential	Land-cover, land-use, land-condition patterns on park and adjacent lands
Terrestrialization - conversion of aquatic systems to terrestrial vegetation	Adjacent land use (streamflow depletion)	Loss of springs, ephemeral, perennial stream function with conversion of aquatic vegetation to upland or xeroriparian species	Surface and groundwater flow rates, adjacent land-use activities, land-cover and land-use patterns on park and adjacent lands, stream/spring vegetation structure and composition, climatic elements
Pollution-mediated changes in aquatic systems	Recreation and local use	Altered biotic structure, composition, and function of aquatic systems	Patterns of recreation use, water chemistry, aquatic biotic structure and composition

2.3.2 Foothill Ecosystem

The Foothill Ecosystem occurs at elevations between 1,370 m and 1,981 m (4,500–6,500 ft), and includes piedmonts, foothills, mesas, and canyons. This ecosystem comprises about 9% of the CHDN, and foothills occur in four CHDN parks. The Foothill Ecosystem is a transition area between the lower desert and higher montane environment. As with the Desert Ecosystem, springs, seeps, and perennial or ephemeral streams are included as subsystem elements. Habitat types of this ecosystem include grasslands, shrublands, and woodlands (see Appendix D for more detailed description). The ecosystem characterization model for the Foothill Ecosystem is shown in Figure 2.3.2, and discussed below.

Focal resources of the Foothill Ecosystem are shaped by the same three categories of drivers described for the Desert Ecosystem: climate and atmospheric conditions, geomorphic and hydrologic conditions, and natural disturbance. The nature and magnitude of influence of these drivers differ from the Desert Ecosystem as a function of topography and climate variation associated with higher elevation. Upper elevations receive more precipitation and have cooler temperatures. Surface water channels can be more incised, narrower, and have steeper gradient than arroyos and washes of the desert basins; thus, there is greater erosion potential during periods of high precipitation. Low-intensity ground fires were a natural disturbance of the shrub and woodland components of the foothill system, and historically maintained a mosaic of age classes and patch patterns across the landscape.

As in the Desert Ecosystem, vegetation provides the primary source of production, stabilizes soils, and provides food and cover for other organisms. Given the greater topographic relief than in the Desert Ecosystem, orographic effects provide additional stratification of local environments that can enhance beta-diversity. Also, higher levels of soil organic matter enhance water and nutrient retention, allowing for higher primary production. Cacti, yucca, and agave plant forms are present, and shrub forms may also dominate some plant communities. Large expanses of grassland are atypical, except on high mesas. Trees are common.

Streams within open to steep-walled canyons may support development of narrow but distinct riparian corridors. The cooler, moister conditions of foothill canyons and draws provide plant-rich microcosms and, in some cases, form stringers of closed-canopy woodlands with developed understories of herbs and shrubs (Baker et al. 2004). These areas provide refugia for 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 serve as primary routes of biotic transition between the upper elevations and desert basin.

The Foothill Ecosystem includes species that are less adapted for life in arid conditions. Bird communities can be particularly diverse in riparian or canyon habitats of the Foothill Ecosystem. The structure, composition, and microclimate of riparian vegetation provide suitable nesting and foraging conditions for a number of bird species (Mills et al. 1991, Bryan and Karges 2001), including some threatened or endangered species, such as Mexican spotted owls (*Strix occidentalis lucida*; Ward et al. 1995). Strong keystone roles by species in the Foothill Ecosystem have not been identified. However, species such as 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. 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).

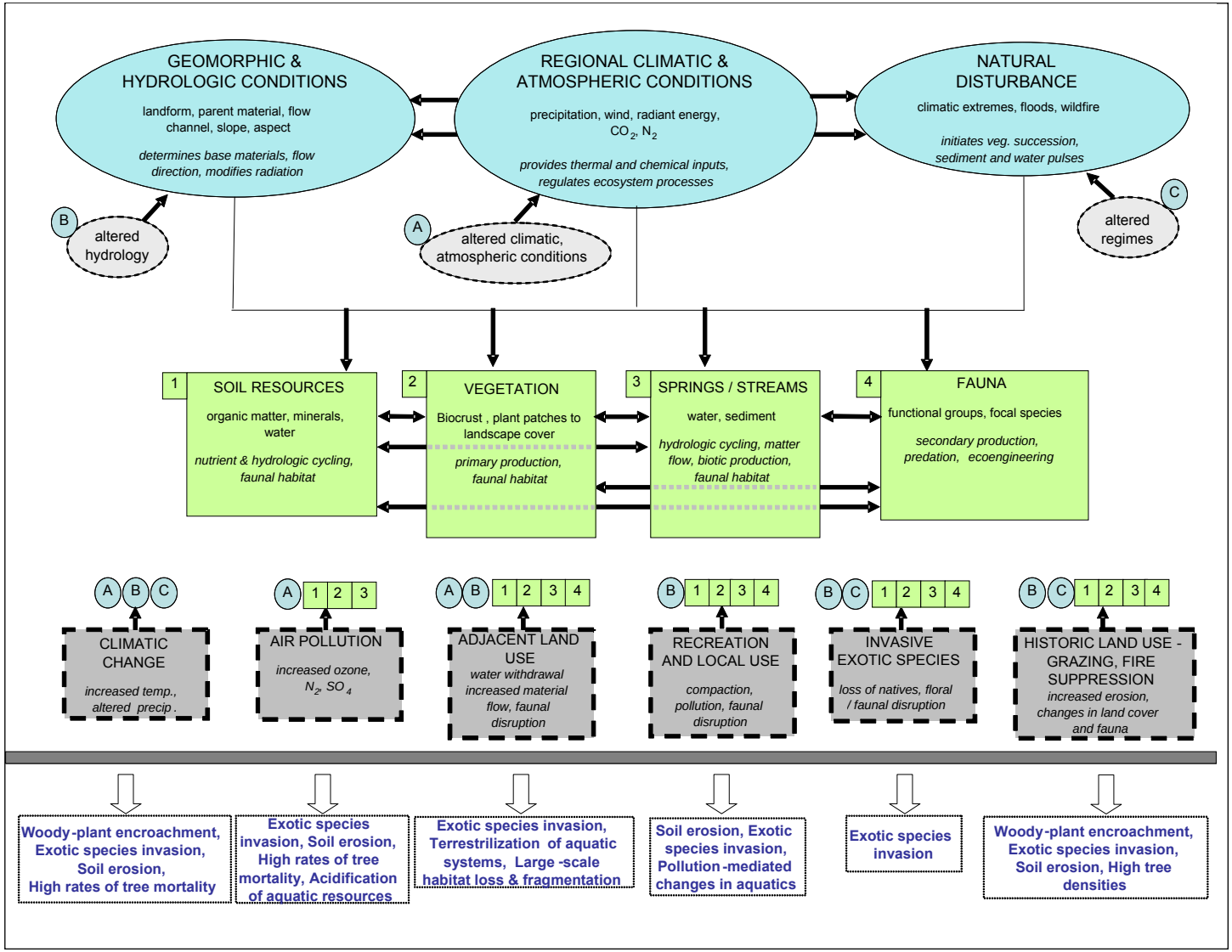

Figure 2.3.2. Ecosystem characterization model for the CHDN Foothill Ecosystem. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2.3.2). Text for interactive controls indicates components or structure followed by function. Text for stressors indicates proximate effects.

Air pollutants and climatic change are modeled to have two general effects. Similar to the Desert Ecosystem, CO_2 and nitrogen enrichment can enhance woody-plant encroachment and establishment of exotic plants. Additionally, air pollutants, such as ozone, can reduce tree growth due to increased foliar injury, and temperature-induced stress can increase susceptibility of trees to insects and pathogens, both of which are modeled to increase tree mortality. Increased downed-woody fuels on the landscape increases the risk of high-severity fires.

Human uses are modeled in two general ways. Adjacent land use impacts quantity and quality of surface and ground waters through domestic extraction or as a byproduct of oil and gas development. Dust emissions from road and oil/gas pad construction, as well as atmospheric pollutants from vehicle, drill, and pump engines, can lead to resource enrichment and favor the spread of exotic invasive plants. Land-use activities near park boundaries can promote the spread of invasive plants and animals into parks and alter egress and ingress potential for wildlife species. Visitor use impacts parks through trampling of soil and vegetation, by introducing exotic invasive species, and through repeated use of aquatic systems. Disruption of soil stability through trampling has ramifications for soil-water runoff, soil erosion, and decreased site potential. Repeated trampling around springs, seeps, and streams reduces the vegetation structure that provides shading and nutrient inputs to aquatic resources. Human pollution in commonly used riparian areas impacts water quality and associated biotic communities.

Exotic invasive species can have a large impact on foothill systems. Feral hogs (*Sus scrofa*) can drastically affect the structure of riparian vegetation and springs, and limit resources for collared peccaries. Trespass cattle also occur throughout the foothills and continue to alter plant composition with the removal of palatable native grasses and by trampling.

Historical grazing and fire suppression are modeled as interacting stressors. Grazing occurred throughout the CHDN foothills prior to park designations, and contributed to the conversion of native grasslands to shrublands and to the spread of exotic plants. Fire suppression over the last century has significantly altered the fire regime. The increase in woody biomass due to excessive livestock grazing in the past and the continuation of fire suppression has increased fuel loads and the risk of high-severity fires. After high-severity fires, the loss of soil-stabilizing vegetation on steep slopes can lead to significant soil erosion and long-term or permanent loss of site potential. Stand-replacing fires, especially in riparian woodlands, have important consequences for local biodiversity.

Degradation processes include the seven listed for desert systems, plus high tree stocking and mortality (Figure 2.3.2, Table 2.3.2). The higher levels of biomass and downed-woody fuels resulting from historical grazing, fire suppression, and climatic and atmospheric stresses increase the risk of high-severity fire and concomitant impacts on soil properties and plant communities.

Table 2.3.2. Key degradation processes in the Foothill Ecosystem, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation process	Stressors	Ecological effects	Potential measures
Woody-plant encroachment	The reduction of perennial grasses from grazing, CO_2 enrichment under climatic change	Altered soil-hydrologic and nutrient cycling and habitat structure, loss of herb species, increased soil exposure and erosion	Vegetative composition and structure, occurrence of trespass grazing, climatic-atmospheric elements
Exotic species invasion	Recreation and local use, adjacent land-use activities, climatic and atmospheric changes	Plants: Altered nutrient dynamics, soil-water dynamics, major shift in functional-group structure Animals: Loss of native fauna	Vegetative composition and structure, adjacent land-use activities, climatic-atmospheric elements, abundance of exotic animal species
Soil erosion and redistribution	Trampling by visitors and trespass grazing, air pollution, climatic change, dewatering of surface and groundwater by adjacent land-use activities	Erosion and loss of soil function due to reduction of biological soil crusts, soil compaction, soil-surface roughness, soil-aggregate stability, and water infiltration; decreased N fixation; changes in vegetative composition and structure	Depth, structure, and stability of soils; biological soil crust cover and distribution; vegetative composition, structure, and pattern; climatic and atmospheric elements; adjacent land-use activities; trespass grazing frequency and severity
Acidification of aquatic resources	Acid rain (atmospheric nitrogen)	Loss of native aquatic biota	Water chemistry, aquatic biota structure and composition, atmospheric elements
Large-scale habitat loss & fragmentation	Adjacent land-use activities	Regional-scale habitat loss, reduced connectivity of metapopulations, reduced ingress and egress potential	Land-cover, land-use, land-condition patterns on park and adjacent lands
Terrestrialization - conversion of aquatic systems to terrestrial vegetation	Adjacent land use (streamflow depletion)	Loss of springs, ephemeral, perennial stream function with conversion of aquatic vegetation to upland or xeroriparian species	Surface and groundwater flow rates, adjacent land-use activities, land cover and land use on park and adjacent lands, stream/spring vegetation structure and composition, climatic elements
Pollution-mediated changes in aquatic systems	Recreation and local use	Altered biotic structure, composition, and function of aquatic systems	Patterns of recreation use, water chemistry, aquatic biotic structure and composition
High tree density and high rates of tree mortality	Historical grazing, fire suppression, climatic change, atmospheric pollutants	Higher spatio-temporal frequency of snags and downed coarse-woody debris; larger contiguous fire patterns due to high fuel loads and fuel connectivity; erosion and loss of soil function due to sterilization, reduction in soil stability, reduction in site potential, and changes in attendant plant communities resulting from high-severity fire	Fire regime attributes, tree mortality rates, tree and shrub structure and composition

2.3.3 Montane Ecosystem

The Montane Ecosystem occurs at elevations above 1,981 m (6,500 ft), and includes steep-sloped terrain and intermittent valleys or canyons. This ecosystem comprises about 2.5% of the CHDN, and occurs in GUMO and BIBE. Landforms in this ecosystem are often connected to Foothill Ecosystems. Plant communities include pine-oak woodland, mesic mixed conifer forest and woodland, and montane deciduous woodland. Springs, seeps, and perennial or ephemeral streams are included as functional groups. The ecosystem characterization model for the Montane Ecosystem is shown in Figure. 2.3.3, and discussed below.

The occurrence of woodlands and forests is directly related to the mountainous terrain and elevation-mediated precipitation gradients. Ambient temperatures are generally cooler than at lower elevations, and vary inversely with elevation, landform, and aspect. Precipitation is greater than in lower-elevation systems and contributes to higher productivity relative to other CHDN terrestrial systems. The higher montane elevations capture and contribute substantially to the water balance of lower watersheds and ecosystems. The slope gradients, and high precipitation levels and rates of mineralization, facilitate transport of materials from the montane to the Foothill and even Desert ecosystems.

Fire has been an important disturbance agent. In mixed-conifer forests in GUMO, fires prior to 1800 tended to be frequent (mean fire return interval of 24 years) and small, creating mixed-age forests (Sakulich and Taylor 2007). A similar fire regime is documented for BIBE (Camp et al. 2006). Less frequent and larger fires typified the period from 1800 to 1922, when livestock grazing was introduced. This period corresponded to a decline in local populations of Native Americans and associated ignitions. Reduced fire frequency and fuel accumulation possibly increased the importance of lightning ignitions (Sakulich and Taylor 2007).

The presence and diversity of trees is a distinguishing characteristic of this ecosystem. Trees affect productivity and diversity of montane plant communities more than in the other terrestrial CHDN ecosystems. The higher productivity of montane systems promotes the development of organic horizons in soils which, in turn, enhances water retention and availability to plants. The vertical structure of forests supports higher biomass than shrublands, and the heterogeneity of tree canopy enhances understory plant diversity and productivity.

Because of cooler temperatures and more precipitation, surface water is often available longer in montane than in desert and foothill systems. Streams and springs are frequently the headwaters for aquatic systems at lower elevations. The health of montane aquatic systems is tightly linked to upland conditions. Sediment influx to streams is determined by upland soil stability and plant cover, and temperature regulation and nutrient input are mediated by riparian vegetation. Montane springs and seeps are isolated and provide habitat for rare and endemic plants or animals.

Many animal 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. Some species, however, are resident. Black bears (*Ursus americanus*) in BIBE 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). Mogollon voles (*Microtus mogollonensis*) and Mexican woodrats (*Neotoma mexicana*; Sullivan 1994) are notable residents of the montane system. Because of geographic isolation, resident species with limited reproductive rates or dispersal abilities are vulnerable to extirpation. Dynamics of isolated populations can be indicators of local (resource conditions) or regional (dispersal and recruitment) processes. Keystone species of the Montane 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).

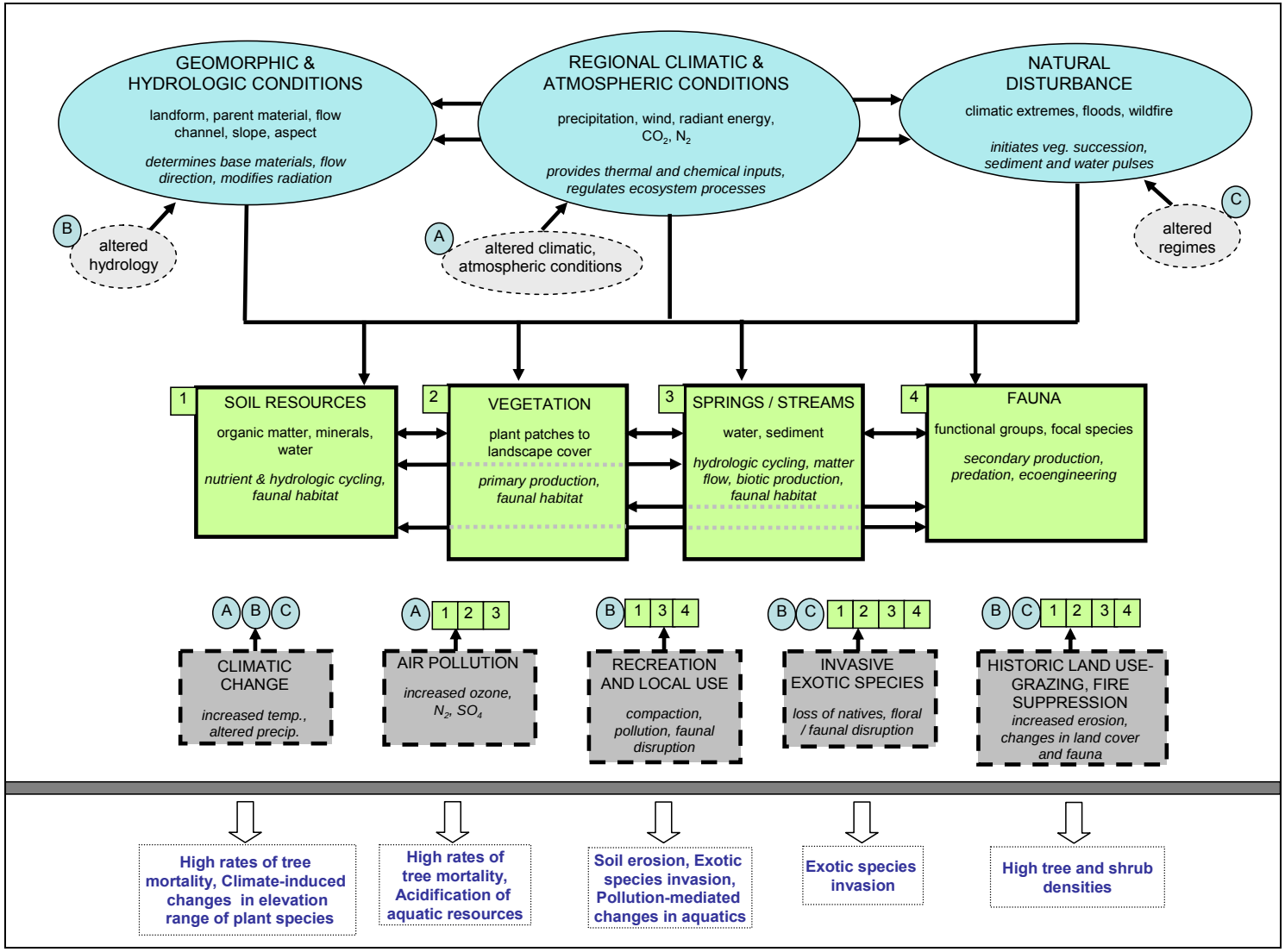

Figure 2.3.3. Ecosystem characterization model for the CHDN Montane Ecosystem. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2.3.3). Text for interactive controls indicates components or structure followed by function. Text for stressors indicates proximate effects.

Interactions among increasing temperature, changes in the precipitation regime, and atmospheric pollutants are modeled to impact vegetation communities and disturbance regimes of montane systems. Higher rates of tree mortality, mediated by temperature-induced stress and foliar ozone damage, have implications for increased volumes of downed-woody fuels. Increased fuel loadings can support high-severity fires and lead to soil sterilization, an increase in water erosion of soils, and an overall reduction in site potential. Changes in soil properties from high-severity fires can alter post-disturbance successional development from the historical range of trajectories, with impacts to system function. Acid rain originating from nitrogen emissions can severely alter the chemistry of high-elevation aquatic resources and reduce biotic integrity of surface waters lower in the watershed. A potential consequence of climatic change is the alteration of bioclimatic zonation along elevational gradients (Ryan et al. 2008). It is possible that the climate envelope of CHDN montane species will move upward in elevation. The ability of individual species to track this change will determine degree of similarity in community composition between current and future montane systems.

Similar to the other CHDN systems, recreational and local use of montane systems have the potential to pollute aquatic systems; physically alter vegetation characteristic of streams, springs, and seeps; and enhance the spread of exotic invasives. Soil compaction and erosion may occur in localized, over-used areas, but the deeper, well-developed soils are more resistant to trampling effects than in other terrestrial systems of the CHDN.

Historical grazing and fire suppression have altered vegetation conditions and the fire regime. Previous grazing led to an increase in tree density by reducing competition between grasses and tree seedlings. Consumption of fine fuels by livestock also reduced the ability of ground fires to spread. Additionally, fire suppression since the 1920s has contributed to a significant reduction in fire frequency (Sakulich and Taylor 2007). With the removal of livestock grazing, enhanced conditions for the spread of fire and the increase in fuel loadings increases the risk of high-severity fires, with concomitant long-term impacts to soil stability, soil erosion, and changes in vegetation composition and structure.

Five key degradation processes are predicted for the montane system (Figure 2.3.3, Table 2.3.3). All processes overlap with those of the Foothill Ecosystem. Exotic species invasion is included as a potential threat although the relative isolation of montane systems somewhat buffers against human-mediated introductions of exotics.

Table 2.3.3. Key degradation processes in the Montane Ecosystem, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation process	Stressors	Ecological effects	Potential measures
Exotic species invasion	Recreation and local use	Plants: Altered nutrient dynamics, soil-water dynamics, major shift in functional-group structure Animals: Loss of native fauna	Vegetative composition and structure, climatic-atmospheric elements, abundance of exotic animal species
Soil erosion and redistribution	Trampling by visitors, trespass grazing, air pollution, climatic change	Erosion and loss of soil function due to reduction of biological soil crusts, soil compaction, soil-surface roughness, soil-aggregate stability, and water infiltration; decreased N fixation; changes in vegetative composition and structure	Depth, structure, and stability of soils; biological soil crust cover and distribution; vegetative composition, structure, and pattern; climatic and atmospheric elements; trespass grazing
Pollution-mediated die-offs in aquatic systems	Recreation and local use	Altered biotic structure, composition, and function of aquatic systems	Patterns of recreation use, water chemistry, aquatic biotic structure and composition
Acidification of aquatic resources	Acid rain (atmospheric nitrogen)	Loss of native aquatic biota	Water chemistry, aquatic biota structure and composition, atmospheric elements
High tree density and high rates of tree mortality	Fire suppression, climatic change, atmospheric pollutants	Higher spatio-temporal frequency of snags and downed coarse-woody debris; larger contiguous fire patterns due to high fuel loads and fuel connectivity; erosion and loss of soil function due to sterilization, reduction in soil stability, reduction in site potential, and changes in attendant plant communities due to high-severity fire	Fire regime attributes, tree mortality rates, tree and shrub structure and composition

2.3.4 Reservoir Ecosystem

The CHDN Reservoir Ecosystem is International Lake Amistad and also includes the environments created by the confluence of three major rivers into Lake Amistad: the Rio Grande and the Pecos and Devils rivers (Figure 2.3.4). International Lake Amistad is a reservoir divided by the boundary of Coahuila, Mexico, and Texas, and has the second-largest drainage basin of any major reservoir in Texas (323,643 km^2). At its conservation elevation of 340.5 m above sea level, the reservoir has a mean depth of 16.5 m. The entire reservoir system covers approximately 4% of the total CHDN area. The ecosystem characterization model for the Reservoir Ecosystem is shown in Figure 2.3.4, and discussed below.

The four interacting drivers influence the water properties of reservoirs which, in turn, mediate the behavior of the four functional groups (Figure 2.3.4). Precipitation inputs to the reservoir occur as summer rains associated with the "Mexican monsoon." Additionally, river flow and groundwater sources contribute to maintaining reservoir volume. The Edwards-Trinity Aquifer enters into the rivers near the reservoir and directly into the reservoir, and is especially important in maintaining reservoir water volume and quality, and buffering the variability of river flows. Variability of reservoir conditions over monthly, annual, and decadal spans is largely driven by climatic factors, such as hurricanes, drought cycles, and wet years. Surface geology, physiography, and topography within the watershed contribute to the transport of particulates and dissolved weathering products to the reservoir. Solar input and the movement of air masses are important for the mixing of dissolved gases and particulates throughout the water column.

Bottom sediments form as particulates fall out of the water column. They contain high concentrations of bacteria and other decomposers that contribute to the energetics of the reservoir. 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 (reduction-oxidation) 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.

The water column consists of the complete body of water that fills the reservoir basin, and various physical, chemical, and biological components. Within the water column, the light environment, temperature, static and mobile layers of different density, dissolved electrolytes and non-electrolytes, nutrients, dissolved gases, and mixing pattern determine the structure and function of biological components. Phytoplankton, periphyton, and macrophyte communities are the sources of primary production, and drive the aquatic food webs of the reservoir. In the lacustrine zone of AMIS (main body of the reservoir), the water column has low phytoplankton biomass and nutrients, and this zone functions like an oligotrophic ecosystem (Groeger et al. in press). Nutrients and productivity are higher in the transitional zone, where riverine systems enter the reservoir.

The shallow areas along the reservoir edge and inundation of riparian vegetation during high water levels form the reservoir's littoral zone. These areas are extremely productive and serve as excellent habitat for vertebrate species because they provide cover (e.g., from predators for young and small fish) 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, proving a boon for the sport fishery. Littoral habitat is much better developed on the Rio Grande side of the reservoir than on the Devils River side.

Reservoir fauna predominantly include fish and invertebrates, including zooplankton in the water column and benthos associated with deep-water sediments. Many fish species are not native to the Rio Grande and tributaries but are valued as a sports fishery (Appendix C).

