National Park Service
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Natural Resource Program Center

Southern Plains Network
Vital Signs Monitoring Plan

Natural Resource Technical Report NPS/SOPN/NRR-2008/028

ON THE COVER

Column 1: Alibates Flint Quarries NM, Sand Creek Massacre NHS, Washita Battlefield NHS, Bent's Old Fort NHS
Column 2: Fort Union NM, Chickasaw NRA, Lake Meredith NRA,
Column 3: Capulin Volcano NM, Fort Larned NHS, Lyndon B. Johnson NHP, Pecos NHP

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Acronyms

AIC	Akaike's Information Criterion
ALFL	Alibates Flint Quarries National Monument
BEOL	Bent's Old Fort National Historic Site
BOD	Board of Directors
CAVO	Capulin Volcano National Monument
CESU	Cooperative Ecosystem Studies Unit
CHIC	Chickasaw National Recreation Area
DS-CESU	Desert Southwest Cooperative Ecosystem Studies Unit
FOIA	Freedom of Information Act
FOUN	Fort Union National Monument
FTP	file transfer protocol
FY	fiscal year
GC-CESU	Gulf Coast Cooperative Ecosystem Studies Unit
GIS	geographic information systems
GP-CESU	Great Plains Cooperative Ecosystem Studies Unit
GPRA	Government Performance and Results Act
GPS	global positioning system
GRTS	generalized random-tessellation stratified design
IT	information technology
LAMR	Lake Meredith National Recreation Area
LAN	local area network
LCAS	Learning Center of the American Southwest
LYJO	Lyndon B. Johnson National Historical Park
NADP	National Atmospheric Deposition Program
NMHU	New Mexico Highlands University
NPS	National Park Service
NRC	Natural Resource Challenge
PECO	Pecos National Historical Park
PEPC	Planning, Environment, and Public Comment system
PI	principal investigator
PMIS	Project Management Information System
RAMS	Resource Activity Management System
RM-CESU	Rocky Mountains Cooperative Ecosystem Studies Unit
RPRS	Research Permit and Reporting System
SAND	Sand Creek Massacre National Historic Site
SOP	standard operating procedure
SOPN	Southern Plains Network
TAMU	Texas A&M University
TC	Technical Committee
USGS	U.S. Geological Survey
VPN	virtual private network
WABA	Washita Battlefield National Historic Site
WAN	wide-area network
WRD	NPS Water Resources Division

Executive Summary

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to manage park resources "unimpaired for the enjoyment of future generations". The National Park Service has implemented a strategy to improve its science information base so that parks with significant natural resources possess the resource information needed for effective decision-making and resource protection. Vital signs monitoring is a key element of that strategy. The approximately 270 park units with significant natural resources have been grouped into 32 monitoring networks linked by geography and natural resource characteristics. The network organization will facilitate collaboration, information sharing, and economies of scale in natural resource monitoring. Parks within each of the 32 networks collaborate with shared funding and professional staff to design and implement long-term monitoring. The Southern Plains Network (SOPN) is composed of 11 National Park Service units located in Colorado, Kansas, New Mexico, Oklahoma, and Texas. The member parks are Alibates Flint Quarries National Monument, Bent's Old Fort National Historic Site, Capulin Volcano National Monument, Chickasaw National Recreation Area, Fort Larned National Historic Site, Fort Union National Monument, Lake Meredith National Recreation Area, Lyndon B. Johnson National Historical Park, Pecos National Historical Park, Sand Creek Massacre National Historic Site, and Washita Battlefield National Historic Site.

Developing an ecological monitoring strategy 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 readily accessible to managers. The SOPN monitoring program is being developed over a multi-year time frame with specific objectives and reporting requirements at each of three planning milestones.

The first planning steps involved compiling and organizing relevant science information and conducting detailed park scoping to identify the most important resources and issues for each park (Chapter 1). A second step was to collaborate with regional scientists to develop the conceptual ecological models of the Southern Plains ecosystems (Chapter 2). The network then held a series of workshops in 2004 and 2005 to identify and evaluate vital signs for long-term monitoring. During these workshops park managers, subject-matter experts from the scientific community, and SOPN staff identified and evaluated resources and potential indicators as candidates for monitoring. Following those workshops, the SOPN Technical Committee and the Board of Directors met to make the final selection of network vital signs (Chapter 3). The diversity of ecosystems in SOPN parks, the geographic distribution of these parks, and differences in resource management priorities among parks are 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 SOPN has identified 29 vital signs that would represent a comprehensive monitoring program. However, the current level of funding will not enable SOPN to monitor all 29 vital signs. Therefore, SOPN has identified 11 core vital signs that will represent the majority of our program in the near future.

The 11 core vital signs are:

1. *Grassland Vegetation Communities*
2. *Riparian Vegetation Communities*
3. *Exotic Plants*
4. *Soil Structure and Chemistry*
5. *Water Quality–Core Parameters*
6. *Water Quantity–Surface*
7. *Ground Water Levels*
8. *Bird Communities*
9. *Fire and Fuel Dynamics*
10. *Landscape Dynamics*
11. *Human Demographics*

This Monitoring Plan (Phase III Report) for the SOPN is the third phase of a three phase development process and includes updated material from the Phase I and II documents. The Phase II Vital Signs Monitoring Report included: 1) monitoring goals and the planning process used to develop the monitoring program; 2) summaries of existing information concerning park natural resources and resource management issues across the network; 3) a conceptual model framework for SOPN park ecosystems; and 4) descriptions of the prioritization and selection processes for vital signs. This report adds to those previous efforts and describes our plan for implementing long-term monitoring of natural resources in the network parks. The plan will be peer reviewed in the next few months, leading to finalization of the network's Monitoring Plan by December 2008, with most monitoring to begin during FY 2009.

Over the next few years, network staff and collaborators will develop 6-7 monitoring protocols to address the 11 core vital signs for the SOPN. Chapter 5 discusses the protocol development process. These monitoring protocols will provide detailed study plans that explain how data are to be collected, managed, analyzed, and reported and will serve as a key component of quality assurance for vital signs monitoring.

Developing sampling designs for long-term monitoring is essential to ensure that the data collected are representative of the target populations and sufficient to draw defensible conclusions about the resources of interest. Chapter 4 discusses sampling design and how sampling locations will be chosen for each vital sign and how the sampling effort will distributed through time among locations. In order to be useful to park managers over the long term, monitoring data must be well-maintained and regularly reported. Chapter 6 describes our standards and procedures to ensure the quality, security, longevity, and availability of monitoring data and associated information products. SOPN staff will use appropriate computer information technology tools and will provide high quality data stewardship at every step of the monitoring process, from protocol development and data collection through analysis, reporting, and archiving. Chapter 7 discusses data analysis and reporting and presents an overview of the guiding principles of how data collected by the network will be analyzed and how we will effectively share the monitoring results with park managers, scientists, and the general public through a collaborative learning center. Chapter 9 discusses the frequency and seasonality of monitoring for each core vital sign.

Chapter 8 discusses how the SOPN will be administered. The network relies on two groups to provide program oversight and guidance, and Board of Directors (BOD) and a Technical Advisory Committee (TC). The Board of Directors is composed of three SOPN superintendents, one resource manager, the SOPN network and IMR regional coordinators, and the unit leaders from the Great Plains and Gulf Coast CESUs. The BOD oversees network administration and provides program guidance and advocacy. The Technical Advisory Committee, made up of park representatives (usually natural resource managers) advises the network regarding scientific and technical planning aspects, park-based logistic support, and resource management applications of monitoring results.

Chapter 10 discusses the SOPN budget. The SOPN receives $391,325 from the NPS Servicewide Inventory and Monitoring Vital Signs Program, and $29,100 from the NPS Water Resources Division annually. The SOPN staff was based at Lyndon B. Johnson National Historical Park in Johnson City, Texas through FY 2007. Beginning in FY 2008, our center of operations has moved to New Mexico Highlands University at Las Vegas, New Mexico. This site is more centrally located, and provides an opportunity for interaction with an academic institution. The SOPN's permanent staff will include a network coordinator/ecologist, one additional scientist (ecologist or biologist), and a data manager. The network will also rely on its cooperative relationship with other organizations and institutions to meet the need for seasonal monitoring crews and will use CESU agreements, the Student Conservation Association (SCA), and the Student Educational Employment Program to accomplish some monitoring projects.

Acknowledgements

The Southern Plains Network (SOPN) has benefited greatly from other networks that are developing or have developed their monitoring plans. In particular, SOPN "borrowed" extensively, sometimes whole blocks of text, from the Sonoran Desert, Central Alaska, Cumberland-Piedmont, Greater Yellowstone, Gulf Coast, Heartland, Northern Colorado Plateau, and Southern Colorado Plateau Networks. All of the Intermountain Region I+M Networks have been enormously helpful as a sounding board and providing advice to our relatively young network. We have also benefited greatly from an extensive pool for cooperators, collaborators, and partners. The SOPN Board of Directors and Technical Committee have provided extensive support and guidance. We really appreciate the excitement they have shown for our program. This report has benefited greatly from the thoughtful review of the SOPN Board of Directors and Technical Committee and Tim Seastedt at the University of Colorado. Through FY2007, the Lyndon B. Johnson National Historical Park was a gracious host to our network in providing excellent office space and administrative support. We appreciate their support.

Chapter 1
Introduction and Background

> *". . . that is the way to start, with stones forming a wide circle, marsh marigolds in bloom, hawks hunting mice, boys climbing hills, to sit under the sun, to dream of eagle wings and antelope; words cannot be spoken first."*
>
> ~ *Maurice Kenny,* Mohawk Nation

The Southern Plains Inventory and Monitoring Network (SOPN) is composed of 11 National Park Service (NPS) units: Bent's Old Fort National Historic Site (BEOL) and Sand Creek Massacre National Historic Site (SAND), Colorado; Fort Larned National Historic Site (FOLS), Kansas; Capulin Volcano National Monument (CAVO), Fort Union National Monument (FOUN), and Pecos National Historical Park (PECO), New Mexico; Chickasaw National Recreation Area (CHIC) and Washita Battlefield National Historic Site (WABA), Oklahoma; and Alibates Flint Quarries National Monument (ALFL), Lake Meredith National Recreation Area (LAMR), and Lyndon B. Johnson National Historical Park (LYJO), Texas (Figure 1, Table 1). The SOPN is one of 32 networks included in the Servicewide Inventory and Monitoring (I&M) Program, and one of seven networks in the Intermountain Region. Park units within the SOPN are located in shortgrass and mixed-grass ecosystems, and range in size from 326 acres (WABA) to 46,349 acres (LAMR). Detailed natural resource summaries are provided in Appendix A.

1.1 Integrated Natural Resource Monitoring

The purposes of the National Park Service Vital Signs Monitoring Program relate directly to the purposes of the National Park System. This section reviews the justifications for integrated natural resource monitoring; the legislation, policy, and guidance that directs the program;

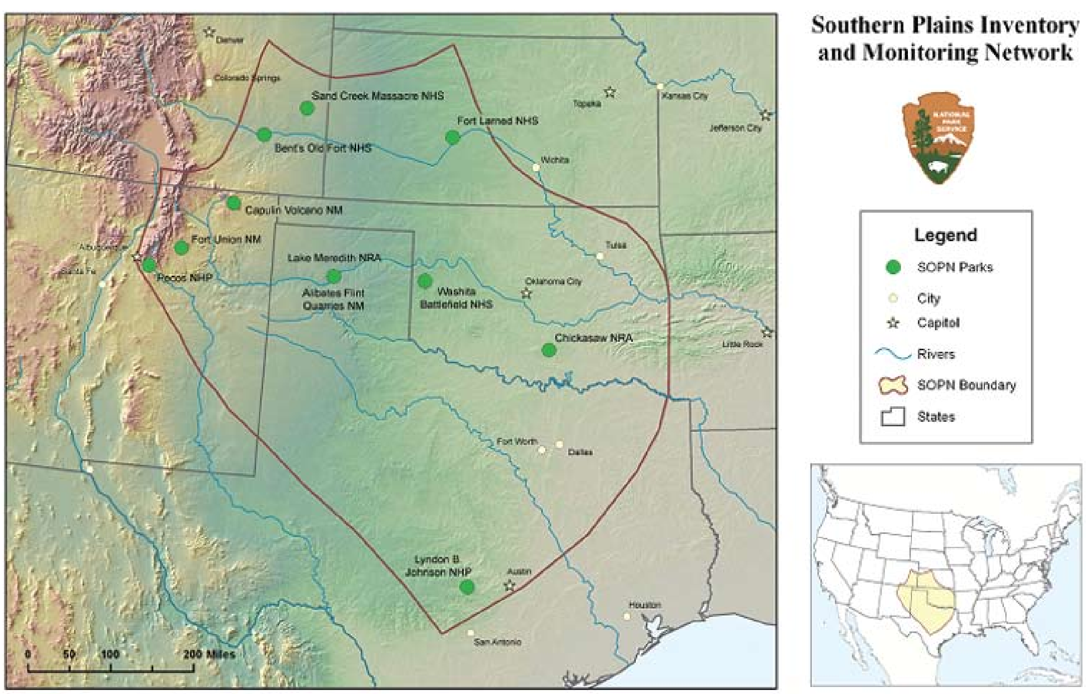


Figure 1. The Southern Plains Inventory and Monitoring Network.

Table 1. List of abbreviations, affiliations, and basic statistics for the 11 Southern Plains Inventory and Monitoring Network parks.

Park name	Abbre-viation	State	Region	Year est.	Acres (ha)	Base fund-ing (FY05)	FTE (FY04)	Number of visitors (FY04)
Alibates Flint Quarries National Monument	ALFL	TX	Intermountain	1965	1,371 (555)	$0	0	1,794
Bent's Old Fort National Historic Site	BEOL	CO	Intermountain	1960	799 (323)	$1,052,000	19	31,487
Capulin Volcano National Monument	CAVO	NM	Intermountain	1916	793 (321)	$651,000	10	58,705
Chickasaw National Recreation Area	CHIC	OK	Intermountain	1906	9,889 (4,002)	$3,032,000	41	2,939,119
Fort Larned National Historic Site	FOLS	KS	Midwest	1964	718 (291)	$941,000	13	35,535
Fort Union National Monument	FOUN	NM	Intermountain	1956	721 (292)	$773,000	13	13,572
Lake Meredith National Recreation Area	LAMR	TX	Intermountain	1990*	46,349 18,757)	$2,150,000	40	806,481
Lyndon B. Johnson National Historical Park	LYJO	TX	Intermountain	1969	674 (273)	$3,361,000	52	94,963
Pecos National Historical Park	PECO	NM	Intermountain	1965	6,670 (2,699)	$1,324,000	19	34,435
Sand Creek Massacre National Historic Site	SAND	CO	Intermountain	2000	2,400 (971)	$356,000	3	0
Washita Battlefield National Historic Site	WABA	OK	Intermountain	1965	326 (132)	$640,000	3	15,723
TOTAL					**71,606 (29,878)**	**$14,280,000**	**213**	**4,032,814**

*LAMR has been administered by the NPS since 1965, but did not officially become an NPS unit until 1990.

the goals of the monitoring program; and an overview of the network approach to vital signs monitoring.

1.1.1 Justification

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's ability to manage park resources "unimpaired for the enjoyment of future generations" (Organic Act of 1916, 16 U.S.C. 1§1). National park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the benefit of park resources. For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas in order to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats.

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

Natural resource monitoring is important for two major reasons. First, it provides site-specific information needed to understand and identify changes in complex, variable, and imperfectly understood natural systems. Second, monitoring determines whether observed changes are within natural levels of variability or may indicate unwanted human influences. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decisionmaking aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999).

"Vital signs," as defined by the National Park Service, are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve, including water, air, geological resources, plants, animals, and the various ecological, biological, and physical processes that act on those resources. Information obtained through monitoring can help managers understand how to develop the most effective approach to ecologically sound management and restoration. This is particularly helpful in situations where natural areas have been so highly altered that physical and biological processes no longer operate.

Monitoring is a central component of natural resource stewardship in the NPS and—in conjunction with natural resource inventories, management, and research—provides the information needed for effective, science-based managerial decisionmaking and resource protection (Figure 1.1.1). Natural resource inventories are extensive, point-in-time efforts to determine the location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Monitoring differs from inventories by adding the dimension of time; the general purpose of monitoring is to detect changes or trends in a resource. Elzinga et al. (1998) defined monitoring as, "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective." Detection of a change or trend may trigger a management action or generate a new line of inquiry. Research is generally defined as the systematic collection of data that produces new knowledge or relationships, and usually involves an experimental approach in which a hypothesis concerning the probable cause of an observation is tested in situations with and without the specified cause. A research design is usually required to determine the cause of changes observed by monitoring. The development of monitoring protocols also involves a research component to determine the appropriate spatial and temporal scale for monitoring.

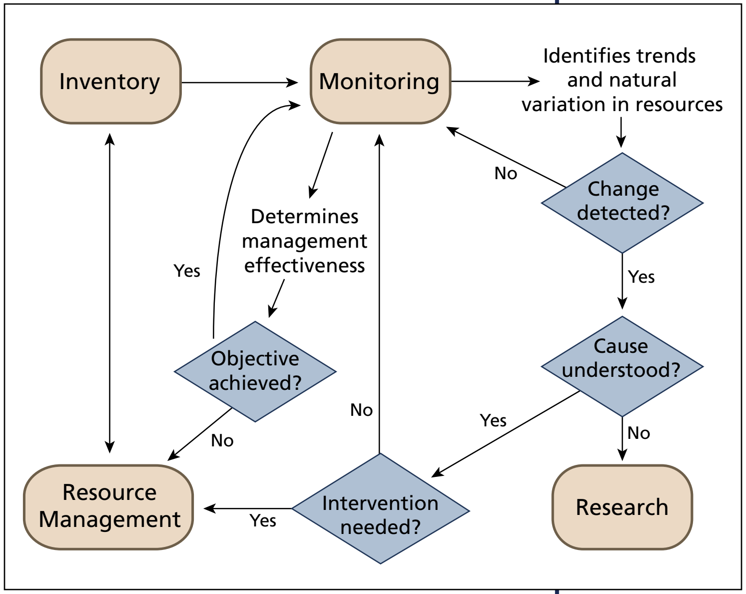


Figure 1.1.1. Stewardship of natural resources in national parks involves the interconnected activities of inventories, monitoring, research, and resource management (modified from Jenkins et al. 2002).

1.1.2 Legislation, policy, and guidance

In establishing the first national park in 1872, Congress "dedicated and set apart (nearly 1,000,000 acres of land) as a . . . pleasuring ground for the benefit and enjoyment of the people" (16 U.S.C. 1§21). By 1900, a total of five national parks had been established, along with additional historic sites, scenic rivers, recreation areas, monuments, and other designated units. Each unit was to be administered according to its individual enabling legislation, but was created with a common purpose of preserving "precious" resources for people's benefit. Sixteen years later, the passage of the National

Park Service Organic Act of 1916 (16 U.S.C. 1§1) established and defined the mission of the National Park Service. 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 Organic Act vis-à-vis the General Authorities Act of 1970 (16 U.S.C. 1a-1a8) and effectively ensured that all park units were united into the National Park System through a common purpose of preservation, regardless of title or designation. In 1978, the agency's protective function was further strengthened when Congress again amended the Organic Act to state, ". . . the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established. . . ." thus further endorsing natural resource goals of each park. A decade later, NPS management policy reiterated the importance of this protective function, directing the NPS to "understand, maintain, restore, and protect the inherent integrity of the natural resources" (NPS Management Policies 2001).

More recent and specific requirements for a program of inventorying and monitoring park resources are found in the National Parks Omnibus Management Act of 1998 (P.L. 105-391). The intent of the act was to create an inventory and monitoring program used "to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."

Subsequently, in 2001, NPS management updated previous policy and specifically directed the agency to inventory and monitor natural systems in efforts to inform park management decisions: "Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions" (NPS Management Policies 2001).

In addition to the legislation directing the formation and function of the National Park System, there are several other federal laws 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 generally. Many of these laws also require natural resource monitoring within national park units. As NPS units are among some of the most secure areas in the country for numerous threatened, endangered, or otherwise-compromised natural resources, the guidance offered by federal environmental legislation, policy, and executive guidance is an important component to the development and administration of a natural resource inventory and monitoring system in the national parks. Relevant federal legal mandates are, therefore, summarized in Appendix B.

1.1.2.1 GPRA goals

The Government Performance and Results Act (GPRA) plays a central role in NPS operations and the I&M program. For the NPS, four overarching goals provide direction for developing more specific goals:

1. Category I goals preserve and protect park resources.
2. Category II goals provide for the public enjoyment and visitor experience of parks.
3. Category III goals strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners.
4. Category IV goals ensure organizational effectiveness.

This monitoring plan assists in meeting numerous Category I goals, and augments Category II, III, and IV goals. The servicewide goal pertaining to natural resource inventories specifically identifies the objective of inventorying the resources of the parks as an initial step in protecting and preserving park resources (GPRA Goal Ib1). This plan identifies the indicators, or "vital signs," of the SOPN (GPRA Goal Ib3a). The network plans to implement vital signs monitoring, detecting trends in resource condition (GPRA Goal Ib3b), in fiscal year (FY) 2008. In addition to the national strategic goals, each park has a five-year plan identifying specific, park-based GPRA goals. Goals relevant to natural resource monitoring and management are presented in Appendix C.

1.1.2.2 SOPN park-unit enabling legislation

The SOPN includes four national historic sites, three national monuments, two national historical parks, and two national recreation areas. Definitions for NPS designations are found in Appendix D.

The enabling legislation of an individual park provides insight into the natural- and cultural-resource values it was created to preserve. Along with national legislation, policy, and guidance, a park's enabling legislation provides justification and, in some cases, specific guidance for the direction and emphasis of resource management programs, including inventory and monitoring. In some cases, the enabling legislation is further interpreted and expanded in park planning documents such as general management plans. See Appendix A for a more detailed description of each SOPN park's enabling legislation and excerpts from general management plans.

1.1.3 Servicewide goals for vital signs monitoring

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

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress towards performance goals.

These goals guide the SOPN's program scope and direction. The program will include effects-oriented monitoring to detect changes in the status or condition of selected resources, stress-oriented monitoring to meet certain legal mandates (e.g., Clean Water Act), and effectiveness monitoring to measure progress toward meeting performance goals (Noon et al. 1999, National Research Council 1995).

An effective monitoring program provides information that can be used in multiple ways. First, it enables managers to make better-informed management decisions (White and Bratton 1980, Croze 1982, Jones 1986, Davis 1989, Quinn and van Riper 1990). Monitoring information can also be used simply to increase familiarity with resources and systems (Croze 1982, Halvorson 1984); when data are gathered over long periods, correlations between different attributes become apparent, and resource managers gain a better general understanding of ecosystems. A third use of NPS monitoring information may be to convince others to make decisions benefiting national parks (Johnson and Bratton 1978, Croze 1982). Monitoring sensitive species, invasive species, culturally significant species, or entire communities can provide park managers, stakeholders, and the public with an early warning of the effects of human activities before they are noticed elsewhere (Davis 1989). Finally, a monitoring program can provide basic background information that is needed by park researchers, public information officers, interpreters, and those wanting to know more about the area around them (Johnson and Bratton 1978).

1.1.4 Network approach to vital signs monitoring

The NPS inventory and monitoring strategy consists of a framework with three major components: (1) completion of 12 basic resource inventories upon which monitoring efforts can be based; (2) a network of 11 experimental, or "prototype," long-term ecological monitoring programs, begun in 1992, to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters (i.e., "vital signs") in approximately 270 parks with significant natural resources, grouped into 32 vital signs networks linked by geography and shared natural resource characteristics.

The network approach is designed to minimize redundancy, maximize cost-effectiveness, and increase consistency in data collection and information transfer. The amount of funding available for vital signs monitoring would allow most parks to individually monitor only a few indicators. Therefore, a key efficiency of the network approach is to identify and monitor a core set of ecosystem attributes and resource/stressor relationships that are important across a group of parks. In addition to increased efficiency, applying standard monitoring approaches across ecoregions will result in greater potential for comparison and explanation in the resulting datasets. The NPS encourages networks and parks to seek partnerships with federal, tribal, and state agencies and adjacent landowners to leverage monitoring funding. Ideally, network monitoring will form the middle tier of an integrated monitoring framework linking national and regional monitoring programs to park-specific monitoring efforts.

1.1.5 Network administration

The SOPN currently has two full-time staff and is overseen by its Technical Committee and Board of Directors. The technical committee (TC) comprises one representative from each park—generally the person who oversees natural resources—and the SOPN network coordinator. All are permanent members of the committee. Each park member serves as chair of the TC on a two-year, rotating basis. The board of directors has both permanent and rotating members. There are three superintendents, who each serve a three-year term on a staggered rotation, and the TC chair is a member during his/her two-year term. The Intermountain Region I&M coordinator and the SOPN network coordinator are permanent members of the board.

1.2 Ecological Context of the Southern Plains Network

This section sets the scene for ecological monitoring in the Southern Plains ecosystem by discussing physical, natural, and cultural issues relevant to SOPN parks. The following sections describe the range of environmental conditions and anthropogenic influences prevalent in the SOPN region. More information about SOPN natural resources can be found in detailed accounts of each SOPN unit (Appendix A), maps for the network and each park (Appendix E), and lists of species of concern (Appendix F), exotic plants (Appendix G), and exotic animals (Appendix H).