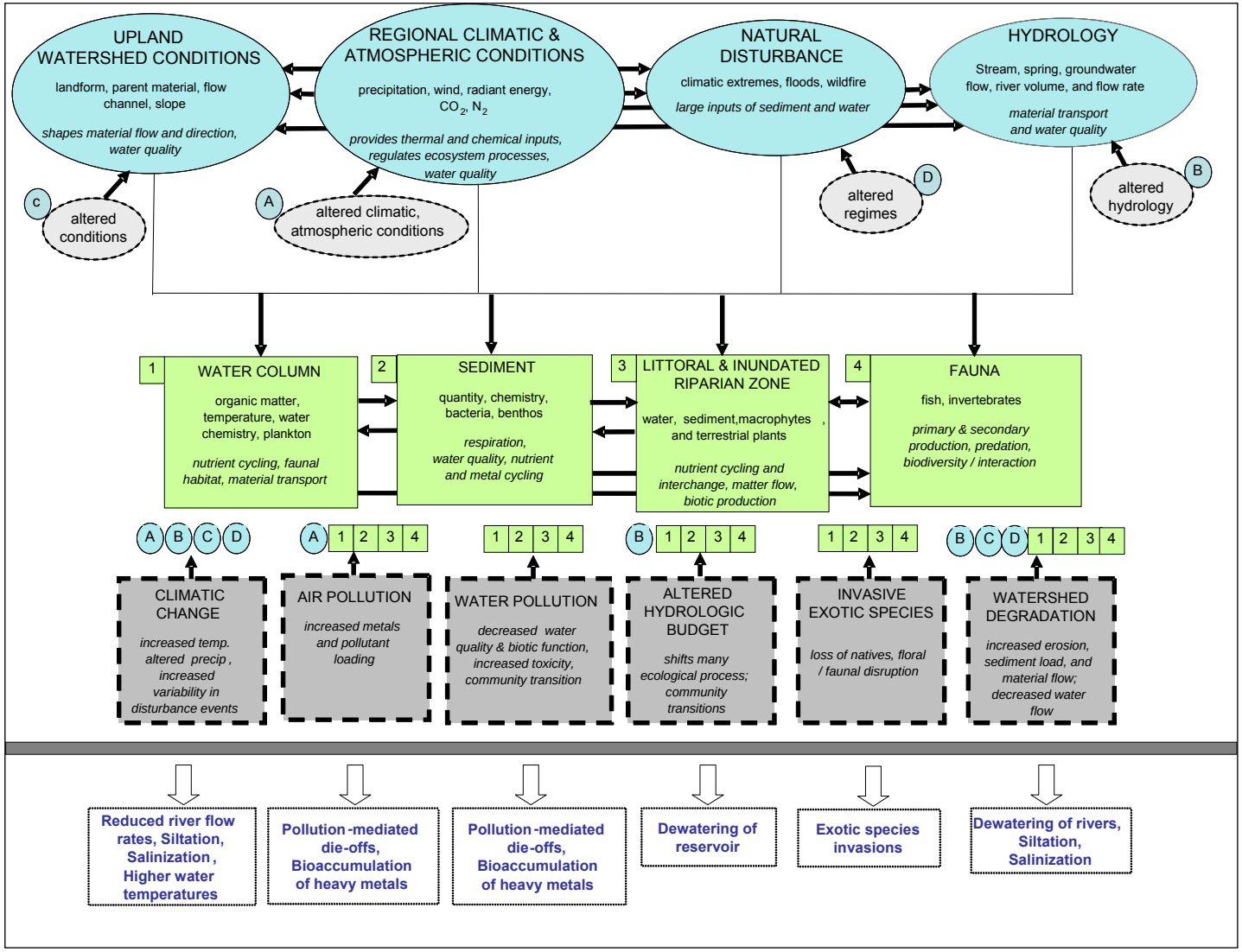

Figure 2.3.4. Ecosystem characterization model for the CHDN Reservoir Ecosystem. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2.3.4). Text for interactive controls indicates components or structure followed by function. Text for stressors indicates proximate effects.

Climatic change is a potentially important stressor that interacts with all four drivers of the system. With increasing air temperatures, the water column may become warmer in the winter and create a warmer hypolimnion during the summer, with an extended period of anoxia in this layer. Also, predicted increases in the variability of weather events, such as droughts and hurricanes, will add to the variability of river flow, littoral zones, reservoir water levels, and overall hydrologic conditions. Climate-induced stress of vegetation throughout the upland watershed has the potential to reduce soil-retention capacity and lead to higher sediment loadings of rivers and, eventually, the reservoir. Lower precipitation levels and increased temperatures have the potential to increase salinization of the rivers feeding the reservoir and, ultimately, increase the salinity of the reservoir.

Pollutants and nutrients dumped directly into the source rivers and from the atmosphere, and in runoff from degradated uplands in the watershed, are threats to the quality of reservoir water. Sewage and other organics impact the reservoir through increased organic-matter loading, which leads to a higher oxygen demand and earlier (and more intense) anoxia in deeper waters. Eutrophication resulting from organic inputs also detracts from water clarity. Deposition of airborne heavy metals and volatile organics increases the toxicity of reservoir sediments and the bioaccumulation of toxic compounds throughout the food chain. Higher salinity levels in surface and groundwater due to agriculture, energy development, and urban centers impacts biotic integrity by killing native biota. Land uses within the watershed that accelerate erosion and transport of sediments may threaten to fill in the reservoir, impacting overall ecological integrity.

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 zones, shift turbidity fronts further toward the dam, and reduce faunal abundance.

Invasive exotic species present a potential loss of biodiversity are a stressor that can change and degrade this ecosystem. Two examples include *Hydrilla* spp., an invasive rooted submergent macrophyte, and *Prymnesium parvum*, a toxic, brackish-water phytoplankton responsible for massive fish kills (also see Appendices C and I).

Eight degradation processes are identified for the reservoir ecosystem (Figure 2.3.4, Table 2.3.4). Climatic change, air pollutants, and human-mediated changes in water quantity and quality throughout the watershed have the potential to degrade the integrity of the reservoir ecosystem. Exotic invasives, especially exotic aquatic plants, additionally can lead to large-scale die-offs of reservoir biota.

Table 2.3.4. Key degradation processes in the reservoir ecosystem, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation process	Stressors	Ecological effects	Potential measures
Siltation (increase in sediment loading)	Climatic change (extreme events), watershed degradation	Altered habitat structure; decreased productivity due to reduced light penetration; altered biotic structure, composition, and structure	Water quality measures (dissolved oxygen, pH, specific conductance, fecal indicator bacteria, common dissolved inorganic constituents), abundance of biota, climate elements
Salinization	Climatic change, watershed degradation	Die-off of native biota not adapted to high salinity levels, reduced biotic integrity	Climate elements, water quality measures, surface and groundwater flow rates, land-use activities, watershed condition
Reduced river flow rates (reduced precipitation and dewatering of rivers)	Climatic change, alteration of hydrologic budget by impoundments & water diversions, watershed degradation	Alteration of habitat structure due to reduced flow and reduced flow variability, reduced biotic integrity	Climate elements, water quality measures, surface and groundwater flow rates, land-use activities, watershed condition
High water temperatures	Climatic change	Increased respiration, lower dissolved oxygen, lower productivity	Water temperature, water quality measures
Dewatering of reservoir	Altered hydrologic budget of reservoir (outflow exceeding inflow)	Reduced spatial extent of reservoir ecosystem, lower abundance of biota, lower productivity, reduced biotic integrity	Reservoir elevation, river flow rates, reservoir outflow rates
Pollution-mediated die-off	Municipal and agricultural wastes, air pollutants	Eutrophication, depletion of dissolved oxygen, altered structure and composition of biota	Water quality measures, abundance of biota, atmospheric elements
Bioaccumulation of heavy metals	Airborne pollutants; runoff from agricultural, industrial, urban land uses	Toxin-mediated malformations in higher trophic levels, die-offs of biota	Atmospheric elements, water quality measures, heavy metal assay of higher trophic fauna
Exotic species invasions	Exotic aquatic plants and animals	Altered biotic structure, composition, and function; altered ecosystem processes; toxin-induced mortality of native fauna	Abundance of exotic plant and animal species

2.3.5 River Ecosystem

There are three free-flowing rivers in the CHDN: the Pecos and Devils rivers and the Rio Grande. The Rio Grande flows through BIBE, RIGR, and AMIS. The Pecos joins the Rio Grande before flowing into Amistad Reservoir. Devils River flows into the reservoir. The River Ecosystem comprises approximately 0.8% of the total area within CHDN. The ecosystem characterization model for the River Ecosystem is shown in Figure 2.3.5, and discussed below.

Climate and atmosphere are key drivers of CHDN rivers. Solar energy drives seasonal and diel cycles. CHDN rivers lack extensive shading by trees, and solar input when a river is not turbid promotes high productivity. Precipitation drives fluvial geomorphic processes. Natural wet and dry seasons are typical, with highest flows from July through October (Huff et al. 2006). During monsoonal rains, river flow rates can quickly increase to a torrent, and rapid flows can be exacerbated by the funneling of waters by steep, constricted canyons. Large or sudden high-velocity inputs of water can alter river channels, transport large amounts of sediment, and ultimately rearrange deltaic deposits within Lake Amistad. Precipitation variability largely regulates the development of riparian zones, where low water levels during drought periods enhance riparian-zone development within river canyons. Because all three rivers flow into the Amistad Reservoir, water regulation of this reservoir also mediates water levels in the rivers and development of riparian areas.

Upland watersheds influence water quantity and quality of CHDN rivers. Dissolved substances within the river are primarily formed from weathering of rock, or dissolution of rock and soil minerals in the uplands. High sediment inputs to the Rio Grande create turbid conditions, with light penetration less than 1 m. The Pecos River is the most saline of the three rivers; salts are derived from contact with natural evaporate deposits. The Devils River is influenced by the weathering of limestone, and the salinity of this river is mediated by the saturation dynamics of inorganic carbon with limestone (Groeger and Gustafson 1994). Disturbances, such as fire, can alter upland vegetative cover which, in turn, may increase runoff and sediment inputs to rivers. Such inputs may enhance structural complexity or degrade conditions for river biota, depending on the intensity and extent of the disturbance.

The flow regime determines the mechanical forces that erode, transport, and deposit sediment and influence channel dimensions of river systems. Additionally, annual streamflow variation influences the occurrence of suitable habitat patches and species abundance (Auble and Scott 1998). Groundwater, surface springs, and surface runoff during storms are the water sources for the Pecos River and Rio Grande (Huff et al. 2006). The spring-fed Devils River is intimately linked with local groundwaters for its entire length. Especially in the Rio Grande, a higher volume of surface runoff contributes to higher variability in seasonal flows, which promotes spatial variability in in-stream structure and habitat for aquatic biota.

The chemical and physical composition of the water column consists of (1) dissolved components of electrolytes (ions or salinity) and non-electrolytes (e.g., dissolved organic carbon [DOC] and silica); (2) particulate matter, including clays and other inorganic minerals (some will actually tend to be colloidal), non-living particulate organic carbon [POC], and organisms, mostly microscopic in nature (primarily bacteria and algae); and (3) gases, such as O_2 and CO_2. The amounts and distribution of these constituents in the water column define water quality and determine the ability of a river to support higher life forms.

River sediment and substrate are composed of particles ranging in size from fine silt and clay particles to cobble, and ultimately to solid bedrock. Macrophytes, bacteria, algae, and other microbes form a biofilm on the sediment and substrate, and play a key role in river energetics (e.g., photosynthesis, respiration, nutrient uptake and transformation, and mineralization of detritus). The sediment and substrate may also be associated with a hyporheic zone, where surface and ground waters mix and where metabolic productivity and metabolism also may be quite high.

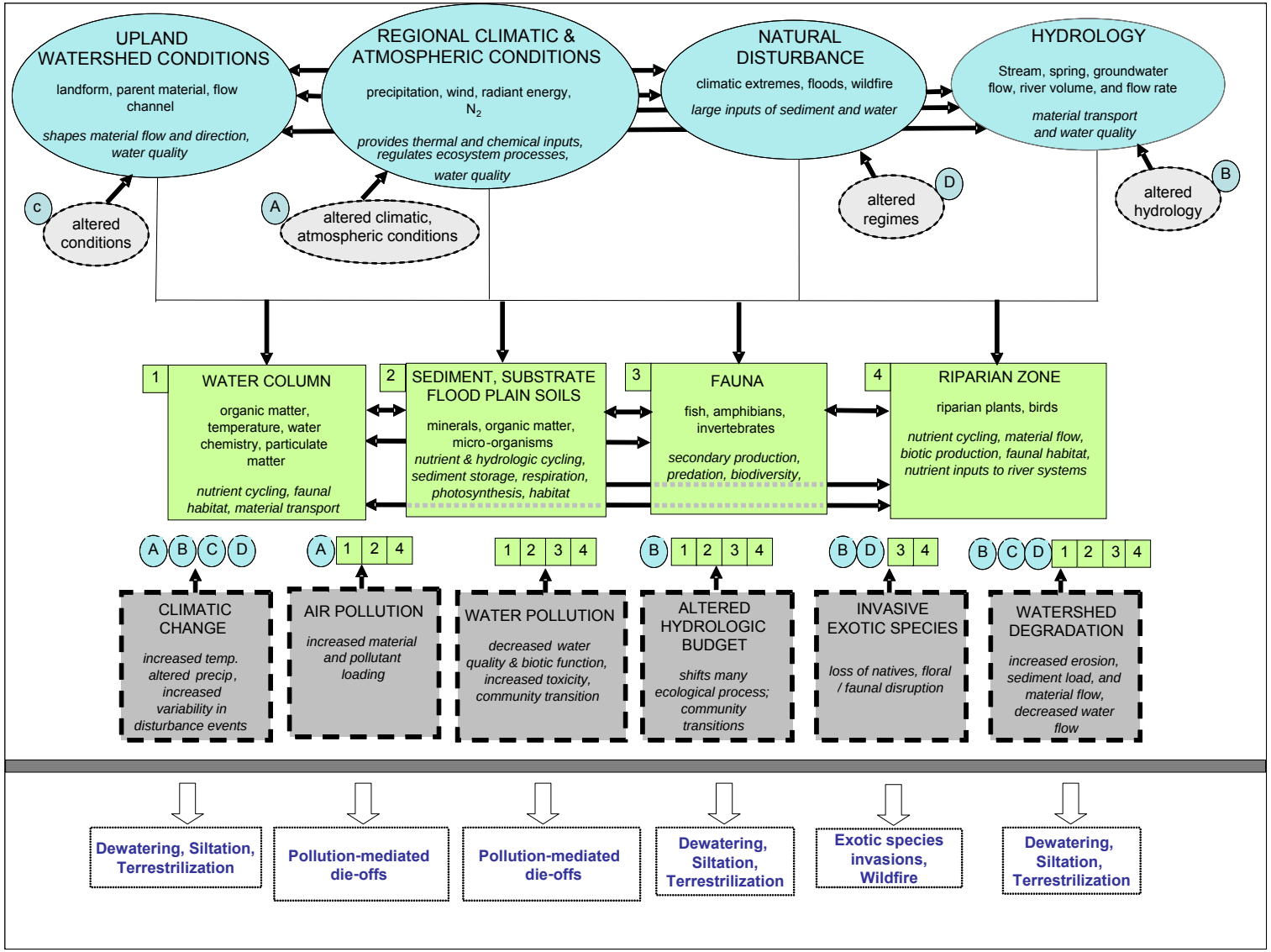

Figure 2.3.5. Ecosystem characterization model for the CHDN River Ecosystem. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2.3.5). Text for interactive controls indicates components or structure followed by function. Text for stressors indicates proximate effects.

The River Ecosystem provides habitat for two primary classes of fauna: macroinvertebrates (e.g., insects) and vertebrates (e.g., fish and amphibians). Macroinvertebrates are a vital link in river systems, as they consume algae and provide food for aquatic and terrestrial vertebrates. Macroinvertebrates respond to physical parameters, such as temperature, substrate, and current velocity, and also are influenced by the chemical environment, including pH, oxygen availability, and contaminates. In the Texas stretch of the Rio Grande, high water quality sites have higher diversity, and tend to be dominated by mayflies (*Thraulodes, Travella, Choroterpes mexicanus, Tricorythodes*) caddisflies (*Cheumatopsyche, Hydroptila, Protoptila*), and chironomids (*Orthocladius, Cricotopus trifascia*). Fish and amphibian species respond to water quality, form the higher tropic levels within rivers, and are a food resource for terrestrial vertebrates. Historically, the diversity of fish in the Rio Grande basin was high, and included a particularly rich minnow fauna (Dahm et al. 2005). Macroinvertebrates and fish are commonly used as biological indicators of River Ecosystem health (Karr et al. 1986, Barbour et al. 1999).

The riparian zone functions as unique habitat and contributes disproportionately to conservation of biodiversity (Naiman et al. 1993). Native riparian plant communities of the southwestern U.S. provide feeding and breeding habitat for many migrating and resident bird species (Mills et al. 1991, Skagen et al. 2005). Riparian zones are also important foraging habitat, and travel or dispersal corridors for many species of mammals (Ffolliott et al. 2004). During periods of drought, riparian zones may provide refugia habitat for some faunal populations. Riparian zones are a source of woody plant-material inputs to river systems. The decomposition of woody material by aquatic invertebrates adds nutrients to the aquatic system. Invertebrate populations, in turn, are an important food source for higher trophic fauna. Decreases in elevation of the Amistad reservoir water surface promote development of riparian vegetation along the extended upstream river corridor. In high-water years, re-inundation of the riparian zones creates river littoral zones that serve as important habitat for aquatic vertebrates and macroinvertebrates, and as sediment traps, both of which contribute to the productivity of this zone.

Soils of riparian zones contain biota that contribute to the structure and functioning of riparian ecosystems by mediating nutrient cycling, water infiltration and storage, and nutrient uptake by plants. Functioning of these below-ground processes depends on the amounts and types of organic-matter inputs from vegetation and on soil conditions, such as soil aeration and soil temperature.

Predicted changes in climate include increases in soil and air temperatures, altered precipitation patterns, lower snowfall and earlier snowmelt, and more variable and extreme climatic events (Solomon et al. 2007). Recent studies (Milly et al. 2005, Seager et al. 2007) have specifically suggested increased aridity for the U.S. Southwest. Lower precipitation and runoff concentrates ions and may increase the salinity of the Rio Grande and Pecos River. Extended periods of drought can dry sections of a river, isolate populations of plants and animals, alter environments beyond physiological limits, and denude watershed vegetation. More intense storms can lead to excessive erosion, watershed degradation, flooding, river turbidity, reduced water quality, and lower productivity.

Air pollutants emitted from industrial sources, such as the burning of coal, enter the water column of CHDN rivers. Compounds, such as mercury, lead, and cadmium, and strong acids can lead to widespread mortality of native flora and fauna. Nutrient additions, such as nitrogen deposition, can increase algae blooms with a subsequent decrease in light penetration and oxygen levels. A contemporary human health issue in the Rio Grande and Devils River arms of the Amistad reservoir is mercury concentration levels in sport fishes, such as largemouth bass (Becker and Groeger 2010).

Human activities impact river systems through pollution and alteration of hydrologic budgets and watershed conditions. Municipal sewage discharge, industrial discharges, and nitrogen and phosphorus from agricultural runoff promote eutrophication and depletion of dissolved oxygen, which stress riverine biota. Impoundments, reservoirs, and irrigation reduce the amount (Gutiérriez et al. 2004) and variability

of streamflow, which can lead to dewatering of channels and floodplains, decreased bank stability, loss of riparian vegetation, increase in channel incision, increase in salinization, and overall degradation of water quality (Kelly 2001, Gutiérrez and Johnson in press) and habitat for aquatic organisms. In addition, water demand downstream from the Amistad reservoir can decrease reservoir surface elevation, which directly leads to a lengthening of the upstream river segments, exposes coves, and permits lateral littoral habitat to transition into riparian or terrestrial habitat. Land-management actions, such as rangeland agriculture, urban/exurban expansion (Purchase et al. 2001), timber extraction (Kelly 2001), mining, energy development, and the development of maquiladoras (affecting the Rio Conchos, the Rio Grande's main Mexican tributary), alter surface runoff rates and sediment transport, add organic and metal contaminants to rivers, and reduce groundwater recharge and, thus, groundwater levels and streamflow. Alteration of upland fire regimes through fire suppression or conversion to high-biomass conditions increase the risk of extensive, high-severity wildfires that can result in large-scale soil erosion, transport, and sediment loading to rivers. Overall, human-mediated changes to the Rio Grande have reduced the diversity of the benthic community (Dahm et al. 2005), reduced populations of unionoinid mussels (Dahm et al. 2005), and led to the extirpation of a number of fish species, with 12 other fish species being listed as species of conservation concern (Purchase et al. 2001).

Exotic species invasions can lead to major changes in community composition, competitive displacement of native species, and alterations of ecosystem-level properties, such as disturbance regimes (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998) and soil-resource regimes (Vitousek 1990). Invasive exotic species of concern in CHDN river systems include salt cedar (*Tamarix* spp.) and giant reed (*Arundo donax*) in the riparian zones (Purchase et al. 2001), Asian clam (*Corbicula fluminea*) and nutria (*Myocastor coypus*), and, in the Pecos River, the toxic alga, *Prymnesium parvum* (Appendices D and E). Tamarisk is of special concern because it can promote fire disturbance by producing large numbers of dead stems. Higher fire frequency can lead to erosion, temperature increases, and altered flow rates. Ash from fires can increase nutrients, ions, turbidity, and pH, and decrease oxygen levels of aquatic systems.

Six critical degradation processes are identified for river systems (Figure 2.3.5, Table 2.3.5). Climatic change, air pollutants, and human-mediated changes in in-stream flow rates and sediment inputs alters in-stream habitat structure, decreases productivity, alters biotic composition, and can lead to the loss of riparian zones. Organic and inorganic pollutants can severely alter productivity and directly kill aquatic organisms. Exotic plants, especially, have the potential to alter wildfire regimes with concomitant impacts to riparian zones and stream nutrient and sediment loadings.

Table 2.3.5. Key degradation processes in the River Ecosystem, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation process	Stressors	Ecological effects	Potential measures
Siltation (increase sediment loading)	Climatic change (extreme events), watershed degradation	Altered in-stream habitat structure; decreased productivity due to reduced light penetration; altered biotic structure, composition, and structure	Water quality measures (dissolved oxygen, pH, specific conductance, fecal indicator bacteria, common dissolved inorganic constituents), abundance of biota, climate elements
Dewatering (decrease stream flow & increase in salinization)	Climatic change, alteration of hydrologic budget by impoundments & water diversions, watershed degradation	Alteration of in-stream habitat structure due to reduced flow variability, salinity-induced changes to biota	Climate elements, water quality measures, surface and groundwater flow rates, land-use activities, watershed condition
Terrestrialization (invasion of riparian zones by upland vegetation)	Climatic change, alteration of hydrologic budget by Impoundments & water diversions, watershed degradation	Conversion of riparian vegetation with upland or xeroriparian species due to reduced water availability	Climate elements, surface and groundwater flow rates, riparian vegetation structure and composition, land-use activities, watershed condition
Pollution-mediated die-off (organic, inorganic pollutants)	Municipal and agricultural wastes, air pollutants	Eutrophication, depletion of dissolved oxygen, altered structure and composition of biota	Water quality measures, abundance of biota, atmospheric elements
Exotic species invasions	Exotic invasives	Altered biotic structure, composition, and function; altered ecosystem processes	Abundance of exotic plant and animal species
Wildfire	Exotic plant invasions of riparian zones	Alteration of fire regime with higher frequency and severity of wildfires; increase in ash, nutrient, and sediment inputs to river systems during fire events resulting in alteration of lotic productivity and biotic composition	Abundance of exotic riparian plants, fire regime attributes

2.3.6 Dune Ecosystem

The Dune Ecosystem comprises 6.2% of the total park area in CHDN, but is restricted to two areas with ancient lake beds in the Tularosa Basin, New Mexico, and the Salt Flat, Texas. The dunes at WHSA are composed almost entirely (99%) of gypsum, while the dunes at GUMO include some dominated by gypsum with a carbonate content and others composed of quartz sand (Wilkins and Currey 1999). Dune fields originated from prehistoric lakes that repeatedly dried up under warmer climates and eventually produced an abundant source of eolian sand that formed the dune fields observed today (Allmendinger 1972, Wilkins and Currey 1997, Langford 2003). The ecosystem characterization model for the Dune Ecosystem is shown in Figure 2.3.6, and discussed below.

Precipitation has an indirect influence on dunes through the recharge of groundwater which, in turn, is a key driver of dune dynamics (described below). Precipitation in the dune fields is generally low (20.3–30.5 cm/8–12 in), and highly variable in amount and timing among years and seasons. Recharge generally occurs during spring storms, and with the monsoonal rains of late summer and early fall (Crabaugh 1994, Langford et al. 2009). Precipitation influences depth to groundwater and salinity, both of which influence dune stability. In years with high rainfall, active dunes can be partially stabilized by dilution of otherwise saline groundwater. Periods of high precipitation and recurrent flooding can cause eolian aggradation of the interdunes (Kocurek 2007).

Groundwater hydrology is a key element in creating and maintaining the gypsum dune field in WHSA. Groundwater brines leaching from bedded evaporites are likely important sources of gypsum (McLean 1970, Allmendinger 1972, McLean 1975, Myers 1983, Cruz 1985, Myers and Pinckley 1987, Sutton et al. 1988, Myers and Sharp 1989; 1992, Basabilvazo et al. 1994, Langford, 2003). Evaporation at the surface drives wicking of saline water from the shallow water table, 1–3 m below the surface (Allmendinger 1972). Gypsum crystallizes as a powdery efflorescence on the surface and as small crystals at and below the surface but above the water table (Allmendinger 1972). The gypsum that makes up the bulk of the extant dunes was derived from deflationary episodes, when large areas of the present-day salt flats were excavated during prolonged droughts. High groundwater salinity influences dune stability by inhibiting vegetation growth (Langford et al. 2009). Older dunes are vegetated and stable, and portions of WHSA dunes are estimated to have been stable for at least 3,400 years (Langford et al. 2009).

Winds determine the movement of sand across the dune fields (Fryberger 1979, Frank 1994, Frank and Kocurek 1994; 1996, Fryberger 2003). At WHSA, dominant winds from the west-southwest transport sand to the northeast across the dune field. Frank (1994) and Frank and Kocurek (1994; 1996) correlated local sand transport and wind velocities to the elevations on dunes, finding that sand transport was highest at the tops of the dunes. The parabolic dunes and active dune sand areas migrate continuously, and extreme wind events accelerate their movement. The parabolic interdunes and vegetated dune areas are stable and sufficiently vegetated that extreme wind events result in little to no dune movement.

Floods and droughts can mediate dramatic changes to dunes. If flood waters remain fresh or brackish, they may result in expansion of vegetation within interdunes and the stabilization of migrating dunes (Langford et al. 2009). On the other hand, if fresh water is mixed with saline groundwater and becomes toxic for the local vegetation, then loss of vegetation and expansion of the migrating dunes may result (Langford et al. 2009). Extended droughts may have the most significant impacts. The geologic record shows that the various parts of the dune field were formed rapidly during short, hyperarid events. A prolonged, significant drop and subsequent loss of available water may result in mobilization of the parabolic interdunes and other areas that are currently stable in the park.

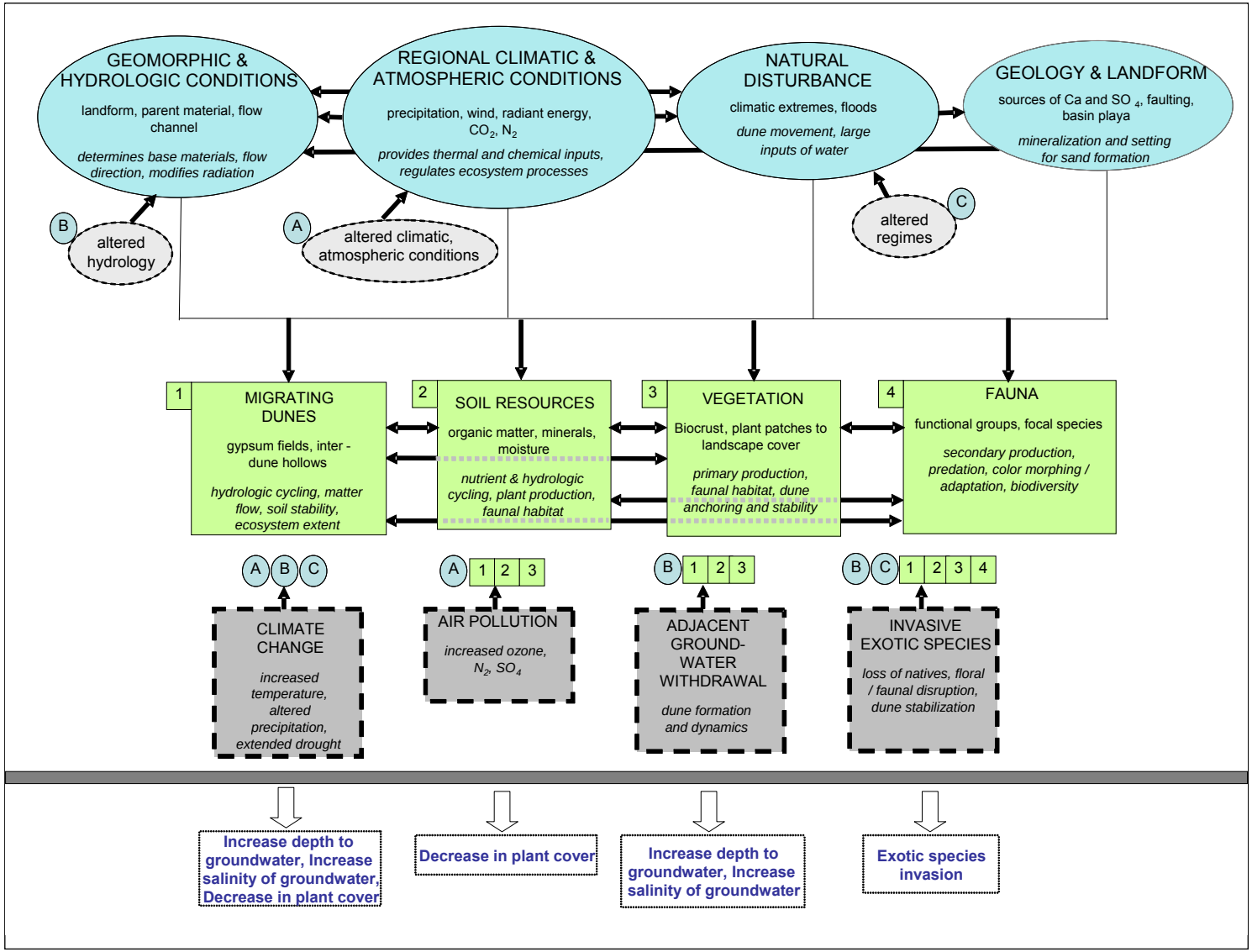

Figure 2.3.6. Ecosystem characterization model for the CHDN Dune Ecosystem. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2.3.6). Text for interactive controls indicates components or structure followed by function. Text for stressors indicates proximate effects.

Quaternary and Holocene landforms are responsible for the current distribution of dunes (Fryberger 2003). At WHSA, the older dunes currently occupy a topographic high that was an island in a lake that covered the landscape between 12,000 and 38,000 years ago (Seager et al. 1987, Fryberger 2003). The main dune field now occupies what was the lake floor at that time. This pluvial lake (Lake Otero) formed under a cooler, wetter climate, when inflow from the surrounding mountains exceeded outflow to the groundwater. A similar pluvial lake, Lake King, covered a large part of the present-day gypsum dune field at GUMO (Wilkins and Currey 1997). The dune fields of WHSA and GUMO are currently migrating across a stepped landscape, with the ancient shorelines marking the steps. These steps also mark changes in groundwater salinity (Langford et al. 2009), sulfur isotopes (Szynkiewicz et al. 2007), and dune morphology (Kocurek et al. 2007, Langford et al. 2009).

The gypsum dune fields at WHSA and GUMO can be divided into three general classes (or system states): older dunes, parabolic dunes, and active dune areas. Stable dunes, some of which may be older than 16,000 years, result from the accumulation of soil and subsequent establishment of vegetation (Fryberger 1979; 2003). Biological soil crusts are a component of older dunes (Johansen 1993, Kidron and Monger 2001, Trujillo et al. 2007), and serve to stabilize the soil (Kidron and Monger 1999), retain soil moisture (Kidron and Monger 2001), and fix nitrogen (Shields 1957, Johansen 1993). A savanna grassland on these dunes is dominated by alkali sacaton (*Sporobolis airoides*), gyp grama (*Bouteloua breviseta*), little bluestem (*Andropogon scoparius*), and sandhill muhly (*Muhlenbergia pungens*). The parabolic dune areas consist of active patches of gypsum dunes that are migrating through a hummocky, vegetated duneland that covers the largest area in both parks. The boundaries between parabolic and older dune areas are sharp and coincide with vegetation and soil changes. Active portions of the parabolic dune type can support scattered shrubs (Reid 1979, Patrick 1980, Patrick and Reid 1980). Active dune areas are found only at WHSA, and are essentially unvegetated and consist of blowing, loose eolian sand dunes separated by partially vegetated to unvegetated flats (Langford 2003). The substrates and landforms of these three classes of dunes are similar. The changes in state between the active dunes, the parabolic dunes, and the older dune areas are a function of differences in vegetation, soil, and hydrology.

Plant speciation has occurred in connection with the limiting edaphic conditions of gypsum soils (Powell and Turner 1977). Land-use changes outside protected dune areas, and the limited extent of dune systems, have resulted in a number of endangered, threatened, rare or sensitive plants being located in the CHDN Dune Ecosystem. These include grama grass cactus (*Toumeya papyracanthus*), Roetter's hedgehog cactus (*Echinocereus* X *roetteri*), button cactus (*Epithelantha micromeris*), gypsum milkvetch (*Astragalus gypsodes*), Burgess' broomsage (*Lepidospartum burgessii*) and Warnock's groundsel (S*enecio warnockii*) (Northington and Burgess 1979, Guadalupe Mountains NP 2005). Other plants of special status are Guadalupe rabbitbrush (*Chrysothamnus spathulatus*), gypsum blazingstar (*Mentzelia humilis*), and gypsum ringstem (*Anulocaulis gypsogenus*).

The gypsum dunes provide a unique template for the evolution and adaptation of a number of faunal variants. Notably found within WHSA are toads, lizards, snakes, insects, and rodents that have developed white coloration to blend with the white gypsum sands (Benson 1932, Blair 1941, Stroud and Strohecker 1949, Hager 2002, Rosenblum 2005; 2006). Eric Metzler (Research Entomologist, pers. comm.) estimates that more than 1,000 species of Lepidoptera (butterflies and moths) inhabit WHSA, and researchers have discovered more than a dozen species of moths there that are new to science. The only endemic fish known in the Tularosa Basin, the White Sands pupfish (*Cyprinodon tularosa*), occurs in one waterway in the dunes of WHSA during high water flows (Pittenger and Springer 1999), and is a State Threatened Species in New Mexico.

Climatic change is modeled to influence groundwater quantity and salinity levels, and eolian processes. Two recent studies (Milly et al. 2005, Seager et al. 2007) have suggested increased future aridity for the U.S. Southwest. With frequent, prolonged periods of drought, the depth to groundwater may increase,

especially in conjunction with greater groundwater pumping on adjacent lands. Similarly, salts may become more concentrated, affecting dune movement. Short-term weather patterns that result in greater wind velocities may change the dynamics of sand transport and dune distribution. Increased temperatures and periods of drought, in addition to foliar damage by ozone and other air pollutants, may decrease plant cover and destabilize dunes.

Urban and agricultural areas near the WHSA and GUMO dune fields typically harvest groundwater for life requisites and food production, respectively. Use of groundwater has increased in the Tularosa Basin (WHSA area) with modest development. The rapid growth of El Paso, Texas, may also require groundwater mining west of GUMO in the near future. Lowering of the groundwater table and an increase in salinity have the potential to mobilize the gypsum dunes. Migrating dunes bury dune-stabilizing vegetation, creating a positive feedback loop that can perpetuate dune instability and movement.

Exotic plants are of particular concern in dune systems. Exotic species, such as salt cedar (*Tamarix gallica*), Russian thistle (*Salsola kali* var. *tenuifolia*), and African rue (*Peganum harmala*) (Appendices C and D) are present in WHSA or GUMO. Invasive plant species can stabilize dunes and eventually shift function and interactions within biological communities. Loss of some native plant species may result in loss of unique variants of pollinators or other insects. In high abundance, some invasive plants can alter local hydrology. Water consumption by salt cedar, especially, has the potential to severely impact the Dune Ecosystem (Zavleta 2000). One acre of salt cedar uses about 7.7 acre feet of water annually, or 2.8 million gallons (Carmen and Brotherson 1982, Davenport et al. 1982, Hart 2004). WHSA has over 3,000 ac of salt cedar, equaling a possible water loss of 23,100 acre feet each year. Because dune stability is enhanced by a high water table, high densities of salt cedar would destabilize dunes.

Four key degradation processes are predicted for dune ecosystems (Figure 2.3.6, Table 2.3.6). Climatic change, groundwater withdrawal on adjacent lands, and exotic plants are predicted to increase the salinity and depth of groundwater. Temperature and moisture-induced stress under climatic change may lead to higher plant mortality in this xeric system. All processes have the potential to affect stabilization of dunes.

Table 2.3.6. Key degradation processes in the Dune Ecosystem, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation process	Stressors	Ecological effects	Potential measures
Increase depth to groundwater	Climatic change, exotic plant invasion, groundwater withdrawal on adjacent lands	Altered soil-water dynamics leading to decrease in dune stability	Groundwater quantity and quality measures, land use related to water extraction on adjacent lands, abundance of exotic species, climatic elements
Increase salinity of groundwater	Climatic change, exotic plant invasion, groundwater withdrawal on adjacent lands	Altered soil-water dynamics leading to decrease in dune stability	Groundwater quantity and quality measures, land use related to water extraction on adjacent lands, abundance of exotic species, climatic elements
Exotic species invasion (plants)	Exotic plant invasion	Altered soil-water dynamics leading to decrease in dune stability, increase in dune stability where water table is unaffected, shift in functional-group structure	Vegetation composition and structure, climatic and atmospheric elements
Decrease in plant cover	Climatic change, air pollution	Altered soil stabilization properties leading to decrease in dune stability, altered biotic integrity with decrease in plant cover	Vegetation composition and structure, climatic and atmospheric elements

Chapter 3: Vital Signs

3.1 Introduction

"Vital Signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve unimpaired for future generations, including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources (http://science.nature.nps.gov/im/monitor/glossary.cfm).

This chapter describes the core set of 21 vital signs identified for the CHDN, the process used to identify these vital signs, their relationships in the conceptual models, and the subset of core vital signs that will be implemented with current funding.

3.2 Overview of Vital Signs Selection Process

The focus of the CHDN is on attaining network-wide inference for most of our vital signs. The network developed its prioritized list of vital signs through a multifaceted process that involved interviews of park staff and non-park staff intimately familiar with specific park issues, park-based scoping meetings, topic-specific workshops, online web ranking, vital signs prioritization workshops, conceptual model development, and meetings with Technical Committee members and the Board of Directors (Table 3.2).

The network took a multi-step approach to identify, prioritize, and select vital signs. This step-wise, iterative process allowed various ecological indicators to be compared and collectively selected for inclusion in the network's vital signs monitoring program. An overview of the steps used for the selection of CHDN vital signs is listed below. Note that due to certain logistical constraints, we did not necessarily follow these six steps in sequential order.

1. Conduct a series of interviews and small, park-based workshops to identify important resources (abiotic, biotic, processes), resource threats, stressors, management concerns, potential monitoring questions, and vital signs for each network park.

2. Identify similarities and differences across parks and summarize vital signs, threats, management concerns, and monitoring questions at the network level.

3. Prioritize vital signs for each park based on management and ecological significance and legal mandate.

4. Identify ecosystem drivers, stressors, and important processes through development of initial conceptual ecological model for the network's ecosystems.

5. Conduct a network-level vital signs workshop to complete scientific review of network-level vital signs and associated information; complete prioritization of vital signs based on ecological significance and justification from scientific literature or other models; provide additional information helpful to monitoring high-priority vital signs (e.g., partnership opportunities, monitoring objectives).

Table 3.2. Events and associated outcomes in the steps followed to identify and prioritize CHDN vital signs.

Date	Event	Steps taken	Outcome/Product
Dec. 2004–Mar. 2005	Scoping meetings at each park.	"Laundry list" of potential vital signs generated at each park.	Parks focus on vital signs selection process.
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.	Potential set of vital signs reduced to 97.
Oct. 2005	Water Quality & Water Resources Workshop.	Further refined water resources related vital signs.	See Appendix I, Table I.1-1.
Jun. 2006	Chihuahuan Desert Network Prioritization Workshop (CHDN-PW).	Reviewed and scored 97 unique vital signs.	See Appendix I, Table I.2-1.
Jul. 2006	Technical Committee provides management significance scores for new and renamed vital signs from (CHDN-PW).	New vital signs fully scored and ranked.	Generated list of 36 high-priority vital signs (see Appendix I, Table I.2-3).
Aug. 2006	Technical Committee & Board of Directors meets to review 36 high-priority vital signs prioritization and selection process.	Vital sign prioritization selection process and high-priority list of 36 vital signs unanimously supported by the Technical Committee and Board of Directors.	High-priority vital signs list accepted, network moves forward with monitoring plan development.
Aug. 2006	Request to add two vital signs.	TC/BOD discussions with park staff about vital signs lead to request.	High-priority list increased to 38 vital signs.
Sep. 2006–Feb. 2007	Development of framework for seven proposed monitoring protocols collapsing 38 high-priority vital signs down to 28.	Discussions and approvals by Technical committee and Board of Directors on final 28 vital signs.	New list of 28 vital signs grouped into seven protocols accepted.
July–Nov. 2007	Teleconference with Carlsbad Caverns NP resources staff and outside cave experts; and with ARD on use of lichens & mosses vital signs.	Discussion on cave-related vital signs and potential duplication with park-specific cave management and monitoring plan. Discussion and additional research into nature of use of lichen as air-quality biomonitors in arid lands lead to decision by CHDN to eliminate this vital sign from consideration.	Cave-related vital signs monitoring relinquished to park staff. Biomonitoring vital sign eliminated from further consideration.
July 2007–Mar. 2008	Various cooperators independently work on Protocol Development Summaries (PDS).	PDS written for the seven monitoring protocols that includes 25 CHDN vital signs.	25 core vital signs make up CHDN monitoring program.
June–Dec. 2008	Review and finalize list.	CHDN Vital Signs Plan reviewed by Technical Committee, Board of Directors, external reviewers, and WASO.	Core vital signs reduced to 21; additional PDS written.

6. Conduct meetings with network, parks, and CHDN Technical Committee to select a final list of high-priority and core vital signs for the CHDN parks. The outcome is reviewed and concurrence given by the Board of Directors.

Park- and network-level workshops and meetings were held for the CHDN from 2004 to 2007. The outcomes of key workshops and meetings are summarized in the next sections.

3.2.1 Park-level vital signs scoping workshops (2004–2005)

During December 2004–March 2005, the network conducted park-level vital signs scoping workshops at AMIS, BIBE (including RIGR), CAVE, FODA, GUMO, and WHSA. The purposes of those workshops were to present the vital signs program to all interested park staff and receive staff input on potential vital signs for the park and network. The objective of the workshop was to identify important park resources and management issues, park drivers and stressors, potential park monitoring and research questions, and candidate vital signs. To prepare for these park-level workshops, network staff summarized priority resources, stressors, and resource concerns using General Management Plans, Resource Management Plans, and available Geologic Scoping Workshops. Network staff also conducted one-on-on interviews with park staff, including superintendents. Interviews followed up on responses submitted from a 22-item questionnaire (Appendix G).

Participation in most workshops ranged from 10 to 20 individuals representing park and network staff and park cooperators/scientists. Candidate vital signs at the park level were identified within six broad categories: Air/Climate, Geology/Soils, Water, Biota (Animals and Plants), Human Use, and Ecosystem Pattern and Processes. For each category, participants identified specific resources and resource issues important to their park. Responses ranged from small-scale, discrete resources (e.g., Guadalupe Mountains violet) to broad-scale ecosystem processes (e.g., geomorphic processes), and resources of value for societal reasons (e.g., soundscapes, viewscapes). Responses were directly recorded into a database to simplify the evaluation and analysis process.

For each resource, park staff identified associated ecosystem stressors, specific threats, management concerns, and potential monitoring questions. Following all park-level scoping workshops, each park's vital signs were uploaded into a CHDN database. This database included 145 non-unique candidate vital signs. CHDN staff designed an online, web-based application that allowed park resources staff and superintendents to score these 145 non-unique vital signs based on three criteria: ecological significance (50%), legal mandate (15%), and management significance (35%). This list included duplications. Individual, park-level databases were merged into a single, network-level database. After scores were tallied, a list of 97 unique vital signs was used to develop a vital signs framework for the network.

3.2.2 Network-level vital signs prioritization workshop (2006)

On June 14–15, 2006, the network-level vital signs prioritization workshop was held in El Paso, Texas, to (1) review identified management and scientific issues, resource threats, and monitoring questions; (2) review, revise, and prioritize candidate vital signs for long-term ecological monitoring at the network and park levels; (3) revise justification statements, develop potential monitoring objectives, identify existing protocols/methods, potential partnerships, cost-sharing opportunities, and ecological/operational scales for measurement for the top 25% of vital signs; and (4) develop a network of stakeholders with the common goal of preserving important network resources. Sixty-four individuals from more than 30 organizations participated in the workshop, including representatives from federal and state agencies, academic and research institutions, and non-profit organizations.

Based on the participants' expertise, they were assigned to one of five breakout groups: (1) Animals, (2) Aquatic Resources and Water Quality, (3) Landscape, (4) Plants and Soils, or (5) Unique Systems (Caves & Dunes). Each work group reviewed a specific set of candidate vital signs and was assigned a facilitator,

recorder, and at least one park staff member with appropriate expertise to facilitate workflow and capture workshop results in an MS Access database. Ninety-seven unique vital signs from the park-based scoping meetings were evaluated by relevant ecosystem, based on justification source and ecological significance score (Table I.1-1 in Appendix I). After individual work groups presented their results, the groups reconvened to conduct the overall prioritization of vital signs. Following the workshop, the Technical Committee scored all new vital signs generated from the workshop for management significance. These scores were added into the scores generated from the prioritization workshop.

After the vital signs prioritization workshop, CHDN staff evaluated existing and new vital signs from the five breakout groups, performed additional analysis of the vital signs generated by the workshop, and reduced the lists generated by the work groups to a more integrated, defined a set of 86 unique candidate vital signs that were fully scored and ranked (Table I.2-3 in Appendix I). We then separated the scored vital signs by ecosystem and generated rank score diagrams (Tables I.6–12 in Appendix I). Based on scores and diagrams, we identified high-priority vital signs from each ecosystem, resulting in a list of 36 high-priority vital signs. The 2006 CHDN Vital Signs Prioritization Workshop Report can be found in Appendix I.

The CHDN Technical Committee and Board of Directors 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 for development in the monitoring plan. High-priority vital signs were identified based on a review of the prioritized network list. The Technical Committee also discussed vital signs ranked highly at the park level but not at the network level and made decisions based on management and ecological significance, potential partnership and cost-sharing opportunities, and existing baseline data. At this meeting, no additional vital signs from the set of 86 vital signs were brought forward for inclusion in the high-priority list of 36 vital signs.

The Technical Committee agreed that given budgetary constraints, only a small subset of vital signs could be monitored over the long term. Nevertheless, the Technical Committee did not want to constrain the final list of core vital signs. They expressed that a spirit of cooperation with park resource staff and members of the scientific community, along with information from additional models and scientific literature, should determine final vital signs for monitoring.

The Board of Directors reviewed and discussed the Technical Committee's recommendations, the list of 86 candidate vital signs, and the subset of 36 high-priority vital signs. The Board of Directors expressed confidence in the process. The Board felt the high-priority list was comprehensive and strongly reflected indicators that should assist them and their staffs in resource management. The Board unanimously concurred with the Technical Committee's recommendations and voted to adopt the list of 36 high-priority vital signs.

During the ecological modeling process, two additional vital signs, distribution and abundance of heteromyid rodents and geomorphology of river channels, were added, reviewed, and approved, bringing the total number of high-priority vital signs to 38.

3.2.3 Selection of core vital signs (2006–2008)

During the last phase of review and refinement, consideration was given toward practical implementation of the CHDN monitoring program. Given that funds for monitoring will have limits, vital signs were grouped in such a way as to maximize information gain for the types of effort and costs that would need to be expended. A conscious decision also was made to select vital signs of common concern, rather than park-specific in nature. Thus, the final list is relevant to most of the parks.

In meetings and discussions with the Technical Committee and Protocol Development Summary authors, the criteria used to select core vital signs included:

- Opportunities to collaborate (e.g., TCEQ, park monitoring, International Boundary and Water Commission)
- Opportunities in which co-location or other techniques (similarity in sampling and measurement requirements) could reduce costs
- Suites of indicators that, when monitored together synergistically, add value by providing greater information for improving ultimate interpretation of monitoring trends
- Low-cost indicators that could be accomplished with little additional funding despite ranking slightly lower than more expensive indicators

This evaluation led to a final set of 21 core vital signs that could be monitored under seven umbrella protocols. After the list was adjusted a bit to better coordinate with the servicewide I&M program, the number of monitoring protocols was expanded from seven to eleven to improve clarity. Table 3.2.3 shows the final set of core vital signs within the context of the NPS Ecological Monitoring Framework, a system-based, hierarchical outline that facilitates comparison of vital signs among parks, networks, and other programs.

Table 3.2.3. Chihuahuan Desert Network core vital signs, presented by park and funding category within the context of the NPS Ecological Monitoring Framework.

LEVEL 1	LEVEL 2	LEVEL 3	CHDN vital sign	Parks where implemented/Funding category						
				AMIS	BIBE	CAVE	FODA	GUMO	RIGR	WHSA
Air and Climate	Air Quality	Ozone	Ozone		◊	◊		◊		
		Wet and Dry Deposition	Wet and Dry Deposition		◊			◊		
		Visibility and Particulate Matter	Visibility and Particulate Matter		◊			◊		
	Weather/Climate	Weather/ Climate	Basic Meteorology	◊	◊	◊	◊	◊	●	◊
Geology and Soils	Geomorphology	Windblown Features and Processes	Dune Formation and Stability					●		+
		Windblown Features and Processes	Dune Morphology					●		+
		River Channel Characteristics	River Channel Characteristics	●	◊				●	
	Soil Quality	Soil Function and Dynamics	Soil Hydrologic Function	●	§	§	§	§		§
			Biological Soil Crusts		§	§	§	§		§
			Soil Erosion (Wind and Water)		§	§	§	§		§
			Bare Ground		+	+	+	+		+
Water	Hydrology	Groundwater Dynamics	Groundwater Quantity	§	§	§	§	§		§
		Surface Water Dynamics	Surface Water Dynamics	◊	◊	◊		§	●	
			Persistence of Springs		§	§		§		
	Water Quality	Water Chemistry	Surface Water Quality	§	§	§		§	●	
		Aquatic Invertebrates	Aquatic Invertebrates	●	§	§		§	●	§

Table 3.2.3. Chihuahuan Desert Network core vital signs, presented by park and funding category within the context of the NPS Ecological Monitoring Framework, cont.

LEVEL 1	LEVEL 2	LEVEL 3	CHDN vital sign	Parks where implemented/Funding category						
				AMIS	BIBE	CAVE	FODA	GUMO	RIGR	WHSA
Biological Integrity	Invasive Species	Invasive/Exotic Plants	Invasive/Non-native Plants	§	§	§	§	§	§	§
	Focal Species or Communities	Desert, Grassland and Shrubland Communities	Plant Community Composition		§	§	§	§		§
		Birds	Bird Communities	§	§	§	§	§		§
		Mammals	Heteromyid Rodent Communities		●	●		●		●
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Land Use	Land Cover	+	+	+	+	+	+	+
			Land-use Changes	+	+	+	+	+	+	+

◊ Vital signs being monitored by a network park, another NPS program, or another federal or state agency, using other funding. The network will collaborate with or supplement these efforts.

§ Vital signs for which the network will implement monitoring protocols in concert with other networks, using funding from the vital signs or water quality monitoring programs.

+ Vital signs for which the network will develop protocols and implement monitoring using funding from the vital signs or water quality monitoring programs.

● Vital signs that cannot currently be implemented because of limited staff and funding.

3.3 Justification for Vital Signs

This section describes the significance and relevance of each core vital sign in evaluating the condition of CHDN park ecosystems. Vital signs are presented in the same order as they appear in Table 3.2.3, by Level I—Categories of the NPS Ecological Monitoring Framework.

3.3.1 Air and climate

Diminishing air quality is a concern in a number of national parks (NPS-ARD 2002), and can significantly affect visitor experience. Although most CHDN parks are located some distance from urban centers in Texas and Mexico, significant oil and gas development near several network parks in southeastern New Mexico and West Texas, and coal-fired power plants in Central Texas, will likely increase pollution by nitrates and sulfates. CHDN parks affected by pollution from these cities and energy development projects (whether nearby or distant) experience poor air quality due to ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and toxins. Influenced by weather patterns, atmospheric pollutants are carried by the wind, broken down by high temperatures and radiation, and then deposited as wet and dry particles in the air, water, soil, vegetation, and on wildlife and humans. Atmospheric deposition of nitrogen and sulfur compounds can alter soil processes (e.g., soil nutrient cycling), affect plant species composition, directly injure vegetation, affect stability of biological systems, and impair water quality (Fenn et al. 2003). Air pollutants that decrease visibility also can affect human health, impair viewsheds, and degrade the aesthetic appeal of a national park (Malm 1999). Consequently, protection of air quality has become a priority in national parks, and a core vital sign for monitoring in many networks (Maniero 2001).

Under the Clean Air Act of 1970 (as amended in 1977 and 1990), protection of air quality is required in all U.S. national parks greater than 5,000 ac (labeled as Class I areas). The Clean Air Act gives non-attainment Class I areas the greatest protection against further deterioration and requires monitoring to confirm that air quality and visibility improve or, at minimum, do not further degrade. In addition, according to each NPS park's GPRA mandate, land managers in Class I parks are required to provide recommendations on how to protect air, natural, and cultural resources in the park. To evaluate these hazards to ecosystem and human health, it is important to monitor air quality conditions and their interactions with the physical and biological components of ecosystems. Additionally, monitoring these vital signs will provide information for assessing temporal trends in air quality of individual Class I CHDN parks and generalized trends for broader regions (NPS-ARD 2002).

Climate is a primary factor controlling the structure and function of CHDN ecosystems. Measurements of temperature, precipitation, wind, humidity, and soil moisture can indicate changing climatic conditions and patterns. Key to understanding ecosystem dynamics is an understanding of the roles of climate variability, hydrologic interactions with soils, and adaptive strategies of biota to capitalize on spatially and temporally variable moisture dynamics (Noy-Meir 1973, Rodriguez-Iturbe 2000, Reynolds et al. 2004). This information is highly relevant to the interpretation of other vital signs and provides a basis for understanding the response of desert ecosystems to future climate variation (Hereford et al. 2004).

3.3.2 Geology and soils

White Sands National Monument was established in 1933, to preserve the largest gypsum dune field known globally. The park encompasses about half the entire dune field. An understanding of the dynamics of the dunes lies at the core mission of the park. Dune dynamics are taken here to include a broad spectrum of dune and dune-field aspects: dune formation/destruction, surface processes, migration rate, characteristic behavior, dune-dune interactions, and dune-substrate interactions. This vital sign, along with groundwater quantity, are the two priority vital signs for WHSA (Kocurek 2008).

Management and restoration activities in riparian and aquatic ecosystems of the lower Rio Grande in BIBE, RIGR, and AMIS are hindered by a vague understanding of the magnitude of changes in channel morphology. Flow depletions in the northern branch of the Rio Grande in the United States and in Mexico's Rio Conchos have caused significant reduction in channel-forming discharges in the Rio Grande in BIBE. These hydrologic changes have resulted in channel aggradation; channel narrowing and development of inset floodplains; reduction in aquatic habitats, especially for native fish and freshwater mollusks; increase in invasive/non-native riparian vegetation; and reduction in the quality of recreational boating (Schmidt et al. 2003).