1.2.1 Overview

The SOPN consists of mostly mixed- and shortgrass ecosystems. It is bordered on the east by tallgrass prairie, and on the west by the forested systems of the Rocky Mountains. SOPN parks vary in size from 326 acres (132 ha) to more than 46,000 acres (18,615 ha) (Table 1), and contain a wide range of biotic communities and abiotic conditions (Table 1.2.1-1). Most SOPN parks were established primarily for cultural and recreational reasons and, therefore, have relatively few natural resource staff (Table 1.2.1-2). However, all network parks contain significant natural resources. Many of these resources are embedded within a framework focused on a human event or activity, and the enabling legislation for many of the parks refers to ecological systems (e.g., requiring that the scene for the period of significance at a historical park be maintained). SOPN parks are some of the only representatives of short- and mixed-grass ecosystems in protected status. The parks occur in

Table 1.2.1-1. Biophysical overview and natural resource staffing of the Southern Plains Network.

Park	Annual precip. (in.)	Avg. min./ max air temperature (°F)	Elevation (ft)	Vegetation Province (Bailey 1994)
ALFL	20	43/71	2,800–3,320	Southwest Plateau and Plains Dry Steppe and Shrub
BEOL	12	37/69	3,980–4,020	Great Plains-Palouse Dry Steppe
CAVO	9	35/62	6,990–8,180	Great Plains-Palouse Dry Steppe
CHIC	38	49/72	780–1,160	Prairie Parkland (Subtropical)
FOLS	23	41/67	2,020–2,095	Great Plains Steppe
FOUN	17	31/64	6,685–6,835	Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow
LAMR	20	43/71	2,800–3,320	Southwest Plateau and Plains Dry Steppe and Shrub
LYJO	32	52/78	1,190–1,565	Southwest Plateau and Plains Dry Steppe and Shrub
PECO	17	32/63	6,695–7,575	Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow
SAND	13	35/66	3,940–4,085	Great Plains-Palouse Dry Steppe
WABA	25	44/71	1,920–2,000	Great Plains Steppe and Shrub

Table 1.2.1-2. Natural resource staffing in SOPN parks.

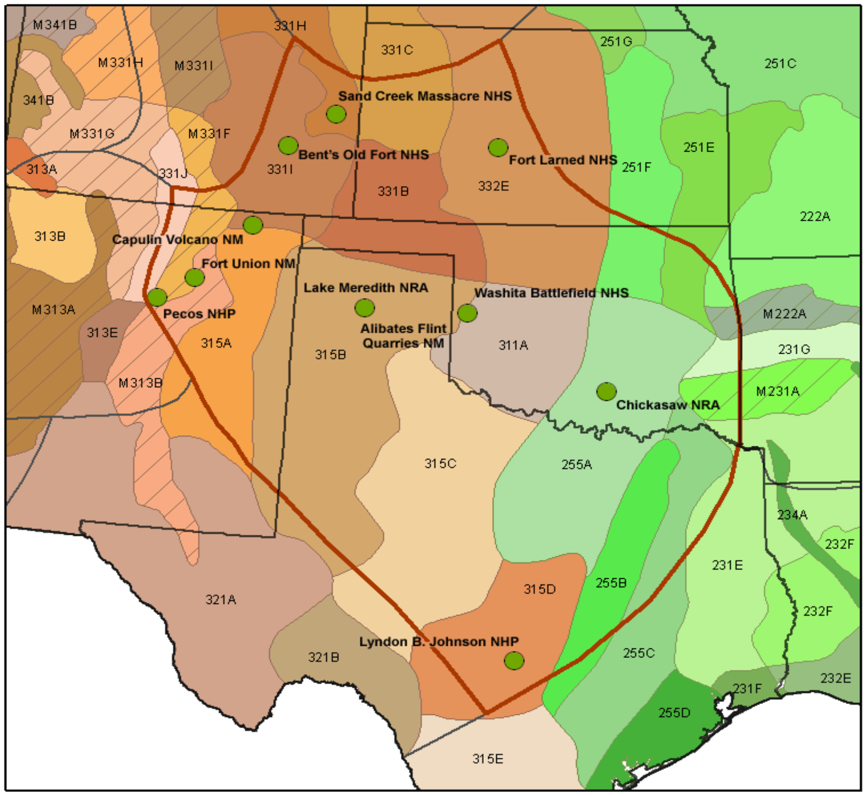
Park	Full-time natural resources staff
ALFL	None
BEOL	Chief, Natural Resources
CAVO	None
CHIC	Chief, Resource Management
FOLS	None
FOUN	None
LAMR	Chief, Environmental Specialist
LYJO	None
PECO	None
SAND	None
WABA	None

a landscape dominated by agriculture, and act as natural oases that are refugia for endemic, threatened, and endangered species, as well as common species.

1.2.2 Vegetation

The SOPN is located primarily in the grassland—or Great Plains—biome, considered by some to be the largest biome in North America (Stubbendieck 1988), and among the most productive ecosystems on Earth (Williams and Diebel 1996). However, the North American prairie is also among the continent's most endangered resources (Samson and Knopf 1994, Rickletts et al. 1999). Most ecologists divide the Great Plains into three types, representing a gradient from tallgrass prairie on the eastern plains, to mixed-grass prairie in the central regions, and shortgrass prairie in the west. CHIC, FOLA, LYJO, and WABA and are in mixed-grass prairie or savannah. ALFL, BEOL, CAVO, FOUN, LAMR, and SAND are located in shortgrass prairie, and PECO is in the ecotone between shortgrass prairie and piñon-juniper forest. At a finer scale, the SOPN parks can be placed in six different vegetative zones or biomes (Küchler 1986, Omernik 1987, Bailey 1995) (Table 1.2.1-1) and eight vegetative sections (Figure 1.2.2).

The dominant native plant species in the western portion of the network are blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*) in the grasslands, and cottonwood (*Populus deltoides*) trees along the riparian areas. In the eastern portion of the network, big



Boundaries: ——— I&M Networks ——— Southern Plains Network

Eastern Broadleaf Forest (Continental)
- 222A. Ozark Highlands

Ozark Broadleaf Forest - Meadow Province
- M222A. Boston Mountains

Southeastern Mixed Forest
- 231E. Mid Coastal Plains, Western
- 231F. Eastern Gulf Prairies and Marshes
- 231G. Arkansas Valley

Ouachita Mixed Forest - Meadow
- M231A. Ouachita Mountains

Outer Coastal Plain Mixed Forest
- 232E. Louisiana Coast Prairies and Marshes
- 232F. Coastal Plains and Flatwoods, Western Gulf

Lower Mississippi Riverine Forest
- 234A. Mississippi Alluvial Basin

Prairie Parkland (Temperate)
- 251C. Central Dissected Till Plains
- 251E. Osage Plains
- 251F. Flint Hills
- 251G. Central Loess Plains

Prairie Parkland (Subtropical)
- 255A. Cross Timbers and Prairie
- 255B. Blackland Prairies
- 255C. Oak Woods and Prairies
- 255D. Central Gulf Prairies and Marshes

Great Plains Steppe and Shrub
- 311A. Redbed Plains

Colorado Plateau Semi-Desert
- 313A. Grand Canyon Lands
- 313B. Navajo Canyonlands
- 313E. Northern Rio Grande Intermontane

Arizona-New Mexico Mountains Semi-Desert-Open Woodland-Coniferous Forest-Alpine Meadow
- M313A. White Mountain-San Francisco Peaks
- M313B. Sacramento-Monzano Mountain

Southwest Plateau and Plains Dry Steppe and Shrub
- 315A. Pecos Valley
- 315B. Texas High Plains
- 315C. Rolling Plains
- 315D. Edwards Plateau
- 315E. Rio Grande Plain

Chihuahuan Semi-Desert
- 321A. Basin and Range
- 321B. Stockton Plateau

Great Plains-Palouse Dry Steppe
- 331B. Southern High Plains
- 331C. Central High Tablelands
- 331H. Central High Plains
- 331I. Arkansas Tablelands
- 331J. Upper Rio Grande Basin

Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow
- M331F. Southern Parks and Ranges
- M331G. South-Central Highlands
- M331H. North-Central Highlands
- M331I. Northern Parks and Ranges

Great Plains Steppe Province
- 332E. South-Central Great Plains

Intermountain Semi-Desert and Desert
- 341B. Northern Canyon Lands

Nevada-Utah Mountains-Semi-Desert-Coniferous Forest-Alpine Meadow
- M341B. Tavaputs Plateau

Figure 1.2.2. Bailey's (1995) sections for the Southern Plains Network.

and little bluestem (*Schizachyrium scoparium*), switch grass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*) become more dominant in the grasslands, and American elm (*Ulmus americana*), sugarberry (*Celtis laevigata*), bald cypress (*Taxodium distichum*), and green ash (*Fraxinus pennslyvanica*) trees occur along with cottonwoods in riparian areas.

Due to alterations in natural-fire and grazing cycles, many SOPN grasslands are being invaded by woody species, such as oneseed juniper (*Juniperus monosperma*). Exotic plant species, such as smooth brome (*Bromus inermis*), cheatgrass (*Bromus tectorum*), kochia (*Kochia scoparia*), and King Ranch bluestem (*Bothriochloa ischaemum*), have invaded the grasslands; tamarisk (*Tamarix* spp.), scotch thistle (*Onopordum acanthium*), and Russian olive (*Elaeagnus angustifolia*) threaten riparian areas.

Species diversity is high in the mixed-grass prairie areas, with hundreds of plant species typically found per square mile. For example, Sanders and Gallyoun (2004) and Sanders (2005) found 471 naturally occurring species at LYJO, and Hoagland and Johnson (2001) found 582 species at CHIC during plant inventory work. Despite high diversity, endemic plant species are rare in the Great Plains when compared to many other biomes. Endemic species found or likely present in the SOPN include Colorado bursage (*Ambrosia linearis*) and dwarf milkweed (*Asclepias uncialis*). Many of the dominant forbs are polycarpic (i.e., they flower and set seed many times) and have long life spans of 10–30 years (Blake 1935, Weaver 1954).

Many grassland systems have undergone significant changes since they were first described by early Europeans. Exotic-species invasions, expanding row-crop agriculture, overgrazing, mineral exploration, and establishment of woodlots and shelterbelts have all contributed to grassland degradation and significant and ongoing loss of genetic diversity in North American grasslands. Estimates for loss of mixed-grass prairie range from 30–99.9%, and 46–82% for shortgrass, depending on the region (Samson et al. 1998). Prairie restoration is receiving increased attention in the Great Plains because many grasslands have been converted to other uses. Several SOPN parks have completed or are in the planning process for restoring prairie. Unfortunately, this can be a long process if the soil has been tilled. Fuhlendorf et al. (2002) estimated that it may take restored sites 30–50 years to recover and may require inputs to restore organic matter, soil carbon, and soil nitrogen.

1.2.3 Fauna

In the mid-1800s, individuals of native mammal species on the Great Plains, such as bison (*Bison bison*), black-tailed prairie dogs (*Cynomys ludovicianus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), grizzly bears (*Ursus arctos*), and gray wolves (*Canis lupus*), occurred in unfathomable numbers. Precipitous declines in the numbers of bison and prairie dogs from their historic levels have strongly affected current grassland dynamics. Grazing by bison and prairie dogs was a primary ecological driver in the Great Plains, and the two species are often viewed as mutualistic. Bison and other large herbivores, such as elk and pronghorn, use prairie-dog colonies for grazing and loafing more than might be expected based on the habitat available, due to the higher nutritional value of plants within dog towns (Koford 1958, McHugh 1958, Coppock et al 1983a, Krueger 1986). As bison herds graze an area and move on, a mosaic of seral stages is created across the landscape (Hart and Hart 1997). This high intensity, low frequency grazing regime influences vegetation community types as well as fire regimes.

The presence of a prairie-dog colony also increases the likelihood that predators, such as mountain plovers (*Charadrius montanus*) (Knowles et al. 1982, Knopf 1996), ferruginous hawks (*Buteo regalis*) (Cook et al. 2003), burrowing owls (*Athene cunicularia*) (Desmond et al. 1995) and swift foxes (*Vulpes velox*) (Agnew et al. 1986) will occur in an area. Their tunnel system provides refuge for a variety of taxa, ranging from invertebrates to amphibians and reptiles. Prairie dogs also play an important role in nutrient and soil cycling.

The Great Plains have lost a greater number of native carnivores and ungulates than any other biome in North America (Laliberte and Ripple 2004). As large carnivores, particularly the gray wolf, were hunted to local extinction, their absence changed Great Plains animal communities. Coyotes and other mesocarnivores expanded and flourished at the expense of

Lark sparrow, Lake Meredith National Recreation Area.

grassland birds, small mammals, and two other rare prairie predators: the swift fox and black-footed ferret (*Mustella nigripes*).

Birds, reptiles, and amphibians all have low species richness on the Great Plains, and the species present have had to adapt to the highly variable weather patterns. This specialization and low species richness make Great Plains wildlife especially vulnerable to habitat alteration. For example, the grassland bird guild has been found to have suffered steeper declines than any other North American bird guild (Knopf and Samson 1996, Peterjohn and Sauer 1999, Brennan and Kuvelsky 2005). Knopf and Samson (1996) argue that the endemic vertebrates of the Great Plains are the most sensitive to changes in ecological drivers of the region and, therefore, should be considered indicators of ecosystem health.

Prairie habitat degradation has led to the regionwide decline of several rare and listed species, including four that are known to occur in SOPN parks: the burrowing owl, black-tailed prairie dog, mountain plover, and Texas horned lizard (*Phrynosoma cornutum*), and three more that may occur on some of these parks, the lesser prairie chicken (*Tympanuchus pallidicnctus*), Arkansas darter (*Etheostoma cragini*), and swift fox. Federally listed species that occur in the region include the Arkansas River shiner (*Notropis girardi*) and wintering bald eagles (*Haliaeetus leucocephalus*) at LAMR, migrating eagles at several parks, and black-tailed prairie dogs (candidate) at BEOL, FOLA, LAMR, and SAND. Additional species of concern are listed in Appendix F.

Fragmentation is perhaps the greatest threat to faunal communities, many of which require large areas for survival and reproduction (Samson 1980, Herkert 1994). As fragments become more isolated, the probability of recolonization diminishes (Kaufman and Kaufman 1997). The combination of small size and isolation can also lead populations to suffer from genetic inbreeding and increased rates of genetic drift (Benedict et al. 1996).

1.2.4 Processes

Fire, grazing, and climate—specifically, drought—are the major natural drivers of Great Plains ecosystems. Climate and fire are the biggest determinants of whether grasslands preclude forests in the Great Plains region (Axelrod 1985, Anderson 1990). Fire can interact with drought by affecting the amount of fuel available, the influence of precipitation on prairie post-burn, and the moisture content of the vegetation can determine where fires are possible (Anderson 1990). The interaction of fire with grazing has a profound effect on the composition, structure, and processes of Great Plains plant communities.

Grazing and fire have generally operated at landscape and local scales, with drought at a broader scale (Fuhlendorf and Engle 2001). Both grazing and fire have been absent or reduced in many SOPN parks—in some cases, for decades—resulting in significant impacts to the grassland community. In addition, these drivers no longer function at the landscape scale, as they did in pre-Columbian times, due to the small size of parks, ownership fragmentation, and land conversion. Therefore, restoring plant community heterogeneity that was previously present is difficult and can only be done at a drastically reduced scale.

Annual precipitation within the SOPN ranges from 12 inches (31 cm) in the western plains to 39 inches (97 cm) in south-central Oklahoma. Approximately two-thirds of this rainfall occurs from April through September. The Great Plains, particularly the shortgrass prairie and the southern mixed-grass that make up SOPN, undergo frequent droughts from reduced precipitation, increased evapotranspiration, and increased water runoff (Weaver 1968, Wilhite and Hoffman 1979). Multi-year droughts are a regular event. Drought can lead to massive local extinctions of annual forbs and grasses that have invaded stands of perennial species, and recolonization can be slow (Tilman and El Haddi 1992). The impact of global climate change may be exacerbated in the Southern Plains due to the region's periodic droughts and the large number of habitat specialists (e.g., prairie dogs and associated species) (Collins and Glenn 1995, Clark et al. 2002).

The average maximum daily temperature in SOPN parks ranges from 78°F (26°C) at LYJO to 62°F (17°C) at CAVO, with average minimum temperatures ranging from 52° F (11°C) at LYJO to 31° F (-0.5°C) at FOUN (Table 1.2.1-1). This change in temperature results in a north-south gradient between cool-season (C3) grasses and warm-season (C4) grasses. Cool-season grasses are most efficient at photosynthesizing in cooler temperatures, and dominate in the northern or higher-elevation plains, while warm-season grasses are more efficient under warmer temperatures (Black 1971), and are more dominant in the grasslands that make up the SOPN.

In general, the agrarian-dominated landscape, the small size of the parks, and the scale at which ecological processes naturally occurred in the region all affect park management. None of the SOPN parks are large enough to restore and maintain complete assemblages of native species, natural conditions on a pre-European scale, nor the ecological processes that sustained them. However, due to the rarity of high-quality shortgrass and mixed-grass prairie, it is essential that prairie in NPS ownership be maintained in optimal condition to provide habitat for rare species, facilitate important nutrient cycling, and serve as an example of grassland fragment management. The development of a long-term monitoring plan must consider these aspects in design and implementation. Adequate assessment and monitoring of the effects of grazing, climate, and fire on grasslands, must be multi-scaled, include spatial and temporal patterns, and match management inferences and applications (Steinauer and Collins 1996).

1.2.5 Soils and Geology

Prescribed fire at Lyndon B. Johnson National Historical Park.

Prairie soils were formed primarily from sediment washed down from the Rocky Mountains, mixed with rubble from glaciers, and wind-blown sand, silt and clay. This combination resulted in a nutrient-rich, deep soil that is some of the most productive on earth. The SOPN has a wide range of soil orders present, including dry mollisols through central Texas, central Oklahoma, and central Kansas; wet mollisols in the vicinity of CHIC; entisols and aridisols in southeastern Colorado; and aridisols and alfisols in northeastern New Mexico.

About 1 inch (2.5 cm) of new topsoil is formed every 100 to 1,000 years, depending on climate, vegetation and other living organisms, topography, and the nature of the soil's parent material (Sampson 1981). Prairie soils are generally

Storm approaching at Pecos National Historical Park.

nitrogen- and carbon-poor, and soil nutrient transport is generally slow. Much of the biotic community and biomass of prairie exists below the surface; roughly 85% of a prairie's vegetative biomass can be below ground (Sims and Singh 1971). In shortgrass prairie soils, 90% of invertebrate energy cycling occurs belowground, less in tallgrass and mixed-grass prairies.

The deep root systems of prairie grasses and forbs act like a sponge to catch and hold rainwater. Water runoff from prairie is relatively small when compared to row crops or other ecosystems where there is no large network of roots. The extensive root system also binds the soil to the earth, protecting it from erosion. When prairie is converted to row-crop agriculture, the mixing and grinding of farm tools reduces surface cover and destabilizes soil structure by reducing aggregate size. In addition, organic carbon loss is accelerated by agriculture, and cultivated crops return little carbon to the soil. The Dust Bowl of the 1930s, centered on the Southern Plains, was a result of removing the protective vegetative layer and exposing vast areas of cultivated prairie soil to wind action and drought (Sampson 1981). In addition, chronic heavy grazing by livestock can compact soils and affect many of their characteristics and functions (e.g., water infiltration). Several SOPN parks contain tracts of formerly cultivated land that are in various stages of restoration.

Soil productivity also decreases dramatically after native sod is converted to row crops. Retention of organic matter and subsequent levels of productivity in grassland soils is only possible if the correct proportions of carbon, nitrogen, and phosphorus are present (Peterson and Cole 1996). Crop harvesting results in the removal of phosphorus, which must be mitigated by using fertilizers, which can increase concentrations of phosphorus in aquatic areas, affecting aquatic plant growth and reducing oxygen content in streams.

Arkansas River at Bent's Old Fort National Historic Site.

1.2.6 Water Resources

SOPN water resources are both ecologically and culturally important. Because all eight of the SOPN parks that were created (at least in part) due to their cultural significance to Native Americans or early settlers are located near flowing rivers, SOPN parks have a higher proportion of surface waters than would occur on a random selection of prairie areas. All SOPN parks, except for CAVO, ALFL, and FOUN, have permanent water resources, with the latter two being located very close to permanent water (Table 1.2.6-1).

Great Plains streams fall into three categories: shallow streams with shifting sand beds; clear brooks, ponds, and marshes supported by seeps and springs; and residual pools of intermittent streams (Cross and Moss 1987). In general, streams in the southern plains are characterized by irregular flow, small particle size in substrates, and a distinct wet-dry cycle.

Great Plains rivers generally flow from west to east and are characterized by extreme turbidity, high evaporation rates, moderate flow velocity, and dynamic channels. Much of the water in the major rivers of the Great Plains originates from the western mountains. Many of the sediments in both rivers and streams originate from thunderstorm runoff on the Great Plains. River temperatures can fluctuate widely, with summer, open-river water temperatures exceeding 30°C. High levels of salinity due to salt- and gypsum-laden groundwater are found in some areas.

Few major rivers in the Great Plains still exhibit the conditions evident before agricultural development and water management began. Altered river hydrographs from dams, irrigation, municipal withdrawals, groundwater depletion, and other land-use changes significantly impact Great Plains aquatic systems (Cross

Table 1.2.6-1. Summary of water resources at the 11 NPS units within the Southern Plains Network.

Park	Water body	Perennial rivers	Intermittent rivers	Adjacent perennial rivers	Lake/Reservoir shorelines	Canal	Lakes/Reservoirs
		Length [mi] (Impaired length[1] [mi])					Area [ac] (Impaired area[1] [ac])
ALFL	Canadian River intermittently flows		3.61 (0)				
BEOL	Arkansas River, Arch Wetland, several small ponds	2.27 (2.27)					
CAVO	None						
CHIC	Lake of the Arbuckles, Veterans Lake, several small streams and ponds	7.02 (0)	5.79 (0)		36.8 (0)		2,503 (0)
FOLS	Pawnee River	1.99 (0)	2.66 (0)				
FOUN	None within park (Wolf Creek is adjacent to park)						
LAMR	Lake Meredith, Canadian River, several small streams and ponds	17.85 (0)	24.67 (0)		108.95 (107.73)		16,242 (16,219)
LYJO	Pedernales River, Town Creek, stock ponds	0.07 (0)	2.51 (0)	4.93 (0)	2.66 (0)		13 (0)
PECO	Pecos River, restored wetland, Pecos tributaries	6.21 (2.86)	12.09 (0.095)				
SAND	Big Sandy Creek and wetlands	2.73 (0)	11.38 (0)			3.09 (0)	
WABA	Washita River	0.92 (0)					
Σ of water body mi/ac in SOPN parks (Σ of impaired waters)		**39.06 (5.13)**	**62.71 (0.095)**	**4.93 (0)**	**148.41 (107.73)**	**3.09 (0)**	**18,758 (16,219)**

[1] See Table 1.5 and Appendix I for description of impaired waters.
Source: NPS Hydrographic and Impairment Statistics, 2004.

and Moss 1987, Longo and Yoskowitz 2002). In virtually all the river systems, dewatering has altered the timing and extent of flows, downstream temperatures, levels of dissolved nutrients, sediment transport and deposition, and the structure of plant and animal communities. Dams exist at three SOPN parks, and all SOPN aquatic resources are affected by altered flows primarily from agriculture and development.

Water quality throughout the Great Plains has been affected by herbicides and other pollutants, and SOPN parks are no exception. Agricultural use of nitrogen fertilizers is the largest source of nitrates in near-surface aquifers in the mid-continent (Koplin et al. 1994). Effects of these pollutants on the quality of human life and integrity of the ecological community are largely unknown. Elevated *E.coli* levels, usually associated with fecal contamination, are also a concern at CHIC.

Groundwater depletion is of regional concern for both Great Plains ecology and human needs. Kromm and White (1992) observed that groundwater depletion has destroyed much of the water-supported habitat for fish and mammals in parts of the Great Plains. The High Plains (Ogallala) aquifer, which is essential to agriculture, urban communities, and environmental resources, declined from 1940 to 1980 by an average (area-weighted, water-level) decline of 9.8 feet (3 m) (Dugan et al. 1994). Subsurface water quantity and quality is a management issue at CHIC and BEOL due to groundwater depletion from neighboring lands

Table 1.2.6-2. SOPN water bodies with 303(d) designation.

Park	State	WBID[1]	Water body	Portion impaired	Impairment	Source of Impairment
BEOL	CO	COARLA01B	Arkansas River	From above Fountain Creek to state line (problems increase downstream); 2.27 miles	Selenium	Unknown/Natural
LAMR	TX	TX-0102	Lake Meredith	Nearly all of lake; 16,218.84 acres	Mercury in fish tissue	Atmospheric deposition
PECO	NM	NM-2214. A_003	Pecos River	From Canon de Manzanita to Alamitos Canyon; 2.86 miles	Temperature and turbidity	Construction, industry, urban and/or stormwater runoff, waste sites, mining

[1] Every state must assign a Water Body Identification (WBID) code to each body of water on its 303(d) list, which is then submitted to the U.S. Environmental Protection Administration.

(primarily for irrigation and development) and potential development.

The NPS GPRA goal for water resources requires that parks report on "impaired waters" as defined by section 303(d) of the Clean Water Act. The SOPN has three 303(d)-listed waters (Table 1.2.6-2). A complete report of the water quality resources for the SOPN is found in Appendix I.