In deserts, geology and soils provide the template upon which biota build integrated ecological systems. The availability of water is crucial, and small variations can drastically alter plant and animal communities. Both physical and chemical geologic attributes, such as soil texture that influences moisture infiltration rates and bulk density, control water availability. Soil type, in conjunction with plant communities and their dynamics, topography, and climate regimes, are primarily responsible for broad-scale differences in soil moisture across the landscape. Plant-available soil moisture is a key factor in understanding ecosystem maintenance in desert ecosystems.

Biological soil crusts are concentrated in the top 1–4 mm of the soil and comprise over 70% of the living ground cover. The main components of soil crusts are cyanobacteria, bryophytes, and lichens, which cover most soil spaces not occupied by green plants and are critical in reducing erosion, increasing water retention, and increasing soil fertility (Belnap 2001). Because plant cover is sparse in deserts, crusts are an important source of organic matter for desert soils. Initial studies in the Chihuahuan Desert indicate that crusts require decades for recovery, and these recovery rates are dependent on climatic history, particularly variability in precipitation, severity of disturbance, and soil texture.

Disturbance of the soil surface is a natural process (e.g., animal burrowing, flooding) that can be aggravated by anthropogenic activities (e.g., grazing, off-highway vehicle use, mining), leading to large-scale disturbance. Soil-surface disturbance causes dust generation, erosion, surface runoff, increased bare ground, decreased soil organic matter, increased invasive plant species cover, and vegetation community change, all of which may alter plant and animal communities and pose a significant threat to ecosystem integrity. Loss of topsoil changes the capacity of soil to function and restricts its ability to sustain future uses. Erosion removes or redistributes topsoil, the layer of soil with the greatest amount of organic matter, biological activity, and nutrients (Belnap 2003). Erosion breaks down soil structure by exposing organic matter within aggregates, which accelerates decomposition and loss. Degraded soil structure reduces the rate of water infiltration and increases runoff, which can lead to further erosion. The materials deposited by erosion can bury plants; cover roads and trails; accumulate in streams, rivers, and reservoirs; degrade water and air quality; and damage or degrade cultural landscapes.

Herrick and others (1996) developed a suite of indicators for monitoring the health of arid and semi-arid ecosystems. These 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 arid and semi-arid landscapes, and (4) were readily and inexpensively measured. Similarly, Whitford (2002) described several indicators that were useful in monitoring programs specific to Chihuahuan Desert rangelands, including average size of bare patches, cover of long-lived grasses, a palatability index, and a soil surface stability index. Other indicators that 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).

3.3.3 Water

Groundwater is the source of most springs in the parks, creating habitat for diverse aquatic, riparian, and terrestrial biota. Consequently, understanding and monitoring groundwater dynamics has been identified as a top priority for network parks. Determining the status and long-term trends in, and developing a better understanding of water table levels, groundwater flow paths, and the connection between groundwater and surface water resources, are required for predicting the effects of natural and human-induced hydrological changes (e.g., municipal groundwater withdrawal) and the fate of contaminants (e.g., landfill leachate). Precipitation events slowly recharge desert basin aquifers, and this recharge feeds scattered springs and wetland habitats. Removing only a small fraction of groundwater from these basins can lower the water table and potentially dry up critical surface water resources. Land subsidence can disrupt surface drainage, reduce aquifer storage, cause earth fissures, and damage wells and other infrastructure (Bawden et al. 2003). Groundwater withdrawal is considered a significant ecosystem stressor within the CHDN.

Surface water resources in CHDN parks (e.g., springs, seeps, streams, rivers, reservoirs) are sparsely distributed on the landscape, but critical to the persistence of native biota and many endemic species. Surface water dynamics and water chemistry have strong effects on aquatic biota; therefore, biological assemblages (e.g., aquatic macro- and microinvertebrates) are often excellent indictors of flow regime, water chemistry, and disturbance history. Alteration of surface water resources within desert ecosystems has profound ecological and management implications, including loss of species diversity, extinction or extirpation of special-status and endemic species, alteration in the composition and distribution of plant and animal communities, alteration of culturally significant sites, and inability of parks to meet legal and policy mandates. Therefore, CHDN resource managers are very concerned about degradation of surface water resources.

Because CHDN surface waters frequently derive their flow from regional groundwater systems, a primary cause of degradation is groundwater withdrawal and diversion. Based on recent drought conditions and predictions of weather and water use, future pressures on groundwater resources are expected to increase, posing significant threats to surface water availability in network parks. Finally, atmospheric deposition of pollution and nutrients carried from agricultural and urban development areas may contaminate park surface waters. These chemical and hydrologic changes can cause fundamental shifts in the chemical properties of park waters that lead to subsequent shifts in the biotic communities that depend on these waters for survival.

3.3.4 Biological integrity

The structure and composition of vegetation communities strongly define ecological communities and significantly affect ecosystem processes. Invasive plants pose one of the greatest threats to natural and cultural resources of the national parks. Non-native plant species are invading new areas and establishing at unprecedented rates because global trade and transportation have allowed them to cross biogeographical barriers. Potential ecological damage from exotic invasive species includes alteration of natural disturbance regimes and ecosystem processes and subsequent effects on native flora and fauna. Specific concerns include sustainability of threatened and endangered species; alteration of the density, biomass, and diversity of native plant communities; species extirpation/extinction due to changes in fire regime; and alteration of basic soil processes. Numerous non-native plant species have been identified in CHDN park units.

The desert ecosystems found within the seven CHDN park units host a rich, diverse collection of plant communities and landforms. Vegetation and soil constitute the very foundation by which all ecosystem functions are intricately connected and upon which they are dependent. Changes in vegetation composition and structure can have profound effects on nutrient cycling and soil properties. Climate models predict a warmer, drier future for the southwestern United States (Seager et al. 2007). Parks also

are faced with the unknown effects of air pollution, habitat loss, and altered disturbance regimes (e.g., fire, energy development). These factors likely will have significant impacts on CHDN upland plant communities.

The opportunity to see wildlife attracts many visitors to CHDN parks. The geographic location and arid/semi-arid environment of these parks provide suitable habitat for a variety of desert, woodland, and montane species of the southwestern United States. In particular, desert riparian and grassland communities provide important habitats for migrating and wintering birds in the Southwest, despite a reduction in quality and quantity during the past 100 years (Ffolliott et al. 2004, Merola-Zwartjes 2005, Skagen et al. 2005). The relatively less-disturbed systems in CHDN parks provide refugia for avian species seeking these habitats and enhance regional biodiversity. For certain birds, properties of faunal assemblages and populations are important indicators of environmental change because they serve a great diversity of ecological functions that affect ecosystem productivity, resilience, and sustainability (Marcot 1996, Bryce et al. 2002, Sullivan et al. 2007). Similar conservation issues affect landbirds in the southwestern U.S. and northwest Mexico, making bird monitoring an important international issue, as well (Rich et al. 2004).

Birds are also desirable subjects for long-term ecological monitoring because they have widespread public appeal, and changes in park fauna are likely to garner a high level of public interest and generate support for corrective or remedial management actions. CHDN parks are well-positioned to contribute to regional and national bird monitoring initiatives (e.g., with the adjacent Sonoran Desert, Southern Colorado Plateau, and Southern Plains I&M networks; Partners in Flight; Rocky Mountain Bird Observatory, parks in adjacent Chihuahua and Coahuila, Mexico) that will provide insight into changes of this important focal resource.

Rodents of the family Heteromyidae are species of significance to Chihuahuan Desert ecosystems. Banner-tailed kangaroo rats (*Dipodomys spectabilis*) are frequently associated with, and are indicators of, vegetative condition in Chihuahuan Desert grasslands, whereas other species of *Dipodomys* often are associated with grassland-shrubland transitions (Whitford et al. 1978). Heteromyid rodents can create feedbacks in desert systems through burrowing, herbivory, and granivory, all activities that redistribute limited resources or change the course of plant community development (Brown and Heske 1990, Guo et al. 1995, Whitford and Bestelmeyer 2006). In addition, small mammals play a key role in ecosystem and biotic community function as trophic bases for secondary and tertiary consumers. Research suggests that environmental variables (including seasonal extremes in temperature, annual energy, moisture, and elevation) may predict up to 88% of the variation in mammalian species density for all of North America (Badgley and Fox 2000).

3.3.5 Landscape dynamics

Landscape-level processes, such as habitat patch mosaic structure, may strongly influence local flora and fauna populations. The character of a landscape's pattern (patch size and structure, distribution, connectivity) directly influences the distribution, abundance, and movement of animals (e.g., bighorn sheep), and the distribution, abundance, germination, and dispersal of plants. In deserts where many organisms are living at or near the threshold for surviving climatic extremes, the availability of resources in patches and ability to move among patches are critical factors (Whitford 2002). Fragmentation, grazing, and changes in climate and fire regime have had the greatest past and current impacts on landscape pattern in CHDN parks.

Desert habitats (grasslands, shrublands, Tamaulipan thornscrub, and playas) comprise over 75% of CHDN land cover. Land cover in GUMO and CAVE, however, is dominated by woodland and forest. Land cover is affected by natural events, including climate variation, flooding, vegetation succession, and fire, all of which are susceptible to changes in frequency or magnitude due to human activities. Today,

human-induced change in land cover is a primary factor in habitat loss, the most significant contributor to the listing of threatened plant and animal species. Monitoring changes in land cover provides critical insights into current or future changes in ecosystem processes (e.g., geomorphic, hydrologic, soil, biological) and services (e.g., habitat, stabilizing soils).

Local and regional land-use practices can dramatically affect soil quality, water quality and quantity, air pollution, habitat fragmentation, habitat loss, and contribute to the introduction and spread of invasive species. Monitoring changes in land use lends interpretive power to other vital signs and may contribute to early detection and management of future resource issues.

3.4 Links of Vital Signs to Conceptual Models

Use of the conceptual models, coupled with the workshop participants' high level of experience with environmental indicators for the Chihuahuan Desert, led to selection of vital signs with strong linkages to the key issues and resources discussed in Chapter 2 (see Table 3.4).

Table 3.4. Linkage of vital signs to valued resources and key issues (physical drivers and stressors) from conceptual ecosystem models. Vital signs are identified as being a direct measure (DM) or having a strong response (sr) to the issue or resource.

National I&M Framework Level 1 CHDN vital sign	Resources/Key issues																Ecosystem					
	Climate change	Air pollution	Upland watershed condition	Altered disturbance regimes	Geomorphic conditions	Altered hydrologic budget	Geology and landforms	Hydrology	Recreation and local land use	Invasive species	Groundwater withdrawal	Adjacent land use	Watershed degradation	Historic land use (grazing)	Historic land use (fire suppression)	Water pollution	Desert	Foothills	Montane	River	Reservoir	Dune
Air and Climate																						
Ozone		**DM**															●	●	●			●
Wet and Dry Deposition		**DM**															●	●	●	●	●	●
Visibility and Particulate Matter		**DM**															●	●	●			●
Basic Meteorology	**DM**																●	●	●	●	●	●
Geology and Soils																						
Dune Formation and Stability	**sr**	**sr**		**sr**	**sr**		**sr**	**sr**		**sr**	**sr**											●
Dune Morphology	**sr**						**sr**	**sr**			**sr**											●
River Channel Characteristics			**sr**	**sr**	**DM**	**sr**		**sr**					**sr**							●		
Soil Hydrologic Function									**sr**		**sr**	**sr**		**sr**			●	●				
Biological Soil Crusts		**sr**							**sr**								●	●	●			●
Soil Erosion (Wind and Water)	**sr**	**sr**		**sr**				**sr**	**sr**	**sr**	**sr**	**sr**		**sr**			●	●	●			
Water																						
Groundwater Quantity	**sr**				**sr**	**sr**		**sr**			**DM**	**sr**	**sr**				●	●	●	●		●
Surface Water Dynamics	**DM**		**sr**	**sr**		**sr**		**DM**		**sr**	**DM**	**sr**	**sr**	**sr**			●	●	●	●	●	
Persistence of Springs	**sr**		**sr**		**sr**	**sr**				**sr**	**sr**	**sr**	**sr**	**sr**			●	●	●			
Surface Water Quality		**DM**	**sr**			**sr**			**sr**				**sr**			**DM**	●	●	●	●	●	
Aquatic Invertebrates	**sr**	**sr**	**sr**			**sr**			**sr**	**sr**			**sr**	**sr**		**DM**	●	●	●	●	●	

Table 3.4. Linkage of vital signs to valued resources and key issues (physical drivers and stressors) from conceptual ecosystem models, cont.

National I&M Framework Level 1 CHDN vital sign	Resources/Key issues																Ecosystem					
	Climate change	Air pollution	Upland watershed condition	Altered disturbance regimes	Geomorphic conditions	Altered hydrologic budget	Geology and landforms	Hydrology	Recreation and local land use	Invasive species	Groundwater withdrawal	Adjacent land use	Watershed degradation	Historic land use (grazing)	Historic land use (fire suppression)	Water pollution	Desert	Foothills	Montane	River	Reservoir	Dune
Biological Integrity																						
Invasive/Non-native Plants	**sr**	**sr**	**sr**						**sr**	**DM**	**sr**	**sr**		**sr**	**sr**		●	●	●	●	●	●
Plant Community Composition	**sr**	**sr**	**sr**							**sr**	**sr**			**sr**	**sr**		●	●	●	●		●
Bird Communities	**sr**		**sr**						**sr**	**sr**	**sr**	**sr**		**sr**	**sr**	**sr**	●	●	●	●		●
Heteromyid Rodent Communities	**sr**									**sr**				**sr**			●	●				●
Landscape (Ecosystem Pattern and Processes)																						
Land Cover	**sr**			**sr**								**DM**		**sr**	**sr**		●	●	●	●	●	●
Land Use												**DM**					●	●	●	●	●	●

Chapter 4: Sample Design

4.1 Introduction

Monitoring goals and objectives are linked to data collection through sampling designs. A quality sampling design is necessary to achieve intended monitoring goals and produce rigorous, robust, and defensible conclusions. To achieve the greatest precision, accuracy, and resolution, the design must carefully consider the physical, chemical, and biological characteristics of each vital sign, and the patterns of variability in space and time associated with that vital sign (Oakley et al. 2003). Development of sampling designs is often an iterative process that results in adjusting monitoring/sampling objectives to accommodate the practical constraints of cost, time, logistics, safety, available information, and technology (Elzinga et al. 1998).

Providing information on the status and trends of selected vital signs is the overarching goal of the Chihuahuan Desert Network Inventory and Monitoring program. Status refers to the condition of a vital sign at a given point in time, and trend is a directional change in status over time (MacCluskie and Oakley 2005). Status and trend estimates inform management of resource change, and aid in determining potential remediation actions. A sampling design is used for both forms of monitoring to describe the process for selecting the population to monitor, the monitoring locations, and the number of locations. The strategy for allocating sampling or census efforts through time and space within and among park units also is a key component of a sampling design. This chapter provides an overview of sampling concepts used to develop CHDN sampling designs and describes the designs CHDN will use to monitor each vital sign.

4.2 Sampling Design Concepts and Definitions

4.2.1 Overview of sampling designs

Sampling designs should be concise and understandable. Overly complex designs can be confusing and may reduce accessibility of results to the monitoring program audience, many of whom are not well versed in statistics and sampling design theory. The CHDN program will be designed as simply as possible, with complexity added only as needed to achieve objectives. Of course, when monitoring ecosystem structure, function, and processes, some level of complexity cannot be avoided, particularly when dealing with large, remote, and difficult-to-access landscapes (McDonald and Geissler 2004).

After defining clear and concise objectives for each monitoring protocol, the next step in developing a sampling design is to define the collection of animals, plants, natural resources, or environmental attributes of interest within a specified study. A population consists of **elements**, the objects on which a measurement is taken (Scheaffer et al. 1990). The actual elements sampled are referred to as the **sampling unit**; they are non-overlapping collections of elements (in most cases, the sampling unit is the same as the element). A **target population** is defined as the complete collection of sampling units upon which inference is made. Note that this is a statistical population and may or may not refer to a biological population. Without a clear idea of the target population, the remaining decisions concerning sampling design development are impossible to make.

We try to quantify our target population by using a **sampling frame**, defined as the collection of sampling units. Common examples of sampling units in the CHDN monitoring program include plots and polygons on a digital map, or discrete phenomena, such as lakes, springs, or stream segments. The sampling frame could be a list of elements (e.g., springs) or a map of discrete areal elements (e.g., vector-

based GIS coverage of a park). A **sample** is a subset of sampling units of a population (**sampled population**) that are measured.

Area and linear frames use geographic boundaries to delineate the target population. Typically, a map of the target population serves as the basis for drawing samples. An **area frame** typically designates the population as polygons. A linear frame designates the population as a linear feature, such as a line. **Linear frames** are typically used to represent stream and even riparian systems. The CHDN uses probability sampling (described below) to select locations from area and linear sampling frames.

A **list-based frame** is a list of possible sample units derived from inventories or intimate knowledge of the extent of a resource. A list of all known springs and seeps within a park is an example of this type of frame. Samples from a list-based frame can be selected in various ways. A census (described below) can be conducted by selecting all samples in a list. Probability sampling can be employed to select samples, providing the ability to make inference to all units in the list. When monitoring resources are limited, the list can be the basis for the selection of index sites in which either the most representative or the most accessible samples are selected for monitoring.

Potential sources of non-sampling error are another consideration in sampling-design development. Non-sampling error may affect the precision and accuracy of estimates from sampling efforts (Lessler and Kalsbeek 1992). **Frame error** is the error resulting from the disparity between the target population and sampled population. Frame error, similar to sampling error, is reduced by increasing the number of units in the sampled population (i.e., increasing the sample size). Over-coverage occurs when the sampled population contains elements not included in the target population. Under-coverage occurs when elements of the target population are omitted from the sampled population. **Non-response error** results from the failure to obtain responses (i.e., measurements) for the entire chosen sample. When missing outcomes are very different from the outcomes obtained, the estimates calculated from the responding portion of the sample are biased. **Measurement error** is defined as the difference in measurements obtained and the true value of the measure and may include detection errors from observers and instrument errors. The three components of non-sampling error (frame, non-response, and measurement), may not always be avoidable, but survey planning and design that accounts for these error sources may be helpful in reducing the effects of non-sampling error on target population estimates.

After the target population has been defined, decisions about where and how to distribute sampling locations can be made. The CHDN monitoring plan uses three approaches to define the spatial extent of monitoring and inference and to determine locations for acquiring observations of vital signs. These approaches include probabilistic survey design, index sites, and census.

A **probabilistic survey design** requires the delineation of a finite target population and uses probability sampling to select sampling units at random from the population (Cochran 1977). These designs have fewer assumptions and provide more reliable and legally defensible parameter estimates than other approaches, such as those designed to sample from infinite populations (Schreuder et al. 2004, Edwards 1998, Neusser et al. 1998). The target population is represented by a finite number of non-overlapping elements. These non-overlapping elements comprise the sampling frame, and this frame is used in the selection of sampling locations and as the basis for making inference from samples to the population (Schreuder et al. 2004). Probability sampling is central to survey designs, where each element in the sampling frame has a known probability of being included in a sample (i.e., selection probability). This selection probability determines the weight of each sample when making inference to the target population. The selection probability can be uniform or vary among groups of elements (i.e., unequal probability sampling). Additionally, selection probabilities can vary in subsequent additions of sampling sites. Proper estimation of population parameters requires maintaining a record of the selection

probability for each element in each sample-site selection event. Because CHDN parks are typically large, probabilistic survey designs will be employed for most vital signs.

The CHDN employs spatially balanced probability sampling with and without stratification to allocate sample units in designs that involve sampling (i.e., that do not use index sites or a census). The network relies on the Generalized Random Tessellation Stratified (GRTS; Stevens and Olsen 2004) scheme for probability sampling. GRTS is designed to produce a spatially balanced random sample (Stevens and Olsen 2004). This method is based on creating a function that maps two-dimensional space into one-dimensional space and uses a restricted randomization algorithm to select spatially balanced, random samples. Spatially balanced means that sample units are spread out approximately uniformly. Inherent in the GRTS scheme is the use of probability sampling and the assignment of selected sampling units to panels, such that each panel is spatially balanced. A panel is a collection of sample units visited in the same monitoring event (i.e., year). Multiple panels are often used to spread out sampling units over time. GRTS samples can be selected using area or linear sampling frames and list-based frames. With list-based frames, the term *finite GRTS sample* is used to indicate that the GRTS process only selects from the listed sample units. With area and linear frames, GRTS procedures involve an internal conversion of the frame to contiguous minimum mapping units and the selection of sample units from the population of units.

With stratification, the sampling frame is divided into mutually exclusive strata, and samples are drawn for each stratum. Stratification affords greater information about subpopulations (Lohr 1999) and increased precision when samples from within strata are more homogeneous than between strata (Cochran 1977). Sampling locations within strata can be selected in any manner, such as probability sampling with GRTS. The CHDN is considering the use of stratification in the monitoring of soil and vegetation vital signs (Integrated Uplands monitoring protocol). In the Upland protocol, the strata will be based on vegetation types. For other vital sign monitoring efforts, target populations are not stratified.

Index sites are sample units whose locations are based on judgment; they are usually picked to be "representative" sites. Costs, accessibility, and reliance on existing external programs that do not use probability sampling for site selection motivate the use of index sites for certain vital signs. A key limitation of index sites is that they are not selected using probability sampling; thus, inference beyond the actual monitored sites is subject to selection bias. This bias can be mitigated if the relationship between sampled and unsampled units is reasonably modeled (e.g., known environmental associations), or bias may be minimal if a large portion of the finite population is actually used.

A **census** involves the complete enumeration of a vital sign at all possible sample units. However, the target population must still be defined to bound the limits of a census. Different strategies can be used in the temporal allocation of census efforts within and among park units.

After the target population, sampling frame, and a strategy for drawing samples are determined, the temporal aspect of sampling must be considered. Specifics concerning the sampling occasion, time of year (season or month), and time of day depend on the particular aspect of the vital sign being measured. However, for larger parks, it may not be feasible to visit the entire sample within a given sampling occasion, due to travel time and other factors. Thus, most sample designs proposed for the CHDN will rotate field sampling efforts through various sets of sample units over time. In this situation, it is useful to define a panel of sample units to a group that is always sampled during the same sampling occasion or time period (Urquhart and Kincaid 1999, McDonald 2003). Sample units in the sample population become members of a panel through the **membership design** (McDonald 2003). The allocation procedure could be a probabilistic sample, a judgmental sample, or a census.

The temporal scheduling of sampling, particularly when multiple panels are being used, requires a **revisit design** (Urquhart and Kincaid 1999, McDonald 2003). The revisit design indicates the time of the initial visit and the frequency of subsequent visits to sample units of a panel. Sample effort can be rotated

among panels through time, which also effectively rotates sampling through space. Temporal visitation schemes are used for two main reasons. First, the number of plots necessary to achieve the desired precision of status and trend estimates may exceed what can be realistically monitored annually. Distributing samples through time can achieve the desired precision, but it takes longer to achieve this precision than with annual sampling. The second reason pertains to plot fatigue. Annual visitation can lead to inadvertent cumulative impacts to a site, such as those resulting from trampling of vegetation and soils. A revisit scheme minimizes cumulative and severe impacts. Strict procedures to minimize site disturbance during sampling events, however, can allow for annual visitation without deleterious effects.

Response design (measurements taken at sampling locations) and **sample size** (the number of samples required to meet stated monitoring objectives) are two essential components of any sampling design. Response design and sample size components are developed after basic decisions regarding target and sampling population, spatial allocation and membership, and revisit strategies have been made. In addition, a response design is usually necessary before sample size can be estimated appropriately. This is particularly true when response decisions, such as plot shape and size, strongly influence the variability of population estimates. However, we must decide about sample size in order to finalize decisions about membership and revisit design and, in practice, sampling designs arise out of an iterative process in which the order of operations is not rigid. As with the design decisions described above, sample size is primarily an exercise in cost-benefit trade-offs, and must be determined through careful consideration of program objectives.

4.2.2 Sample size considerations and magnitude of change

Populations in the real world are dynamic, and change over time is expected. What is important is whether or not there has been meaningful change (meaningful to the ecosystem, public, or park manager), what has caused the observed change, and whether further change in the resource is expected.

To understand what constitutes meaningful, significant change, we must differentiate between statistical significance and biological significance. Statistical significance relies on probability and is influenced by sample size. Even minor changes (from a biological perspective) will be statistically significant if the sample size is large enough. Regardless of statistical significance, we would consider something biologically significant if it facilitates a major shift in ecosystem structure or function (e.g., loss of one or more species, addition of non-native species, changes in ecosystem processes).

Thus, from a monitoring standpoint, we are concerned with both statistical and biological significance. We want to know whether we are likely to detect a statistically significant change that we also consider biologically meaningful. To answer this, we need to decide what level of statistical significance we want to attain (i.e., our Type I error rate, or α, discussed below), what level of change we consider biologically meaningful and that we hope to detect (i.e., the "effect size"), the amount of variation among sampling units, and the number of sampling units.

In addition to our monitoring objectives, we need to define our **sampling objectives**. Sampling objectives establish a desired level of statistical power ($1-\beta$) to detect a specified minimum detectable change or effect size and acceptable levels of false-change (α or the probability of a Type I error; Elzinga et al. 2001). In other words, the timeframe for detecting the desired minimum change given the levels of acceptable error and the variance of vital sign measures determines sample-size requirements. All things being equal, more samples will allow detection of change sooner, but by extending the reference time for change detection, fewer samples per sampling event are required. The number of samples collected is a function of each of these components, and decreasing sample size, which can be desirable for cost effectiveness, will often force acceptance of higher error and lower power. These tradeoffs are mitigated by reducing variance estimates, either through modifications in response design, another component of the sampling design (e.g., revisit design), or by accepting a higher minimum effect size (Steidl et al.

1997). In general, sample size should be large enough to give a high probability of detecting any changes that are of management, conservation, or biological importance, but not unnecessarily large (Manly 2001). Scientists traditionally seek to reduce Type I errors, and accordingly prefer small α levels. In a monitoring program such as ours, with a strong resource-conservation mandate, however, it is preferable to employ an early warning philosophy by tolerating a higher α but subsequently increasing the power to detect differences or trends (Sokal and Rohlf 1995, Roback and Askins 2005).

Estimates of status and trends from monitoring information are derived in two ways. **Direct estimation** uses recorded observations weighted by the selection probabilities of samples and assumes that the measured vital sign is fully detectable. Where the probability of detecting an individual or species within a sampling unit when it is present is less than 100%, **modeled estimates** are required. Failing to properly account for individual or species detectability leads to a biased value of a vital sign at a sample unit and, thus, biased estimates of status and trend (Thompson 2002). In particular, temporal changes in detection rates can confound the ability to detect a true change. Incomplete detectability occurs due to perception and availability bias (Marsh and Sinclair 1989, Pollock et al. 2004). Perception bias arises from missing an individual or species that is available for detection (i.e., non-zero detection probability). For instance, an observer is more likely to detect a bird 10 m away than a bird 100 m away. Methods such as capture-recapture (Pollock 2000) and distance sampling (Buckland et al. 2001, 2004) account for this component of individual detectability (see also Williams et al. 2002). Availability bias results when individuals or species are present but unavailable for detection (e.g., Pollock et al. 2004). For instance, if a plant species is unrecorded during a sampling occasion because it was dormant underground, availability bias results. The CHDN uses model-based estimates, where possible, to properly account for incomplete detectability.

4.3 Sampling Design by Vital Sign

CHDN sampling designs can be organized by the underlying sampling frame (area or linear-based, and list-based) or the use of index sites or a census. Table 4.3 lists the protocols planned for development, the vital signs they address, and the proposed sampling design for each protocol. For each protocol, the table identifies the sample design type, target population, sample frame, and proposed revisit design.

The CHDN monitoring program emphasizes, where possible, co-location of vital-sign monitoring locations and co-visitation. Co-location refers to monitoring multiple vital signs at the same physical locations. Co-visitation refers to recording observations on multiple vital signs during a sampling occasion. An obvious benefit of both is operational efficiency. Overall time and costs for plot establishment and sampling are reduced when multiple vital signs are measured at the same place and time. Also, measures of multiple vital signs at the same locations can provide important insights into ecological processes with direct application to management. For example, monitoring drivers and responses aids in interpreting reasons for observed changes. Co-located vital signs enhance the understanding of causes and consequences of interactive behaviors (Michener et al. 2001), and when the lack of precision masks statistically significant change, the collective temporal consistency in trends among vital signs can serve as a weight of evidence of change. Co-location and co-visitation of vital signs minimize confounding factors and enhance assessments of such subtle, but possibly important, trends.

Table 4.3. Summary of Chihuahuan Desert Network sample design specification by protocol.

Protocol	Vital sign(s)	Sample design type	Generalized target population	Sample frame	Revisit design
Air Quality	Ozone, Wet and Dry Deposition, Visibility and Particulate Matter	Index (existing air-quality stations)	Index sites, although measures are representative of a larger area	NA	Continuous
Climate	Basic Meteorology	Index (existing weather stations)	Index sites, although measures are representative of a larger area	NA	Continuous
Dune Dynamics	Dune Formation and Stability, Dune Morphology	Census	Census	NA	First resample: 5 yrs post-initial. Second sampling: 5–10 yrs.
River Channel Morphology	River Channel Characteristics	Index	Index sites	NA	Every 5 yrs
Groundwater Quantity	Groundwater Quantity	Index	Index sites	NA	Periodic to Continuous
Surface Water Quality and Dynamics	Surface Water Dynamics	Index	Index sites	NA	Periodic to Continuous
	Persistence of Springs	BIBE: GRTS (finite)	BIBE: List-based frame	List-based frame: List of springs and seeps	Annually in two seasons (late winter, post-monsoonal in the fall)
		Other parks: Index, census, or GRTS (finite)	Index sites, census, or park's list-based frame	List-based frame: List of known springs and seeps in a park	
	Surface Water Quality	Index	Index sites	NA	Periodic to Continuous
	Aquatic Invertebrates (rivers and streams)	Index	Index sites	NA	Periodic
	Aquatic Invertebrates (seeps and springs)	BIBE: GRTS (finite)	BIBE: List-based frame	List-based frame: List of known springs and seeps	Annually in two seasons (late winter, post-monsoonal in the fall)
		Other parks: Index, census, or GRTS (finite)	Index, census, or list-based frame	List-based frame: List of known springs and seeps	

Table 4.3. Summary of CHDN sample design specification by protocol, cont.

Protocol	Vital sign(s)	Sample design type	Generalized target population	Sample frame	Revisit design
Invasive/Non-native Plants	Invasive/Non-native Plants	GRTS (finite)	Areas along roads, arroyos, and other areas predicted as suitable habitat for focal plant species	Area frame developed using park maps of topos, roads, trails, veg.	Every 2–3 yrs
Landbirds	Bird Communities (desert grassland)	GRTS (area)/model-based estimates of abundance or occupancy at the sample-unit level, co-located with subset of Integrated Uplands vital signs locations	Desert grassland ecological sites in desert ecosystems	Area frame: Map of ecological sites that correspond to desert grasslands in desert ecosystems	Annually
	Bird Communities (riparian)	GRTS (area)/model-based estimates of abundance or occupancy at the sample-unit level	Riparian systems in river, desert, foothill, and montane ecosystems	Area frame: Maps of riparian areas in river, desert, foothill, and montane ecosystems.	Annually
Integrated Uplands (Soils and Vegetation)	Plant Community Composition, Soil Hydrologic Function, Biological Soil Crusts, Soil Erosion (Wind and Water), Bare Ground	GRTS (area) (co-location and co-visitation of all vital signs)	Desert grasslands, and shrublands in desert and foothill ecosystems	Area frame: Maps of ecological sites that correspond to grasslands, shrublands, woodlands in desert and foothill ecosystems	Every 5 years
Landscape Patterns and Dynamics	Land Cover, Land-Use Changes	Census	Census	NA	Every 5–10 yrs

Protocols follow the order presented in the NPS Ecological Monitoring Framework.

Chapter 5: Monitoring Protocols

"Monitoring protocols are detailed study plans that explain how data are to be collected, managed, analyzed, and reported and are a key component of quality assurance for natural resource monitoring programs. Protocols are necessary to ensure that changes detected by monitoring actually are occurring in nature and not simply a result of measurements being taken by different people or in slightly different ways.

. . . A good monitoring protocol will include extensive testing and evaluation of the effectiveness of the procedures before they are accepted for long-term monitoring. Peer review of protocols and revisions are [sic] *essential for their credibility. The documentation should include reviewers' comments and authors' response."*

—Oakley and others (2003)

5.1 Protocol Overview

Currently, the CHDN plans to develop 10 protocols covering 21 vital signs during the first three years of the monitoring program. Table 5.1 lists the relevant vital signs for each CHDN protocol and relates their association to justifications for monitoring, monitoring objectives, and parks in which each protocol will be implemented. For vital signs monitored with I&M funding, one protocol will be new and applied only in the CHDN (Dune Dynamics). Other protocols (Integrated Uplands, Landbirds, Invasive Plants, River Channel Morphology) will be existing NPS or other approved protocols. The remaining protocols will be developed through multi-network (Air Quality, Climate, Groundwater, Surface Water Dynamics) or servicewide (Landscape Patterns and Dynamics) efforts. Chapter 9 summarizes our schedule for development and implementation of these protocols. The CHDN also will develop supplemental documents pertaining to data management, data analysis, and data reporting from existing NPS program protocols (e.g., Air Quality).

There is not a 1:1 relationship between CHDN vital signs and protocols (Table 5.1). Rather, a single protocol may cover multiple vital signs, and data relevant to a vital sign may result from more than one protocol. This organizational scheme increases both the efficiency and integration of protocol development and in-field sampling. For example, when and where crews are collecting landbirds data, they could also sample soil and vegetation vital signs (Integrated Uplands protocol).

5.2 Protocol Development Process

Monitoring protocols identify methods for gathering data, outline a process to collect data, and establish how data will be analyzed and reported. A good monitoring protocol should be appropriate for the task, accurate, reliable, feasible, and cost-effective (Margoluis and Salafsky 1998). Protocols contain detailed study plans, clear objectives, unambiguous standard operating procedures (SOPs) for data collection and management, quality assurance/quality control (QA/QC), analysis, training and equipment requirements, documentation of protocol changes, and relevant support information. Careful design and documentation of protocols are necessary to ensure that changes detected by monitoring actually are occurring in nature and do not stem from measurement variability introduced when different people or methods are used (Oakley et al. 2003). Rigorous protocols are essential for effective monitoring of vital signs through time.

Table 5.1. CHDN protocols with relevant vital signs, parks included, justifications, and monitoring objectives.

Protocol Vital signs	**Air Quality**[1] Ozone Wet and Dry Deposition Visibility and Particulate Matter
Parks	BIBE, GUMO, CAVE[2]
Justification	The quality of the air and atmospheric conditions can influence the functioning of park ecosystems and visitor experience. A number of plant species are negatively impacted by excessive ozone and atmospheric pollutants (e.g., nitrates, sulfates) deposited through fallout over parks. Continued development of energy sources in southeastern New Mexico and West Texas likely will increase pollution. Excessive particulate matter from industrial wastes can obscure viewscapes and trigger human respiratory responses, diminishing the aesthetic appeal of park visitation. Class I park areas must meet federal air-quality standards. Among CHDN units, active monitoring occurs only at two Class I air-quality parks, and partial monitoring at a third park. Existing efforts through several regional and national networks of climate stations collect these data and provide the NPS national I&M programs a portal to access summaries and raw data
Monitoring objectives	1. Report on the seasonal and long-term trends in concentrations of nitrogen and sulfur from wet deposition at BIBE and GUMO. 2. Report on the seasonal and long-term trends in dry deposition chemistry at BIBE. 3. Report on the seasonal and long-term trends in ozone concentration at BIBE, CAVE, and GUMO. 4. Report on seasonal and long-term trends in visibility-reducing pollutants at BIBE and GUMO. 5. Determine patterns of year variability and long-term trends in air quality vital signs in CHDN parks to detect changes in air quality that correlate with changes in other CHDN vital signs.
Protocol Vital signs	**Climate**[1] Basic Meteorology
Parks	AMIS, BIBE, CAVE, FODA, GUMO, WHSA
Justification	Climate is the most extensive ecological driver in the Chihuahuan Desert. Timing, intensity, and duration of precipitation and temperature influence most ecological processes. Change in meteorological conditions that define climate may have dramatic influence on system processes and species distributions. Shifts in timing and duration in life cycles of certain plants may indicate aspects of climate change and provide a link for understanding climate-change effects on other organisms. Existing efforts through several regional and national networks of climate stations collect these data and provide the NPS national I&M programs a portal to access summaries and raw data.
Monitoring objectives	1. Report on status and longer-term trends (monthly, seasonal, and annual) of common meteorological variables (i.e., temperature, precipitation) at existing monitoring stations in and near CHDN parks. 2. Determine patterns of year variability and long-term trends in common meteorological variables in CHDN parks to detect changes in climate that correlate with changes in other CHDN vital signs.

Table 5.1. CHDN protocols with relevant vital signs, parks included, justifications, and monitoring objectives, cont.

Protocol Vital signs	**Dune Dynamics** Dune Formation and Stability Dune Morphology
Parks	WHSA, GUMO[2]
Justification	WHSA was established in 1933, to preserve the world's largest gypsum dune field. The monument encompasses about half of the dune-field extent. An understanding of relevant dune-field dynamics is vital to the park's core mission. Dune dynamics are taken here to include a broad spectrum of dune and dune-field aspects: dune formation/destruction, surface processes, migration rate, characteristic behavior, dune–dune interactions, and dune–substrate interactions. This vital sign, along with groundwater quantity, are the top two priority vital signs for WHSA.
Monitoring objectives	1. Determine characteristics of single-dune dynamics on a seasonal and composited yearly basis. 2. Determine long-term trends in dune dynamics at the dune-field scale during 5–10-year intervals. 3. Determine seasonal and composited yearly trends in the sediment budget at the dune-field scale during 5–10-year intervals.
Protocol Vital signs	**River Channel Morphology[3]** River Channel Characteristics
Parks	AMIS[2], BIBE, RIGR[2]
Justification	Changes in channel morphology affect sediment loads and alter riparian habitats. Increased channelization contributes to reduction in active floodplains, reducing or eliminating recruitment of cottonwoods. Reduction in active sediment movements causes reduction in suitable habitat for native fish and freshwater mollusks. Coarse-scale changes in river channel characteristics can be measured through aerial imagery.
Monitoring objectives	Determine long-term trends in channel location and characteristics of the Rio Grande at intervals following major bankfull- or out-of-bankfull events. (These are events that cause changes in river geomorphology.)
Protocol Vital signs	**Groundwater Quantity[4]** Groundwater Quantity
Parks	AMIS, BIBE, CAVE, FODA, GUMO, WHSA
Justification	The arid and semi-arid terrestrial ecosystems within the CHDN generally are adapted to water-limited environments. The quantity of subsurface water (groundwater) is becoming increasingly important for CHDN parks. Groundwater is the major source of potable water for human subsistence within and adjacent to CHDN parks, and the discharge component of springs and seeps. Dams, irrigation, municipal withdrawals, and instances of groundwater depletion have significantly changed the hydrographs of many surface waters in CHDN parks, with large-scale effects on aquatic and riparian ecosystems. By summarizing and evaluating data from USGS stream gages, groundwater-level monitoring instrumentation at some parks, and state-based (regional) monitoring of groundwater levels, CHDN will help to identify changes in river flow and detect impending threats to park groundwater sources. Sampling for these vital signs will be co-located and co-visited by the same personnel monitoring surface water quality vital signs to increase monitoring efficiency and ensure standardization of procedures.
Monitoring objectives	Determine the seasonal and annual status, and longer-term trends in groundwater resources (as estimated from existing wells) in or adjacent to all CHDN park units.

Table 5.1. CHDN protocols with relevant vital signs, parks included, justifications, and monitoring objectives, cont.

Protocol Vital signs	**Surface Water Quality and Dynamics**[4] Surface Water Dynamics Persistence of Springs Surface Water Quality Aquatic Invertebrates
Parks	AMIS, BIBE, CAVE, GUMO
Justification	The arid and semi-arid terrestrial ecosystems within the CHDN are generally adapted to water-limited environments. Surface water quality is a monitoring priority for tracking park ecological health, measuring compliance with federal and state laws and standards, and detecting threats to human health. In the CHDN, the Rio Grande and Amistad International Reservoir are the major sources of surface water for humans and aquatic-biological communities along the Texas–Mexico border. The quality of water in the Rio Grande is of particular concern, given the economic and ecological role it plays in the border region and its historical exposure to contaminants. Smaller perennial streams, and scattered springs and seeps, provide additional water for support of park biota. Although limited in extent, these microcosms can add considerably to the biodiversity of arid and semi-arid landscapes. Monitoring water quality vital signs will help to demonstrate whether park water quality is being protected or maintained, and indicate whether restoration is required. Sampling for these vital signs will be co-located and co-visited by the same personnel to increase monitoring efficiency and ensure standardization of procedures.
Monitoring objectives	Regulatory and Park Critical Objective: 1. Report on seasonal and annual status and trends for core water quality vital signs for Segments 2306 and 2307 of the Rio Grande, impaired water under Section 303(d) of the Clean Water Act. 2. Determine seasonal and annual status and trends for core water quality vital signs at selected sites in water resources classified as critically important by each park in AMIS, BIBE, CAVE, and GUMO. Surface Water Quality and Dynamics 1. Determine the seasonal and annual status and longer-term trends in water quantity and core water quality measures for select sites in the Rio Grande in BIBE and RIGR, and report on these trends from existing stations. 2. Determine the seasonal and annual status and longer-term trends in water quality and quantity measures at selected sites for perennial streams in BIBE, CAVE, and GUMO. 3. Determine the seasonal and annual status and longer-term trends in measures of wetness in select springs in BIBE, CAVE, and GUMO. 4. Determine the status and longer-term trends in measures of aquatic invertebrate communities in selected sites of the rivers, perennial streams in BIBE[3], CAVE, and GUMO, and report on these trends from existing stations. 5. Determine the status and longer-term trends of aquatic invertebrate communities at select springs in BIBE[3], CAVE, and GUMO. 6. Report on status of monthly, seasonal, and annual reservoir levels and long-term trends from existing International Boundary Water Commission stations in AMIS.

Table 5.1. CHDN protocols with relevant vital signs, parks included, justifications, and monitoring objectives, cont.

Protocol Vital signs	**Invasive/Non-native Plants**[4] Invasive/Non-native Plants
Parks	All
Justification	Invasion and establishment of non-native plants is one of the most serious threats to maintaining ecosystem integrity in CHDN parks. Aggressive species, such as salt cedar, giant cane, and Lehmann lovegrass, can rapidly change plant community composition and function. If invasive plant species dominate a community, biotic diversity is greatly reduced, not only by simplifying the number of plant species, but also by eliminating interactions with higher trophic levels. Some invasive plant species can alter driving processes, such as fire regimes. Multiple laws and executive orders deal specifically with invasive species. Detecting new problem species early before they have a chance to spread, and while they are still in small controllable populations, is important to cost-effective resource management.
Monitoring objectives	1. Detect the initial occurrence for any of a subset of high-priority species in areas of high invasion probability. 2. Determine changes in the status and trend (density, abundance or extent) of a subset of high-priority species in areas of high invasion probability. 3. Determine changes in species composition of a subset of high-priority species in areas of high invasion probability, taking into account any management treatments that occurred between sampling intervals.
Protocol Vital signs	**Landbirds**[4] Bird Communities
Parks	All
Justification	CHDN parks can serve as reference sites for helping interpret ecoregional trends for common breeding birds. Riparian bird communities, in particular, are a desired focal resource for many park visitors in this network and provide a condition indicator for a rare and limited habitat type. Monitoring of bird communities in conjunction with other adjacent I&M networks (Sonoran Desert and Southern Plains), as well as regional initiatives, will provide insight into changes of this important focal resource at larger regional scales.
Monitoring objectives	1. Provide occupancy and trend in occupancy estimates for breeding landbirds. 2. Estimate species richness, composition, and associated parameters of landbird community dynamics. 3. Where feasible, estimate population density and trend estimates for common breeding landbirds. 4. Where feasible, incorporate vegetation monitoring from Integrated Uplands protocol to augment landbird sampling and increase efficiency.

Table 5.1. CHDN protocols with relevant vital signs, parks included, justifications, and monitoring objectives, cont.

Protocol Vital signs	**Integrated Uplands (Soils and Vegetation)**[4] Plant Community Composition Soil Hydrologic Function Biological Soil Crusts Soil Erosion (Wind and Water) Bare Ground
Parks	BIBE, CAVE, FODA, GUMO, WHSA
Justification	Soils and plants provide the foundation for most terrestrial and some aquatic communities. Condition of these focal resources reflects effects of key ecological drivers and system stressors. Soil and plants figure prominently in ecosystem function and biological diversity. Incursion of desert-grassland-dominated communities by woody shrubs, and loss of riparian plant communities, have predominated through much of the Southwest. Continuation of these trends will result in loss of biotic diversity in some parks. Reduction in the numbers of these communities also may indicate impacts of climate change. CHDN monitoring will target these areas and other areas to co-locate with other vital signs.
Monitoring objectives	1. Determine the status and long-term trends in soil stability, bare ground, magnitude and extent of soil erosion, and soil hydrologic function within selected grassland and shrubland communities of the desert and foothill ecosystems. 2. Determine long-term trends in the composition, structure, and relative abundance of dominant and subdominant perennial plant species and biological soil crusts within selected grassland and shrubland communities in the desert and foothill ecosystems.
Protocol Vital signs	**Landscape Patterns and Dynamics**[5] Land Cover Land-Use Changes
Parks	AMIS, BIBE, CAVE, FODA, GUMO, WHSA
Justification	Changes in landscape patterns beyond park boundaries are often informative about the risk of impending impacts. Changes in land use (e.g., road densities, increasing number of oil, gas, and wind energy sites) can impact park resources. Changes in landscape can identify impending issues, such as future loss and fragmentation in wildlife habitats, isolation of park resources, potential for water scarcity and pollution, and invasion of non-native species. Trends in land-cover amounts and distribution may provide insight into future changes to biotic diversity. These changes will be interpreted along with other temporal and spatial patterns observed from ground-level field sampling of vegetation communities and trends in climate.
Monitoring objectives	Determine patterns and long-term trends in spatial and temporal landscape change within and adjacent to CHDN parks based on changes in land-use (e.g., road density, building density, energy developments sites) and land-cover distribution (vegetation classes).

Protocols follow the order presented in the NPS Ecological Monitoring Framework.

1 = These protocols are primarily focused on summarization, analysis, and reporting of data obtained through ongoing monitoring by other programs. Opportunities to partner/collaborate with other NPS programs (e.g., Air Resource Division), networks, or other agencies will be explored.

2 = This park will be monitored if resources permit.

3 = Protocol implementation will complement work already being conducted on the Rio Grande and will be cost-shared with Big Bend National Park. CHDN's role will largely be data management and reporting.

4 = An existing protocol will be implemented to monitor this vital sign. Data collection and management will be conducted in partnership with other networks.

5 = This protocol will be fully developed following the conclusion of the servicewide I&M program's effort. The national office has taken a lead role in developing standards and useful analytical techniques.

Where CHDN funding is to be used for monitoring, the network will either (A) make use of protocols completed by other I&M networks, other agencies, or programs that already have been peer-reviewed and field-tested, or (B) if protocols are developed internally, they will (1) follow the Oakley and others (2003) protocol standards, (2) be peer-reviewed, and (3) be approved by the regional I&M program manager before they are finalized for long-term monitoring. The CHDN intends to adopt protocols developed by the Southern Plains Network for Landbirds and Invasive Plants, and the Sonoran Desert Network for Integrated Uplands. Other efficiencies, such as sharing administration of agreements, using common databases and data management efforts, and using common analysis and reporting, will also be explored. The CHDN is working in concert with these and other networks to develop protocols for Air Quality, Climate, Groundwater Quantity, and all vital signs monitoring associated with seeps and springs. For the River Channel Characteristics vital sign, the CHDN will manage data collected by BIBE and others using peer-reviewed protocols and use that data for reporting. Dune Dynamics is the only vital sign protocol that the CHDN will develop internally.

The standard format for an NPS monitoring protocol (Oakley et al. 2003) consists of three sections: (1) a narrative, (2) a set of SOPs, and (3) supplemental or supporting materials. The narrative provides an overview of the background and objectives, sampling design, field methods, data handling, analysis and reporting, personnel requirements and training, and operational requirements. The SOPs provide detailed procedures for all components described in the narrative. For example, additional details may include specifics on how to use, maintain, or calibrate a particular piece of equipment. Supplemental materials include materials such as databases, GIS layers, related data and reports, and reviewer comments.

Additionally, regardless of the source of the monitoring protocols (internally developed or adopted and modified), during the development period, areas of uncertainty will be addressed through pilot field testing of sampling procedures. Following reviews and revision, the approved protocol will be accepted for full implementation, and formal monitoring will commence.

For each protocol, CHDN staff ultimately are responsible for ensuring that the objectives and final protocol meet the needs of CHDN parks, are realistic and efficient, and take advantage of opportunities to integrate monitoring among multiple protocols (e.g., through co-location of vital signs to be sampled). For vital signs already being monitored by existing programs, the CHDN will work to gather and archive copies of the existing protocols, SOPs, and QA/QC guidelines. For protocols that already exist or are being cooperatively developed by multiple networks, the CHDN will focus its efforts on ensuring that appropriate sampling frameworks are designed, and on developing SOPs focused on data access, analysis, and reporting on the vital signs.

The CHDN plans to monitor or report on a maximum of 21 vital signs associated with 10 protocols. Monitoring of these vital signs will be guided by the protocols in Table 5.1. Again, when possible, existing sources of NPS-approved monitoring protocols will be adopted or modified as necessary. Subject-matter experts will be used to modify existing, or develop new, protocols (including sampling designs) for monitoring CHDN vital signs, when necessary (Appendix J). Submittal of protocols for peer review and approval is expected to occur from the end of 2010 through 2013. The timeframe is dependent on the amount of modification or development required for each protocol.

5.3 Protocol Development Summaries

A Protocol Development Summary (PDS) is required for each monitoring protocol planned for development and implementation by the CHDN monitoring program. The CHDN has written a PDS for each of the 10 protocols shown in Table 5.1 (see Appendix J).

Chapter 6: Data Management

6.1 Introduction

The central mission of the NPS I&M program is to acquire, manage, analyze, and distribute scientific information on the status and trends of specific park natural resources. Intended users of this information include park managers, cooperators, researchers, Congress, policymakers, and the general public. A cornerstone of the I&M program is the strong emphasis placed on data management. The Chihuahuan Desert Network expects to invest over 33% of its available resources in data management, analysis, and reporting activities. Because of the size and complexity of the elements comprising network data management, a separate Data Management Plan (DMP) has been developed and is included in this report as Appendix K.

6.2 Data Management Plan

The goal of the CHDN data management program is to maintain, in perpetuity, the ecological data and related analyses that result from the network's inventory and monitoring work. The CHDN DMP describes the resources and processes required to ensure the accuracy, security, longevity, and accessibility of data acquired or managed by the CHDN.

6.2.1 Data accuracy

The quality of the data collected and managed by the I&M program is paramount. Analyses performed to detect ecological trends or patterns require data with minimal error and bias. Inconsistent or poor-quality data can limit the detection of subtle changes in ecosystem patterns and processes. This could lead to incorrect interpretations and conclusions that may lead to poor management decisions and greatly compromise the credibility and success of the I&M program. To ensure that the CHDN produces and maintains data of the highest possible quality, procedures are established to identify and minimize errors at each stage of the data life cycle.

6.2.2 Data security

Digital and hard-copy data must be maintained in environments that protect against loss, either due to electronic failure or to poor storage conditions. Digital data of the CHDN are stored in multiple formats on a secure server and backed up through an integrated backup routine that includes rotation to off-site storage locations. In addition, the CHDN will work with NPS museum curators and archivists to ensure that related project materials, such as field notes, data forms, specimens, photographs, and reports, are properly cataloged, stored, and managed in archival conditions.

6.2.3 Data longevity

Countless data sets have become unusable over time, either because the format is outdated (e.g., punchcards), or because metadata are insufficient to determine the data's collection methods, scope, intent, quality assurance procedures, or format. Proper storage conditions, backups, and migration of data sets to current platforms and software standards are basic components of data longevity. Comprehensive data documentation is another essential component. The CHDN uses a suite of metadata tools to ensure that data sets are consistently documented and in formats that conform to current federal standards.

6.2.4 Data accessibility

One of the most important responsibilities of the I&M program is to ensure that data collected, developed, or assembled by CHDN staff and cooperators are made available for decisionmaking, research, and education. Providing well-documented data to park managers in a timely manner is especially important to the success of the program. The CHDN must ensure that:

- Data are easily located and obtained,
- Data are subjected to full quality control before release,
- Data are accompanied by complete metadata, and
- Sensitive data are identified and protected from unauthorized access and distribution.

The CHDN's main mechanism for distributing the network's data will be the Internet, which will allow data and information to reach a broad community of users. As part of the NPS I&M program, web-based applications and repositories have been developed to store a variety of park natural resource information (Table 6.2.4).

Table 6.2.4. Data to be provided on the CHDN and national I&M web sites.

Web application name	Data available at site
CHDN web site	Reports and metadata for CHDN projects; certified species lists; search and reporting tools for data; data downloads; database templates (http://science.nature.nps.gov/im/units/chdn/).
IRMA	Integrated Resource Management Application: Entry portal for the applications listed below.
NPSpecies	Database of vascular plant and vertebrate species known or suspected to occur on NPS park units (http://science.nature.nps.gov/im/apps/npspp/).
NatureBib	Bibliography of park-related natural resource information (http://www.nature.nps.gov/nrbib/).
NPSFocus	Portal to a variety of NPS information sources; will include NatureBib and NPS Data Store links (http://npsfocus.nps.gov/).
NPS Data Store	Park-related metadata and selected data sets (spatial and non-spatial) (http://science.nature.nps.gov/nrdata/).

The Chihuahuan Desert Network's information acquires its real value when it reaches those who can apply it. If these web portals do not meet a specific user's requirements, CHDN data management staff will work with users on an individual basis to ensure receipt of the desired information in the requested format.

6.3 Data Sources and Priorities

There are multiple sources of data related to natural resources in CHDN parks. Types of work that may generate these data include:

- Inventories
- Monitoring
- Protocol development pilot studies
- Special-focus studies performed by internal staff, contractors, or cooperators
- External research projects

- Studies performed by other agencies on park or adjacent lands
- Resource impact evaluations related to park planning and compliance
- Resource management and restoration work

Because the I&M program focuses on natural resource inventories and long-term monitoring, the data that result from these efforts are the CHDN's first data-management priority. However, the standards, procedures, and approaches to data management developed by the CHDN are being applied to other natural resource data sources.