1.2.7 Air Quality

Under the Clean Air Act, national park managers have a responsibility to protect air quality and related values from the adverse effects of air pollution. Protection of air quality in national parks requires knowledge about the origin, transport, and fate of air pollution, as well as its impacts on resources. To effectively protect park air quality, NPS managers need to know the type and level of air pollutants of concern, park resources at risk, and the potential or actual impact on these resources. Through the efforts of park personnel, support-office staff, and the NPS Air Resources Division, the NPS meets its clean-air responsibilities by obtaining critical data and using the results in regulatory-related activities.

All SOPN parks are designated as Class II areas according to the Clean Air Act. However, increases in airborne pollutants such as nitrate, sulfate, and ammonium have been noted for the Great Plains region (Pohlman 2005). Many SOPN parks have cited air quality as a significant concern for natural and cultural reasons including ozone damage, pollutants, night skies, and viewsheds. A full description of SOPN air quality issues is found in Appendix L in Perkins et al. (2005).

There are no air quality monitors in the units, but nearby monitors may be representative of conditions in SOPN units (Figure 1.2.7). Types of air monitoring being conducted locally are shown in Table 1.2.7.

Ozone-sensitive and bioindicator plant species have been formally identified for all SOPN units except for SAND (NPS 2003). Updated lists of ozone-sensitive species can also be obtained though NPSpecies. Ozone-sensitive species are those that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or for which ozone foliar injury symptoms in the field have been documented by more than one observer. Bioindicator species for ozone injury meet all or most of the following criteria:

1. They exhibit foliar symptoms in the field at ambient ozone concentrations that can be easily recognized as ozone injury by subject-matter experts;
2. Their ozone sensitivity has been confirmed at realistic ozone concentrations in exposure chambers;
3. They are widely distributed regionally; and
4. They are easily identified in the field.

Based on a risk assessment developed from the risk of foliar injury due to presence of sensitive species, concentrations of ozone exceeding an ambient threshold for injury, and environmental conditions fostering gas exchange and uptake of ozone by the plant, CHIC was desig-

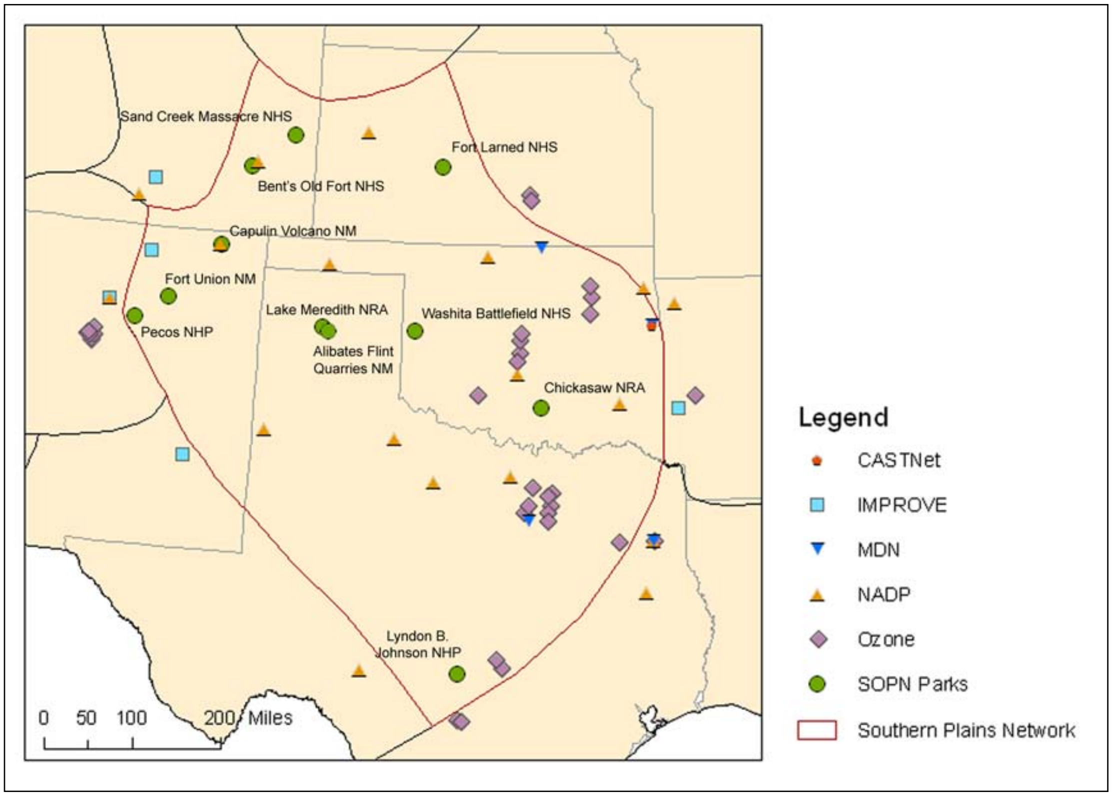


Figure 1.2.7. Air quality monitoring stations in and in the vicinity of the SOPN.

nated as high-risk, LYJO as moderate-risk, and all other SOPN parks as low-risk.

1.2.8 Land use/land cover issues

Landscape ecology—which focuses on patterns and processes at multiple spatial and temporal scales of the landscape mosaic—is particularly important to grassland systems, which evolve to a shifting mosaic of successional stages as the grassland is continually reset by disturbances from fires, drought, and grazing. The ecological communities within SOPN parks are as influenced by the ecological processes and anthropomorphic activities occurring outside park boundaries as they are by management within the park.

Anthropogenic influence appears to be one of the major stressors on SOPN systems, as it tends to interrupt key processes, like fire and grazing, which historically maintained the grassland ecosystem. Human development has also fragmented the landscape, decreasing the size of the functional ecosystem, reducing connectivity among native habitat patches, isolating species in small patches, and introducing edge effects across the landscape. These disruptive processes have lessened the fitness of native species residing in the park, increasing the probability of extinction within parks.

Table 1.2.7. Types of air quality monitoring occurring in the SOPN area.

Monitoring type	Focus	Conducted by
Ozone	Ozone	States
Wet deposition (rain, snow)	Atmospheric pollutants	National Atmospheric Deposition Program/ National Trends Network
Wet deposition	Mercury	Mercury Deposition Network
Dry deposition (dryfall)	Atmospheric pollutants	Clean Air Status and Trends Network
Visibility	Visibility	Interagency Monitoring of Protected Visual Environments

Fort ruins at Fort Union National Monument.

SOPN landscape patterns are also affected by processes operating at spatial and temporal scales broader than the Great Plains. Changes in global climate may alter precipitation and temperature gradients, subsequently changing landscape patterns. Atmospheric constituents can influence vegetation composition. Acidification via sulfide-dioxide (SO_2) pollution has altered the grassland community (Heil et al. 1988, Lauenroth and Preston 1984). More recent concerns involve acidification caused by increased nitrification from increased nitrogen deposition; this phenomenon may be amplified at nutrient-poor sites.

1.2.9 Human history

The Great Plains have been an important area for agriculture, recreation, and human expansion over the last 150 years. As all SOPN cultural parks have designated periods of significance dating to after European settlement, the management goals at these parks include achieving a landscape that had already been dramatically altered by Europeans. Settlers quickly impacted the prairie's rich faunal communities. Though scholars have argued over the specific combination of causes leading to its decimation, the bison population was especially hard-hit, subject to mass slaughter due to market hunting as well as political agendas. Lt. General Phil Sheridian told the Texas legislature that buffalo hunters were doing more to:

> *settle the vexed Indian question than the entire regular army . . . for the sake of a lasting peace let them kill, skin, and sell until the buffaloes are exterminated. Then your prairie can be covered with speckled cattle, and the festive cowboy, who follows the hunter as the second forerunner of an advanced civilization.*

Following the Homestead Act of 1862, nearly 1.5 million people acquired more than 308,880 square miles (800,000 km^2) of Great Plains land, resulting in a huge conversion of native prairie to row-crop agriculture. As much as 70% of Great Plains grasslands may have been lost. In the SOPN, losses ranged from 69% in the Edwards Plateau of Texas, to 46% in the central mixed prairie, to 36% and 45% in the central and southern shortgrass prairie, respectively (Samson et al. 2004). In addition, Samson et al. (2004) estimated that 36,000 square miles (93,000 km^2) of grasslands were converted to agriculture between 1982 and 1997.

Today the shortgrass prairie is predominantly used for grazing, and the mixed-grass prairie comprises the "wheat belt." Many birds have moved into the region due to human practices (e.g., tree planting, agriculture, development). In contrast, some native species (e.g., prairie dogs) are still heavily persecuted and managed because of perceived and real conflict with current land-use practices.

Agriculture is still the most important industry, with ranching predominate in the western portion of the SOPN and farming predominate in the eastern portion. Ownership has changed from small family farms to consolidated large farms owned by corporations. Wildlife resources still present in the region, especially game species, are valued by local residents; in some areas, profits from hunting leases exceed those from agriculture. However, high fences erected to protect trophy-quality native game as well as exotic game fragment populations of medium- and large-sized mammals. Mineral and energy development are important, especially in western Oklahoma and the Texas panhandle. Urbanization is a concern at CHIC, LAMR, and LYJO, yet many SOPN park units are located significant distances from the nearest towns with year-round services. In these areas, light development near park boundaries is a concern, as even a small new development can have a very large impact on the night sky.

1.2.10 Individual park summaries

1.2.10.1 Alibates Flint Quarries National Monument

Alibates Flint Quarries National Monument (1,371 acres [555 ha] in size and adjacent to LAMR) was created in 1965, to preserve the extensive flint quarries that were once used by prehistoric humans as a source of raw material for weapons and tools. ALFL also protects the ruins of several village sites of the Plains Village Indians, who inhabited the area circa 1200–1450 A.D. The park remains undeveloped; therefore, it is only open for guided tours. The landscape is rough and broken, having been cut by the Canadian River and its tributaries. The primary vegetative community at ALFL is mixed grassland. The most serious concern for ALFL is erosion, which is affecting both the structural ruins and the terrain and is facilitating the invasion of non-native plant species.

1.2.10.2 Bent's Old Fort National Historic Site

Bent's Old Fort National Historic Site covers 799 acres (323 ha) along the Arkansas River in southeastern Colorado. The original adobe fort was constructed in 1833, to serve as a trade center on the Santa Fe Trail. For much of the original fort's history, it was the only major permanent white settlement on the Santa Fe Trail. In addition to supplying goods to pioneers and the military, the fort became a staging area for the U.S. Army during the U.S.–Mexican War in 1846. The fort was abandoned in 1849, and established as a national historic site in 1960. BEOL falls within the Arkansas Tablelands section of the Great Plains-Palouse Steppe ecoregion (Bailey 1995). In addition to the Arkansas River, BEOL contains several wetlands and ponds. Maintaining the integrity of the riparian habitats, particularly the cottonwood/willow communities, is one of the highest concerns for BEOL managers. Native vegetation in the riparian habitats, as well as in other areas of the park, is being displaced by undesirable invasive species.

1.2.10.3. Capulin Volcano National Monument

Capulin Volcano National Monument was established to preserve a volcanic cinder cone that formed more than 60,000 years ago. The park include 793 acres (321 ha) in northeastern New Mexico. Primary vegetation types at CAVO are grasslands, which are growing upon the remnants of lava flows that originated thousands of years ago, and piñon-juniper woodlands that may be encroaching upon the grasslands on and at the top of the cone. One of the biggest concerns for CAVO is erosion of the cinder cone. The endemic Alberta arctic butterfly (*Oeneis alberta capulinensis*) is found only at CAVO and five other mountaintops in the region.

1.2.10.4 Chickasaw National Recreation Area

Chickasaw National Recreation Area comprises 9,889 acres (4,002 ha) in south-central Oklahoma. In the late 1800s, the Chickasaw and Choctaw Native American tribal units recognized threats to the freshwater and mineral springs in this area and, consequently, requested that the federal government establish sustainable management practices (Wikle et al. 1998). This request ultimately led to the establishment of CHIC. Today, water-based recreation, such as fishing, boating, and water-skiing, is the largest attraction for visitors. CHIC lies within the Arbuckle Mountains geographic region and the Red River drainage basin. Mixed grasslands and oak forests cover a large portion of the upland areas, while riparian vegetation dominates the lowlands. The two largest bodies of water at CHIC are the Lake of the Arbuckles and Veterans Lake. The most significant threats facing CHIC include erosion along lakes and streams, exotic plant invasions, visitor effects on natural resources, water mining, and adjacent land-use practices.

1.2.10.5 Fort Larned National Historical Site

Fort Larned National Historical Site encompasses 718 acres (291 ha) along the banks of the Pawnee River, most of which falls within the Pawnee River floodplain. Fort Larned, originally established to protect traffic along the Santa Fe Trail, became a key U.S. military base during the Indian Wars. Prior to European settlement, the landscape at FOLS was covered with mixed-grass prairie and small wooded areas in the riparian areas of the Pawnee River. With agricultural development, prairies were converted to croplands, and woodlands were destroyed. The consequences of these changes are still a concern for park managers. Prairie restoration tops the list of management issues at this park.

1.2.10.6 Fort Union National Monument

Fort Union National Monument (721 acres [292 ha]) was established in 1956, to preserve and protect the historic fort situated on the Santa Fe Trail in New Mexico. FOUN was originally constructed in the mid-19th century as a military fort to guard the trail and supply other forts in the Southwest. Later, significant military campaigns were operated out of FOUN against Native American Tribes and in the U.S.–Mexican and Civil wars. The primary ecosystem present at FOUN is shortgrass prairie. The two largest natural resource concerns for FOUN managers are invasive plant species and burrowing animals, which affect the ruins.

1.2.10.7 Lake Meredith National Recreation Area

Lake Meredith was formed in the 1962, when the U.S. Bureau of Reclamation constructed the Sanford Dam on the Canadian River. The lake was created to supply water to 11 surrounding communities, with recreational use of the area as a secondary purpose. LAMR was designated as a national recreation area in 1990, at which time its management was transferred from the U.S. Bureau of Land Management to the NPS. The landscape at LAMR, covering 46,349 acres (18,757 ha), is characterized as rough and broken, and can be divided into two distinct areas: (1) the upland area, including the mesa top, with a steep, gravelly slope; and (2) the bottomland area surrounding the reservoir.

1.2.10.8 Lyndon B. Johnson National Historical Park

LYJO preserves the birthplace, boyhood home, ranch, and final resting place of the 36th president of the United States, as well as several other structures associated with the president and his ancestors. The two districts of LYJO, one consisting of the LBJ Ranch and the other of properties in Johnson City, Texas, total 674 acres (273 ha). LYJO lies in the Hill Country of south-central Texas, and has a landscape of forested hills and grasslands. The Pedernales River, a tributary to the Colorado River, flows through the park. Several other small streams and ponds are also located within park boundaries. Erosion along stream banks and restoration of grasslands are the predominant concerns for LYJO.

1.2.10.9 Pecos National Historical Park

Pecos National Historical Park (6,670 acres [2,699 ha]) was designated in 1965, to preserve an exceptional cultural and natural area with a long human history. Historically, the Pecos River Valley was a diverse area, with successive populations funneling through it. Paleo-Indians, archaic people, basket makers, and Puebloan peoples all left evidence of early use and settlement in the valley. At PECO, a fortress-like pueblo was established during the 15th century and became a trading center for the region. The Spanish established a mission at PECO in the late 16th century. PECO became a trading post in the 19th century, and was later used for military expeditions during the U.S.–Mexican and Civil wars. The Battle of Glorieta, which occurred at this site, is considered one of the most important southwestern battles of the Civil War. Most of PECO lies in the upper Pecos River valley, bordered by the 13,000-foot Sangre de Cristo Mountains to the north, the rugged hills of the Tecolote Range to the east, and the steep Glorieta Mesa to the west. Glorieta Pass connects Apache Canyon area and the northern Rio Grande Valley to the High Plains and shortgrass prairie of New Mexico (Reed et al. 1999). Two of the largest natural resource management concerns are invasion of grasslands by piñon pine and exotic plant species.

1.2.10.10 Sand Creek Massacre National Historic Site

Sand Creek Massacre National Historic Site (2,400 acres [971 ha]) lies along a 5.5-mile (8.85 km) stretch of Big Sandy Creek in southeastern Colorado. The landscape of SAND consists largely of mixed-grass prairie and wooded riparian areas. Trees on the site are eastern cottonwood, found in even-aged groves close to current or historic seasonal stream traces of Big Sandy Creek. SAND is within the Central High Plains section of the Great Plains-Palouse Dry Steppe Province ecoregion. SAND commemorates the Sand Creek Massacre of November 1864, when 700 U.S. volunteer soldiers were led into the area to attack and kill more than 150 Cheyenne and Arapaho people, mainly women, children, and the elderly, who were peacefully encamped along Big Sandy Creek. SAND recognizes the significance of this massacre in American history, and its ongoing importance to the Cheyenne and Arapaho people and descendants of the massacre victims. The park's authorizing legislation directs the NPS to manage the site as close as practicable to the 1864 cultural landscape.

1.2.10.11 Washita Battlefield National Historic Site

Washita Battlefield National Historic Site (326 acres [132-ha]), located on the banks of the Washita River, protects and interprets the site where the 7th U.S. Cavalry, led by George Armstrong Custer, attacked the Southern Cheyenne village of Chief Black Kettle in November 1868. The site has cultural and historical value for the Cheyenne and other Southern Great Plains tribes; its protection supports their ongoing efforts to maintain control of their traditional homelands (Milner 2003). The surrounding landscape is classified as dry plains, steppe with moderate valley slopes (2–20%), and a gently rolling topography (Bergey 2003). The 1930s Dust Bowl (Inglis 2001) drastically changed local ecosystems, particularly soil health and water quality and quantity. Restoring natural environmental conditions is the primary concern of land managers at WABA.

1.3 Vital Signs Development

This section presents the SOPN's approach to developing its initial list of potential vital signs. Important management issues for SOPN parks were identified through a variety of methods, including park-based scoping sessions, an issue/stressor survey, a survey of park planning documents, a review of peer-reviewed literature, and ecosystem workshops and reviews.

1.3.1 Park-based scoping

SOPN staff visited all 11 SOPN parks from January through May 2004. At each park, natural resource staff gave SOPN staff a tour and overview of natural resources, and network staff collected information in the form of reports, maps, and GIS coverages. SOPN staff then gave an overview presentation to park staff and held a scoping session regarding the park's most important resources and biggest monitoring needs. A total of 64 people attended these presentations.

The scoping sessions took the form of an interview and discussion that covered important natural resource issues and their stressors, current and historic monitoring projects in and around the park, potential partners, outside scientists with expertise in the park, natural resource needs, and ways to best communicate with parks. Thirty-four park staff participated in the scoping sessions. Natural resource staff, superintendents, and any additional staff or outside experts that park staff chose to include were invited, and scoping questionnaires were sent to an additional 11 people whom the parks identified as having experience with park natural resources. The information gathered was essential in laying the foundation for a monitoring program that will meet park needs. Reports of the park-based scoping sessions are in Appendix M of Perkins et al. (2005).

1.3.2 Issues identified in park documents

An extensive review of park planning documents was completed in 2004 and 2005. This review included general management plans, resource management plans, fire management plans, integrated pest management plans, administrative histories, gray literature, and enabling legislation (often as interpreted through planning documents) for all 11 SOPN parks. These documents establish the local mandates for management in these units, and are therefore directly relevant to ecological monitoring.

1.3.3 Natural resource issue/ stressor survey

Upon completing the scoping sessions, SOPN staff compiled lists of all the natural resources and stressors that were identified from the 11 parks. Resources and stressors discovered during the literature review were then added to the list. This information was converted into an MS Access database and sent to each park's TC representative, who was asked to assign one of the following rankings to each resource and stressor: high-priority, priority, issue at park but low priority, and not an issue. Parks were asked to limit their high-priority rankings to fewer than five issues and five stressors. The responses were compiled to create a prioritized list of natural resources and stressors for each SOPN park and for the SOPN as a whole. A complete list of the 85 ranked issues is found in Appendix O of Perkins et al. (2005).

1.3.4 Ecosystem workshops and reviews

In 2005, the SOPN held two ecosystem workshops that brought together representatives from each park and subject-matter experts from state and federal agencies, universities, and non-profit organizations. The objectives of the workshops were to (1) review draft conceptual models (see Chapter 2) and provide suggestions for modifications and possible additional models; (2) review the database of SOPN natural resources and stressors; and (3) develop and review the list of potential vital signs and their preliminary justification statements and monitoring objectives. All parks were represented at each workshop, and a total of 31 outside experts attended. The first workshop was divided up into a mixed-grass and shortgrass workgroup. The second workshop had three workgroups: reservoirs, rivers and streams, and landscape issues (i.e., land cover, air quality, land uses). A report was sent to all participants at the conclusion of the workshop (Appendix P in Perkins et al. 2005).

1.3.5 Network-wide issues

The above approach allowed park-specific information to receive multiple layers of review and evaluation, leading to the identification and aggregation of issues important at both the network and park scales and a preliminary determination of high-priority issues across the network (Table 1.3.5). The workgroups ranked an issue as high only if there was consensus among group members. Ratings from the five workgroups resulted in identification of 23 high-priority network issues out of a total of 93 reviewed.

1.3.6 Park-specific issues

Issues of high priority to parks, but not to the network as a whole, were also considered in vital signs selection. Table 1.3.6 shows 23 issues ranked as high-priority by individual parks during scoping sessions and the natural resource/issue survey, but were not identified as high-priority at the workshops.

1.3.7 Vital signs selection

The selection process concluded over two meetings in with the network's technical committee and board of directors. A draft list of 29 potenial vital signs was produced during the January 2005 meeting. The final list of 11 SOPN vital signs was selected at the March 2005 meeting and are listed below.

- Soil Structure and Chemistry
- Ground Water Levels
- Water Quantity–Surface
- Water Quality–Core Parameters
- Exotic Plants
- Riparian Vegetation Communities
- Grassland Vegetation Communities
- Bird Communities
- Human Demographics
- Fire and Fuel Dynamics
- Landscape Dynamics

1.4 SOPN Monitoring Approach

Monitoring is an ongoing effort to better understand how to sustain or restore ecosystems, and serves as an "early warning system" to detect declines in ecosystem integrity and species viability before irreversible loss has occurred. One of the key initial decisions in designing a monitoring program is deciding how much relative weight should be given to tracking changes in focal resources and stressors that address current management issues, versus measures that are thought to be important to long-term understanding of park ecosystems. In other words, should vital signs monitoring focus on the effects of known threats to park resources, or on general properties of ecosystem status? Possible alternatives include a strictly threats-based monitoring program, or taxonomic, integrative, reductionist, or hypothesis-testing monitoring designs (Woodley et al. 1993, Woodward et al. 1999, Jenkins et al. 2002). The SOPN will attempt to achieve a balance among differ-

Table 1.3.5. Issues identified as high-priority across the network according to workgroups at SOPN grassland, aquatic, and landscape workshops.

Issue name	Mixed-grass	Shortgrass	Rivers and streams	Reservoirs	Landscape
Exotic plants	X	X	X	X	X
Grassland communities	X	X			
Carbon balance	X				
Prairie restoration	X	X			
Water quality	X	X	X	X	
Water quantity	X	X	X		
Weather patterns	X	X			X
Woody invasive species	X	X			X
Fire dynamics		X			X
Grassland birds		X			
Effects of park visitors		X			
Erosion	X		X	X	
Exotic ungulates	X				
Viewshed		X			X
Groundwater levels			X	X	
Arkansas River shiner			X		
Upland springs communities			X		
Riparian communities			X		
Cottonwood communities			X		
Riverine communities			X		
Lacustrine communities				X	
Native species communities					X
Zebra mussels			X		
Landscape dynamics					X
E. coli				X	

Table 1.3.6. High priority issues identified by individual parks that are not on the network-wide list of high-priority issues.

Park	High-priority issues
ALFL	Night sky, soundscape, Texas horned lizard
BEOL	Effects of wildlife diseases on visitors and resources, flooding processes, wetland communities
CAVO	Montane–grassland ecotone communities, cryptobiotic soils, Alberta arctic butterfly
FOLS	Small mammal communities, black-tailed prairie dogs
LAMR	Texas horned lizard, big game
LYJO	Fire ants
PECO	Effects of insect outbreaks, feral dogs, big game, reptile communities, migratory songbird stopover areas, bald eagles, large carnivores
SAND	Effects of grazing
WABA	Soundscapes

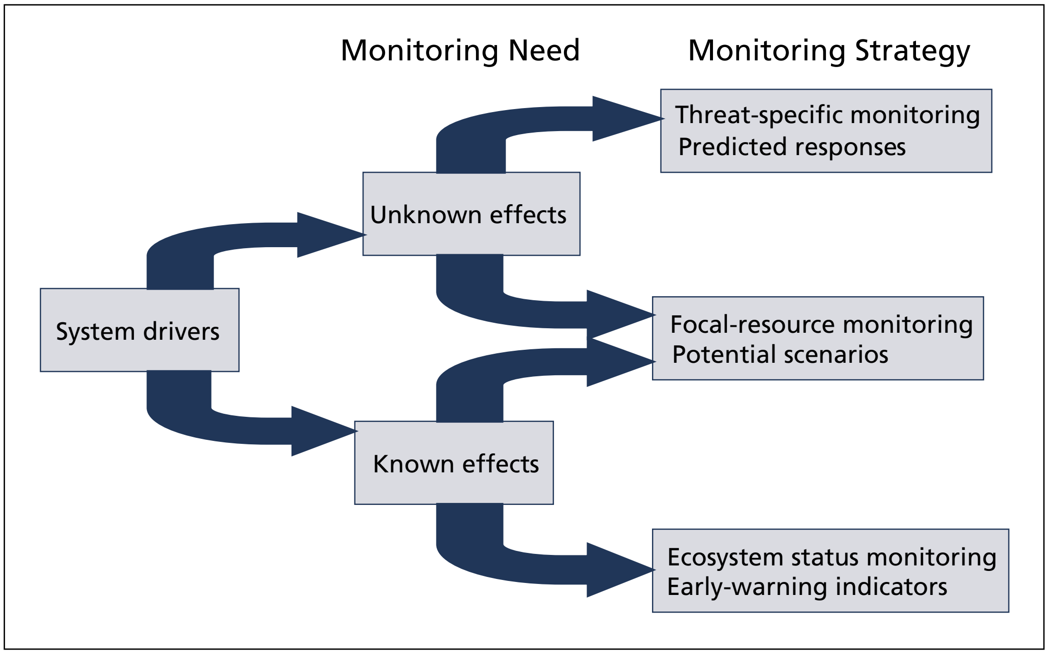


Figure 1.4.1. Conceptual approach for selecting monitoring indicators (from Woodley et al. 1993).

ent approaches (termed the "hybrid approach" by Noon 2003). A multi-faceted approach for monitoring park resources has been adapted, based on integrated and threat-specific monitoring approaches and building upon concepts originally presented for the Canadian national parks (Figure 1.4.1; Woodley et al. 1993). This system segregates indicators into one or more of four broad categories:

1. Ecosystem drivers that fundamentally affect park ecosystems;
2. Stressors/threats and their ecological effects;
3. Focal resources of parks; and
4. Key properties and processes of ecosystem integrity.