For example, all I&M network parks need a basic suite of resource inventory data to effectively manage their resources and support a successful monitoring program. The servicewide I&M program has determined that all network parks sould acquire a minimum of 12 inventory data sets, including both biotic and abiotic components. The CHDN is working with individual parks and national NPS programs to acquire and standardize these basic resource data sets, and make them widely available. These data sets are:

- Natural resource bibliography
- Base cartographic data
- Air quality data
- Air-quality-related values
- Climate inventory
- Geology resources inventory
- Soil resources inventory
- Water body location and classification
- Baseline water quality data
- Vegetation inventory
- Species lists
- Species occurrence and distribution

6.4 Data Management Categories

Data from park and network sources generally can be placed in the following data management categories:

1. Data managed in servicewide databases.

2. Data managed in three databases developed by the I&M WASO office. NatureBib is a bibliographic tool for cataloging reports, publications, or other documents that relate to natural resources in park units. NPSpecies is used by the network to develop and maintain lists of vertebrates and vascular plants in network parks, along with associated supporting evidence. Dataset Catalog is used to document primarily non-spatial, natural-resource-related databases or other data assemblages. As development of the Integration of Resource Management Applications project progresses, the CHDN will use this data portal as the primary portal for accessing data.

3. Data developed or acquired directly by the network as a result of inventory, monitoring, or other projects, and managed by the CHDN.

4. Project-related protocols, field data, reports, spatial data, and associated materials, such as field forms and photographs provided to the CHDN by the parks or contractors, or developed by CHDN staff.

5. Data that, though not developed or maintained by the CHDN, are used as primary data sources or provide context to other data sets. Examples of this category include GIS data developed by parks, other agencies, or organizations; national or international taxonomic or other classification systems; and climate, air quality, or hydrologic data collected or assembled by regional or national entities.

6. Data that the CHDN assists in managing but is acquired and maintained by network parks. Because of the range of data management expertise in network parks, the CHDN provides data management assistance for high-priority data sets or those that may benefit from standardized procedures.

The categories listed above can contain one or more of the following data formats:

- Hard-copy documents (e.g., reports, field notes, survey forms, maps, references, administrative documents)
- Physical objects (e.g., specimens, samples, photographs, slides)
- Electronic text files (e.g., MS Word files, e-mail, web sites)
- Electronic tabular data (e.g., databases, spreadsheets, tables, delimited files)
- Spatial data (e.g., shapefiles, coverages, remote-sensing data)
- Miscellaneous electronic files (images, sounds, other files with proprietary formats)

Each of these data formats has specific requirements for ongoing management and maintenance, which are addressed in the DMP.

6.5 Data Management and the Project Life Cycle

Inventory and monitoring projects are typically divided into five broad stages: planning and approval, design and testing, implementation, product integration, and evaluation and closure (Figure 6.5). During all stages of data management, staff collaborate closely with project leaders and participants. Specific data management procedures correspond to these stages and are fully detailed in the chapters of the DMP. Building upon the data management framework presented in Chapters 1–4 of the DMP, Chapter 5 is devoted to data acquisition and processing, and Chapter 6 provides a framework for verifying and validating data that have been collected and entered into databases. Dataset documentation is the subject of Chapter 7, reporting in Chapter 8, and data dissemination, including issues such as data ownership, data sensitivity, and compliance with the Freedom of Information Act, are addressed in Chapter 9. Chapter 10 provides a framework for the long-term maintenance, storage, and security of CHDN data. For monitoring projects, extensive protocol SOPs provide detailed guidance on all stages of a project's data life cycle. These SOPs are specific to each project, yet all fall within the guidelines established in the DMP.

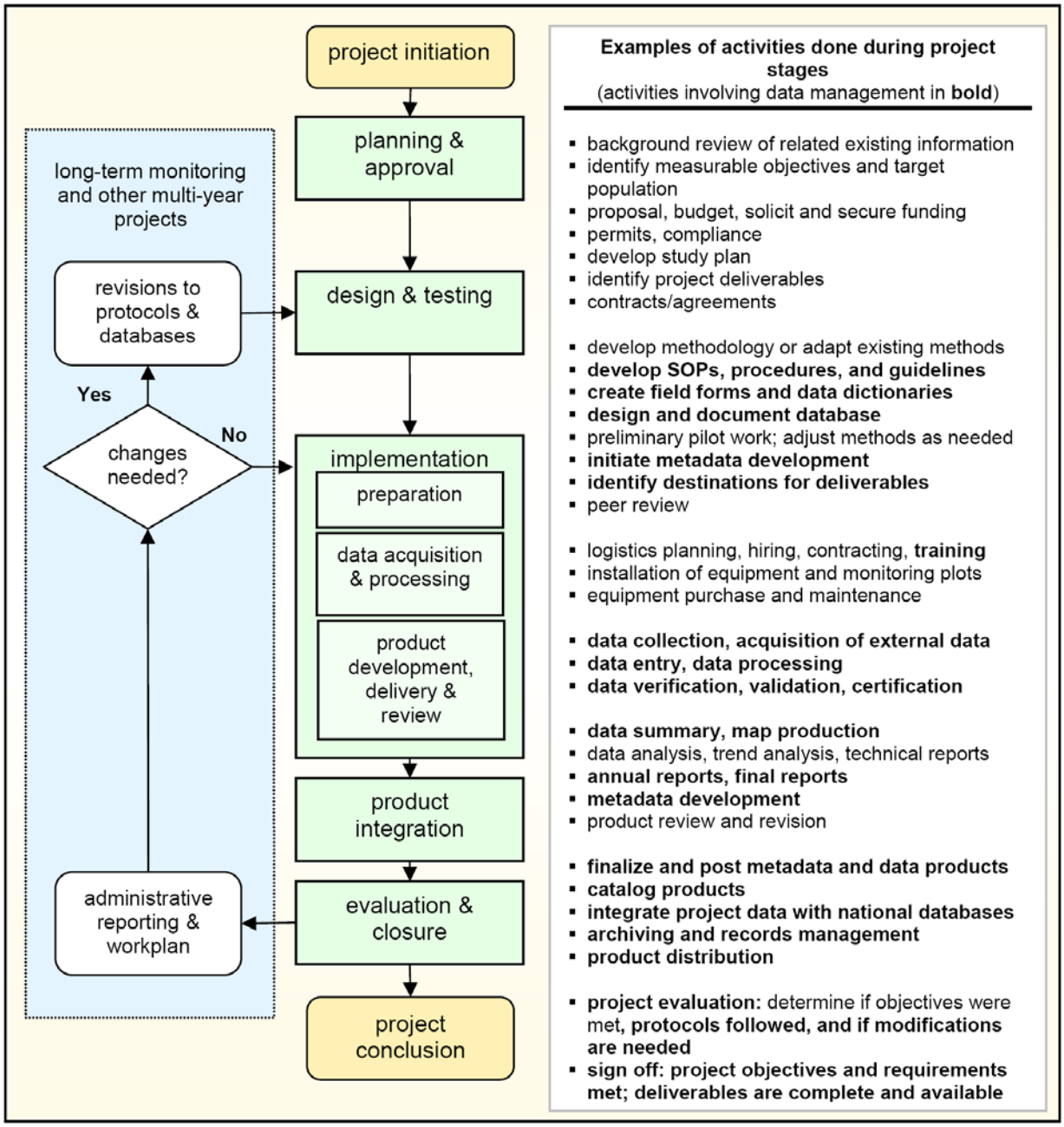

Figure 6.5. Model of data life cycle stages.

6.6 Water Quality Data

Water quality data collected as part of the network's monitoring program have distinct data management requirements. This includes using the NPSTORET desktop database application at the network to help manage data entry, documentation, and transfer to the NPS Water Resources Division (NPS-WRD). The CHDN will ensure the content is transferred at least annually to the NPS-WRD for upload to the Environmental Protection Agency's STORET (STORage and RETrieval) database (Figure 6.6). For the other water resources indicators (listed below), the CHDN will report on summarized data sets for which the network parks already have established archiving procedures:

- Groundwater Dynamics
- Aquatic Invertebrates (macro and micro)
- Surface Water Hydrology

The CHDN will obtain a download of all relevant data for a specific water year and transfer the file to the Water Resources Division for upload into STORET.

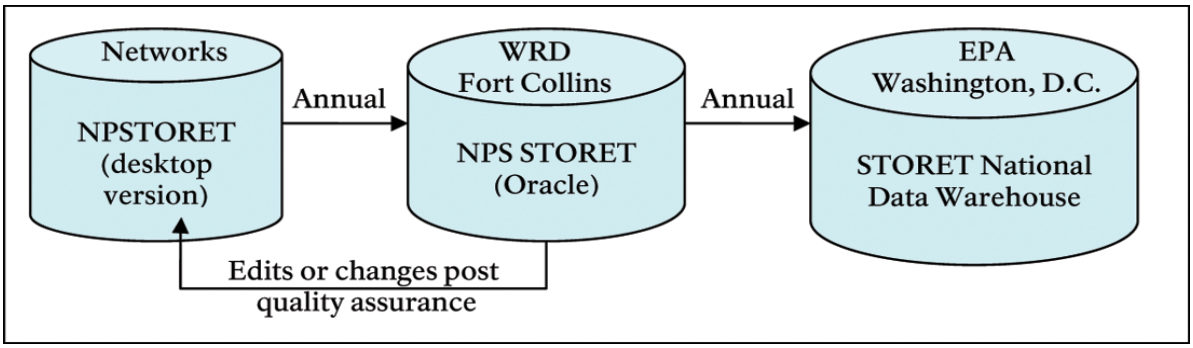

Figure 6.6. Data flow diagram for water quality data.

6.7 Data Management Plan Maintenance

The CHDN will strive to maintain a DMP that is useful to a broad audience and can provide guidance on data management practices at a number of different levels. The CHDN intends to keep the plan simple, flexible, and evolving, and to include data users in the decisionmaking process whenever possible. The document will undergo an initial prescribed review process that will include both an internal network review (i.e., by members of the technical committee and network staff), and a servicewide review that involves data management staff from the I&M program's WASO office. External reviewers also will be sought to provide a more balanced and comprehensive review of this plan. The CHDN will update the plan to ensure that it accurately reflects the network's current standards and practices. Recommendations for changes can be forwarded to the network data manager by any interested party or user of network inventory and monitoring data (e.g., park resource managers, project leaders, technicians, superintendents, external users). Data management and network staff will discuss these recommendations and determine what actions, if any, should be taken. Simple changes can be made immediately, whereas substantive changes will be made during version updates. Plan updates will be distributed to members of the network's Technical Committee before implementation. Otherwise, the plan will be scheduled for a full revision and review at a minimum of every five years. The most current version of the plan is available on the CHDN website, http://science.nature.nps.gov/im/units/CHDN/.

6.8 Implementation

The data management plans for each of the 32 I&M networks are the first comprehensive documents of their kind in the NPS, and contain practices that may be new to staff and cooperators. However, almost every requirement stems from federal law, Executive Orders, Director's Orders, or national I&M program guidance. The DMP helps put these requirements into context and provides operational guidance for achieving them. The main body of the plan broadly addresses relevant subjects but directs most of the details into individual appendices that serve as stand-alone documents for ease of locating and retrieving specific information of greatest value to most users. The next plan revision should be completed within three years or by October 1, 2011, and every five years thereafter. Plan appendices, including SOPs, detailed guidelines, reference manuals, and policy statements, likely will require more frequent updates to account for changes in technology or availability of better information. Implementation will require education and training in order to familiarize park staff and cooperators with the tools, procedures, and guidelines outlined in the plan. Formal (training sessions) and informal (one-on-one communication and assistance) methods will be used. These efforts will begin in 2009 and be led, at least initially, by CHDN data management staff, with participation by interested parties at all parks actively encouraged. Goals for the first three years should include:

- Ensuring that all staff of targeted programs and their cooperators understand the fundamentals of data and information management, including:
    - File management
    - Documentation
    - Quality assurance and quality control
    - Electronic storage
    - Archive storage
- Implementing improved data management practices:
    - Accepted database design standards
    - Thorough testing of databases, data collection methods, and their integration prior to field work
    - Quality assurance and control procedures at every stage of project development
- Writing common SOPs and guidance documents for multiple protocols
- Including detailed specifications for data management, consistent with the DMP, in every vital signs monitoring protocol
- Implementing procedures and outlets for communication within and among network parks and with the public

Beyond the first three years, goals should include the development and assessment of:

- Procedures to facilitate the summarization and reporting of monitoring data
- A framework and gateway for integrating CHDN monitoring data with those of other agencies or networks
- Methods for improving file management (e.g., a content-management system) and database administration and security (e.g., migration to SQL-Server), integrating offsite users into the network, and meeting other needs identified in the DMP

Implementation and improvement of the data management system will be an ongoing process. The practices and procedures identified in this plan will continue to be broadly encouraged within the network and, in time, we expect them to be widely accepted and adopted by all CHDN park programs.

Chapter 7: Data Analysis and Reporting

This chapter summarizes our approach to analysis and reporting of monitoring data, and dissemination of this information to diverse audiences. Our guiding principle is to provide relevant, reliable ecological monitoring data that enable park staff to make appropriate management decisions and protect park resources. Three factors contribute to the process of maintaining a successful monitoring program: reliable data collection and analysis, relevant and timely information, and effective communication to address multiple audiences with a diverse range of information needs.

7.1 Strategies and Key Audiences for Analysis and Reporting of Monitoring Results

An essential role for the CHDN is the analysis, synthesis, and reporting of inventory and monitoring data and information to a wide audience, including park superintendents and other managers, park planners, scientists (agency and academic), interpreters, and the general public. Data and information are the common currency among the many different activities and people involved in the stewardship of a park's natural resources. Activities such as planning, resource inventories and monitoring, research studies, restoration, control of invasive species, management of threatened and endangered species, fire management, and interpretation all either require or provide natural resource data and information to others. As such, the I&M program plays an integral role in the NPS's effort to improve park management through greater reliance on scientific knowledge. The CHDN will work with data from many sources, including data collected by park staff and other programs and agencies, as well as new field data collected by network or park staff. The results of these analyses will be provided to multiple audiences at the local, regional, and national levels.

Information quality depends on effective, appropriate analysis of high-quality data. The CHDN will initially ensure data quality through careful design and implementation of sampling designs and monitoring protocols that are supported by robust data management procedures, as described in Chapters 4 and 6. The network will ensure that these monitoring data are effectively converted into reliable information about resource status and trends by emphasizing careful, detailed development of data analysis and interpretation as a key component of each monitoring protocol (see Section 7.2). The network will collaborate and coordinate with other data-collection and analysis efforts and promote the integration and synthesis of data across projects, programs, and disciplines. Timeliness of information reporting will be ensured by establishing a firm data analysis routine and schedule for each protocol, followed by a reporting system and schedule whereby we can effectively and promptly disseminate important resource information to a wide range of users.

The CHDN recognizes that information reporting is not effectively met by a uniform approach; we have to meet the needs of many audiences. The primary utility for many of our products is at the park level, where the key role of the I&M program is to provide park managers, planners, interpreters, and other park staff with the information they need to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources. These key audiences have different needs and desires relative to what, how, and when information is provided to them. In addition, certain data are needed at the regional or national level and, as stated by the National Park Advisory Board, the findings "must be communicated to the public, for it is the broader public that will decide the fate of these resources." Figure 7.1 summarizes the major approaches to analyses and reporting tools that the CHDN will pursue and how they interact with outside research to support the network's programmatic goals.

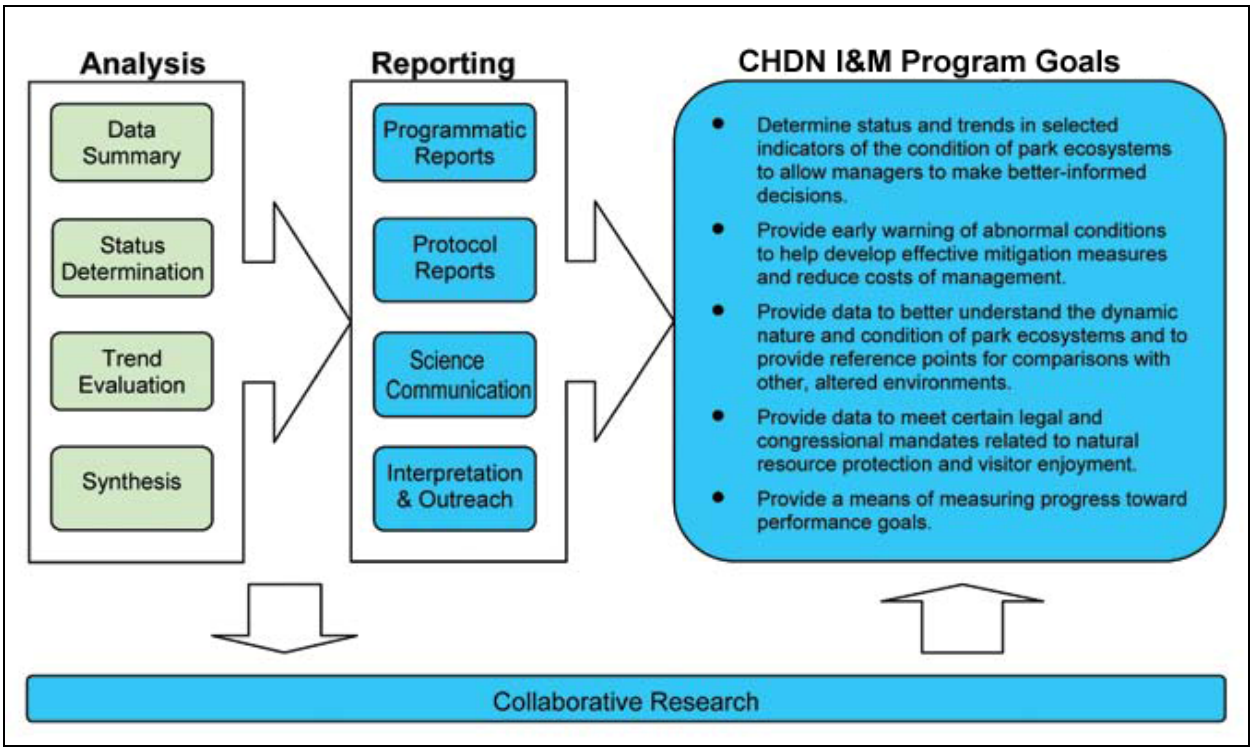

Figure 7.1 Relationships between analyses, reporting, research, and Chihuahuan Desert Network program goals (adapted from Chung-MacCoubrey et al. 2008).

The CHDN vision for reporting includes the following central themes: (1) we will prepare monitoring reports that are understandable and useful to our primary audience: park resource managers and planners; (2) we will prepare reports promptly; and (3) all reports will be readily available. To achieve this vision, the network has adopted the following strategies:

- The budgets and staff time allotted for each vital sign will include adequate funding to support the production of required annual and periodic reports.
- All monitoring data, and all reports and information generated from monitoring data, will be made available promptly via the NPS Intranet. Information that does not contain sensitive or commercially valuable data that might jeopardize a species or resource will be made available on the network's Internet website following appropriate peer review.
- Protocols, inventory reports (as appropriate), annual data summary reports, trend reports, synthesis reports, and other products of the I&M efforts will be published in the NPS Natural Resource Report, Natural Resource Technical Report, or Natural Resource Data series, unless they are published in a peer-reviewed journal or a numbered report series of a collaborating agency or university. Reports published in these numbered series meet a set of minimum standards and are peer-reviewed to ensure that the information provided is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.
- The use of graphical methods for presenting data will be encouraged.

7.2 Data Analysis

Selection of specific analytical tools for interpreting monitoring data is a function of monitoring objectives, assumptions regarding the target population, the spatial and temporal aspects of the sampling design, and the level of confidence that is desired or practical given natural and sampling variability (Chapter 4, McBean and Rovers 1998, Thompson et al. 1998, Artiola et al. 2004). Each monitoring protocol will contain detailed information on analytical tools and approaches for data analysis and interpretation, including rationales for a particular approach, advantages and limitations of each procedure, and standard operating procedures for each prescribed analysis (Oakley et al. 2003, Chapter 5, Appendix J).

Four general levels of data analysis are anticipated during implementation of our monitoring protocols and program: (1) descriptive and summary statistical analysis, (2) determination of conditional status for a monitored resource, (3) determination of trends in condition over time for a monitored resource, and (4) synthesis of status and trend information across multiple resources over time to depict larger-scale aspects of ecosystem health and function (Table 7.2). Descriptive analysis may be performed at any time following data collection and entry. Status and trends analysis will be performed on protocol-specific schedules. Larger-scale synthesis across multiple resources and monitoring efforts will occur only after adequate amounts of data have become available for all considered resources and variables. In addition, trend analysis and synthesis can only occur after appropriate time has passed to adequately capture temporal scales of considered phenomena. Long-term trend reports and syntheses will be subject to peer review, as appropriate.

Data analysis may be performed by different people, including the network ecologist, program manager, and data manager, as well as key project leads (e.g., when assessing monitoring data related to water quality and quantity or air quality). GIS specialists and/or associated technicians and interns also will be involved with various aspects of data collection and analysis. Generally, analysis will be supervised and coordinated by the network ecologist or project leads assigned to a particular protocol. Overall program oversight will be provided by the network program manager.

7.3 Communications and Reporting

To effectively communicate monitoring information and results with a variety of audiences, analysis and interpretation must occur on a regular basis, and results must be communicated in formats specific to intended audiences. With the assistance of a Cooperative Ecosystem Studies Unit (CESU) cooperator at Colorado State University and the NPS-Natural Resource Program Center, the CHDN will develop a science communication plan that identifies natural resource education and communications techniques to be used for internal and external audiences.

CHDN reporting mechanisms are based on national guidance, have been modified to fit network needs, and fall into four categories: programmatic, protocol-related, science communication, and interpretation/outreach. The categories listed below are described in the following sections and Table 7.3-1. Each monitoring protocol will also contain additional and specific information on data summary, analysis, and reporting requirements and procedures.

1. Annual reports for specific protocols and projects
2. Annual briefings to park managers
3. Resource briefs
4. Analysis and synthesis reports
5. Protocol and program reviews
6. Natural resource summary table
7. Scientific journal articles and book chapters, and presentations at scientific meetings
8. Network Internet and Intranet websites
9. Learning Center of the American Southwest.

Table 7.2. Four general approaches to data analysis for Chihuahuan Desert Network vital signs, and the lead analyst responsible.

Type of analysis	Description	Lead analyst and support
Data summarization/ characterization	• Calculation of basic statistics from monitoring data, including measures of location and dispersion. • Summarization that encompasses measured and derived variables specified in the monitoring protocol and forms the basis of more comprehensive analyses and for communication of results in both graphical and tabular formats.	Lead: Project lead Support: Network program manager or ecologist and data management staff.
Status determination	• Analysis and interpretation of the ecological status (point in time) of a vital sign to address the following types of questions: o How do observed values compare with historical levels? o Do observed values exceed a regulatory standard, or a known or hypothesized ecological threshold? o What is the spatial distribution (within park, network, ecoregion) of observed values for a given point in time? o Do these patterns suggest directional relationships with other ecological factors? • Status determination will involve expert interpretation of both the basic statistics and statistical analysis. • Assumptions about the target population and the level of confidence in the estimates will be ascertained during the analysis.	Lead: Network program manager or ecologist and/or principal investigator (PI) for protocol Support: Other network staff, cooperators, interns, subject-matter experts
Trends evaluation	• Evaluations of trends in vital signs will address the following questions: o Is there directional change in a vital sign over the period of measurement? o What is the rate of change, and how does this pattern compare with trends over broader spatial scales and known ecological relationships? • Analysis of trends will employ parametric, nonparametric, or mixed models based on assumptions made about the target population. Where appropriate, exogenous variables (natural, random phenomena that may influence the response variable) will be accounted for in the analysis.	Lead: Network program manager or ecologist and/or PI for protocol Support: Other network staff, cooperators, or interns

Table 7.2. Four general approaches to data analysis for Chihuahuan Desert Network vital signs, and the lead analyst responsible, cont.

Type of analysis	Description	Lead analyst and support
Synthesis and modeling	• Examination of patterns across vital signs and ecological factors to gain broad insights on ecosystem processes and integrity. Analyses may include: o Qualitative and quantitative comparisons of vital signs with known or hypothesized relationships; o Data exploration and confirmation (e.g., correlation, ordination, classification, multiple regression, structural equation modeling); o Development of predictive models. • Synthetic analysis has potential to explore ecological relationships in the context of vital signs monitoring and will require close interaction with academic and agency researchers.	Lead: Network program manager or ecologist (data synthesis and modeling); PI for protocol Support: Cooperators, partners, or other network staff

Table 7.3-1. Summary of proposed products for the Chihuahuan Desert Network.

Report type	Purpose	Primary audience(s)	Frequency	Review
Programmatic reports				
Annual administrative report and work plan	• Accounts for funds and FTE expended • Describes highlights, objectives, tasks, accomplishments, and products • Provides an administrative history of the network	BOD, TC, other park and network staff, regional and national I&M program managers	Annual	Reviewed by TC, reviewed and approved by BOD, IMR I&M program manager and national program manager
Monitoring program review	• Formally reviews operations and results at 5-yr intervals • Implements the quality assurance and peer-review process	Superintendents, park resource staff, CHDN staff, national program managers, external scientists, partners	5-year intervals	BOD & TC review, followed by administrative and peer review at IMR and national levels
Protocol-related reports				
Specific protocol development and pilot projects	• Provide background and methods of protocol development • Provide record of decision for protocol design • Document results of pilot studies	Network staff, park professional staff, TC, scientific cooperators, other networks with shared vital signs	As completed FY10–FY13	Peer-reviewed at IMR level
Annual reports for each protocol	• Summarize annual data and document monitoring activities for the year • Describe status of the resource • Document changes in monitoring protocols • Communicate monitoring efforts to parks	Superintendents, park resource, managers, CHDN staff, national program managers, external scientists and partners	Annual	Peer-reviewed at network level

Table 7.3-1. Summary of proposed products for the Chihuahuan Desert Network, cont.

Report type	Purpose	Primary audience(s)	Frequency	Review
Trend analysis and synthesis reports	• Determine patterns/trends in resource condition • Identify new characteristics of resources and correlations among resources • Interpret data within park, multi-park, network, and regional contexts • Recommend changes to management (feedback for adaptive management)	Superintendents, park resource managers, CHDN staff, external scientists	3–5-yr intervals for resources sampled annually	Peer-reviewed at network level
Summary of trend reports	Summarize comprehensive trend analysis and synthesis reports to highlight key findings and recommendations	Superintendents, park resource managers, interpreters, general public	Commensurate with frequency of Comprehensive Reports	Peer-reviewed at network level
Protocol review report	Reviews procedures of individual protocols; determines where actual procedures fall short or expectations suggest revisions	BOD, TC, park resource managers, network staff, servicewide program managers, external scientists	Within 1–3 years of protocol implementation; thereafter, dependent on monitoring "cycle" that varies by protocol	Internal NPS review; External peer review solicited as necessary
CHDN vital signs program report	• Describe current conditions of park resources • Report interesting trends and highlights of monitoring activities • Identify situations of concern • Explore future issues and directions	Superintendents, park resource managers, network staff, external scientists, public	Annual	Internal NPS Review

Table 7.3-1. Summary of proposed products for the Chihuahuan Desert Network, cont.

Report type	Purpose	Primary audience(s)	Frequency	Review
Science communications				
Scientific journal articles & book chapters	• Make scientific contributions to ecological and monitoring science • Subject I&M activities and approaches to unbiased peer review • Elevate scientific standing and authority of program	Park resource managers, network staff, external scientists	Varies	Peer-reviewed by journal or book editor
Symposia, workshops, and conference presentations	• Review and summarize information on specific topics • Communicate latest findings to peers • Identify emerging issues and generate new ideas • Expose I&M activities to regional or national scientific community • Elevate scientific standing and authority of program	Other federal and state agencies, academics, NGOs, and other external scientists; park and network staff	Variably as material becomes available	Generally not reviewed unless presentations are published
Interpretation and outreach				
Resource briefs	• For each protocol, report activities and explain the significance and relevance of the scientific findings in non-technical manner • Provide short, digestible synthesis of vital sign monitoring results on status and trends of resource condition	Superintendents, park resource managers, interpreters, public	Varies	Peer-reviewed at network level
Internet and Intranet Websites	• Improve public awareness through web presence • Centralize repository of all final reports to ensure products are easily accessible in commonly used electronic formats • Facilitate internal distribution of NPS documents	Superintendents, park resource managers, CHDN staff, national program managers, scientific community, general public	As reports are finalized	Only reviewed, finalized products without sensitive information will be posted

Table 7.3-1. Summary of proposed products for the Chihuahuan Desert Network, cont.

Report type	Purpose	Primary audience(s)	Frequency	Review
Learning Center of the American Southwest	• Provides a one-stop portal to view resource information for 49 park units and four I&M networks across a six-state area • Explains the need for and results of research and monitoring to a variety of science-oriented audiences and the interested public • Promotes mission-oriented research within the region	Superintendents, park resource managers, interpreters, CHDN staff, national program managers, scientific community, general public	As products are finalized	Only reviewed, finalized products without sensitive information will be posted

7.3.1 Annual reports for specific protocols and projects

The primary purposes of annual reports for specific protocols and projects are to:

- summarize and archive annual data and document monitoring activities for the year;
- document changes in monitoring protocols;
- increase communication within the park and network; and
- describe the current condition of the resource.

The primary audiences for these reports are park superintendents and resource managers, network staff, park-based scientists, and collaborating scientists. Most annual reports will receive peer review at the network level, although a few may require review by subject-matter experts from universities or other agencies. Many of our monitoring protocols involve annual data collection, and those protocols will generate an annual report each year (Table 7.2). However, some sampling regimes do not involve sampling every year. Those projects will produce "annual" reports only when there are significant monitoring activities to document. Wherever possible, annual reports will be based on automated data summarization routines built into the MS Access database for each protocol. The automation of data summaries and annual reports will facilitate the network's ability to manage multiple projects and produce reports with consistent content from year to year at timely intervals. For analyses beyond simple data summaries, data will first be exported to external statistical software.

7.3.2 Annual briefings to park managers

Each year, in an effort to increase the availability and usefulness of monitoring results for park managers, the network program manager will take the lead in organizing a one-day science briefing for park managers (possibly in conjunction with a Board of Directors meeting) in which network staff, park scientists, USGS scientists, collaborators from academia, and others involved in monitoring the parks' natural resources will brief managers on the highlights and potential management action items for each protocol or discipline. These briefings may include park staff and collaborators from other programs and agencies to provide managers with an overview of the status and trends in the high-priority vital signs being monitored by the CHDN. Unlike typical presentations intended for the scientific community, someone representing each protocol, program, or project will be asked to simply identify key findings or "highlights" from the previous year's work, and to identify potential management action items. The scientists will be encouraged to prepare a 1- or 2-page resource brief or other short briefing statement that summarizes the key findings and recommendations for their protocol or project.

7.3.3 Resource briefs

The CHDN will develop resource briefs for the 10 protocols it is implementing and, possibly, for other vital signs (if appropriate), and will encourage parks and collaborating scientists to do so, as well. The resource brief or other short briefing statement summarizes the key findings, status and trends, and recommendations for the protocol or project.

7.3.4 Analysis and synthesis reports

The role of analysis and synthesis reports is to:

- determine patterns/trends in condition of resources being monitored;
- identify new characteristics of resources and correlations among resources being monitored;
- analyze data to determine the amount of change that can be detected by a given type and level of sampling;
- interpret data for a park within a multi-park, regional, or national context; and
- recommend changes to management of resources (i.e., feedback for adaptive management).

The primary audiences for these reports are park superintendents and resource managers, park-based scientists, network staff, and collaborating scientists. These reports will receive peer review by at least three subject-matter experts. Analysis and synthesis reports can provide critical insights into resource status and trends, which can then be used to inform resource management efforts and regional resource analyses. This type of analysis, more in-depth than that of the annual report, requires several seasons of sampling data. Therefore, these reports are usually written at intervals of 3–5 years for resources sampled annually, unless there is a pressing need for the information to address a particular issue. For resources sampled less frequently, or that have a particularly low rate of change, intervals between reports may be longer.

7.3.5 Protocol and program reviews

Periodic program reviews are an essential component of quality assurance for any long-term monitoring program. The servicewide I&M program office will organize and lead a review of the CHDN monitoring effort approximately three years after this monitoring plan has been approved and implemented. Subsequent reviews of the program will occur at approximately five-year intervals. Topics to be addressed during the program review include program efficacy, accountability, scientific rigor, contribution to adaptive park management and larger scientific endeavors, outreach, partnerships, data management procedures, and products. These reviews cover monitoring results over a longer period of time, as well as program structure and function, to determine whether the program is achieving its objectives and whether the list of objectives is still relevant, realistic, and sufficient.

7.3.6 Natural resource summary table

"Connect the Dots" is a strategic, long-term framework developed and supported by multiple individuals and programs at the park, network, regional, and national levels, to better connect science to park management through the planning process. Coordination and integration between scientists, planners, and park managers is facilitated through use of a "Natural Resource Summary Table" developed for each network park, which will eventually become a key source of summarized information for a park's Resource Stewardship Strategy. Tables established by the CHDN for each park (http://www1.nrintra.nps.gov/im/units/chdn/monitor/index.cfm) are to be used as a long-term framework for coordinating the efforts of the network, Natural Resource Condition Assessment program, park planning, park-funded monitoring and research relevant to assessing natural resource condition, and research and monitoring efforts related to natural resource condition conducted by NPS Natural Resource Program Center divisions and other agencies. This framework allows multiple programs, individuals, and funding sources to assist the park in populating the table as opportunities arise.

7.3.7 Scientific journal articles, book chapters, and presentations at scientific meetings

The publication of scientific journal articles and book chapters is done primarily to communicate advances in knowledge and is an important and widely recognized means of quality assurance and quality control. Putting a program's methods, analyses, and conclusions under the scrutiny of a scientific journal's peer-review process is basic to science and one of the best ways to ensure scientific rigor. Network staff, park scientists, and collaborators will also periodically present their findings at professional symposia, conferences, and workshops as a means of communicating the latest findings with peers, identifying emerging issues, and generating new ideas.

All journal articles, book chapters, and other written reports will be listed in the network's annual administrative report that is provided to network staff, the Technical Committee, Board of Directors, and regional and national offices each year. Additionally, all scientific journal articles, book chapters, and written reports will be entered into the NatureBib bibliographic database maintained by the network.

7.3.8 Network Internet and Intranet websites

Websites are a key tool for promoting communication, coordination, and collaboration among the many people, programs, and agencies involved with the network monitoring program. The 32 I&M networks are required to develop and maintain a parallel series of Intranet (NPS only) and Internet (Public) websites to be used as a key means of communicating and disseminating inventory and monitoring results to park managers, planners, interpreters, and other internal and external audiences. Network staff will use these websites as a primary means of making resource briefs, data summaries, progress reports, technical reports, trend reports, interpretive materials, and other information available to internal and external audiences.

All written products of the monitoring effort, unless they contain sensitive or commercially valuable information that needs to be restricted, will be posted to the main network website, http://science.nature.nps.gov/im/units/chdn.

7.3.9 Learning Center of the American Southwest

The CHDN, along with Sonoran Desert, Southern Colorado Plateau, and Southern Plains networks and many external partners, is helping to develop the Learning Center of the American Southwest. The primary focus of the Learning Center is to explain the need for and results of research and monitoring to land managers, students, researchers, policymakers, and the interested public, and promote mission-oriented research within the region. This website will serve as a one-stop portal to view resource information for 49 national park units and four I&M networks across a six-state area. The website will be especially useful for park interpreters developing their programs.

Chapter 8: Administration and Implementation

This chapter describes the CHDN plan for administering the monitoring program. The network has developed a near-term (3–5-year) plan under which protocols will be implemented and monitoring will begin. In this chapter, we describe the core duties of the network, the makeup of the Board of Directors and Technical Committee, the network decisionmaking process, the staffing plan, how network operations are integrated with other park operations, key partnerships, and the periodic review process for the program.

8.1 Core Duties

The WASO office provided guidance regarding activities that are considered "core" to I&M networks and those considered secondary of nature in the document, "Updated Guidance Relative to the Ongoing Operation and Maintenance of Vital Signs Monitoring Networks," which accompanied Memorandum N16 (2370), from Associate Director Mary Foley, on February 28, 2008. The following is excerpted from that document:

> As defined in the Natural Resource Challenge, the primary mission of the monitoring networks is to collect, manage, analyze, and report long-term data for a modest set of vital signs (measurements of resource condition), and to effectively deliver those data and related information on resource conditions to local park managers, planners, interpreters, and other key audiences. Fundamentally, network personnel are expected to devote the majority of their time and effort to completing tasks associated with that mission. Their FTEs were requested from OMB and have been assigned to the networks for that purpose. Chief among the network responsibilities that must be performed are the following:
>
> - **Providing "one stop shopping" for resource condition and trend information.** For the high-priority vital signs identified in the network's monitoring plan and currently being monitored, this should be thought of as "the" core network function. Accordingly, network staff should maintain Intranet and Internet websites (see below) as the key means of communicating data and information collected and organized by the network to park managers, planners, and park staff for decisionmaking, education, and research.
> - **Synthesizing key findings in succinct statements for managers and planners.** This likewise is considered a core network function, especially for network priority vital signs. Network staff should place priority on developing resource briefs and technical documents for each vital sign, and preparing synthesis reports that analyze data across vital signs, as well as data from other sources and disciplines, to help interpret results of vital signs monitoring. In addition, priority should be given to posting these reports on the network's websites to ensure their availability to all interested parties.
> - **Collaboration with other programs and agencies.** As noted above, collaboration and coordination with other programs and agencies has always been considered to be a primary function of monitoring networks. However, lower priority is justified in those instances in which the collaboration and coordination efforts do not directly contribute to accomplishing the network's core mission.

- **Organizing and cataloging data collected by others.** The task of collecting, organizing, and cataloging data collected by others (i.e., non-network) should be considered to be a core function of the network, to the extent that the data are applicable to the high-priority vital signs being monitored by the network.

Other activities in which the network may play an assisting or secondary (but not lead) role include assisting in occasional resource assessments, reporting to GPRA and Land Health Goals, defining desired resource conditions based on current status and trend, and providing materials to interpreters, educators, and the general public.

8.2 Board of Directors

The Chihuahuan Desert Network I&M program is accountable to the parks through the Board of Directors (BOD or "board") and Technical Committee (TC), as well as to the Office of Management and Budget, Congress, and the taxpayers through oversight by the BOD, regional I&M program manager, and servicewide I&M program manager. The CHDN BOD includes the superintendent from each network park, the Intermountain Region I&M program manager, the network program manager, and chair for the TC (Table 8.2). One of the superintendents serves as board chair and one serves as vice chair. A new chair and vice chair are selected annually, with the vice chair becoming chair the following fiscal year. The superintendents and regional program manager are the voting members of the board, and the other members serve as advisors. A charter (Appendix L) for the BOD, updated and approved in 2007, guides the function and operation of the board.

The CHDN board is responsible for ensuring the overall effectiveness and success of the network's monitoring efforts and for ensuring that funds are spent for their intended purposes. The Board makes decisions about the development and implementation of the network's monitoring strategy, including approval of annual budgets, work plans, and network staffing plans, and promotes overall accountability for the network monitoring program. The BOD is committed to operate in and foster an atmosphere of fairness, trust, selflessness, and respect. A key feature of the charter is that all decisions are made by consensus. As described in the network charter, the major responsibilities of the BOD are to:

- Provide leadership to conduct a credible I&M program for the benefit of the network.
- Promote accountability and effectiveness for the I&M program by reviewing progress and ensuring quality control for the networks.
- Provide guidance to the TC and resource management staffs in the network for the design and implementation of inventories, vital signs monitoring, and other management activities related to the Natural Resource Challenge.
- Establish strategies and procedures for leveraging network funds and personnel to best accomplish the inventory, monitoring and other resource needs of network parks.
- In concert with the CHDN program manager, review the staffing plan, and coordinate and approve the commitment of existing park personnel, facilities, and equipment to I&M programs and activities.
- Provide input and secondary review to the midseason and annual performance appraisals of the network program manager.
- Seek additional funding from other sources to leverage the funds provided through the servicewide program.
- Solicit professional guidance from and partnerships with other individuals and organizations.

Table 8.2. Composition of the Chihuahuan Desert Network Board of Directors (as of March 2010).

Title, Park	Name	Voting member	Ex-officio
Superintendent, AMIS	Alan Cox	X	
Superintendent, BIBE	Bill Wellman	X	
Superintendent, CAVE	John Benjamin	X	
Superintendent, FODA	John Morlock, Chair	X	
Superintendent, GUMO	John Lujan	X	
Superintendent, WHSA	Kevin Schneider	X	
IMR Program Manager	Bruce Bingham	X	
Chief, Natural Resources and Interpretation, GUMO	Fred Armstrong, TC Chair		X
Research Coordinator, DS-CESU	Larry Norris		X
CHDN Program Manager	Kirsten Gallo		X

8.3 Technical Committee

The BOD, TC, and CHDN staff work together to develop and implement the monitoring program. The BOD is the final decisionmaking body and is accountable for the entire network. The TC provides technical assistance and advice to the board. Permanent TC members consist of at least one representative of the resource management staff for each park (usually the chief), as delegated by the superintendent (Table 8.3). One of the permanent voting members serves as the TC chair and one serves as vice chair. A new chair and vice chair are selected annually, with the vice chair becoming chair the following fiscal year. The network program manager serves as an ex-officio member of the TC. Additional key ex-officio members of the committee include the network data manager, network ecologist, regional fire ecologist, and CHDN and SOPN exotic plant management team leader. Other relevant resource staff from network parks are also invited to participate in TC meetings, depending on the circumstances.

Other key cooperators, members of the academic community, and representatives from other federal agencies are involved in development of conceptual models, monitoring protocols, and water quality monitoring plan. These ad hoc advisors to the TC are not considered permanent members, but play an important role in providing technical expertise to the TC and BOD.

Table 8.3. Composition of the Chihuahuan Desert Network Technical Committee.

Title, Park	Name	Voting member	Ex-officio
Chief, Education & Resource Management, AMIS	Greg Garetz	X	
Chief, Science & Resource Management, BIBE	Phil Wilson	X	
Chief, Resource Stewardship & Science, CAVE	Kent Schwarzkopf	X	
Chief of Interpretation, FODA	John Heiner	X	
Chief of Resources & Interpretation, GUMO	Fred Armstrong, Chair	X	
Chief, Science & Resource Management, WHSA	David Bustos	X	
Program Manager, CHDN	Kirsten Gallo		X
Data Manager, CHDN	Tom Richie		X
Science Advisor, CHDN	Hildy Reiser		X
Regional Fire Ecologist, BIBE	Richard Gatewood		X
CHDN/SOPN EPMT Leader, CAVE	Vacant		X

Current as of March 2010.

8.4 Staffing Plan

In accordance with servicewide I&M goals, network activities revolve around five program functions:

1. Conducting baseline inventories of natural resources in network parks (including those currently underway: vegetation mapping, soils mapping) and fulfilling other critical inventory needs of network parks.

2. Implementing and conducting an integrated, scientifically credible, long-term ecological monitoring program to efficiently and effectively monitor status and trends of selected vital signs.

3. Implementing and conducting data management and decision support systems, including GIS and other tools, to aid park managers in identifying, implementing, and evaluating management options.

4. Integrating inventory and monitoring programs with park planning, maintenance, interpretation, and visitor-protection activities to help the parks in their efforts to make natural resource protection even more of an integral part of overall park management.

5. Cooperating with other agencies and organizations to share resources, achieve common goals, and avoid unnecessary duplication of effort and expense.

The network staffing plan is designed to support these functions and provide park managers with the professional expertise needed to implement a successful inventory and monitoring program. The staffing plan is designed with the goal of keeping fixed costs, such as permanent staff, vehicles, and office space, at or below 60% of the network budget during the first five years of implementation (FY2009–FY2013), to allow flexibility in partnerships and data acquisition. We do not expect the majority of monitoring data to be collected by permanent network staff. Shorter-term technical and field-data collection positions will be filled by NPS seasonals hired by CHDN, cooperative agreements with other state and federal agencies and universities, students, interns, and volunteers from the Student Conservation Association. Currently, the core permanent network staff consists of a program manager, science advisor, and a data manager. A permanent full-time field coordinator will soon be added to the team (Table 8.4). Short descriptions of these and other positions follow.

Table 8.4. Current and proposed Chihuahuan Desert Network staff positions and their primary duties.

Position	Primary duties	% of time
Current		
Program Manager GS-13, Permanent	Provides direction and manages overall planning and implementation of the network I&M program	35%
	Coordinates project-specific acquisition, data analysis, summary, and reporting	30%
	Ensures that information is provided to parks and partners in useful formats	15%
	Coordinates I&M partnerships	5%
	Provides program oversight and supervision	10%
	Provides field assistance as needed	5%
Science Advisor GS-13, Permanent	Provides guidance, oversight, and management of collaborative resource science and management programs between the parks and the network	50%
	Conducts project-specific data analysis, summary, and reporting on collaborative projects as needed or time allows	15%
	Works with program professionals to provide information to parks and partners in useful formats and assist parks with implementing sound reporting practices and data management	15%
	Coordinates with regional office and WASO to complete the 12 basic servicewide inventories funded by the servicewide I&M program	15%
	Provides field assistance as needed	5%
Data Manager GS-11, Permanent	Conducts data validation, dissemination, and archiving; database development; overall QA/QC for the network program	50%
	Works with ecologists to ensure that information is provided to parks and partners in useful formats	20%
	Implements data management partnerships	10%
	Provides oversight and supervision for data management activities, ensures CHDN program meets regional and national data management policies	10%
	IT collateral duties include the installation, configuration and maintenance of network components, servers, workstations, etc.	10%
Field Coordinator GS7/9, Permanent (to begin in CY2010)	Oversees field crews, including arranging training and ensuring crew safety; completes QA/QC for implementation of field components of monitoring protocols; coordinates field logistics; maintains equipment	70%
	Assists data manager with data entry and QA	10%
	Assists program manager and/or ecologist with compiling data summaries	10%
	Works with legacy datasets and synthesizes a wide variety of published and unpublished material in support of the CHDN monitoring program	5%
	Assists other CHDN staff with development of monitoring products	5%

Table 8.4. Current and proposed Chihuahuan Desert Network staff positions and their primary duties, cont.

Position	Primary duties	% of time
Budget Analyst[1] GS-9, Permanent	Performs budget tracking, reporting, programming in AFS3, fiscal year-end accrual preparation, employee credit card statements, etc.	5%
	Monitors accounts and provides general support for payroll (FFS); expense and credit card adjustments; entering fiscal year-end accruals; AFS3 programming support, including financial plans; BCP module programming and outputs; IDEAS budget approvals	8%
Administrative Assistant[2] GS-5, Term (to begin in CY 2010)	Payroll preparation – time and attendance, personnel action preparation and submittal, SF-182 prep, etc.	3%
	Procurement (e.g., equipment, upgrades, large & small supplies, professional services invoices, IA's, CA's, etc.)	3%
	Travel management (authorizations, vouchers)	9%
Proposed		
Ecologist GS-9/11, permanent	Designs, develops, and tests monitoring protocols	
	Directs data collection procedures	
	Conducts data analysis and reporting	
	Reports significant findings to park managers and interested public	
GIS Specialist GS-7/9, Term	Develops procedures for compiling, utilizing, and disseminating spatial data	
	Manages, documents, and distributes spatial data resulting from I&M projects	
	Works with park staff to build and maintain a library of relevant park spatial data	
	Provides GPS assistance and training to staff and cooperators as needed	
	Serves as a co-investigator on landscape monitoring projects	
	Acts as program liaison with GIS providers to ensure appropriate development of spatial data layers, and integration of monitoring datasets and coverages	
GIS/Data Management Tech GS-5/6/7, Term-SCEP	Updates, maintains, and coordinates the certification process for the NPSpecies database	
	Maintains the CHDN websites, writes and manages their content	
	Works with data manager to design, build, and maintain project databases, NPS servicewide databases, GIS, digital document libraries, and information distribution system	
	Assists with maintaining spatial datasets with metadata and performing GIS analysis	

[1]This position is shared with 4 other IMR I&M networks; CHDN share is 0.007 FTE.

[2]This position is shared with 6 other IMR I&M networks; CHDN share is 0.12 FTE.

8.4.1 Program manager

The program manager provides overall direction for the CHDN I&M program. The program manager works with network parks, the TC, BOD, and the Intermountain Region I&M coordinator to develop inventory and monitoring strategies and recommend implementation schedules for funding and staffing consideration. This position coordinates project-specific data analysis and reporting and ensures that information is provided to park managers in useful formats. The program manager supervises the CHDN professional-level positions and provides general oversight and accountability for the network program.

8.4.2 Science advisor

This position serves as the primary contact between WASO and IMR natural resources science and management programs in network parks. This includes coordination and support for resource inventories; planning and stewardship projects; cooperative projects and research involving other agencies or universities; and other cooperative WASO, regional, network, and park-level initiatives and projects. The science advisor also coordinates with the regional office and WASO to complete the 12 basic servicewide inventories funded by the I&M program, and other high-priority natural resource inventories identified by the parks. The science advisor assists parks in evaluating and applying research and management project results, participates in ecosystem management planning and partnerships as required, and works cooperatively with conservation partners involved in the preservation of natural resources.

8.4.3 Data manager

The data manager has a central role in ensuring that project data conform to program standards, designing project databases, disseminating data, and ensuring long-term data integrity, security, and availability. In order to maintain high data-quality standards and promote ready use of project data, the data manager collaborates with the ecologist and/or project managers to develop data entry forms, QA/QC procedures, and automated reports. The data manager also coordinates all information technology (IT) activities and collaborates with university and other agency computer support personnel. Because of the small size of the CHDN staff, the data manager also performs IT collateral duties that include the installation, configuration, and maintenance of network components, servers, workstations, peripheral equipment, software, and other services used by the network. Additionally, these duties include IT security and compliance with the U.S. Department of the Interior (DOI) Security Handbook (USDOI 2008).

8.4.4 Field coordinator

The field coordinator has the primary responsibility for overseeing the monitoring field crews, including hiring, training, and supervising crew members and ensuring their safety in the field. This individual plans and provides for field equipment and logistics, helps the data manager to input data and conduct quality control, and collaborates with the ecologist and other project managers on data summary reports. He/she updates, maintains, and coordinates the certification process for the NPSpecies database and maintains CHDN content on the Learning Center for the American Southwest website (see Table 8.4).

8.4.5 Budget analyst

The budget analyst provides administrative and budget support services to all seven Intermountain Region I&M networks, including the CHDN. Primary duties are budget tracking and budget analyst support, including credit card processing (i.e., responsible as Reviewing Official, verifying that all transactions are documented properly, meet credit card policy and guidelines, and are listed on the credit card purchase log, and that copies of all receipts are attached, if applicable). Other responsibilities include acting as a liaison between all I&M networks and the IMR regional property management team and assisting with purchasing and contracting.

8.4.6 Administrative assistant

The administrative assistant provides administrative and budget support services to five Intermountain Region I&M networks, including the CHDN. Primary duties are (1) time and attendance (i.e., maintain time and attendance files and documentation for audit purposes for each pay period), (2) travel processing (i.e., review each authorization to ensure it meets with Federal Travel Regulations and NPS policy and procedures to the best of his or her knowledge and that trip purposes and details are entered appropriately), and (3) purchasing.

8.4.7 Ecologist

The ecologist provides statistical and analytical support to network monitoring projects and coordinates the pilot testing and implementation of monitoring protocols. The ecologist develops sound analytic approaches and inference strategies, conducts data validation and verification, works with cooperators, oversees field data collection, and conducts analysis and reporting. The ecologist also coordinates and supports partnerships and works with program professionals to provide information to parks and partners in useful formats.

8.4.8 GIS specialist

The GIS specialist is responsible for managing the network's spatial data and providing GIS support to network I&M projects. The GIS specialist will compile and refine relevant park spatial data, including that for the 12 basic inventories and other network-sponsored inventories. This person works with the data manager to develop infrastructure, procedures, and policies for utilizing and disseminating spatial data from I&M activities, works with the network program manager and other staff to support spatial aspects of protocol development (e.g., sample frame delineation and site selection), and works with network staff and cooperators to develop a landscape monitoring protocol. This individual is also a program liaison with GIS providers to ensure appropriate development of spatial data layers and integration of monitoring datasets and metadata. The GIS specialist works with the data manager to disseminate spatial data to park managers, cooperating agencies, and scientists.

8.4.9 GIS/Data management technician

The Geographic Information System (GIS)/Data Management Technician assists with information requests, both internal and external. Core duties are database development, developing and maintaining the CHDN Internet and Intranet sites, and GIS data management and manipulation. This position will help with digital data collection and transfer, data manipulation, data visualization, and data archiving and storage. This position is a term position to ensure that new technologies are applied to existing I&M programs as software and hardware advance. Having this position rotate over time will provide experience transfer from those trained with the latest and most innovative software and hardware to the institutional knowledge built on the core staff. This position will not only provide GIS support, but will be an integral member of the data management team.

8.4.10 University interns and other associated positions

In addition to the staff (current and proposed) listed in Table 8.4, the network currently has one student intern from New Mexico State University assisting with data management and program support. The CHDN maintains an agreement with New Mexico State University for office space, GIS assistance, and both undergraduate and graduate student interns. Interns have assisted the network with data management activities, data mining, and computer programming tasks.

8.4.11 Field efforts

CHDN fieldwork will represent a continuum of efforts ranging from work conducted entirely in-house (by park and CHDN staff) to work performed by cooperators and partners. In some cases, the CHDN will obtain data from external sources at no cost—for instance, data collected by the National Weather Service. The completed protocols, including analysis of potential sources, alternatives, and costs of field monitoring, will identify which fieldwork will be done by the network and which by outside partners.

Worker safety is paramount for CHDN field efforts (as for all CHDN operations). The CHDN will operate in accordance with all safety laws and regulations and DOI and NPS policies. Each CHDN protocol will include a safety-related SOP and identify necessary safety training and equipment for fieldworkers. Depending on the park and protocol, training will include backcountry safety and first aid, and DOI watercraft safety. The CHDN will cooperate with network parks to coordinate safety training for field staff and park seasonal staff. CHDN planning and budgets will include safety training and equipment.

8.5 Program Integration

Integration with park operations will be an important component of this program. Data, summaries, and reports will be made available to all park operations, including resource management, interpretation, law enforcement, and maintenance. Most network parks already integrate cultural and natural resource management activities. We have selected vital signs and monitoring approaches with the purpose of providing data that can be used by the parks, and that will allow for assessment of vital signs across the network. Where possible, we also are striving to make data summaries available to other agencies within the Chihuahuan Desert Ecoregion, especially those organizations that are monitoring the same or similar resources on the lands they manage.