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

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

1.4.2 Limitations of monitoring

Managers and scientists need to acknowledge that monitoring has limitations due to the inherent complexity and variability of park ecosystems, coupled with limited time, funding, and staffing available for monitoring. Natural systems as well as human activities change over time, and it is extremely challenging to separate the natural variability inherent to ecosystems from the undesirable changes in park resources and ecosystems that may result from anthropogenic causes.

The SOPN monitoring program simply cannot address all resource management interests.

Table 1.4.2. Timeline for monitoring plan development and implementation in the SOPN.

FY2004		FY2005		FY2006		FY2007		FY2008		FY2009
Oct–Mar	Apr–Sept	Oct–Mar	Apr–Sept	Oct–Mar	Apr–Sept	Oct–Mar	Apr–Sept	Oct–Mar	Apr–Sept	Oct–Mar
Inventories to support monitoring										
Data gathering										
Park-based scoping sessions										
		Ecosystem workshops								
		Conceptual modeling								
				Vital signs prioritization and selection						
					Protocol development and monitoring design					
								Peer review of Phase 3		
				Phase 1, Oct. 05		Phase 2, Oct 06		Phase 3, Dec 07		Final Phase 3, Oct 08

Rather, the intent is to monitor a select set of ecosystem components and processes that reflect the condition of the park ecosystem and are relevant to management issues. Cause-and-effect relationships usually cannot be demonstrated with monitoring data, but monitoring data might suggest a cause-and-effect relationship that can then be investigated with a research study. As monitoring proceeds, datasets are interpreted, our understanding of ecological processes is enhanced, and trends are detected, future issues will emerge (Roman and Barrett 1999). This monitoring plan should therefore be viewed as a working document, subject to periodic review and adjustments over time.

1.5 Summary of Existing Monitoring Within and Surrounding Network Parks

While the I&M program presents an opportunity to establish new facets of an ecological monitoring program, it is also important to examine past and current monitoring conducted by parks and their neighbors (Table 1.5). Doing so will allow us to build upon those efforts and gain the best understanding of park natural resources. SOPN park projects were only considered to be either past or existing monitoring if measurements were taken at the same locations on several occasions. Each monitoring program is described in greater detail in Appendix Q of Perkins et al. (2005).

Table 1.5. Current and historic monitoring projects in SOPN according to their Level 3 vital signs category.

Park	Level 3 category	Project	Years data collected	Data in database?	Detailed protocol available?	Data analyzed?	Project oversight
ALFL	Fire and Fuel Dynamics	Effects of Large Wildfire	1998–2003	No	No	No	LAMR
BEOL	Vegetation Communities	Vegetation Transects	1993–Present	Yes	Yes	No	BEOL
	Mammals	White-Tailed Deer	Unknown–Present	Yes	Yes	No	Colorado Division of Wildlife
	T&E Species and Communities	Prairie Dog Town Extent	2000–Present	Yes	Yes	No	BEOL
	Invasive/Exotic Plants	Exotic Plants	2000–Present	Yes	No	No	BEOL
	Groundwater Dynamics	Water Table	2001–2003	Yes	Yes	No	BEOL
	Fire and Fuel Dynamics	Fire Plots	2002–Present	Yes	Yes	No	BEOL and Southern Plains Fire Cluster
CAVO	Insect Pests	Gypsy Moth	1999–Present	No	No	No	CAVO, US Forest Service
	Fire and Fuel Dynamics	Fire Effects	2004	Yes	Yes	Yes	Pueblo Fire Cluster
	Wet and Dry Deposition	NADP Site	1984–Present	Yes	Yes	Yes	NADP
	Grassland Vegetation	Woody Encroachment	1974–1979	No	Yes	No	Eastern New Mexico University
CHIC	Microorganisms	E. Coli	2000–Present	Yes	Yes	No	CHIC
	Surface Water Dynamics	Lake Level		Yes	Yes	No	USGS
	Groundwater Dynamics	Stream Flow		Yes	Yes	No	USGS
	Groundwater Dynamics	Spring Flow	Through 1990s, 2003–Present	Yes	No	No	Park
	Water Chemistry	Water Quality	2001–Present	Yes	Yes	No	CHIC
	Weather and Climate	Weather	1978–Present	Yes	Yes	No	CHIC
	Fire and Fuel Dynamics	Fire Effects	1999–Present	Yes	Yes	No	Southern Plains Fire Cluster
	Mammals	Deer	1999–Present	Yes	Yes	Yes	CHIC
	Invasive / Exotic Animals	Fire Ants	1999–Present	Yes	Yes	Yes	CHIC
FOLS	No Monitoring Projects						
FOUN	Fire and Fuel Dynamics	Fire Effects	2002–Present	Yes	Yes	No	Fire Cluster
LAMR	Surface Water Dynamics	Reservoir Level	1965–Present	Yes	Yes	Yes	Bureau of Reclamation
LAMR	Surface Water Dynamics	Streamflow	1965–Present	Yes	Yes	Yes	USGS
	Water Chemistry	Water Quality	1965–Present	Yes	Yes	Yes	Texas Natural Resources Conservation Commission and USGS
	Birds	Christmas Bird Count	1971–Present	Yes	Yes	No	Audubon Society

Table 1.5. Current and historic monitoring projects in SOPN according to their level 3 vital signs category, cont.

Park	Level 3 category	Project	Years data collected	Data in database?	Detailed protocol available?	Data analyzed?	Project oversight
LAMR, cont.	T&E Species and Communities	Bald Eagle Winter Survey	1994–Present	No	Yes	No	Audubon Society
	Mammals	Deer	2004–Present	Yes	Yes	No	Texas Parks and Wildlife, LAMR
	Fire and Fuel Dynamics	Fire Effects	1999–Present	Yes	Yes	No	Southern Plains Fire Cluster
	Microorganisms	E. Coli	1999–Present	No	Yes	Yes	LAMR, Canadian River Municipal Water Authority
	Fishes	Game Fish	1994–Present	Yes	Yes	No	Texas Parks and Wildlife
LYJO	Water Chemistry	Water Chemistry	1996–Present	Yes	Yes	No	Lower Colorado River Authority provides oversight
	Plant Diseases	Oak Wilt	2002–Present	No	No	No	Annual survey with Texas Forest Service
	Weather and Climate	Weather Station	2002–Present	Yes	Yes	No	Texas Forest Service
PECO	Weather and Climate	Temperature and Precipitation	1989–Present	Yes	No	No	PECO
	Birds	Christmas Bird Count	2002–Present	Yes	Yes	No	Audubon Society
SAND	Surface Water Dynamics	Stream Flow	2003–Present	No	No	No	Town of Eads Public Works Division
WABA	No monitoring projects						

Chapter 2
Conceptual Models

> ***"A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it does otherwise"***
>
> ~ Aldo Leopold, *A Sand County Almanac*

2.1 Introduction and Background

A conceptual model is a visual or narrative summary that describes the important components of an ecosystem and the interactions among those components. Conceptual models show the interconnectedness of ecological processes, whether naturally occurring or anthropogenically driven. Conceptual models further help identify how major drivers and stressors will impact ecosystem components (Barber 1994). Most relevant to the I&M program, conceptual models can help identify possible indicators for monitoring long-term ecosystem health. The SOPN created conceptual diagrams to identify and show the major natural resource issues and stressors at each park. The network then both developed new models for SOPN-specific ecosystems and adapted models used by other I&M networks with similar ecosystem types.

2.1.1 Purpose of conceptual models

Conceptual models are designed to describe and communicate ideas about how nature works. Given the complexity of natural systems and the range of factors that influence natural processes, models provide a way to organize information. Conceptual models depicting key structural components, system drivers, and their interactions assist us in thinking about the context and scope of the processes that effect ecological integrity (Karr 1991). They are also a heuristic device for expanding our consideration across traditional disciplinary boundaries (Allen and Hoekstra 1992), fostering interaction of biotic and abiotic information.

Conceptual models can take a variety of forms, from narrative descriptions to schematic diagrams or flow charts with boxes and arrows. Models generally work best when they include only the minimum amount of information needed to meet the model's purpose (Starfield 1997).

Conceptual models help meet several key goals in the design and implementation of a monitoring program (Starfield and Bleloch 1986, Turner and O'Neill 1995, Gross 2003). First, they are communication tools that structure discussion and guide collection of background information (e.g., Wright et al. 2002). Second, they aid in understanding the relevant structure and function of multiple levels of ecological organization that then allows inclusion of a system-wide perspective. Third, they allow explicit connection to management concerns by incorporating feedback between management actions and change in ecological attributes ("adaptive management"; sensu Holling 1978) into the structure and design of monitoring programs. Finally, they are key tools for selecting indicators, or vital signs, for use in long-term monitoring programs. Conceptual models provide a framework for clarifying monitoring strategies, enabling us to progress from general monitoring questions to more specific ones (Gross 2003).

2.1.2 Hierarchy of conceptual models

No single conceptual model can satisfy all needs. Spatially explicit applications such as ecological resource assessments, monitoring design (i.e., stratification), and landscape-level ecological modeling ultimately will require site-specific models. However, generalized ecological models are useful to facilitate com-

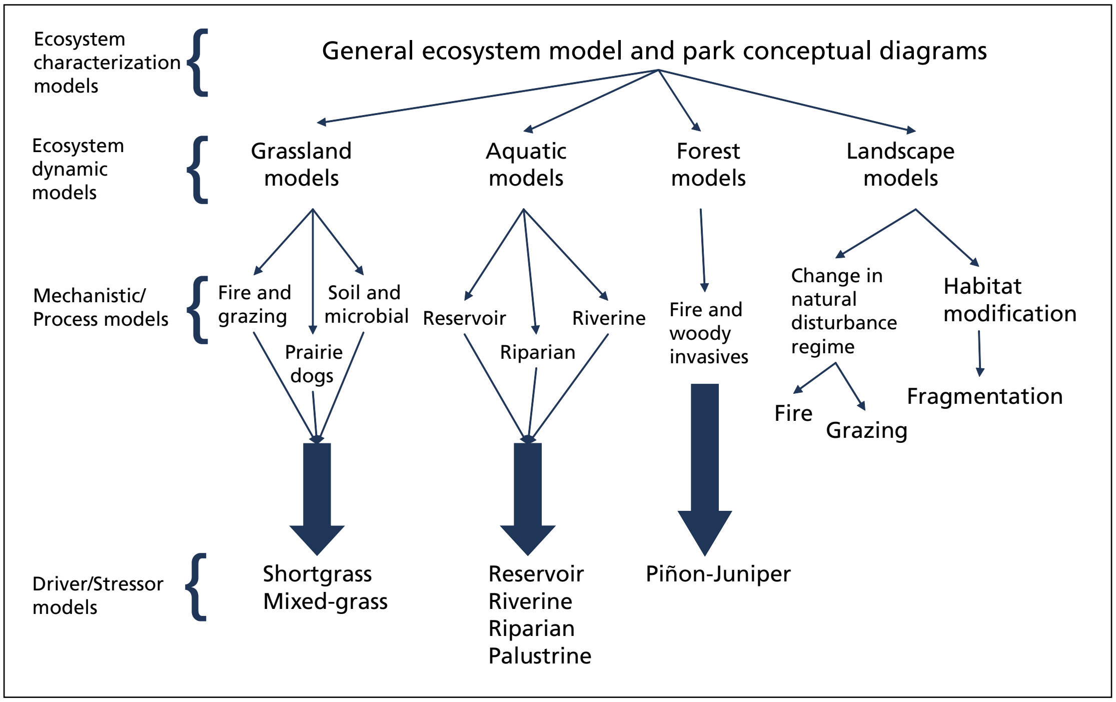


Figure 2.1.2-1. Diagram illustrating the hierarchical relationships of SOPN models. Relatively detailed models are nested within relatively simple models.

munication among scientists, managers, and the public regarding ecosystems and how they are affected by human activities and natural processes. In this way, a complex system can be broken down into a nested set of less-complex submodels that span a range of spatial/temporal scales and ecological levels (O'Neill et al. 1986, Allen and Hoekstra 1992). Processes operating at much larger or smaller scales than the process of interest can usually be aggregated. In other words, processes operating at much larger scales act as constraints on the system, while those operating at much finer scales result in dynamics that occur so rapidly that they are perceived as static.

To formulate its conceptual models, the SOPN used an iterative process that first defined a general ecological model for the network, then developed ecosystem characterization models for broadly defined ecosystem types. The SOPN will adapt and refine these models as site-specific data concerning abiotic constraints, local land-use history, current condition, and spatio-temporal ecosystem dynamics is gathered. Our ultimate aim will be to customize these models to describe local ecosystem dynamics.

The SOPN model hierarchy (Figure 2.1.2-1) includes a general ecosystem model that summarizes ideas about ecosystem sustainability at the top level as well as customized, individual-park conceptual diagrams (Appendix R in Perkins et al. 2005) that emphasize the major natural resources and stressors at each park (see Figure 2.1.2-2 for an example). For each modeled ecosystem (grasslands, aquatic systems, forests, and landscapes), there were three basic types of nested conceptual models (Figure 2.1.2-1): (1) general ecosystem characterization models, (2) ecosystem dynamics models, and (3) mechanistic models.

Ecosystem characterization models may be considered as generalized, highly aggregated models that describe the major system components, indicate the driving forces that control the system, and show the processes connecting ecosystem components. Ecosystem dynamics models present hypotheses concerning dynamics of selected components of the ecosystem. Mechanistic models provide details concerning the actual ecological processes responsible for patterns depicted in the dynamic models. For a given type of ecosystem, several dynamic submodels and mechanistic models may be required.

2.2 General Ecological Model

For monitoring purposes, it is useful to begin with a simple, general model that summarizes

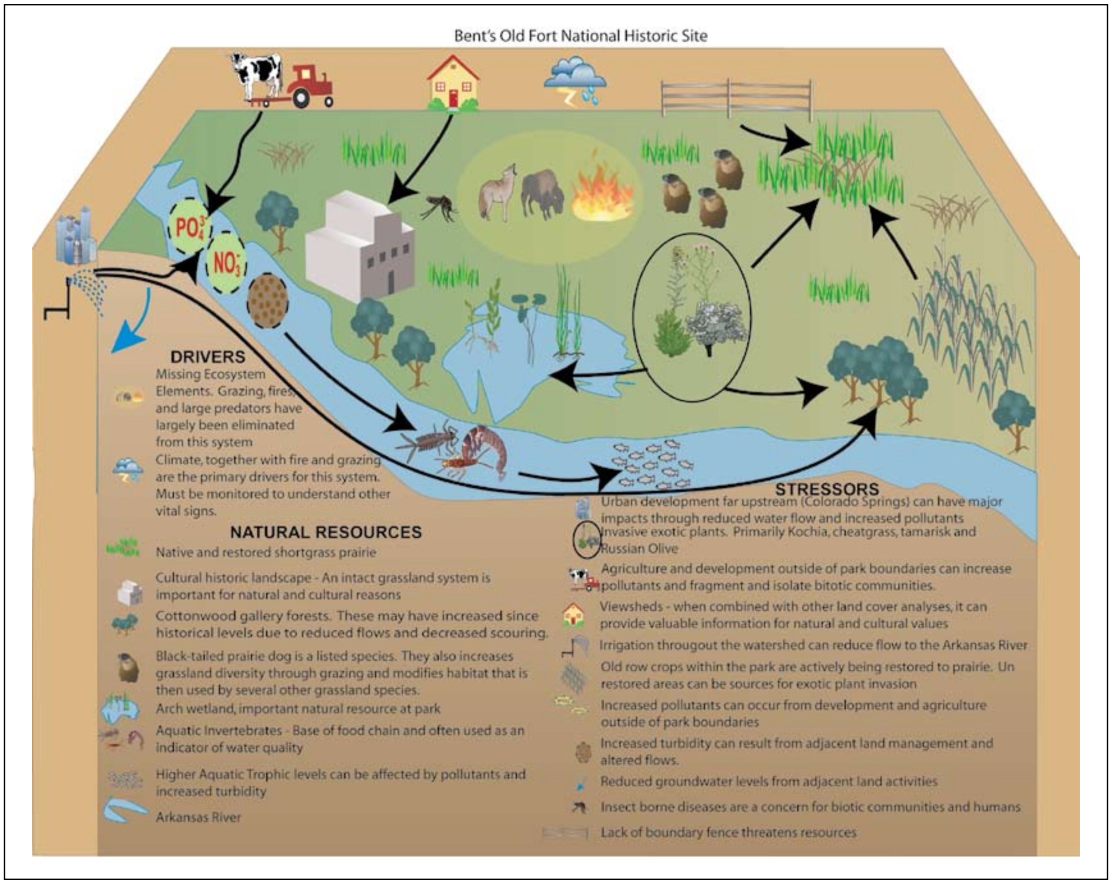


Figure 2.1.2-2. Example of a park conceptual diagram from Bent's Old Fort National Historic Site.

ideas about ecosystem sustainability. The SOPN has adopted a modified version of the interactive-control model (Jenny 1941, Chapin 1996) to serve as the general ecosystem model for conceptual-model development (Figure 2.2). The Jenny-Chapin model defines state factors and interactive controls central to the functioning of sustainable ecosystems. This general model and a set of corollary hypotheses provide a theoretical foundation for aspects of the monitoring plan related to ecosystem structure and function.

Jenny (1941, 1980) proposed that soil and ecosystem processes are determined by five state factors: climate, organisms, relief (topography), parent material, and time since disturbance. Chapin et al. (1996) recently defined a sustainable ecosystem as one that "over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996:1016). These ecosystem characteristics are determined by a set of four "interactive controls:" climate, soil-resource supply, major functional groups of organisms, and disturbance regime, and these interactive controls both govern and respond to ecosystem attributes (Figure 2.2). Interactive controls are constrained by the five state factors, which determine the "constraints of place" (Dale et al. 2000).

By substituting water quality and quantity for soil resources, the interactive-control model can be applied to aquatic as well as terrestrial ecosystems (Chapin et al. 1996). Soil, water, and air are the media from which primary producers acquire resources. As the abiotic matrix that supports the biota, they form the foundation of ecosystems. These media also are characterized by condition attributes (e.g., temperature, stability) that affect the physiological performance of organisms. In terms of the interactive-control model, the concepts of water quality and soil quality will be used interchangeably with the more descriptive concepts of water resources and conditions and soil resources and conditions, respectively. With respect to climate as it is represented in the interactive-control model, the broader concept of atmospheric resources and conditions is more precise, encompass-

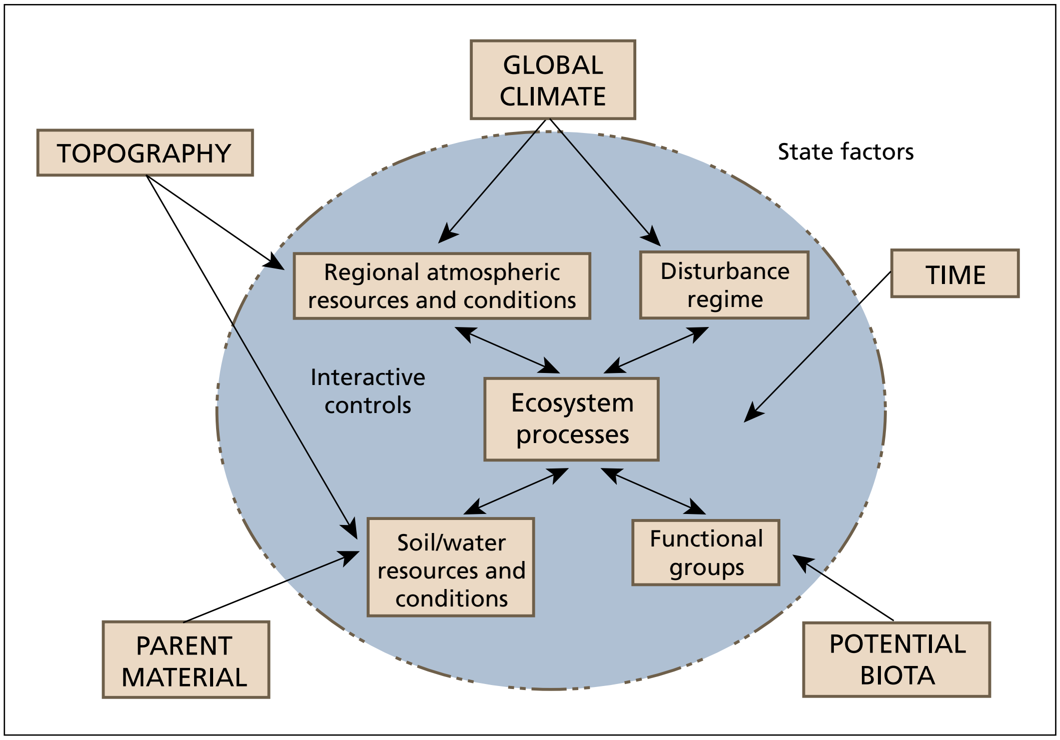


Figure 2.2. Aggregated system characterization model illustrating key ecosystem processes, characteristics and sustainability as a function of a hierarchical set of state factors and interactive controls. It may be used to "set the stage" for mode detailed, system-specific process and driver models. The circle represents the boundary of the ecosystem (from Chapin et al. 1996).

ing climatic conditions, such as temperature, resources such as precipitation and CO_2, and stressors, such as airborne pollutants.

For vital signs monitoring, a key aspect of the Jenny-Chapin model is the associated hypothesis that interactive controls must be conserved for an ecosystem to be sustained. Large changes in any of the four interactive controls are predicted to result in a new ecosystem with different characteristics than the original system (Chapin et al. 1996, Vitousek 1994, Seastedt 2001). For example, major changes in soil resources (e.g., through erosion, salinization, fertilization, or other mechanisms) can greatly affect productivity, recruitment opportunities, and competitive relations of plants, and thus can result in major changes in the structure and function of plant communities and higher trophic levels. An example with particular relevance to vital signs monitoring is that of invasive exotic species that alter ecosystem disturbance regimes (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998) and/or ecosystem resource regimes (Vitousek et al. 1987, Simons and Seastedt 1999).

2.3 Model Types

The SOPN used a variety of model types for the different ecosystems within the network. An overview of the major types used is below.