Network parks have indicated their ability to provide housing for field crews, transportation to monitoring sites, and other assistance to the network. Except in limited circumstances, the network parks are unable to have park personnel conduct monitoring of network vital signs. One-page information sheets will be developed (via an agreement between NPS, Natural Resource Program Center, and Colorado State University) for each park to show what the network is monitoring and why. The CHDN I&M program office is based on the campus of New Mexico State University in Las Cruces, New Mexico. The program offices are only 50 minutes from one of the network parks (WHSA), and three hours or less drive time from the majority of its parks. Park visits by network staff, and regularly scheduled meetings, will be important for developing greater integration into park operations. As field work begins and data are collected, more integration with park staffs will be possible. Opportunities to help all park divisions will be actively sought. Participation by park personnel on the network's BOD and TC further helps to integrate the network's planning with the parks' concerns and activities.

8.6 Partnerships

Cooperative agreements and partnerships inside and outside the NPS will be important to the implementation of the CHDN monitoring program. A collaborative effort between CHDN, the Sonoran Desert Network, and Southern Plains Network is underway for several protocols. For example, the CHDN is adopting the landbird protocol used by SOPN and SODN. In doing so, we avoid duplicating effort in protocol development and peer review, contract administration, training, data management, analysis, some reporting, and project management. We also gain the ability to analyze data across broader spatial scales (the three networks). CHDN, SOPN, and SODN will also share protocols for Exotic Plants and Groundwater quantity, and CHDN will adopt SODN's Integrated Uplands protocol. We are exploring a partnership with the fire program to assist in data collection and sharing. The CHDN, SODN, and SOPN are also working together (and with other networks) to develop protocols for Air Quality, Climate, and vital signs collected at seeps and springs.

Success of the CHDN also depends on partnerships outside the NPS. Table 8.6 lists some of the key partners for implementation of the monitoring program. Additional agreements will be put in place for monitoring implemented in later years. Cooperative agreements used solely for the purpose of the inventories are not included in this list.

8.7 Program Review Process

Periodic reviews of the network's monitoring program and protocols are critical to ensure that the program is on the right course and determine whether course corrections are needed. Reviews should be accomplished in a timely fashion in order to save unnecessary expenditures of resources and time. Review of the program will occur at several different levels and timescales.

1. The annual administrative report provides the TC and BOD with a summary of monitoring activities and accomplishments achieved during the previous fiscal year and an accounting of network expenditures. The work plan details the work CHDN plans to accomplish during the upcoming fiscal year and provides a budget allocation. Together, these documents give the TC and BOD an annual opportunity to review and evaluate the program's previous-year activities and review plans for the upcoming year. The annual administrative report and work plan are presented at the annual BOD meeting, allowing the board to discuss progress and ideally resulting in a substantive evaluation, rather than a routine approval of the plan.

2. The network's annual TC meeting is an opportunity for network staff to present and discuss the technical aspects of the monitoring data, and for park resource managers to convene, present data and analyses, and discuss resource issues of concern with other managers in the network.

3. The CHDN will undergo a "Start-up Review" by the servicewide I&M program WASO office within three years after the monitoring plan is accepted and implemented, and every five years thereafter, as described in Section 7.3.5.

4. Network staff also will analyze and present data in other arenas on a regular basis to subject the network's methodologies to ongoing peer review.

Table 8.6. Key partnerships for the Chihuahuan Desert Network, FY10–FY13.

Primary agency/ Organization	Division/Department	Personnel	Duties
University of Texas at Austin	Geological Sciences and Office of Space Research	Dr. Gary Kocurek Roberto Guiterrez	Collection and interpretation of LIDAR data, development of the Dune Dynamics protocol
Rocky Mountain Bird Observatory		David Hanni, Dr. Jennifer Blakesley	Collection and interpretation of Landbirds data
New Mexico State University	International and Border Programs	Dr. Everett Egginton	Cooperative agreement for administration of the network office, including rental of office space, meeting room use, network connections, telephone services, and coordination of logistics for workshops.
Sonoran Institute		Cheryl McIntyre	Assisting CHDN with Learning Center of the American Southwest
University of New Mexico	Natural Heritage Program	Dr. Estevan Muldavin	Collection and interpretation of legacy vegetation monitoring data sets from BIBE and GUMO, development of multiple vegetation classification maps for network parks
State of Texas	Texas Commission on Environmental Quality	Dr. Bill Harrison Dr. Christine Kolbe	Surface water quality monitoring on Rio Grande
Texas State University	Edwards Aquifer Research and Data Center	Dr. Glenn Longley Stephen Porter Renee Barker Raymond Slade	Development of Surface Water Quality and Dynamics monitoring protocols
Sul Ross University	Department of Geology and Chemistry	Dr. Kevin Urbanczyk	Development of Surface Water Quality and Dynamics monitoring protocols

Chapter 9: Schedule

This chapter describes the proposed schedule for implementing the CHDN Vital Signs Monitoring Program. Not all monitoring activities will begin immediately upon completion of this monitoring plan. The design and pilot phases of protocol development frequently require more time than final protocol implementation, and can last several years. Thus, development of the CHDN program is phased to account for both time needed for completion and realistic, balanced workloads.

9.1 Phased Start-up Schedule for Protocol Development

Developmental phases are required for most CHDN protocols. For some protocols, phases may simply entail some coordination with an entity already collecting applicable data (e.g., state and/or federal water quality programs). For others, implementation will require a more detailed scoping of the vital sign(s), pilot data collection efforts, and/or determining analysis methods for the data. In assigning a target calendar year for protocol completion, we have attempted to account for anticipated difficulties to project the most feasible completion date possible. The CHDN, where appropriate and feasible, will borrow existing monitoring procedures developed by other networks with arid and semi-arid lands. For some protocols, intensive efforts will be conducted largely in a single park, with select testing and application of the results from these projects expanded to other parks during or shortly after the pilot phase. In all cases, protocol-development projects will be based on well-established, peer-reviewed methods and provide relevant monitoring data for the park(s) where pilot testing is conducted. For the protocols under development by CHDN in the next five years, Table 9.1 shows the protocols to be completed by December 31 of each year.

The general goals of the more intensive CHDN protocol-development projects are to develop sampling frames and classification systems, gather data needed for understanding variability in measures (e.g., within and across years, across sites) and its effect on statistical power, develop novel or adopt existing reference conditions or other thresholds, develop novel or adopt existing indices and assessment metrics, estimate monitoring costs, and work with parks to comply with laws, regulations, and policies and minimize adverse impacts of CHDN monitoring activities. Examples of protocols that require this level of development include Integrated Uplands monitoring and Dune Dynamics.

Some protocols (e.g., Landbirds, Groundwater Quantity, Surface Water Quality and Dynamics) will require empirical, site-specific data but may not need to be as intensive as those listed above. Finally, protocols already developed by other programs (e.g., Air Quality, Climate) may only require minimum coordination to acquire data sets that will be useful in analyzing and interpreting results from other vital signs.

9.2 Protocol Implementation Schedule

Table 9.2-1 provides a schedule for development and implementation of monitoring for each CHDN vital sign through 2013. Not every protocol will be implemented at every park or on the same schedule. Table 9.2-2 shows the general times of the year when field sampling for CHDN protocols is expected to occur. Sampling schedules include some year-round or seasonally continuous automated monitoring (air quality, climate, groundwater monitoring wells, river gauging stations). Most non-automated field sampling occurs in late spring through early fall (Table 9.2-2).

Table 9.1. Tasks to be accomplished before full monitoring is implemented.

Protocol and target year for completion	Vital sign(s)	Key events/issues to be addressed
Landbirds 2010	Bird Communities	NPS-approved protocols and databases used by SOPN and SODN will be used. CHDN effort during 2010 will focus on sample design. Sampling will be conducted in CHDN parks in spring 2010.
Invasive/Non-native Plants 2010	Invasive/Non-native Plants	NPS-approved protocols and databases used by SOPN and SODN will be used. CHDN effort during 2010 will focus on prioritizing areas for sampling. Pilot testing will be conducted in CHDN parks in fall 2010.
Integrated Uplands (Soils and Vegetation) 2010	Plant Community Composition, Soil Hydrologic Function, Biological Soil Crusts, Soil Erosion (Wind and Water), Bare Ground	NPS-approved protocols and databases used by SODN will be used with slight modification (inclusion of bare ground vital sign). CHDN effort during 2010 will focus on sample design and exploring partnership with fire program for sampling. Pilot testing will be conducted in CHDN parks in fall 2010.
Dune Dynamics 2010	Dune Formation and Stability, Dune Morphology	Techniques for monitoring changes in dune vital signs are established. Utilization of LiDAR imagery has been tested. Work will focus on determining frequency of sampling, developing a data management strategy, and writing a protocol to NPS specifications. The baseline has been established, and sampling will not occur again until 2016.
Groundwater Quantity 2010	Groundwater Quantity	NPS-approved protocol will be adopted. Initial sampling will begin in late 2010 or early 2011.
River Channel Morphology 2010	River Channel Characteristics	Data collected by BIBE (or its cooperators) using peer-reviewed protocols will be used. CHDN focus will be on data management and reporting. This protocol will be applied only to the Rio Grande.
Surface Water Quality and Dynamics 2011	Surface Water Dynamics, Persistence of Springs, Surface Water Quality, Aquatic Invertebrates	The CHDN is contributing to a multi-network effort to develop peer-reviewed protocols for hydrology, water quality, vegetation, and macroinvertebrates in seeps and springs (including spring-fed streams). These protocols will be used for all CHDN surface waters except the Rio Grande. CHDN focus will be primarily on sample design. Pilot testing will be conducted in spring 2011.
Air Quality 2011	Ozone, Wet and Dry Deposition, Visibility and Particulate Matter	Implemented through other sources. Coordinate with ARD and other networks (SODN, SOPN) on receipt of annual reports and data summaries, and reporting strategies.
Climate 2011	Basic Meteorology	Implemented through other sources. Coordinate with ARD and other networks (SODN, SOPN) on receipt of annual reports and data summaries, and reporting strategies.
Landscape Patterns and Dynamics 2012	Land Cover, Land-Use Changes	WASO I&M has taken the lead role on development of this protocol. The CHDN will coordinate with their efforts.

For standardization, completion date is considered to be December 31 of any given year. Protocols are listed chronologically by year of completion.

Table 9.2-1. Development (D), pilot testing (P), and implementation (I) schedule for each protocol, calendar years 2009–2013.

Protocol	2009	2010	2011	2012	2013	Frequency
Landbirds	P	I	I	I	I	Annual
Invasive/Non-native Plants	D	P	I	I	I	5-year intervals
Integrated Uplands		P	I	I	I	Rotation TBD
Dune Dynamics	D	D	I			First resample: 5 yrs post-initial; second sampling: 5–10 yrs, etc.
Groundwater Quantity	D	P	I	I	I	Periodic to continuous
River Channel Morphology		D	I	I	I	5 year intervals
Surface Water Quality and Dynamics		D	P	I	I	Periodic to continuous
Air Quality		D	I	I	I	Continuous
Climate		D	I	I	I	Continuous
Landscape Patterns and Dynamics[1]			D	I	I	5–10 year interval

[1] = This protocol will be fully developed following the conclusion of the servicewide I&M program's effort. The national office has taken the lead role in developing standards and useful analytical techniques.

Table 9.2-2. General estimate of months when data collection could occur for CHDN protocols.

Protocol	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Landbirds				X	X	X						
Invasive/Non-native Plants[1]				X	X	X	X	X	X			
Integrated Uplands				X	X	X	X	X	X	X		
Dune Dynamics	X	X				X	X					
Groundwater Quantity	X	X	X	X	X	X	X	X	X	X	X	X
River Channel Morphology					X	X	X	X	X	X		
Surface Water Quality and Dynamics			X	X	X	X	X	X	X	X		
Air Quality	X	X	X	X	X	X	X	X	X	X	X	X
Climate	X	X	X	X	X	X	X	X	X	X	X	X
Landscape Patterns and Dynamics							X	X	X	X		

Protocols are listed chronologically by year of completion.

[1]Field sampling for invasive plants will correspond to the vegetation phenology. The time frame may shift a month depending on the species monitored.

9.3 Programmatic reviews

The three-year start-up review by the WASO office is anticipated in 2013, with periodic programmatic reviews every five years thereafter.

Chapter 10: Budget

This chapter presents the CHDN Vital Signs Monitoring Program budget for FY 2010, the first partial year of operation after review and final approval of our plan (March 2010). Table 10 shows the FY10 network budget, including our projections for network resources devoted to information and data management.

In FY10, the CHDN received $799,400 from the Servicewide I&M Vital Signs Monitoring Program, and $66,700 from the NPS Water Resources Division. Combined, these funding sources serve as base funds with which the network vital signs and water quality monitoring programs will be developed and implemented. We expect these amounts to remain relatively fixed, except for periodic cost of living adjustments for federal employees and other across-the-board rescissions. Regional assessments are expected to be $3,854 and $667 for I&M and NPS-WRD monies, respectively. After assessment, the CHDN will have a total of $861,579 (Table 10). Not shown in Table 10 is $50,000 received from the national Vegetation Inventory Program to conduct an accuracy assessment of the WHSA vegetation map. Although CHDN has received funds for vegetation mapping in the past, and expects to receive additional funding for vegetation maps in AMIS and BIBE, these funds do not contribute to base monitoring funds.

Vital Signs Monitoring Program funds are held in WASO base accounts and transferred annually through the Intermountain Regional Office to the CHDN. All funds are managed by the CHDN program manager, with budget and contracting assistance from IMR staff. The BOD approves the work plan with input from the network program manager and TC. The work plan directs expenditure of funds to salaries, projects, and operations. Funds are used solely for purposes of operating the program in a way consistent with NPS policies, rules, and regulations.

In FY 2010, the network will enter the Implementation Phase (FY10–FY12), defined as the period when the network will continue to develop and implement several protocols (e.g., Landbirds, Invasive/Non-native Plants, Integrated Uplands), begin to implement the network's Data Management Plan, and fund inventories that support protocol development. These activities will be accomplished through a combination of core (permanent) network staff, temporary network staff, and external cooperators (via CESU cooperative agreements and interagency agreements), the costs of which constitute a significant portion of the program budget (Table 10). Costs for current network staff are approximately 54% of the FY10 budget, including the one-time relocation expense for the Field Coordinator position. The percentage of funds allocated to network personnel will generally increase over time due to cost of living and step increases. The staffing plan in Chapter 8 presents one approach to achieving field data collection. Additional field assistance will likely be required, and the network will explore all staffing options for implementing protocols (CHDN temporary staff, park staff, partnerships, cooperative agreements, or some combination) with the CHDN BOD and TC as protocols near completion.

In FY 2010, approximately 42% of the program budget will be allocated to external cooperators or contractors to provide assistance on protocol development, data management, and maintaining office space and support at New Mexico State University (Table 10). Through these agreements and contracts, we will obtain technical and statistical support as we initiate or continue protocol development. Operations, equipment, and travel expenses during the Implementation Phase will be allocated to monitoring equipment purchases, general administrative costs, and travel related to meetings, visiting parks, training, and protocol testing. These expense categories will increase as protocols are implemented (e.g., equipment costs, logistics support, field travel).

Table 10. Detailed budget for the Chihuahuan Desert Network Vital Signs Monitoring Program in the first year of implementation after review and approval of the monitoring plan.

Income	FY 2010 amount	% of income
Vital Signs Monitoring	$794,546	92%
Water Resources Division	$66,033	8%
Total income	**$861,579**	

Expenditures			Percentage/amount allocated to data management	
Personnel	**GS-level**	**FY 2010 amount ($)**	**%**	**Amount ($)**
Program Manager (*permanent*)	13	107,266	10%	10,727
Science Advisor (*permanent*)	13	119,167	10%	11,917
Data Manager[1] (*permanent*)	11	84,455	90%	76,009
Field Coordinator (*permanent*) Relocation expenses	7/9	35,980 50,000	30%	10,794
Biological Technician (*term*)	7	28,378	80%	22,701
Biological Technician (*temp*)	7	23,058	50%	11,529
Budget Analyst[2] (*permanent*)	9	8,780	20%	1,756
Administrative Assistant[3] (*term*)	5	3,428		
I&M Writer-Editor[4]	9	3,446		
	subtotal	***$463,956***		***$145,432***
Cooperative agreements				
New Mexico State University (office space & support)		$94,004		
Seeps/Springs, Groundwater Inventory & Protocol Development		$224,440	33%	73,755
Invasive species, uplands protocol implementation		$30,000	33%	9,900
RIGR monitoring		$15,179		
	subtotal	***$363,623***		***$83,655***
Operations/Equipment				
Computer equipment		4,000		
Vehicles		2,000		
Training		5,000		
General supplies and equipment		$3,000		
	subtotal	***$14,000***		
Travel				
Network staff: Meetings, conferences, and training		14,000		
Park staff: Network-related meetings and conferences		6,000		
	subtotal	***$20,000***		
Total Expenditures		**$861,579**	**27%**	**$229,398**

[1] 10% of time allocated to IT duties.

[2] Position shared with all IMR I&M networks. CHDN share is 0.12 FTE.

[3] Position shared with 4 other I&M networks. CHDN share is 0.007 FTE.

[4] 1 pp, for work on monitoring plan.

Guidelines for developing a monitoring program suggest that approximately 33% of the overall budget should be allocated to information and data management to ensure data quality and longevity and facilitate communication of monitoring results. In Table 10, we provide the percent of time that each network position devotes to information/data management. Approximately 27% of the network budget will be put toward data and information management during the Implementation Phase. After the network fully implements monitoring, monitoring-related data management duties will be performed by core and term network staff, as well as temporary field staff.

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Glossary of Terms and Concepts

Adaptive management—a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – "active" adaptive management – employs management programs that are designed to experimentally compare selected policies or practices by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Alluvial fan—an outspread, gently sloping mass of alluvium deposited by a stream, especially in an arid region where a stream issues from a narrow canyon onto a plain or valley floor.

Anthropogenic effects—are caused by or attributed to humans. As used here, they are human influenced factors that cause stress in natural systems.

Attribute—any living or nonliving feature or process of the environment that can be measured or estimated and that provides insight into the state of the ecosystem. The term Indicator is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003; http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Bajada—a broad, gently inclined, detrital surface extending from the base of mountain ranges into an inland basin.

Beta-diversity—"the variation in species composition among sites in a geographic region" (Legendre 2008).

Biological integrity—the ability to maintain and support a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.

Biota—the total fauna and flora of a region.

Conceptual models—purposeful representations of reality that provide a mental picture of how something works to communicate that explanation to others.

Degradation—an anthropogenic reduction in the capacity of a particular ecosystem or ecosystem component to perform desired ecosystem functions (e.g., degraded capacity for conserving soil and water resources). Human actions may degrade desired ecosystem functions directly, or they may do so indirectly by damaging the capacity of ecosystem functions to resist or recover from natural disturbances and/or anthropogenic stressors (derived from concepts of Whisenant 1999, Archer and Stokes 2000, Whitford 2002).

Disturbance—". . . any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985). In relation to monitoring, disturbances are considered to be ecological factors that are within the evolutionary history of the ecosystem (e.g., drought). These are differentiated from anthropogenic factors that are outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

Driver (or ecosystem/system driver)—major driving forces such as climate, fire cycles, hydrologic cycles, and natural disturbance events that have large scale influences on natural ecosystems. Drivers can be natural forces or anthropogenic (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Ecological integrity—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 (http://science.nature.nps.gov/im/monitor/Glossary.htm).

Ecological Monitoring Framework—a National Park Service systems-based, hierarchical outline that facilitates comparisons of vital signs among parks, networks, and other programs.

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 (SRM 1995).

Ecoregion— an ecoregion is a relatively homogeneous, ecologically distinctive area, which has resulted from a combination of geological, landform, soil, vegetative, climatic, wildlife, water and human factors which may be present. Ecoregions contain many landscapes with different spatial patterns of ecosystems.

Ecosystem—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 health—a metaphor pertaining to the assessment and monitoring of ecosystem structure, function, and resilience in relation to the notion of ecosystem "sustainability" (following Rapport 1998, Costanza et al. 1998). A healthy ecosystem is sustainable (see Sustainable ecosystem, below).

Ecosystem management—the process of land-use decisionmaking and land management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated landuse decisions (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Endemic species—any species naturally confined to a particular area or region.

Eolian—pertaining to the wind, esp. said of such deposits as loess and dune sand.

Ephemeral stream—A stream or reach of a stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

Equilibrium—a condition of balance between two opposing forces.

Evapotranspiration—the portion of precipitation returned to the area through evaporation and transpiration.

Focal resources—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.

Focal species/organisms—species and/or organisms that play significant functional roles in ecological systems by their disproportionate contribution to the transfer of matter and energy, by structuring the environment and creating opportunities for additional species and/or organisms, or by exercising control over competitive dominants and thereby promoting increased biological diversity (derived from Noon 2003). Encompasses concepts of keystone species, and umbrella species.

Functional groups—groups of species that have similar effects on ecosystem processes (Chapin et al. 1996); frequently applied interchangeably with functional types.

Generalized Random-Tessellation Stratified (GRTS)—allows for a spatially-balanced random draw of sample units with variable inclusion probabilities and an ordered list of sample units that can support additions and deletions of sample units while retaining spatial balance.

Geomorphic—pertaining to the shape of the earth or its surface features.

Habitats—areas that provide specific conditions (e.g., temperature, moisture, soils, vegetation, and cover) necessary to support a community of organisms adapted to life under those conditions.

Hydrologic function (lotic and lentic systems)—capacity of an area to: dissipate energies associated with (1) high stream flow (lotic); or (2) wind action, wave action, and overland flow (lentic); thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and groundwater recharge; develop root masses that stabilize stream banks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; support greater biodiversity (Prichard et al. 1998).

Hydrologic function (upland systems/soils)—capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt, to resist a reduction in this capacity, and to recover this capacity following degradation (Pellant et al. 2000).

Indicators—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 2003). 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 (Noon 2003, http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Indicators of ecosystem health—measurable attributes of the environment (biotic or a biotic) that provides insights regarding (1) the functioning status of one or more key ecosystem processes, (2) the status of ecosystem properties that are clearly related to these ecosystem processes, and/or (3) the capacity of ecosystem processes or properties to resist or recover from natural disturbances and/ or anthropogenic stressors (modified from Whitford 1998). In the context of ecosystem health, key ecosystem processes and properties are those that are closely associated with the capacity of the ecosystem to maintain its characteristic structural and functional attributes over time (including natural variability).

Intermittent stream—A stream or reach of a stream that flows only at certain times of the year, as when it receives water form springs or from some surface source.

Invasive species—A species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm, or harm to human health

(Executive Order 13112; http://www.invasivespecies.gov/laws/execorder.shtml). Invasive species can be plants, animals, and other organisms (e.g., microbes). Human actions are the primary means of invasive species introductions.

Inventory—an extensive point-in time survey to determine the presence/absence, location or condition of a biotic or abiotic resource (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Karst—an area of limestone formations characterized by sinks, ravines, and underground streams.

Landscape—a spatially structured mosaic of different types of ecosystems interconnected by flows of materials (e.g., water, sediments), energy, and organisms.

Measures—specific feature(s) used to quantify an indicator, as specified in a sampling protocol. For example, pH, temperature, dissolved oxygen, and specific conductivity are all measures of water chemistry (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Metadata—Data about data. Represents the set of instructions or documentation that describe the content, context, quality, structure, and accessibility of a data set (Michener et al. 1997).

Microclimate—A local atmospheric zone where the climate differs from the surrounding area (Wikipedia).

Monitoring—collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 1998). Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Natural variability—the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal (Landres et al. 1999).

Panel—A group of sample units that will always be sampled during the same sampling occasion or time period (McDonald 2003).

Perennial stream—a stream or reach of a stream that flows continuously throughout the year and whose upper surface generally stands lower than the water table in the region adjoining the stream (Jackson 1997).

Phenology—term referring to the timing of an organisms lifecycle (e.g., producing flowers) only with certain periods of light.

Physiography—study of the natural features of the earth's surface including land formation, climate, currents, and distribution of flora and fauna. Also known as physical geography.

Playa—a term used in the southwestern US for a dry, barren area in the lowest part of an undrained desert basin, underlain by clay, silt, or sand and commonly by soluble salts. It may be marked by an ephemeral lake.

Population (Target)—total collection of sample units.

Probability sampling—where each sampling unit in the finite population has a known probability (a selection probability) of being included in a sample.

Protocols—are detailed study plans that provide rationale for monitoring a Vital Sign, and provide instructions for carrying out the monitoring. Protocols consist of a narrative, standard operating procedures, and supplementary materials (Oakley et al. 2003).

Rangeland—land on which the indigenous vegetation is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes and wet meadows (SRM 1999). For purposes of this document, we further include pinyon-juniper woodlands and oak woodlands in this definition.

Reach or Stream reach—A continuous part of a stream between two specified points (http://water.usgs.gov/pubs/circ/circ1208/glossary.htm).

Resilience—the capacity of a particular ecological attribute or process to recover to its former reference state or dynamic after exposure to a temporary disturbance and/or stressor (adapted from Grimm and Wissel 1997). The ability of a natural ecosystem to restore its structure following acute or chronic disturbance (Westman 1978). Resilience is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Resistance—the capacity of a particular ecological attribute or process to remain essentially unchanged from its reference state or dynamic despite exposure to a disturbance and/or stressor (adapted from Grimm and Wissel 1997). Resistance is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Responses—measurements taken on sample units.

Riparian—pertaining to or situated on the banks of a body of water, especially a river.

Sample—the collection of responses from the chosen sample units.

Sample unit—predefined spatial entities in which measurements are taken.

Sampling frame—the pool from which samples are selected in order to make references to the entire population (sampled and unsampled).

Soil/Site stability—the capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Pellant et al. 2000).

Status—as used in this program, refers to the condition of a resource or vital sign at a given point in time.

Strata—artificial constructs defined prior to sample selection that should never change, regardless of conditions on the ground (Geissler and McDonald 2003).

Stressor—physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive (or deficient) level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land use change, and air pollution (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Threshold—as applied to state-and transition models, a threshold is a point ". . . in space and time at which one or more of the primary ecological processes responsible for maintaining the sustained (dynamic) equilibrium of the state degrades beyond the point of self-repair. These processes must be

actively restored before the return to the previous state is possible. In the absence of active restoration, a new state is formed" (Stringham et al. 2003). Thresholds are defined in terms of the functional status of key ecosystem processes and are crossed when capacities for resistance and resilience are exceeded. (Also see state and transition.)

Tinaja—a type of waterpocket formed by the weathering and erosion of a rock basin over time. Typically, tinajas form in incipient or established drainages that are mostly ephemeral or intermittent, and are recharged by precipitation from storms.

Transition—as applied to state-and transition models, a transition is a trajectory of change that is precipitated by natural events and/or management actions which degrade the integrity of one or more of the primary ecological processes responsible for maintaining the dynamic equilibrium of the state. Transitions are vectors of system change that will lead to a new state without abatement of the stressor(s) and/or disturbance(s) prior to exceeding the system's capacities for resistance and resilience (adapted from Stringham et al. 2003).

Trend—as used by this program, refers to directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units) (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Trophic—describes the position that an organism occupies in a food chain (i.e., what it eats and what eats it).

Variable—any quantitative aspect of an object of concern.

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

Watershed—a drainage basin, usually described as into a river or lake.

Xeric—being deficient in moisture, as in, deserts provide xeric environments.

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

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