2.3.1 Ecosystem characterization models

An ecosystem characterization model can be considered as a list of state variables and functions of importance to an ecosystem that also shows how these components are connected by means of processes (Jorgensen 1986). The components and organization of an ecosystem characterization model might look somewhat similar across a range of terrestrial or aquatic ecosystems, while the relative strength of system drivers and the nature of interactions between drivers and key components might vary from system to system. The objectives of ecosystem characterization models are:

1. To illustrate major subsystems and system components and their interactions;
2. To indicate the driving abiotic factors that constrain the system, depict their relationships to key structural components and processes, and describe resultant ecosystem characteristics;
3. To describe the predominant natural disturbances that historically influenced the

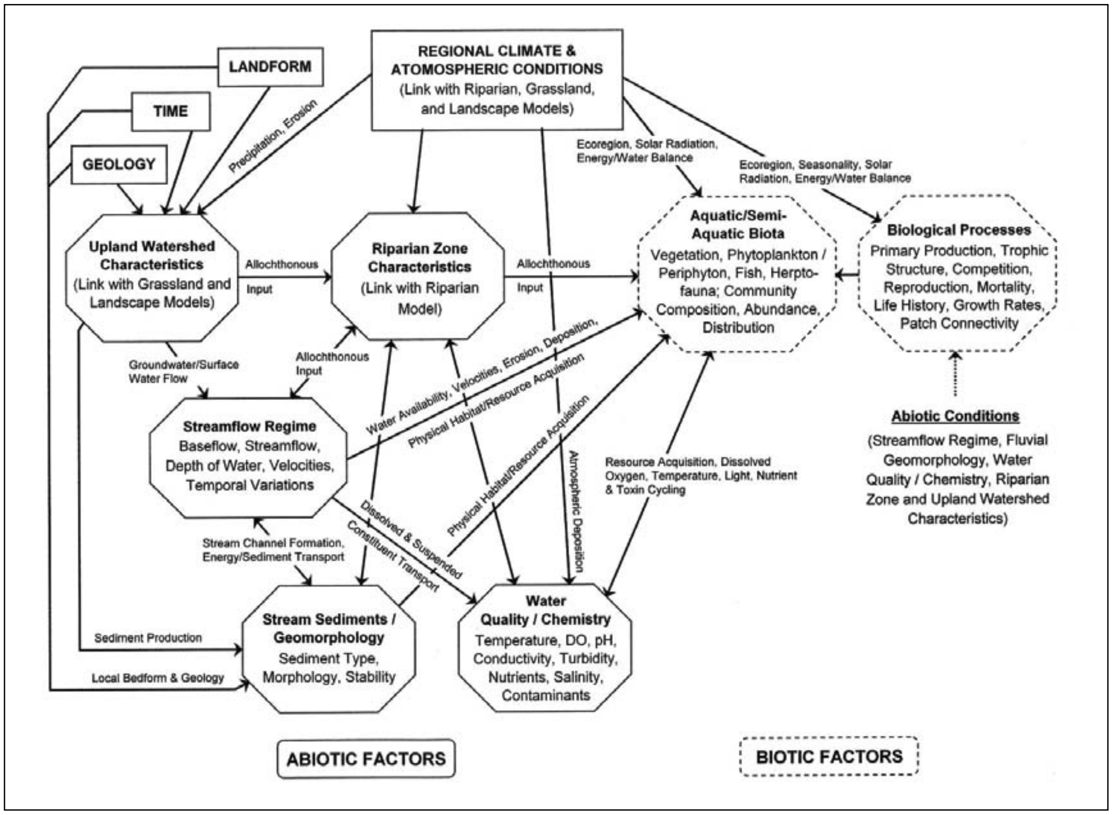


Figure 2.3.1. Example of an ecosystem characterization model for riverine systems. Rectangles indicate major drivers of ecosystem change and variability. Hexagons indicate major ecosystem components and processes (attributes). Arrows indicate ecosystem stresses and responses (functional relationships). The model is constrained by global climatic and atmospheric conditions, topography, parent (geologic) material and potential biota. Modified from Scott et al. (2005).

system, indicate their relative importance in structuring the system, and summarize ecosystem-specific disturbance patterns (return intervals, extent, magnitude, seasonality); and

4. To characterize the prevalent anthropogenic stressors that are currently affecting the system, describe their relationships to key structural components and processes, and describe resultant ecosystem effects.

By comparing and contrasting diagrammatic models for different systems, one should be able to recognize important structural and functional similarities and differences that have implications for monitoring. For example, cyclic or episodic drought may be a common overriding determinant of ecosystem dynamics in the Southern Plains, and would be portrayed similarly across the models. In contrast, the relative importance of fire as a natural driver, and the extent to which a legacy of fire suppression has altered vegetation structure, varies widely across these ecosystems, and should be characterized accordingly. Figure 2.3.1 is a diagrammatic example of an ecosystem characterization model for riverine systems.

2.3.2 Ecosystem dynamics models

Conceptual models developed to support vital-signs monitoring must reflect the current state of knowledge regarding ecosystem dynamics: how and why ecosystems change as a consequence of interacting natural and human factors. Ecosystem-dynamics models thus represent the next level of detail in conceptual modeling required by the SOPN. The objectives for ecosystem dynamics models are:

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

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

3. To illustrate key anthropogenic disruptions to system drivers; and

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

Figure 2.3.2 is an example of an ecosystem dynamics model for grasslands.

Figure 2.3.2. The Fire-Grazing submodel depicts three potential pathways for community composition changes that result from interactions of fire and grazing, as well as a fourth pathway that results in the conversion of any grassland community to agricultural lands.

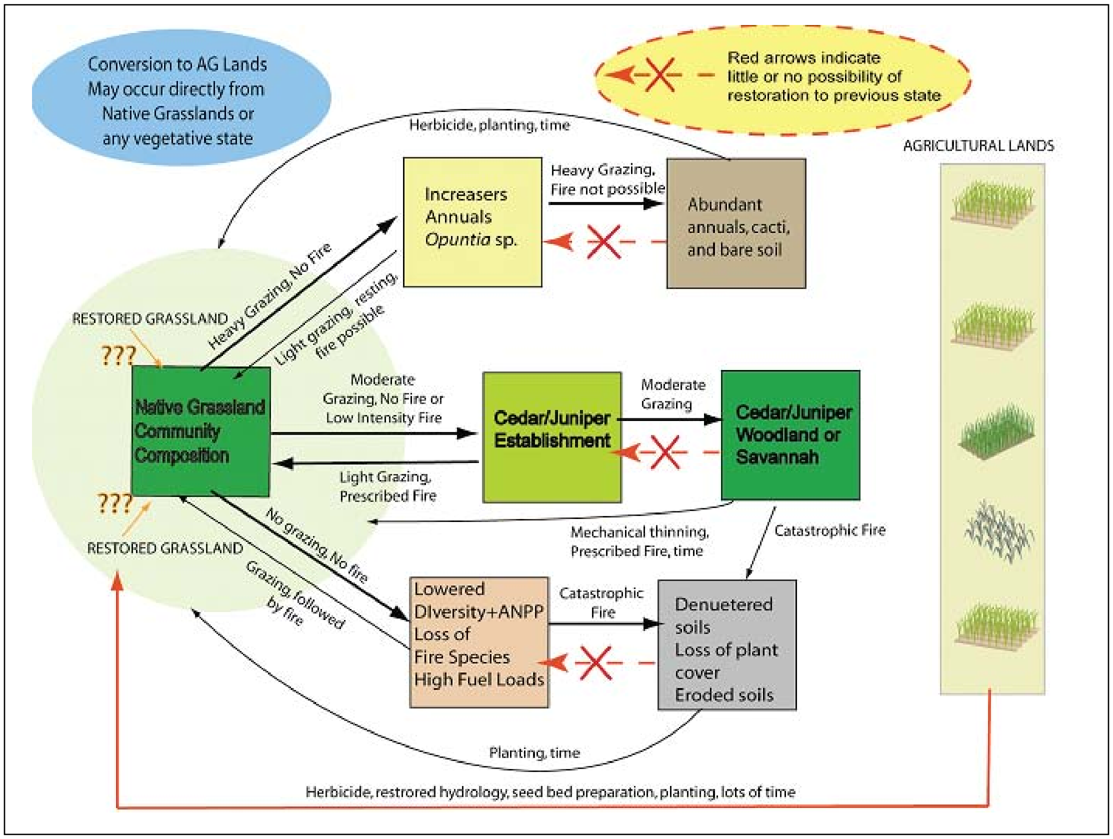
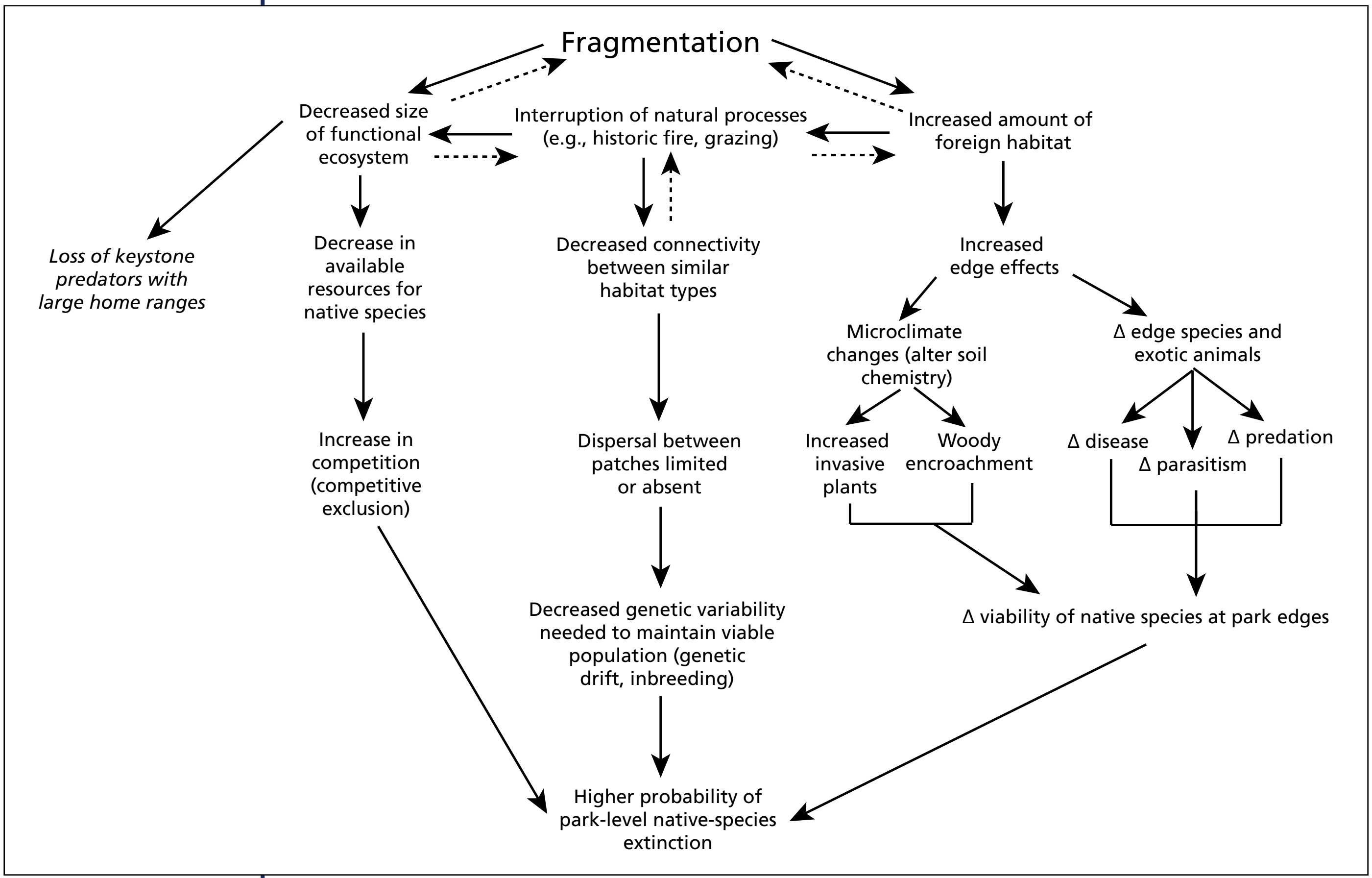


Figure 2.3.3. Example of a mechanistic model for fragmentation in SOPN parks.



2.3.3 Mechanistic and process models

Mechanistic models provide details concerning the ecological processes responsible for patterns depicted in ecosystem dynamics models. Anticipatory indicators can be suggested by detailed mechanistic models that focus on processes leading to particular (undesirable) ecosystem transitions. They may also provide insight into pathways and primary or secondary effects of particular stressors (Figure 2.3.3). Mechanistic models should provide the necessary level of detail to suggest specific monitoring attributes or measures and to link them to the broader ecosystem context.

2.3.4 Stressor models

Stressor modes are designed to articulate the relationships between stressors, ecosystem components, effects, and (sometimes) indicators. Stressor models normally do not represent feedback, and they include only a very selective subset of system components pertinent to a monitoring or other program. The intent of a stressor model is to illustrate sources of stress and the ecological responses of the system attributes of interest. These models are founded on known or hypothesized ecological relationships—frequently derived from control models—but they do not attempt a mechanistic representation of the system. Stressor models are likely to clearly communicate the direct linkages between stressors, ecological responses, and indicators. Figure 2.3.4 is an example of a stressor model for shortgrass prairie ecosystems.

2.4 Ecosystem-Specific Models

The full model descriptions and diagrams are presented in Appendices S, T, U, V, and W, in Perkins et al. (2005). Brief outlines of the models and submodels are presented here.

2.4.1 Grassland models

Grasslands are the most dominant ecosystem within SOPN parks. The grassland models (Appendix S in Perkins et al. 2005) begin with a pictorial diagram of the major processes and components for grassland systems in the Southern Plains region. The next level of models were stressor models for shortgrass and mixed-grass prairies. The major drivers for these systems are climate, fire, and grazing. An ecosystem dynamics model was then developed to show the potential pathways that can result from various levels of grazing and fire. Important components of grassland systems that are important to SOPN parks were then further developed in sub-models. These models were black-tailed prairie dogs and soil and microbial processes.

2.4.2 Aquatic models

Aquatic ecosystems are second in importance only to grasslands in SOPN parks. While they take up a relatively small proportion of the landscape in the Great Plains region, they are often areas of high species diversity. Aquatic models were divided up into three types: rivers and streams (riverine), reservoirs (lacustrine), and prairie wetlands (palustrine). Riverine and lacustrine models can be found in Appendix W in Perkins et al. (2005). The palustrine model was developed by the Heartland network and adapted to fit the SOPN (Appendix V in Perkins et al. 2005).

Riverine models focus on biotic components and three major abiotic components: streamflow regime, fluvial geomorphic processes, and water chemistry. Lacustrine models focus on water sources, morphometry, mixing patterns, and trophic levels. Palustrine models focus on natural hydrologic processes of drying and inundation, anthropogenic threats from development and agriculture, invasive species, and the alteration of the hydrologic regime.

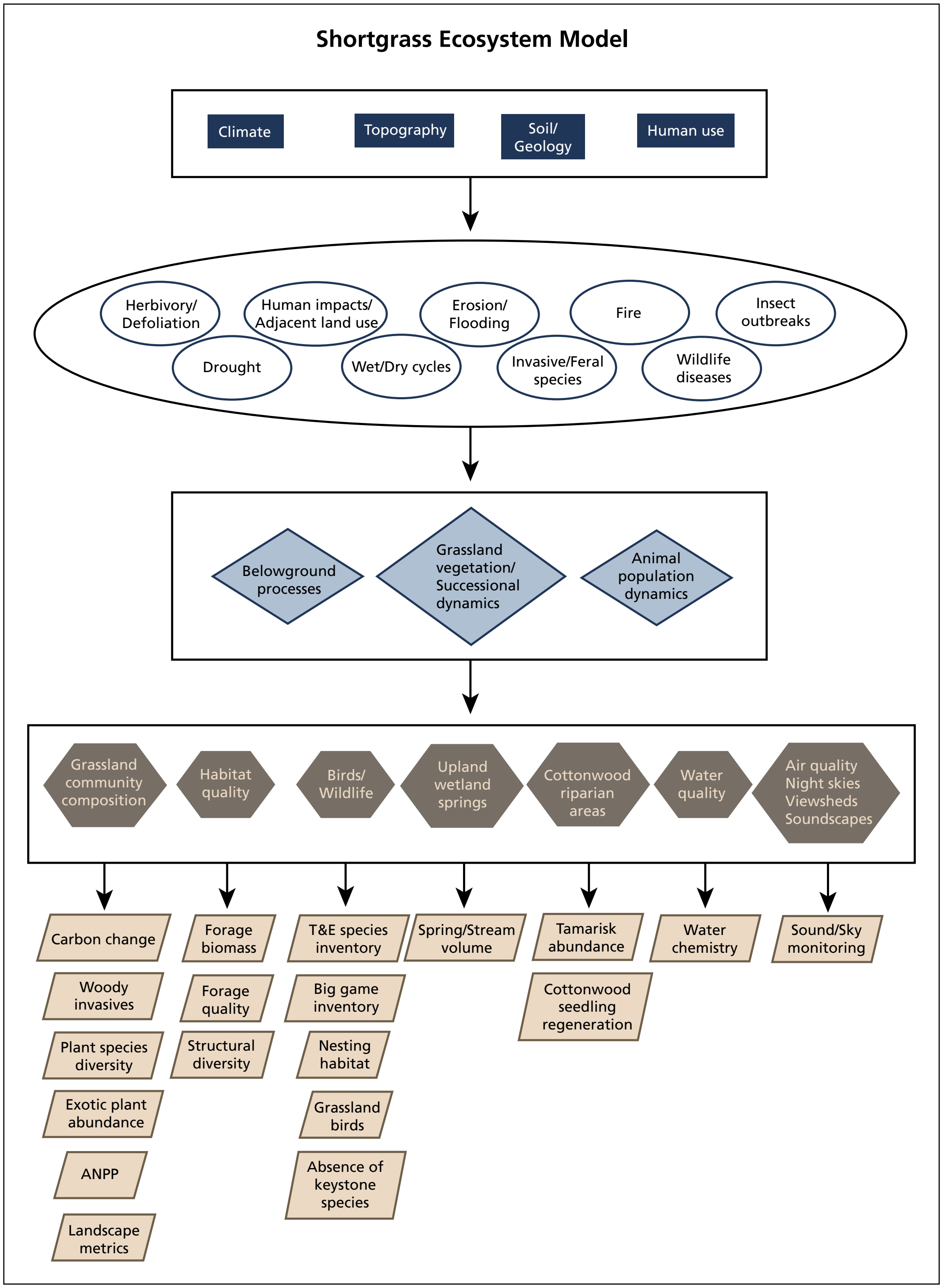
2.4.3 Forest models

Piñon-juniper forests represent a dominant ecosystem at the two SOPN parks in which they are present (CAVO and PECO). Forest models for these systems can be found in Appendix U in Perkins et al. (2005). A stressor model and a mechanistic model that focuses on grazing and fire regimes and how they influence woody plant establishment were developed.

2.4.4 Landscape vulnerability models

Due to the small size of SOPN parks, and their

Figure 2.3.4. Example of a stressor model. These models emphasize the drivers (boxes), stressors (ovals), ecological effects (diamonds), indicators (hexagons) and measurements (parallelograms).



existence within a matrix of agriculture, the SOPN developed landscape vulnerability models. The landscape models can be found in Appendix T in Perkins et al. (2005). The general landscape model identifies residential development, commercial development, agriculture, and management on neighboring lands as the major landscape stressors. These stressors can lead to a change in the natural disturbance regime and habitat modification, for which two submodels were developed. Nested underneath the change in natural disturbance regime were fire and grazing submodels. The major impacts of habitat modification were outlined in a fragmentation submodel.

2.5 Summary

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

- A literature-based context for continued deliberations;
- Multiple ecological frameworks as a basis for vital sign integration discussions;
- deliberate ecological assessment foundations with clear information legacy; and
- assessments of relevant spatial and temporal scales.

Importantly, the SOPN conceptual modeling efforts described revealed several potential vital signs that did not come up in park scoping sessions and helped to justify some potential high-priority issues identified by park managers.

Chapter 3
Vital Signs

> *"The prairie, in all its expressions, is a massive, subtle place, with a long history of contradiction and misunderstanding. But it is worth the effort at comprehension. It is, after all, at the center of our national identity."*
> *~ William Least Heat Moon,* **PrairyErth**

In this chapter, we describe the process used to prioritize and select the SOPN vital signs. As the conceptual ecosystem models developed in Chapter 2 demonstrate, a variety of biological, chemical, and physical factors interact with plant and animal communities; the overall condition, or "health," of park ecosystems is determined by the interactions of these components. Because it would not be possible to monitor all these components, and ecosystem condition cannot be measured directly, we have identified vital signs that characterize entire park ecosystems, yet are simple enough to be effectively and efficiently monitored (Dale and Beyeler 2001). The SOPN developed a list of 29 selected vital signs through a multiple-step process, including scoping sessions, literature reviews, ecosystem workshops, a prioritization workshop, a selection meeting, and, finally, a presentation to the network's board of directors (Figure 3.1).

3.1 Overview

3.1.1 Identifying potential vital signs

The process of selecting vital signs started in 2003, when the SOPN began to develop a list of potential vital signs. This list was developed through scoping sessions with each SOPN park, a review of peer-reviewed and gray literature, a preliminary survey of resource issues and stressors, conceptual-model development, and ecosystem workshops (see chapters 1 and 2). Conceptual ecosystem models and ecosystem workshops ensured that our list or potential vital signs had ecological relevance, particularly if the vital sign was a surrogate for a target process or resource. The park scoping sessions ensured that we were pursuing vital signs relevant to park issues and management decisions. This process resulted in a list of 93 potential vital signs presented in the SOPN Phase I Report (Perkins et al. 2005).

3.1.2 Prioritization of vital signs

SOPN staff revised and combined the 85 potential vital signs (Appendix J) from the Phase I Report into a list of 74 potential vital signs for further evaluation. Early in the process, it was decided that the selected vital signs should focus on issues that were common across the network, rather than high-priority in individual parks. To accomplish this goal, SOPN developed a scoring system based on those used by other networks and discussions with the TC. The scoring system was based on three criteria, weighted as follows: management significance (40%), ecological significance (40%), and feasibility/cost of implementation (20%). Each criterion included between five and eight statements with which participants were asked to either agree or disagree (Table 3.1.2). The score for each vital sign depended on how many statements with which the evaluator(s) agreed. The mean from all parks was taken to generate one, network-wide management-significance score for each vital sign (Table 3 in Appendix K, Perkins et al. 2006).

In January 2005, the SOPN held a workshop in Amarillo, Texas, attended by 44 subject-matter experts from universities, non-profits, government agencies, the TC, and SOPN staff (Table 1 in Appendix K, Perkins et al. 2006). The goal of the workshop was to create a prioritized list of vital signs by combining the existing management significance scores with ecological significance and feasibility/cost of implementation scores created by workshop participants.

The prioritization workshop was divided up into four workgroups: plants and soils, wildlife, aquatic resources, and landscape-level issues. Each workgroup reviewed a unique set of potential vital signs all in an Access database with fields for potential monitoring questions, potential measures, and justification for each vital sign. When the same vital sign was reviewed by more then one group, the mean of the groups was taken. Six new vital signs were added to the original 74 vital signs, resulting in a prioritized list of 80 vital signs (Table 6 in Appendix K, Perkins et al. 2006).

The prioritized list was presented to the workshop participants, and vital signs rated in the top 25% were given back to each workgroup for two final assignments. Each workgroup was asked if they felt there were any essential vital signs that were missing from the top 25% (see Appendix K) and asked to brainstorm potential existing protocols, existing monitoring programs, and potential partners for each of the top vital signs.

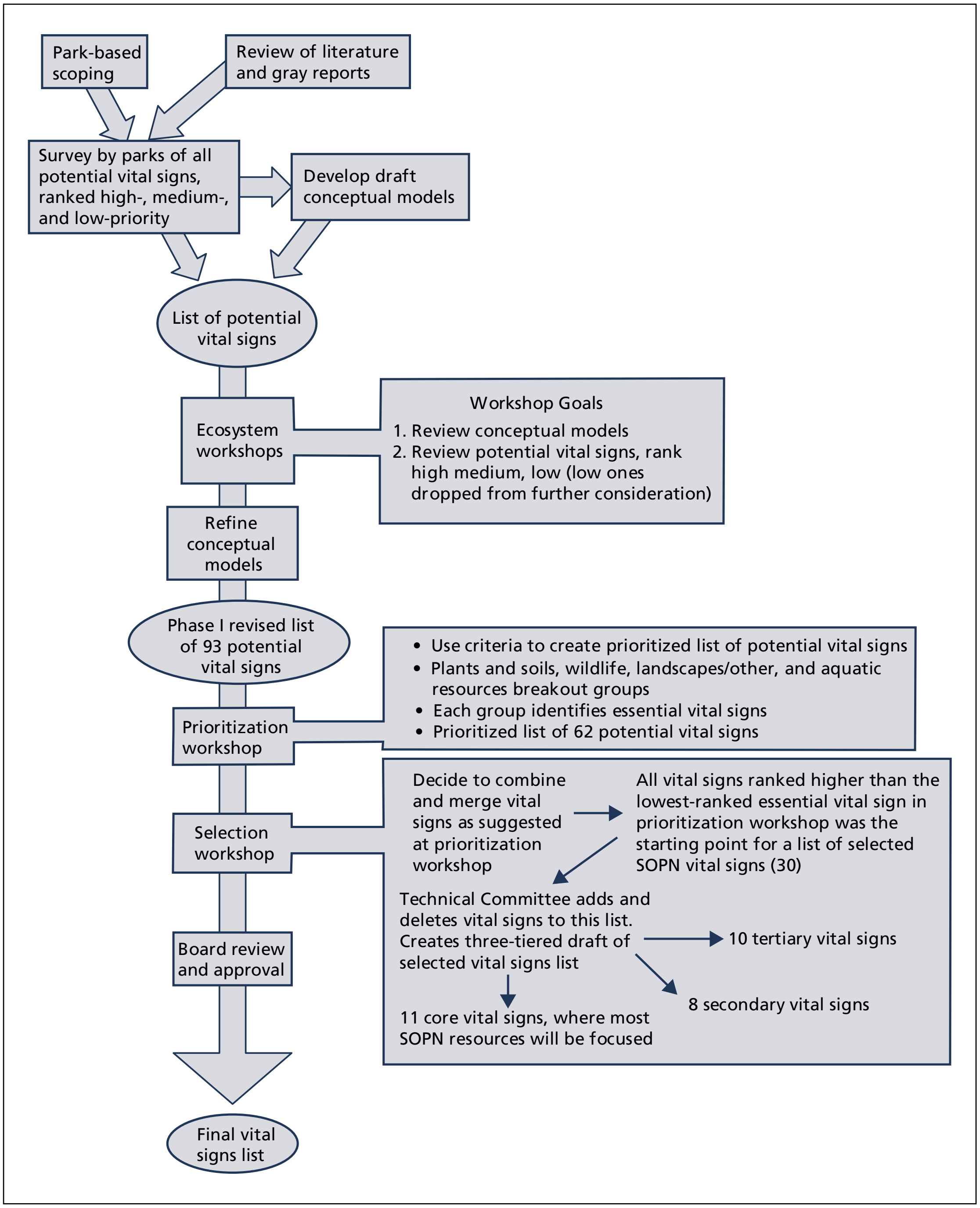


Figure 3.1. Vital signs selection process for the SOPN.

Table 3.1.2. Scoring statements used to rank SOPN vital signs according to three criteria.

Criteria	Scoring statements
Management significance (40%)	There is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions.
	Monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early.
	The vital sign is of high importance to park natural resource management goals.
	Data are of high interest to the public.
	There is an obvious, direct application of the data to performance (GPRA) goals.
	Data are needed to give managers a better understanding of park resources so that they can make informed decisions. Contributes to increased understanding that ultimately leads to better management.
	Parks are required to monitor this resource by legal mandate or identification in major park planning document. Examples might include species that are federally listed as endangered or threatened, are in the park's enabling legislation, or are an issue/species that is a major management concern.
	In cases where data will be used primarily to influence external decisions, the decisions will affect key resources in the park, and there is a great potential for the park to influence the external decisions.
Ecological significance (40%)	There is a strong, defensible linkage between the vital sign and the ecological function or critical resource it is intended to represent (supported by ecological literature or knowledge of system).
	The vital sign provides an early warning of changes to ecosystems or signifies an impending change in the ecological system. [Note: replace the term ecosystem with landscape or population, as appropriate.]
	The vital sign responds to change in a predictable and explainable matter.
	The vital sign has low natural variability (high signal to noise ratio).
	There are reference conditions that exist within the region and/or threshold values that could be determined to assess deviance from a natural condition.
	The vital sign reflects the capacity of key ecosystem processes to resist or recover from change induced by exposure to natural disturbances and/or anthropogenic stressors. [Note: replace the term ecosystem with landscape or population, as appropriate.]
	The vital sign represents a resource or function of high ecological importance based on the supporting ecological literature and knowledge of the system.
Cost of implementation and feasibility (20%)	The cost of monitoring the vital sign is not prohibitive. Consider all costs such as capital equipment, data collection, and analysis.
	The methods of monitoring for the vital sign are well established, repeatable, and are widely used and accepted.
	The vital sign is being monitored by other entities so that efficiencies can be realized in data acquisition, analysis, or other means.
	The methods of monitoring the vital sign are subject to limited human error, including errors due to different observers.
	The sampling will have limited negative impact on park resources.

3.1.3 Selection of vital signs

The selection process concluded over two additional meetings with the network's TC and board of directors. Also held in January 2005, the goal of the TC meeting was to create a draft list of selected vital signs (Table 2 in Appendix K). At this meeting, the TC reviewed the results of the prioritization workshop and created a new, prioritized list of 62 potential vital signs (Table 1 in Appendix K). Then, a list representing everything that the prioritization-workshop workgroups had prioritized above the lowest-rated "essential" vital sign was devised, totaling 30 vital signs. After more deletion and merging, the group agreed upon a list of 28 selected vital signs that would be needed for a comprehensive network monitoring program. When the SOPN vital signs were placed into the national vital signs framework, one vital sign (water quantity) split into two, resulting in a total of 29 vital signs (Table 3.1.3).

As current funding levels will not allow the network to monitor all 29 vital signs, the TC

Table 3.1.3. List of SOPN selected vital signs. (Core vital signs are higlighted)

Level 1	Level 2	Level 3	Vital sign	ALFL	BEOL	CAVO	CHIC	FOLS	FOUN	LAMR	LYJO	PECO	SAND	WABA
Air and Climate	Weather and Climate	Weather and Climate	Weather Patterns	•	•	•	•	•	•	•	•	•	•	•
	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	◊	◊	•	◊	◊	◊	◊	◊	◊	◊	◊
Geology and Soils	Soil Quality	Soil Function and Dynamics	**Soil Structure and Chemistry**	+	+	+	+	+	+	+	+	+	+	+
			Soil Movement	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Water	Hydrology	Ground Water Dynamics	**Ground Water Levels**	+	+	+	+•	+	+	+	+	+	+	+
		Surface Water Dynamics	**Water Quantity**		+		+•	+		+•	+	+	+•	+
			Flooding Processes		◊		◊	◊		◊	◊	◊	◊	◊
	Water Quality	Water Chemistry	**Core Parameters (pH, dissolved oxygen, conductivity, temperature) + E. coli**		+		+•	+		+•	+•	+•	+	+
		Aquatic Macroinvertebrates and Algae	Aquatic Invetebrates		◊		◊	◊		◊	◊	◊	◊	◊
Biological Integrity	Invasive Species	Invasive/Exotic Plants	**Early Detection Exotic Plants**	+	+	+	+	+	+	+	+	+	+	+
		Invasive/Exotic Animals	Fire Ants	◊	◊	◊	•	◊	◊	◊	◊	◊	◊	◊
	Infestations and Diseases	Insect Pests	Insect Pests and Outbreaks	◊	◊	•	◊	◊	◊	◊	•	◊	◊	◊
		Plant Diseases	Plant Pathogens	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
	Focal Species or Communities	Wetland Community	**Riparian Vegetation Communities**		+		+	+		+	+	+	+	+
			Upland Spring Communities				◊			◊	◊	◊	◊	
		Grassland/Herbaceous Communities	**Grassland Vegetation Communities**	+	+•	+	+	+	+	+	+	+	+	+
		Terrestrial Invertebrates	Native Pollinators	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
		Fishes	Moths and Butterflies	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
			Fish Communities		◊		◊	◊	◊		◊	◊	◊	◊
		Amphibians and Reptiles	Amphibian Communities	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
		Birds	**Bird Communities**	+	+	+	+	+	+	+	+	+	+	+
		Mammals	Ungulates	◊	•	◊	•	◊	◊	•	◊	◊	◊	◊
			Small Mammal Communities	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
	At-Risk Biota	T&E Species and Communities	Black-tailed prairie dogs		•			◊		◊			◊	
			Lesser Prairie Chicken	◊						◊			◊	

Table 3.1.3. List of SOPN selected vital signs, cont.

Level 1	Level 2	Level 3	Vital sign	ALFL	BEOL	CAVO	CHIC	FOLS	FOUN	LAMR	LYJO	PECO	SAND	WABA
Human Use	Non-Point Source Human Effects	Non-Point Source Human Effects	**Human Demographics**	+	+	+	+	+	+	+	+	+	+	+
	Visitor and Recreation Use	Visitor Use	Effects of Park Visitors on Natural Resources	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	**Fire and Fuel Dynamics**	+	+•	+	+•	+	+•	+•	+	+	+	+
	Landscape Dynamics	Land Cover and Use	**Landscape Dynamics**	+	+	+	+	+	+	+	+	+	+	+

+This symbol shows that the SOPN is working to develop monitoring plans and protocols (also noted with shading) and are the core vital signs

• This symbol shows vital signs that are monitored by the park or another entity. These programs may or may not meet I+M standards

◊ This symbol shows vital signs with no current or planned monitoring

– This symbol indicates that the vital sign does not apply to that park divided the selected vital signs into three tiers of 11 core, 8 secondary, and 10 tertiary vital signs. The network will first allocate resources to core vital signs, which will likely make up the majority of the monitoring program in the near future. Secondary and tertiary vital signs will be considered for monitoring if additional funding is available, or if there are existing programs that make inclusion of these vital signs cost-effective. The TC unanimously agreed on all 11 core vital signs. Vital signs in the secondary and tertiary categories were determined by a majority vote.

In March 2005, SOPN staff presented the list of 29 selected vital signs (Table 3.1.3) to the board of directors for their review and approval. The board unanimously approved the list, with the caveat that the costs of the 11 core vital signs will need to be determined during protocol development. There may be additional changes to the core vital signs list if the current level of funding cannot adequately address all of them.

3.2 Southern Plains Network Selected Vital Signs

The SOPN has identified 29 vital signs that represent a systems approach to our monitoring program. They relate to air and climate (2), geology and soils (2), water (4), human use (2), landscapes (2), and biological integrity (17). These vital signs appear in Table 3.1.3., presented in the hierarchical framework developed by the I&M program's Washington Office. In-depth summaries for each vital sign are provided in Appendix L. Our multi-faceted process resulted in a list of vital signs that is based on ecological and management significance, has been peer-reviewed, is justifiable, and is supported by conceptual ecosystem models. The final list represents a balance of ecosystem-driving variables (drivers and stressors) and response variables (ecosystems, communities and species). These vital signs include the potential for monitoring at different spatial and temporal scales and include some sensitive, "quick-response" indicators, as well as some slower, more-integrative indicators.

The SOPN will develop protocols for the 11 core vital signs according to preliminary monitoring objectives (Table 3.2). Preliminary monitoring objectives for secondary and tertiary vital signs are in Appendix L. Sampling designs will be devised for each park so that data collected will address the monitoring objectives. Monitoring objectives will likely be further refined during protocol development.

The SOPN will integrate with ongoing monitoring programs to maximize the amount of information that is available to make informed management decisions. The network will work with the parks and other entities to update and revise existing protocols to meet I&M guidelines and to synthesize and report on the state of the parks' ecosystems. In addition, the network will work with park staff to create models for database and information management, with the goal of increasing the usefulness of collected data.

Selected vital signs may be modified as fiscal resources and management issues change. Adjustments to the monitoring program may also occur as subsequent monitoring program reviews are conducted at approximately five-year intervals. These reviews will provide feedback on the efficacy of the selected indicators (to be developed in Chapter 8 of Phase III Report). It may be discovered that it is necessary to expand the list of candidate vital signs to more completely describe natural resource status and trends, or to meet an expanded mandate for monitoring.

3.3 Relationships of Selected Vital Signs to Conceptual Models

Our list of selected vital signs was the result of having discussions with park staff to develop vital signs that were important to park management and using conceptual models to ascertain ecologically relevant vital signs. Before conceptual-model development began, the SOPN provided its model developers with lists of the biggest resources and stressors for each park (Appendix M in Perkins et al. 2005) as determined by park managers. The model developers then used their own extensive knowledge of the systems to add additional resources and stressors that were important at the ecosystem level. This two-pronged approach allowed us to

Table 3.2. Monitoring objectives for the 11 SOPN core vital signs.

Vital sign	Monitoring objective(s)
Soil Structure and Chemistry	Determine trends in annual soil-respiration measurements. Detect changes in ecosystem carbon balance. Determine status and annual trends in soil cover, aggregate stability, compaction, and erosion.
Ground Water Levels	Determine the long-term trends in groundwater-quantity levels. Document changes in hydrologic regime associated with hydrological modifications (e.g., dams, diversions).
Water Quantity–Surface	Determine the long-term hydrologic trends for streamflow and lake-water levels. Document changes in hydrologic regime associated with hydrological modifications (e.g., dams, diversions).
Water Quality–Core Parameters	Determine the long-term trends in water-quality vital signs at SOPN water bodies. Determine trends in water chemistry in association with other network monitoring programs. Determine fecal-coliform levels and trends.
Exotic Plants	Detect incipient populations and new introductions of invasive exotic plant species.
Riparian Vegetation Communities	Determine temporal and spatial trends in species composition and richness, abundance, structure, and diversity of wetland plant communities. Quantify changes in the cover, richness, and species diversity of key woody native and non-native wetland trees within network parks. Determine long-term trends in exotic-plant abundance and distribution. Compare long-term trends in areas where exotic plants are purposefully managed.
Grassland Vegetation Communities	Define the trends in status of the vegetation species composition, structure, and diversity of remnant, disturbed, and restored prairies. Determine trends in cool-season (C3) vegetation versus warm-season (C4) vegetation. Determine long-term trends in invasive woody species abundance and distribution. Determine long-term trends in exotic-plant abundance and distribution. Compare long-term trends in areas where exotic plants and woody invasives are purposefully managed.
Bird Communities	Identify significant temporal changes in composition, abundance, and spatial distribution of bird communities at SOPN parks. Follow trends in bird populations for correlations with fragmentation and loss of connectivity.
Human Demographics	Detect trends in human-demographic data in the vicinity of SOPN parks.
Fire and Fuel Dynamics	Track the location, extent, timing, and severity of wildland and prescribed fires. Track successional effects of fire and burn severity on species composition and vegetation structure; soil temperature and moisture; and animal-community composition.
Landscape Dynamics	Determine variation and trends in the seasonally integrated normalized difference vegetation index (NDVI) for SOPN park lands. Determine long-term trends in land-use change within and adjacent to SOPN parks. Determine habitat conversion to urban landscapes, creation of edge effects, reduction of functional ecosystem size, and elimination of important habitats.

select vital signs that were both relevant to park management and are significant to Southern Plains ecosystems.

Our more than 32 different conceptual models, developed in a hierarchical fashion, identified major components and processes of ecosystems in the SOPN (see Chapter 2). However, they did not attempt to quantify which resources and stressors were most important to the SOPN across models. It is therefore reassuring that the vital signs we have selected through the quantitative, prioritized list (Appendix K, Perkins et al. 2006) and the selection process (Appendix K) are all identified on our conceptual models (Appendices S–W in Perkins et al. 2005). All 11 core vital signs can be found on our highest-level ecosystem models for grassland (Figure 3.3-1) and stream (Figure 3.3-2) ecosystems. In addition, many of our secondary and tertiary vital signs are also found on these two models.

A comprehensive monitoring program should have a mix of driver/stressor vital signs and

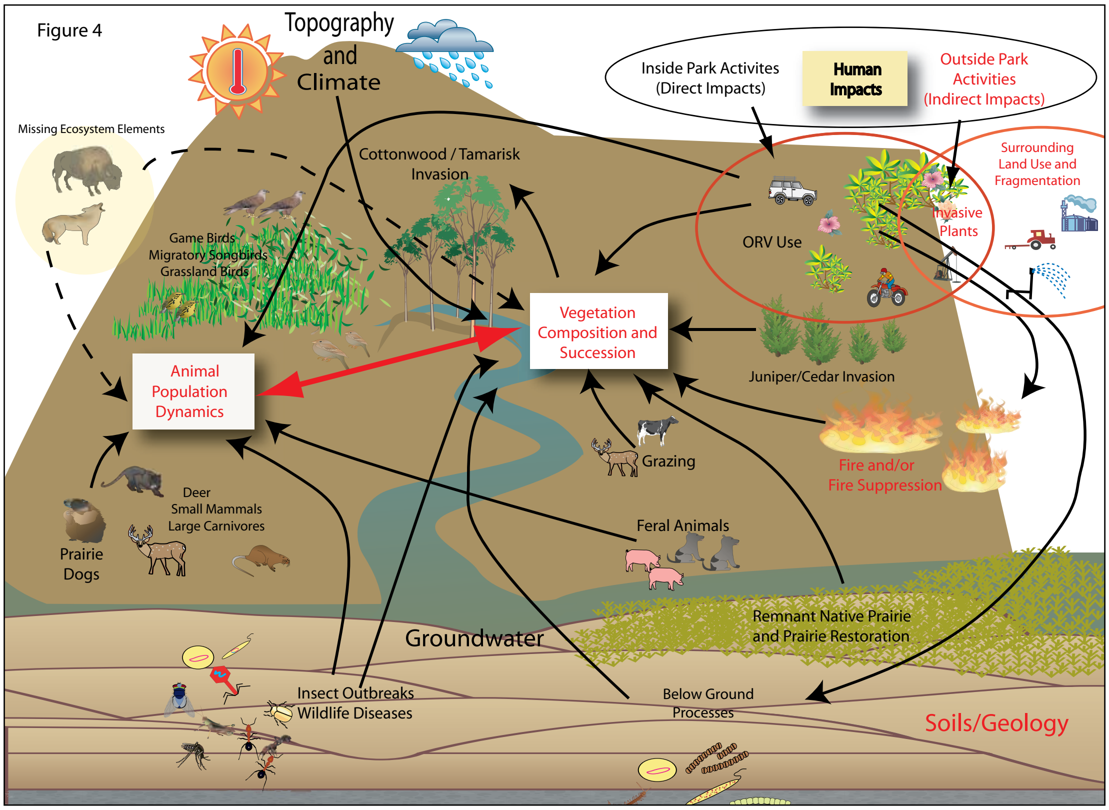


Figure 3.3-1. Overall grassland ecosystem model, with core vital signs identified in red. The complete grassland conceptual model is in Appendix S of Perkins et al. (2005)

ecological response vital signs. Driver/stressor vital signs are necessary because they allow managers to predict changes before they occur and make proactive management decisions. Ecological-response vital signs tell a manager how the biological community is responding. For example, a conceptual model could be developed that demonstrates that cottonwood gallery forests with a certain density, width and age structure are ideal for bird communities. However, if the bird communities do not respond, then the model is either not appropriate for the system or another unknown variable is preventing the predicted response in bird communities. As can be seen in our conceptual models, most of our core vital signs are stressor or driver oriented. Only one (Bird Communities) is a true ecological-response variable. A few, such as Grassland Vegetation Communities, could be seen as a driver or an ecological response. With a limited budget, monitoring the most important ecological drivers/stressors will give managers the most information. As we develop into a comprehensive monitoring program that monitors all 29 selected vital signs, we will add more ecological response variables with our secondary and tertiary vital signs.

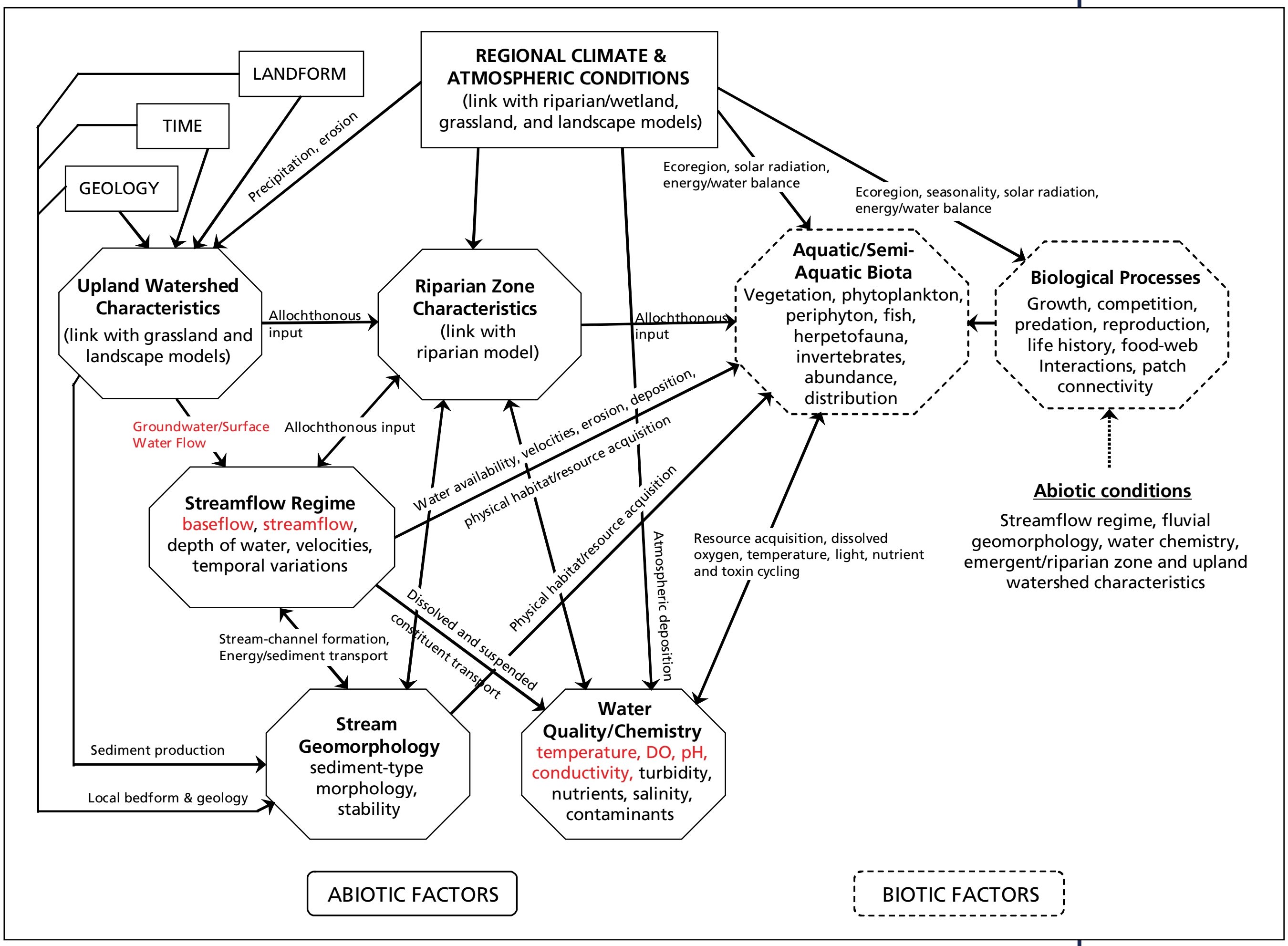


Figure 3.3-2. Overall stream ecosystem model, with core vital signs identified in red. The complete stream conceptual model is in Appendix W of Perkins et al. (2005).

Chapter 4
Sampling Design

"Not everything that counts can be counted, and not everything that can be counted counts."

~ Albert Einstein

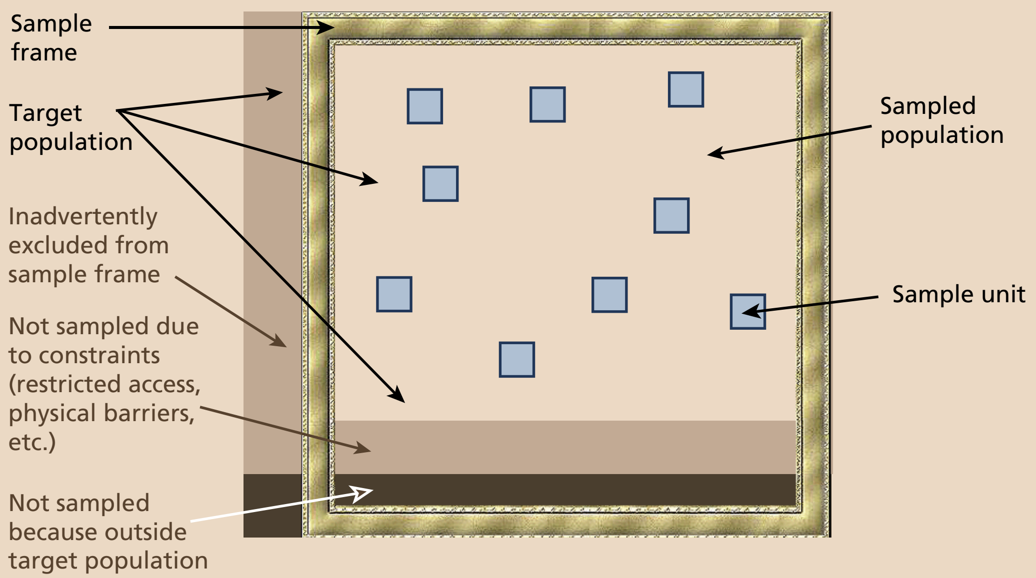
4.1 Introduction

Sampling design is one of the major means by which the NPS Monitoring Program maintains its scientific reliability and defensibility. The primary purpose of a sampling design is to ensure that the data collected are representative of the target populations and sufficient to allow defensible conclusions to be derived about the resources of interest (EPA 2002). As such, the sampling design describes the process for selecting sampling locations and allocating sampling effort through time among locations. This chapter identifies the major themes and concepts behind our sampling designs that have guided our choices for particular vital signs or protocols, as well as the most up-to-date planning for the sampling design of specific SOPN vital signs.

4.2 Concepts and Definitions

4.2.1 Defining the population of interest

There are subtle differences in how terms associated with sampling are often defined. Figure 4.2.1 illustrates how these terms are used by the SOPN in the context of this report. In an ideal situation, the sampled population and the sample frame would be equivalent to the target population for which inference is to be drawn. Unfortunately, numerous constraints exist that may prevent this from occurring. For example, sensitive archeological sites may preclude our ability to sample from the entire population of interest. Thus, in some situations, not all of the units within a desired target population will be included in the sampled population.



Adapted from A.R. Olsen (unpublished presentation) and Lohr (1999).

Figure 4.2.1. Illustration of how sampling terms are used in this report.

4.2.2 Drawing a sample

Because a sample is used to draw valid conclusions about some larger population, it is imperative that the sample be representative of the population of interest (Lohr 1999). Three broad approaches to obtaining samples of a population include probability-based sampling; judgment sampling; and convenience sampling. Of these, probability sampling is the most defensible, because it applies sampling theory and some form of randomization in the selection of sample units (EPA 2002). This randomization ensures a reduction in potential bias compared to judgment or convenience sampling, thus increasing the validity of extending inference from a sample to the population of interest.

4.2.3 Types of sample frames used

The SOPN will use five types of sample frames as a basis for collecting measurements on vital signs:

(1) An ***area frame*** uses geographic boundaries to delineate a given sample unit. An example of an area frame would be counties, which are one of the primary sample units for our human demographics vital sign.

(2) The closely related ***grid-based frame*** is a special type of area frame that uses a grid of points or cells to represent units of a target population.

(3) A ***linear-based frame*** delineates sampling units along linear segments from which to draw a sample.

(4) A ***list-based frame*** either constructs a list of sample units from which to draw a sample, or attempts to census all units.

(5) ***Index sites*** are a special case of a list-based frame, used to collect information on areas or points that were based on judgment in order to yield adequate data on a particular vital sign. These samples are usually picked as "representative" sites, and statistical inference to a larger area is not possible because a probability sample is not employed. For the SOPN, index sites may be used in cases where the sample frame is of insufficient size to warrant a spatial design—particularly, if other factors preclude the use of a probability-based sample. For example, in some cases, substantial legacy data may exist at a site that was previously selected via judgment sampling. In such an instance, we would need to consider whether maintaining the existing site out-

Table 4.2.3. Tentative design features for SOPN vital signs.

SOPN vital sign	Sample frame	Spatial allocation	Strata	Temporal (revisit) design
Soil Structure and Chemistry	Area-grid	GRTS	Primary Mgt Zones	1-9
Ground Water Levels	List	N/A	None	1-0
Water Quantity–Surface	Area/Linear/Index	GRTS	None	1-0
Water Quality–Core Parameters	Area/Linear/Index	GRTS	None	1-0
Exotic Plants	Area-grid/Linear	GRTS/Census	Primary Mgt Zones/ High vs. Low Risk	1-1
Riparian Vegetation Communities		GRTS	None	TBD
Grassland Vegetation Communities	Area-grid	GRTS	Primary Mgt Zones	TBD
Bird Communities	Area-grid	GRTS	Primary Mgt Zones	TBD
Human Demographics	Area-grid	Census	None	1-0
Fire Dynamics	Area-grid	GRTS	Primary Mgt Zones	
Landscape Dynamics	Area-grid	Census	None	1-0
Climate	List	N/A	None	1-0

Final versions will be determined during protocol development.

weighs transitioning to an alternative site selected using a probability sample.

A summary of the overall design features used by the SOPN is presented in Table 4.2.3. For those units large enough to warrant a spatial sampling design, we have primarily used the GRTS design. In some cases, resources are too small to warrant a spatial design, and in others, the value of legacy data from existing monitoring stations needs to be weighed against the increased inference from a valid spatial design. For these cases, the use of index sites has been considered.

4.2.4 Spatial allocation of samples

A multitude of potential sampling designs can be used to select a sample over space, but most are variations on a few basic themes (Figure 4.2.4):

- In simple random sampling, n units are selected from a population of size (N) via a random process, such that every sample unit has the same probability of being included in the sample.
- Systematic sampling is a method in which one sample unit is typically selected at random and subsequent units are selected according to a systematic pattern. Systematic sampling is often used to achieve spatial balance and avoid the potential for clusters of samples in close proximity, which can occur through a purely random process such as simple random sampling. However, systematic sampling can introduce some bias if the properties of interest are aligned along a gradient. When prior information about a resource is known, systematic sampling also may be less efficient, and stratification is sometimes warranted (see below).
- A recently developed alternative to systematic sampling is a generalized random-tessellation stratified (GRTS) design (Stevens and Olsen 2004), which reduces the potential for any bias due to environmental gradients and has additional desirable properties.

4.2.4.1 Generalized Random-Tessellation Stratified (GRTS) design

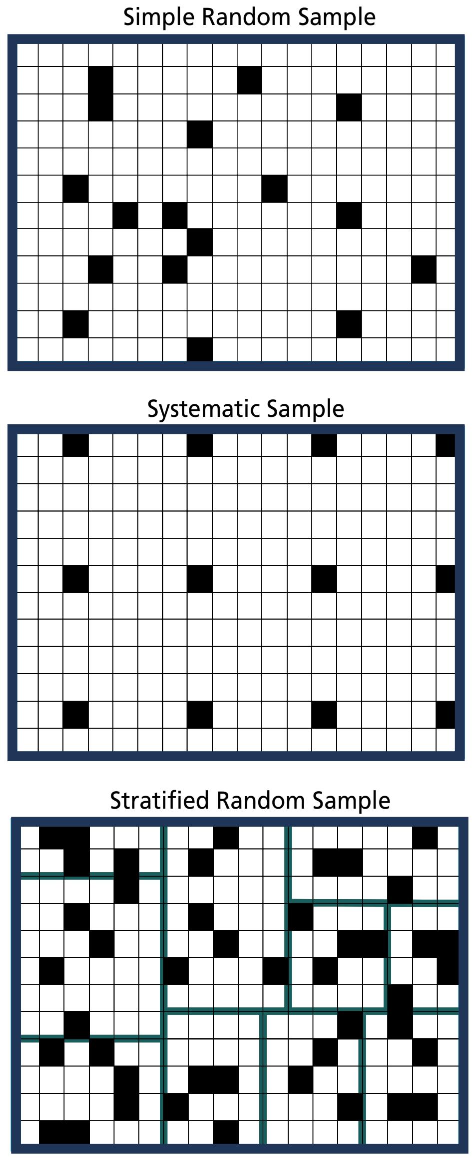


Figure 4.2.4. Conceptual illustration of simple random sampling, systematic sampling, and stratified random sampling designs. Adapted from Thompson (2002) and Lohrs (1999).

Details of the GRTS design are described in Stevens and Olsen (2004). Essentially, the GRTS design uses a hierarchical randomization process to achieve spatial balance across a region and a resource (Figure 4.2.4.1). First, a sample frame is created based on the target resource. Then, a grid is randomly overlaid on the frame and subdivided until there is only one sample unit per cell. Cell addresses are assigned via a hierarchical random process, and each sample unit is assigned to its corresponding cell address, creating a linear sequence of sample-unit cell addresses. By reversing the order of address digits and re-sorting this sequence, a systematic sample can be drawn with a random start point that maintains the spatial balance of

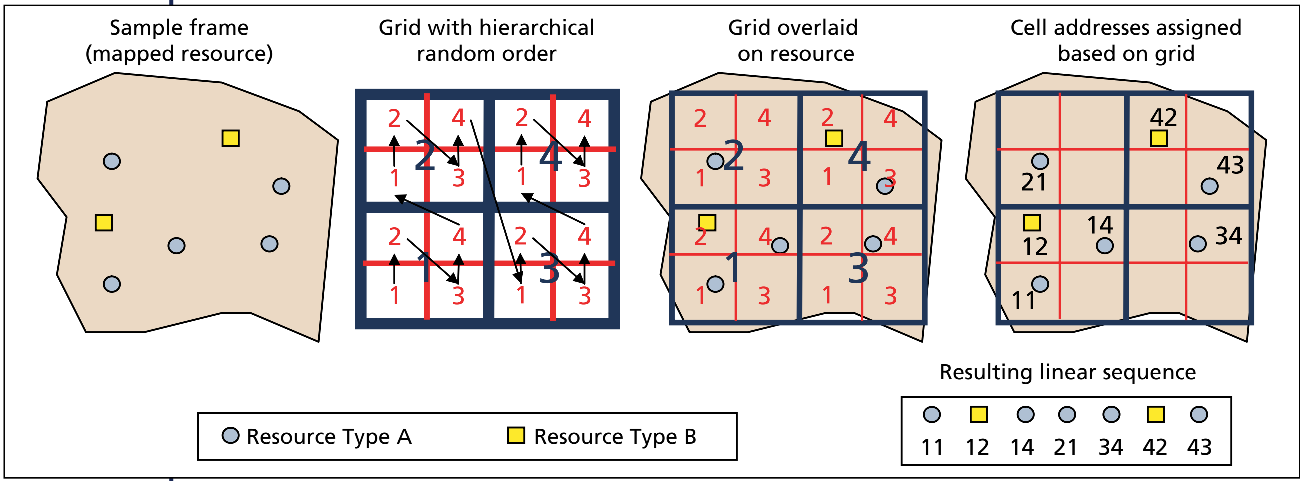


Figure 4.2.4.1. Graphical representation of the steps leading up to selection of sample units using the generalized random-tessellation stratified design. Adapted from Stevens and Olsen (2004, unpublished presentations).

the sample. One of the resulting properties that makes this design an attractive choice for some vital signs is that samples are spatially balanced across the resource, resulting in improved precision. In addition, spatial balance is maintained even at different sampling intensities and among samples and subsamples. Nested subsamples are easily accommodated, which facilitates different suites of indicators to be measured at different subsets of sample sites. This can be important for accomplishing multiple objectives within the same general design. GRTS can also be applied to point, network, or areal resources. Stratification and unequal sampling probabilities of subpopulations are also easily accommodated, which can both improve precision of estimates and increase sampling efficiency.

4.2.5 Stratification

Stratification consists of dividing a population into subsets (called strata) and selecting an independent sample from within each one. From a statistical perspective, stratification can result in substantial gains in the precision of parameter estimates when samples from within strata are more homogeneous than between strata (Cochran 1977). This can often be achieved by accounting for within- and between-strata variance components. For the SOPN, stratification will primarily be based on primary zones of similar management, following the logic that units under a similar management regime are likely to behave more similarly than units under different management regimes, thus meeting the criteria for improved precision through stratification. Additionally, stratification is often used when there is a need or desire for separate parameter estimates for the individual strata. Given that one of the primary goals of the I&M program is to provide a scientific basis for management, having parameter estimates that can be related to a given management regime will certainly improve our capacity to provide such input. Additionally, because the I&M program is focused on monitoring long-term ecosystem health, rather than short-term management effectiveness, our stratification is based on management zones likely to reflect different long-term management regimes, rather than specific management actions, which may be quite variable over time and space. As such, we do not intend to alter our sampling in response to specific management actions; rather, our sampling is intended to reflect ecosystem response to management regimes over longer time scales. We fully recognize that this implies that we may not detect some short-term responses to specific management actions, but believe that we will detect longer-term shifts in ecosystems.

4.2.6 Temporal allocation of samples

As with spatial designs, numerous temporal sampling (revisit) designs also exist, with most being variations on a few basic themes (see Table 4.2.6). A group of sample units that are always sampled together during a sampling occasion is called a panel. Sample effort can be rotated among panels through time, which effectively rotates field effort among sample units and, therefore, space. The way in which units in the population become members of a panel is called the membership design (McDonald 2003). The pattern of visits through time to all panels is the revisit design, which specifies

Table 4.2.6. Tabular and notational representation of three example revisit designs.

Panel	Sample occasion 1	2	3	4	5	6	7	8
Always revisit design [1-0]								
1	X	X	X	X	X	X	X	X
Never revisit design [1-n]								
1	X							
2		X						
3			X					
4				X				
5					X			
6						X		
7							X	
8								X
Split panel design [1-0, 1-4]								
1	X	X	X	X	X	X	X	X
1	X					X		
2		X					X	
3			X					X
4				X				
5					X			

X = all members of the panel are sampled during that occasion.

the temporal sampling schedule. The notation commonly used for revisit designs is a pair of digits. The first digit is the number of consecutive occasions on which a panel is sampled; the second is the number of consecutive occasions on which a panel is not sampled (McDonald 2003). For example, if a single panel is visited on every sampling occasion, its revisit design can be expressed as [1-0]. If a panel is to be sampled once, then never revisited, the notation is [1-n]. The notation [1-0, 1-4] signifies that units in one panel are visited on every occasion, and units in a second set of panels are visited once every five occasions.

4.2.7 Sample size, power, and "error" considerations

Sample size and power are major concerns in monitoring efforts. In general, sample size should be large enough to gain probability of detecting changes of management or conservation importance, but not unnecessarily large (Fry 1992). Where appropriate, we will perform a priori power analyses and/or simulations to estimate sample sizes. An a priori power analysis is a statistical calculation made prior to initiating monitoring using existing data (Thomas and Krebs 1997). Because these data provide an estimate of variability within the considered metrics, power analyses can be used to estimate sample sizes needed to detect trends in the data. An important interplay exists between cost, sample size, and sampling methodology. Different sampling methods differ in cost, and yield data of differing quality and reliability. Variation within data reflects a combination of system, or "true," variation and method error, or "noise" (e.g., imprecision in measurement, counting, data recording). Our program will take all of these into account when selecting both sampling methods and designs.

As with all scientific hypothesis testing, monitoring programs must weigh the relative costs and benefits of Type I versus Type II errors, and set alpha (a) and power (1-a) accordingly (see Fields et al. 2005). Type I errors involve detecting a trend or difference when, in fact, none exists, whereas Type II errors involve failure to detect real differences or trends. Traditionally, scientists focus on reducing Type I errors and, as such, use smaller alpha levels in statistical tests. In monitoring with a strong resource-conservation mandate, however, it may be preferable to support an early-warning philosophy by increasing alpha and consequently increasing the power to detect differences or trends (see Sokal and Rohlf 1995). For example, where the possibility of obtaining large, high-quality samples may be limited, we will consider adopting a higher-alpha, higher-power strategy and adjusting our sampling design accordingly.

4.3 Integration of the SOPN Vital Signs Monitoring Program

4.3.1 Integration among vital signs

Vital signs are not environmentally and ecologically independent entities. Rather, they are often the products of complex interactions among other vital signs and/or other ecosystem components or attributes. Without some

Table 4.3.1. Integration of SOPN vital signs, co-location of samples, overlap of the sample frame, and collaboration with other programs, networks, or organizations.

SOPN vital sign	Co-location of samples	Overlap of the sample frame	Collaboration with other programs	Collaboration with other networks	Collaboration with other organizations
Soil Structure and Chemistry	Co-located Group 1	Frame Group 1	Fire Program		
Ground Water Levels			Water Resources Program		
Water Quantity–Surface	Co-located Group 2	Frame Group 2	Water Resources Program		
Water Quality–Core Parameters	Co-located Group 2	Frame Group 2	Water Resources Program		
Exotic Plants[1]	Co-located Group 1	Frame Group 1	Fire Program		
Riparian Vegetation Communities		Frame Group 2			
Grassland Vegetation Communities	Co-located Group 1	Frame Group 1	Fire Program		
Bird Communities		Frame Group 1			
Human Demographics		Frame Group 3		Sonoran Desert Network	Sonoran Institute
Fire and Fuel Dynamics	Co-located Group 1	Frame Group 1	Fire Program		
Landscape Dynamics		Frame Group 3		Sonoran Desert Network	Sonoran Institute
Climate				Intermountain Region	Intermountain Region

[1] The exotic plant protocol will have additional samples in high-risk zones that are not co-located with other vital signs.

Note: Within a column, color fill is used to more clearly identify vital signs that share the same co-location; sample frame; or program, network, or organizational collaborators.

consideration of how our vital signs interact, the SOPN program has no added value apart from the sum of its parts. Thus, it is necessary to consider how the various parts fit together as a whole. Some level of integration among vital signs is needed if we expect to (1) understand the dynamic responses to changes in drivers or stressors, (2) understand the interaction effects among vital signs, and (3) reduce the confounding effects of other vital signs in the interpretation of a given vital sign.

To account for this interdependence, the SOPN uses two primary approaches for integration among vital signs. The first is co-location among samples for different vital signs. Co-location of samples can facilitate assessment of the response to drivers or stressors and interaction effects. Under some circumstances, co-location can also aid in the interpretation of confounding effects and increase efficiency of sampling. However, co-location of samples is not a panacea for ecological insights, and is not a substitute for clear thinking and planning of our sampling design. Plans for SOPN vital signs include probable co-location of samples in both terrestrial and aquatic systems (Table 4.3.1). Monitoring of grassland plant communities will form the basis of our terrestrial integration. Co-located samples are anticipated for grassland vegetation, soil structure and stability, fire effects, and invasive plants (although the latter will likely have additional samples in high-risk zones that are not co-located with the grassland-community samples). For aquatic and riparian systems, we anticipate co-location of water quality and quantity samples.

Co-location of samples is not always feasible or desirable, even when the resources overlap. For example, repeated visits to the same sample location may cause disturbance and affect the system we are trying to monitor. Consequently, the second approach used by SOPN for integration among vital signs is overlap of the sample frame and its associated strata without co-location of samples. For example, we will attempt to estimate occupancy of landbirds in the same strata used for the grassland and riparian protocols, but do not plan to use the same sample locations because of concerns about trampling, as well as a disconnect of the spatial scales for effective sampling. In both cases, we may use sample points along linear transects, but the spatial pattern along those transects may be quite different. Bird vocalizations carry over space such that the same individuals would be detected at multiple points if samples were located too close together. In contrast, spacing individual sample points along a plant transect too far apart could be quite inefficient.

4.3.2 Integration among other disciplines and programs

The SOPN will monitor many vital signs that cross over administrative and disciplinary boundaries. In addition, concerns about these vital signs are often shared by other NPS programs, networks, organizations, or agencies, and cooperative efforts among such organizations can lead to increased efficiency and broader application. Thus, for vital signs that hold common interest, we will attempt to coordinate and, where possible, collaborate with other programs, networks, or organizations for a more effective monitoring program. Extant examples of such cooperation are shown in Table 4.3.1; we will continue to seek other opportunities for collaboration.

4.3.3 Integrative features and sampling design by vital sign

4.3.3.1 Weather and Climate

Climate conditions are monitored at existing climate and precipitation monitoring stations. An inventory of climate stations across all NPS I&M networks is currently being conducted by the Western Region Climate Center (administered by NOAA, National Oceanic & Atmospheric Administration). When completed for the SOPN, the inventory results will be used to evaluate the existing protocols, metadata, and spatial coverage of climate data across the net-

K. CHERWIN

Prairie and deer, Fort Union National Monument.

work; however, at the present time, we do not anticipate the addition of any sampling sites.

4.3.3.2 Grassland Vegetation Communities

The SOPN grassland monitoring plan will incorporate the Soil Structure and Chemistry vital sign, and will overlap with the Fire and Fuel Dynamics, Exotic Plants, and Bird Communities vital signs. The primary sample unit consists of one permanent, 50-m transect with five sets of nested plots as secondary sample units. The primary stratification will be based on zones of similar management regimes (see above), although some secondary stratification by soils or edaphic characteristics may be incorporated into the final design.

The general spatial design for the grassland protocol will be GRTS design, although a few units may be sufficiently small as to require only one or two transects. The final revisit design has not yet been determined, although it will likely require a rotating panel of an approximate three-year rotation for larger park units, and possibly a [2-2] revisit design for smaller units. We are still evaluating the trade-offs related to logistics, temporal patterns of variability, and the potential that sites may be affected by repeated visits. A final revisit design, which will take these considerations into account, will be presented in our grassland vegetation monitoring protocol expected later in FY2008.

4.3.3.3 Soil Structure and Chemistry

The SOPN soil structure and chemistry monitoring protocol will be largely based on soil sampling and assessment methods previously developed by other agencies (e.g., USDA Natural Resources Conservation Service, Bureau of Land Management, U.S. Geological Survey, and U.S. Forest Service), but will be adapted to suit the needs of SOPN soils. Soils sampling will be co-located with the grassland vegetation samples described above; however, the revisit design will be much less frequent. The final revisit design has not been determined, but will likely something on the order of a [1-9] design, with the possibility that samples will be conducted on a rotating basis.

4.3.3.4 Fire and Fuel Dynamics

This vital sign is still in the initial stages of development, but will likely focus mostly on effects of both prescribed and wildland fire on vegetation and site succession. We anticipate that the strata will coincide with those of grassland vegetation monitoring and, in all likelihood, the fire-effects component will be incorporated into grassland vegetation monitoring. However, we are just beginning discussions with the park fire programs to evaluate the opportunities for collaboration and overall coordination among our respective programs. The SOPN overlaps with four fire program clusters, so considerable effort will be required to ensure that we can develop a cooperative effort that will meet the needs of our respective programs.

Prescribed fire, Bent's Old Fort National Historic Site.

NPS

4.3.3.5 Bird Communities

At the population level, distribution and abundance traditionally have been a mainstay of ecological assessment (e.g., Andrewartha and Birch 1954). However, most of our park units are too small to meaningfully estimate local abundance. For distance sampling, the primary approach used by most networks, Buckland et al. (2001) recommend at least 60–80 transects for reliable estimates, which is not possible for most of our park units without a gross violation of independence among samples. Thus, the primary measure of bird communities in the SOPN will be occupancy, or the proportion of sites occupied (MacKenzie et al. 2002). This approach is based on the presence or absence of a given species, and will enable us to account for local colonizations and extinctions of species at each park unit. This would provide a measure of distribution across the SOPN network, while simultaneously providing useful information at the park level. This measure also: (1) explicitly accounts for detectability of individual species (MacKenzie and Kendall 2002); (2) enables estimation of confidence intervals (MacKenzie et al. 2002); (3) enables estimation of local extinction and colonization probabilities (MacKenzie et al. 2003); and (4) is comparable across sites.

We would supplement estimates of occupancy at each park unit with estimates of community-level parameters (e.g., species richness and relative species richness) based on the approach developed by Boulinier et al. (1998) and Nichols et al. (1998) using the software program COMDYN (Hines et al. 1999). This approach explicitly takes into account species detectability, and is based on the same data as that collected for estimates of occupancy.

Because of the large number of habitat types within the SOPN, and the enormous variability within these habitat types, our protocol will focus on estimating the status and trends of birds within two primary habitat types, grasslands and riparian. These habitat types are the major habitats of concern for most units, and we will have complementary information from data collected for other vital signs. The details of the specific sampling design are still being planned;

however, we anticipate using a GRTS approach for the spatial design. Stratification will be based on the same subunits as for the other vital signs focused on these habitat types (i.e., both Grassland and Riparian Vegetation Communities, Soil Structure and Chemistry, and Fire and Fuel Dynamics). Invasive plants will include an additional strata for high-risk areas (e.g., along roadsides and trails) that will not be used in the bird protocol. The revisit design is yet to be determined, but sampling likely will be done every year (i.e., a [1-0] design), if it is financially and logistically feasible.

4.4.2.6 Exotic Plants

The Exotic Plants sampling design will overlap substantially with that of the Grassland and Riparian Vegetation Communities vital signs, except that additional stratification based on the risk of exotic-species colonization will be incorporated (Figure 4.4.2.6). Landscape features that increase the risk of colonization are those that serve as a pathway for seed dispersal or other reproduction, typcally including roads, trails, and waterways. For the SOPN protocol, areas within 20 m of such a feature will be considered high-risk zones, and those >20 m will be considered normal-risk zones. Normal-risk zones will use the same sampling (GRTS design) as the grassland vegetation protocol to detect a subset of exotic species considered to be high-priority, either because they already present a threat in SOPN parks or are expected to have high potential to be a future threat.

More intensive effort will be dedicated to the high-risk stratum, based on distance sampling across potential dispersal pathways. Overall estimates of density will be based on the estimators described by Buckland et al. (2001), and the occurrence within individual linear segments will be reported. For smaller park units, we anticipate that all high-risk dispersal pathways will be surveyed at each sampling occasion (the revisit frequency is yet to be determined). For larger park units, we will incorporate a rotating panel design to incorporate all such pathways.

4.4.2.7 Landscape Dynamics and Human Demographics

Because the Landscape Dynamics and Human Demographics vital signs are integrally connected, we may treat them under the auspices of a single protocol, rather than as separate protocols, in order to avoid duplication of effort and make for a more efficient development process. The general SOPN approach will be to develop an ongoing socioeconomic atlas that would complement a land-cover component (using remote sensing with existing and planned inexpensive data sources), because many socioeconomic indicators (e.g., human population, housing density, land-use zoning) probably provide better predictive capabilities than land-use or land-cover change alone. Although predictive models are certainly possible using remote sensing, changes are generally observed after they have occurred. We believe that a combination of socioeconomic indicators from public and enterprise data sources and remote sensing will provide the most comprehensive monitoring of landscape dynamics and human demographics.

For this approach, complete-area sampling is used, thus eliminating the need for a spatial design. Socioeconomic data are collected as part of the U.S. Census as well as for market forecasting and other purposes. Often, the data used by market researchers for potential development can be the same data used to predict land-use change. Several organizations currently synthesize socioeconomic data, and ESRI (the manufacturers of ArcGIS) currently has a business-analyst package that makes available hundreds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Hermit thrush (*Catharus guttatus*).

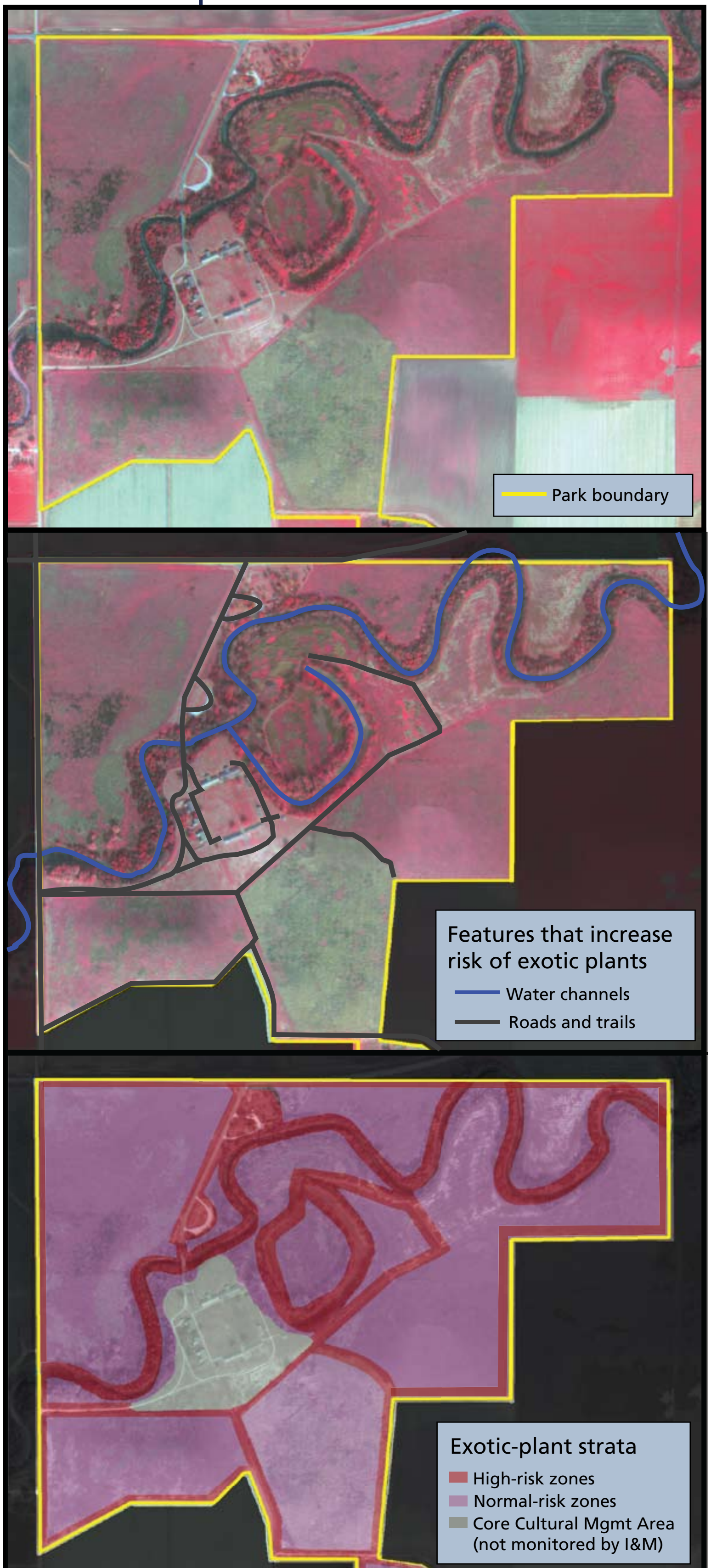


Figure 4.4.2.6. A section of Fort Larned National Historic Site, illustrating how features of the landscape (e.g., waterways, roads, and trails) that increase the risk of exotic plants would be used to delineate strata of high and normal risk.

of such indicators in a ready-to-use format. The SOPN is currently working with Texas A&M University (TAMU) and the Sonoran Institute to determine which set of indicators best suits our needs. The Sonoran Institute is explicitly evaluating the ESRI suite of indicators for such monitoring, and we are working with TAMU on the general protocol development. Such socioeconomic indicators are updated annually; thus, our "revisit" design will be based on the trade-offs of cost vs. information value. We are currently evaluating such trade-offs.

4.4 Additional Considerations

Several other factors will guide and affect SOPN sampling-design development:

One size does NOT fit all. No single sampling design will adequately address or support all vital signs monitoring. Wherever possible, the SOPN program will emphasize broadly applicable sampling concepts and principles, such as probabilistic sampling to ensure ability for statistical inference, in all of its sampling-design development. Development of specific sampling designs tailored to a vital sign and its data requirements will be a critical early step in each protocol-development project the network undertakes.

"Do a few things well" describes our network philosophy. The SOPN program will focus on a relatively small number of high-priority vital signs (see Chapter 3: Vital Signs), allowing us to focus more effort on each to better ensure that quality information is obtained for park managers.

Try to do it right the first time. We stress a priori development of high-quality sample design as a key component of all protocol projects. We subscribe to the concept that putting more effort and attention into development and evaluation of those designs "up front" will result in better monitoring protocols to provide higher quality information over the long term. Sampling-design development will involve appropriate subject matter experts and statisticians, and all designs will be carefully reviewed to ensure statistical robustness and performance prior to implementation.

The SOPN is a geographically large network. We recognize that logistics will affect our ability to effectively monitor vital signs across 11 parks spread out over 5 states. We emphasize careful logistical planning across the scope of the program. Development of effective sampling rotation, revisit schedules, and panel designs are key components of our protocol-development efforts.

4.5 Water Monitoring

The SOPN parks all have very different water resources, as well as very different concerns about those resources. Thus, surface water quantity and quality are good examples of cases in which one size will definitely not fit all. Consequently, our approach to monitoring surface water quantity and quality will be highly customized for each park unit. Figure 4.5 shows an overview of SOPN water monitoring, and shows, for each unit, whether we plan to monitor surface water quality (water chemistry and/or core parameters of at least water temperature, dissolved oxygen, pH, and specific conductance), water quantity (volume or flow), ground water quantity, or biological indicators (e.g., aquatic invertebrates). Our sampling designs will reflect individual needs but, where possible, we will try to use the same principles for sound design as with other vital signs. Further, many of our park units are quite small, and the surface water of interest is often too small—if it even exists—to warrant sampling, given that any attempt at replication would severely violate any assumptions of independence. Thus, rather than engage in any pseudo-replication, we have opted to use index sites (usually the inlet and outlet) for those units too small to warrant a statistical sample, recognizing that broad

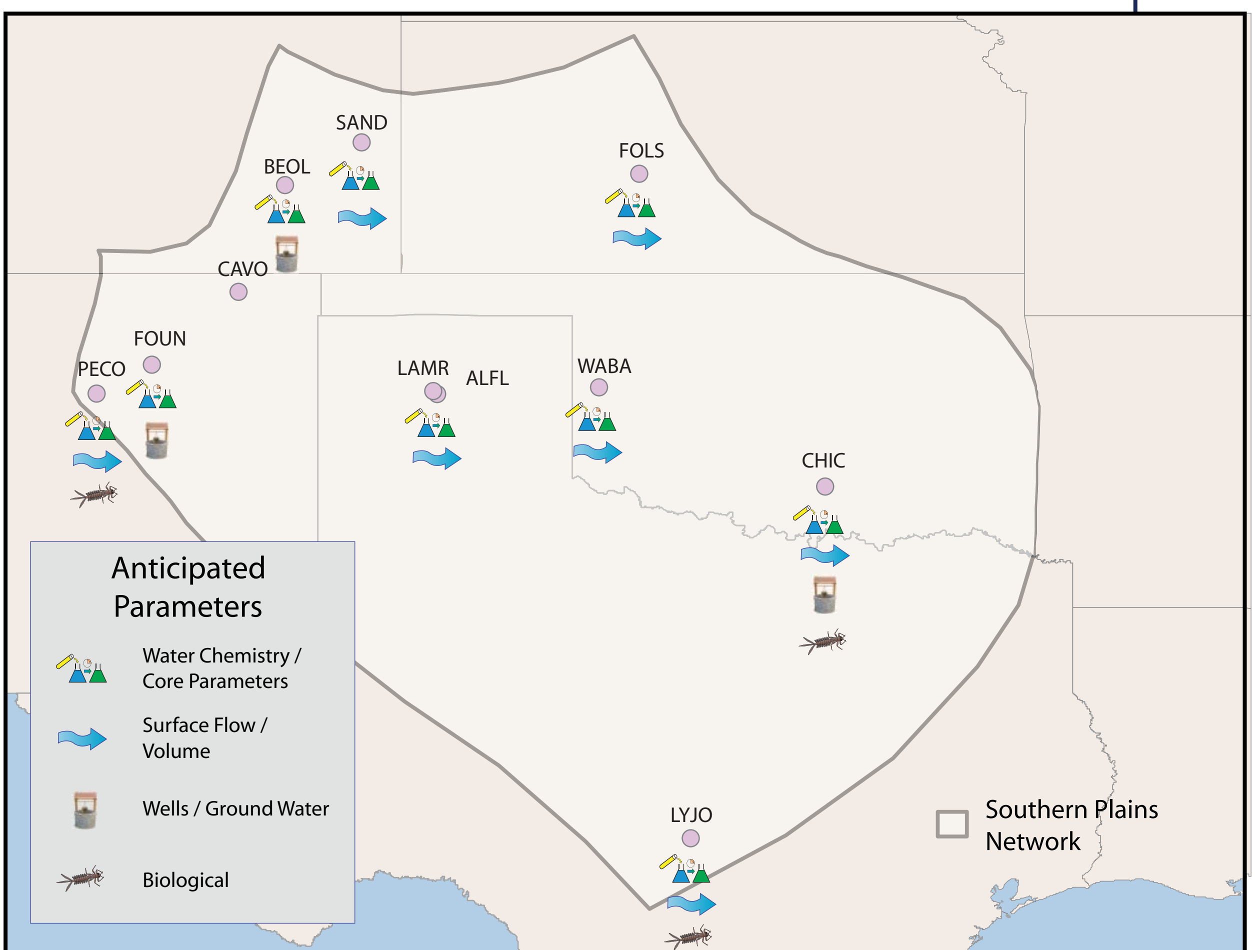


Figure 4.5. SOPN showing preliminary expectations for water monitoring.

inference beyond these sites is not justified. Below, we describe our current plans for water quality monitoring at each park unit, although it should be noted that we are still in the process of determining what will be monitored at each park unit, taking into account the priorities for each unit and our water quality monitoring budget.

4.5.1 Anticipated Water Monitoring at Individual Park Units

4.5.1.1 Bent's Old Fort (BEOL)

Surface Water Quantity and Quality. There are three potential sources of surface water at BEOL that we considered for monitoring. The most prominent is the Arkansas River; however, this river is already well monitored by other agencies and there is little recreation use (e.g., swimming or fishing) near BEOL. Thus, our intention at this time is to establish a stronger working relationship with other agencies that would include routine data access. The other surface water sources include the Arch Wetland and an agricultural ditch. We anticipate some level of monitoring core parameters at least periodically at these sites, with some additional monitoring for agricultural contaminants being a possibility for the agricultural ditch, although the extent of either has not been determined. Given the small size of these units, we anticipate monitoring index sites, rather than spatial sampling.

Arch Wetland at Bent's Old Fort.N.H.S.

H. SOSINSKI

Ground Water. Problems with fluctuations of the water table have been a problem at BEOL in the past, particularly in low areas of the site, including the foundation and subterranean rooms of the fort (Woods et al. 2002). Thus, we anticipate monitoring ground water for at least one well and likely two or three others. Because the concerns are based on very localized effects, rather than ground water in general, here too we anticipate using strategically-located index sites, possibly using renovated wells from Woods et al. (2002).

4.5.1.2 Capulin Volcano N.M. (CAVO)

Surface Water Quantity and Quality. There is no surface water at CAVO and consequently no monitoring is anticipated.

Ground Water. There is a water supply well near the monument headquarters; however, any monitoring of this supply will be done by park operations. Thus, SOPN has no plans of monitoring ground water at CAVO..

4.5.1.3 Chickasaw N.R.A. (CHIC)

Surface Water Quantity and Quality. Chickasaw has considerable existing water quantity and quality data. In addition, the park already collects considerable data as part of their monitoring program. SOPN still needs to synthesize what efforts have been, and are being, done before it can realistically evaluate what contributions the SOPN monitoring program could make and balance that against the cost. Undoubtedly, SOPN will conduct some monitoring at CHIC, but the nature of this effort is yet to be determined. This will be a high priority during FY2008.

Ground Water. Same as above.

4.5.1.4 Fort Larned N.H.S. (FOLS)

Surface Water Quantity and Quality. The primary water resource at FOLS that SOPN is considering for monitoring is the Pawnee River. Although once a clear, sandy perennial river, its flow is now intermittent following rainfall events and relatively stagnant. Given the land use changes in the region, it is unlikely that the river will return to its original state. Thus, at the present time, the primary monitoring being considered at this site is measuring flow and core water quality parameters following rainfall events, for which the specific details have yet to be determined.

Ground Water. SOPN has no plans of monitoring ground water at FOLS at this time..

4.5.1.5 Fort Union N.M. (FOUN)

Surface Water Quantity and Quality. Surface Water Quantity and Quality. Wolf Creek is an intermittent tributary of the Mora River,immediately adjacent to the park boundary. Given its proximity, SOPN will consider periodic monitoring of core parameters on Wolf Creek. There is also at least one spring on the site and a periodic assessment of spring organisms may be warranted.

Ground Water. Some level of simple periodic monitoring of a groundwater production well is likely, although the specific details have not yet been determined.

4.5.1.5 Lake Meredith N.R.A. (LAMR) and Alibates Flint Quarries N.M. (ALFL).

Surface Water Quantity and Quality. Similarly to Chickasaw, LAMR has considerable existing water quantity and quality data. Lake Operations, which are managed by the Canadian River Municipal Water Authority, and oil and gas fields have resulted in considerable previos efforts. SOPN still needs to synthesize what efforts have been, and are being, done before it can realistically evaluate what contributions the SOPN monitoring program could make and balance that against the cost. Undoubtedly, SOPN will conduct some monitoring at LAMR and ALFL, but the nature of this effort is yet to be determined. This will be a high priority during FY2008.

Ground Water. The extent to which SOPN will monitor ground water at LAMR and ALFL has not yet been determined.

4.5.1.7 Lyndon B. Johnson N.H.P. (LYJO)

Surface Water Quantity and Quality. The primary surface water resources at LYJO are the Pedernales River on the Ranch Unit, and Town Creek and a spring at the Johnson City Unit. SOPN tentatively plans on periodic monitoring of core water quality parameters and flow on the Pedernales River, although the specific details re sampling locations and frequency have not yet been determined. We are also considering periodic sampling of invertebrates on the Pedernales, but the specifics of that have also not yet been determined. In contrast to the Pedernales River, Town Creek is an intermittent stream. Thus, we plan on some level of periodic monitoring of core parameters and flow during periods of flow. In addition, there is a relatively large spring at the Johnson City Unit, although we have not yet determined what,if any, monitoring will occur at that site.

Ground Water. SOPN has no plans of monitoring ground water at LYJO at this time.

4.5.1.8 Pecos N.H.P. (PECO)

Surface Water Quantity and Quality. The primary water resource at PECO that SOPN will monitor is the Pecos River. The river has been monitored approximately biweekly since the early 1990s by a volunteer effort, although these data require incorporation into a master database. We anticipate regular monitoring of core parameters within the park unit, possibly using or revising the existing effort. We will evaluate the sampling design of the existing effort during FY08 to determine whether it should be maintained or revised. We also will explore the possibility of periodic macroinvertebrate assessments to compliment the core parameters. Previous assessments have been made on the Pecos River which can serve as a comparison, and plans to open the river for fishing access in the near future may warrant additional consideration.

G. NESOM

Lake Meredith National Recreation Area.

Ground Water. The extent to which SOPN will monitor ground water at PECO has not yet been determined.

4.5.1.9 Sand Creek Massacre N.H.S. (SAND)

Surface Water Quantity and Quality. The primary surface water resources at SAND are several perennial pools along the Sand Creek channel and intermittent flows in the creek itself. SOPN tentatively plans on quarterly monitoring of core water quality parameters at these pools and periodic monitoring on Sand Creek during periods of flow (the specific details of which are yet to be determined). Flow measurements during periods of flow would likely accompany measurements of the core parameters. The three existing gauges of pond water levels would likely be maintained, and we will evaluate whether additional gauges are warranted.

Ground Water. The extent to which SOPN will monitor ground water at SAND has not yet been determined.

One of the ponds at Sand Creek Massacre N.H.S..

D. ZETTNER

4.5.1.10 Washita Battlefield N.H.S. (WABA)

Surface Water Quantity and Quality. The primary water resource at WABA that SOPN will monitor is the Washita River. We anticipate periodic monitoring of core parameters within the park unit, although the specific details have not yet been determined. A Natural Resources Conservation Service (NRCS) gauging station is located just downstream of WABA, which probably is adequate for general flow conditions, although we would likely take localized measurements in conjunction with monitoring core parameters. Periodic testing for pesticides also may be warranted, but will probably not be on a frequent basis. Similarly oil and gas development is occurring in the region and may warrant some event-driven monitoring following any spills.

Ground Water. SOPN does not anticipate any additional ground water monitoring at WABA at this time.

Chapter 5
Sampling Protocols

> *"Anyone who considers protocol unimportant has never dealt with a cat."*
>
> *~ Robert A. Heinlein*

5.1 Introduction

Monitoring protocols are the key, on-the-ground, functional elements of our program. Formal, peer-reviewed protocols ensure consistent and reliable monitoring, and provide for project and program continuity even as personnel change. Our protocols, and the development process used to create them, emphasize careful development and testing of methods and designs to provide effective sampling and monitoring; comprehensive and detailed review by NPS and outside experts to ensure methodological and design adequacy prior to implementation; and careful, detailed documentation to ensure consistent implementation over time. Where possible, the network will take advantage of existing protocols, particularly those that have already undergone I&M and peer review. In those cases, the protocols will need to be adapted for the particular circumstances of SOPN parks. The following sections and tables describe a typical monitoring protocol document, summarize the SOPN protocol development process, and identify, with a proposed development schedule (Table 5.1), the suite of protocols to be developed by SOPN over the next three to five years to address 11 high-priority vital signs. Protocol Development Summaries (PDS) for protocols currently under development are provided in Appendix M.

5.2 Protocol Format and Content

Monitoring protocols will follow the document standards described in Oakley et al. (2003). These guidelines specify protocol document format and content, and emphasize a modular structure that facilitates information access while supporting a well-documented history of change and revision. The following paragraphs summarize the several components of a typical SOPN program monitoring protocol.

Monitoring protocols consist of multiple discrete sections detailing protocol background, sampling objectives, sampling design (including location and time of sample collection), field methods, data analysis and reporting, staffing requirements, training procedures, and operational requirements (Oakley et al. 2003). The first section is a descriptive narrative. This narrative provides the background and rationale for vital sign selection, including a summary of pertinent research background and local research history, and a clear statement of park management information needs concerning the vital sign being monitored. The narrative discusses specific, measurable objectives and monitoring questions, and identifies how the data to be collected in the monitoring effort will address these questions. Narratives also summarize the design phase of protocol development and any decisionmaking that is relevant to the protocol. Documenting the history of a protocol during its development phase helps to ensure that future refinement of the protocol continues to improve the protocol, rather than merely repeating previous trials or comparisons (Oakley et al. 2003). Narratives also provide a listing and brief summary of all standard operating procedures (SOPs), which are developed in detail as independent sections in the protocol.

The narrative is followed by a series of SOPs, which are discrete sections that carefully and thoroughly explain, in a step-by-step manner, how each procedure identified in the protocol narrative will be accomplished. At a minimum, separate SOPs address pre-sampling training requirements, data to be collected, equipment operations, data collection techniques and methods, data management, data analysis, reporting, and any activities required at the end of a field season (i.e., post-sampling equipment maintenance and storage). One SOP identifies when and how revisions to the protocol are undertaken. As stand-alone documents, SOPs are easily updated (when compared to having to revise an entire monitoring protocol). A revision log for each SOP identifies any changes that are implemented, by whom, when, and why—emphasizing, in a practical way, the nature of protocols as "living documents." The final elements or sections in a typical protocol will include Literature Cited and, where appropriate, attachments such as appendices, data tables, handbooks, or any other supporting information.

Complete monitoring protocols identify supporting materials critical to the development and implementation of the protocol (Oakley et al. 2003). Supporting materials are any materials developed or acquired during the development phase of a monitoring protocol. Examples of this material may include databases, reports, maps, geospatial information, species lists, analysis tools tested, and any decisions resulting from these exploratory analyses. Material not easily formatted for inclusion in the monitoring protocol also can be included in this section.

5.3 Protocol Development Process

Once a vital sign has been selected, the next step is to develop a monitoring plan and formal monitoring protocol for that vital sign. Successful development of a monitoring protocol often involves a multi-year research and field-testing effort to determine the appropriate spatial and temporal scale for sampling, and to test sampling procedures before they are implemented for long-term monitoring. In many cases, such development requires specialized technical expertise and access to equipment or resources that may not be directly available to a monitoring program. For the SOPN program, protocol development will be performed through collaborative projects that take advantage of diverse agency, academic, and other professional expertise in order to leverage and augment network resources. Most technical development and field work will be performed by non-NPS personnel working in collaboration with network and park staff, along with associated interns and volunteer groups. Current collaborators providing key technical assistance include academic experts affiliated with the USGS and CESUs. In general, SOPN staff will be the primary developers of protocol-associated data management and documentation procedures, and will oversee both field testing and future implementation in network parks.

The general protocol development process is as follows: Staff and collaborators identify the key monitoring objectives and questions, and types of data needed to best answer those questions. Next, the development team selects (or develops) and field-tests appropriate sampling methods and spatial designs. Method and design development takes into account specific properties of the sampled resource, such as taxon-specific habitat use and phenology. For example, monitoring of amphibians must take into account the details of when and where certain species may be found in a shared habitat. Following field-testing (and possible revision), protocol SOPs are drafted to detail all methods, designs, and related information. Finalized protocol documents are then sent through an informal internal and formal external (peer and expert) review process. Following reviews and revision, the approved protocol will be accepted for full implementation by the program, and implementation will commence according to the design and schedule set for that protocol. Given the lengthy and involved process of protocol development, the network plans to use and modify existing protocols whenever feasible to meet our needs.

5.4 Protocol Development Schedule

The SOPN monitoring program has identified 29 vital signs for possible monitoring in one or more of its parks. Of these, 11 have been identified as being of higher priority (see Chapter 3: Vital Signs), and will be the focus for development and implementation within the next three to five years. The remaining 18 vital signs are not currently slated for protocol development and monitoring, but will be addressed as opportunity and resources permit. The SOPN program currently (FY 2008) has development work underway on all 11 protocols.

5.5 Protocol Development Summaries

Protocol Development Summaries (PDSs) are required for all monitoring protocols planned for development and implementation by the network monitoring program. The PDS is a short (one to two pages) document that identifies the vital sign of interest, describes why the protocol and monitoring is needed, and outlines the specific issues and questions being addressed, specific measurable objectives, proposed methodological approach, and other details. The typical PDS includes the following material:

- **Protocol:** Title of the protocol.
- **Parks Where Protocol Will Be Implemented:** Names or four-character codes for the parks where the protocol is likely to be implemented over the next five years.
- **Justification/Issues Being Addressed:** A paragraph or two justifying why this protocol needs to be developed.
- **Monitoring Questions and Objectives to be Addressed:** Specific monitoring objectives of the Protocol.
- **Basic Approach:** Description of any existing protocols or methods that will be incorporated into the protocol, the basic methodological approach and sampling design.
- **Principal Investigators and NPS Lead:** The name and contact information for the principal investigators (PIs) and for the NPS project manager responsible for working with the PIs to ensure that the protocol meets network and park needs.
- **Development Schedule, Budget, and Expected Interim Products:** Description of expected costs, timelines, and interim products (annual reports, sampling designs, etc.).

The PDS files for SOPN protocols currently in development can be found in Appendix M. Additional PDSs will be developed as the program identifies new protocol development projects.

J. LOTT

Biological inventory being conducted along the Pedernales River (LYJO)

Table 5.1. High-priority SOPN vital signs slated for development between 2007 and 2009.

SOPN vital sign	Parks	Justification	Primary monitoring objectifves	Start year
Soil Structure and Chemistry	All SOPN parks	The structure and chemical composition of soils are fundamental determinants of soil quality, which in turn serves as an indicator as well as a driver of overall ecosystem health.	Determine status and trends in soil structure (erosion potential, infiltration rate, compaction, texture, stability) and soil chemistry (bulk soil C:N ratios).	2009
Ground Water Levels	All SOPN parks except CAVO	Groundwater overdrafts in the SOPN are a leading anthropogenic stressor that can contribute to the establishment and spread of non-native species like tamarisk (***Tamarix*** sp.) that can alter ecosystem dynamics such as the frequency and severity of fires.	Determine the trends in groundwater quantity levels. Document changes in hydrologic regime associated with hydrological modifications (e.g., dams, diversions) in the SOPN.	2009
Water Quantity–Surface	All SOPN parks except CAVO	Available water is one of the key drivers of ecosystem function in the Great Plains and provides insights into overall system productivity, shifts in species abundance and distributions, nutrient cycles, and the occurrence of and ecosystem response to disturbance events.	Determine the hydrologic trends for streamflow and lake water levels. Document changes in hydrologic regime associated with hydrological modifications (e.g., dams, diversions) in the SOPN.	2009
Water Quality–Core Parameters	All SOPN parks except CAVO	Surface water quality is important to maintaining a healthy habitat for many aquatic organisms, wildlife, and humans. Water quality can provide insights into overall system productivity, can shift species abundances and distributions, and alter nutrient cycles.	Determine the ltrends in core (temperature, turbidity, dissolved oxygen, pH) water quality parameters at SOPN water bodies. Where appropriate, determine fecal coliform levels and trends.	2009
Exotic Plants	All SOPN parks	Exotic plants represent one of the most significant threats to natural resources in national parks. Exotic plants are a concern due to their abilities to reproduce prolifically, rapidly colonize new areas, displace native species, alter ecosystem processes across multiple scales, and detract from the interpretive value of park resources.	Detect initial occurrence. Determine changes in status and trends (density, abundance or extent). Determine changes in species composition for any of a subset of high-priority species in zones of high and low invasion probability.	2009
Riparian Vegetation Communities	All SOPN parks	Riparian areas are highly productive environments that serve as habitats for many birds, fish, and other wildlife. The disruption of natural processes (e.g., climate, fire, and grazing) that help to maintain ecological integrity has led to drastic changes in species composition and community structure of riparian plant communities, particularly with the invasion of exotic species.	Determine temporal and spatial trends in species composition and richness, abundance, structure, and diversity of riparian plant communities. Quantify changes in the cover, richness, and species diversity of key woody native and non-native riparian trees within network parks.	2010

Table 5.1. High-priority SOPN vital signs slated for development between 2007 and 2009, cont.

SOPN vital sign	Parks	Justification	Primary monitoring objectifves	Start year
Grassland Vegetation Communities	All SOPN parks	In the Great Plains, grasslands have been converted to agricultural land and urban areas, their hydrology has been altered, and they have been degraded due to overgrazing, increased land fragmentation, fire suppression, and exotic species invasion.	Determine status and trends in plant species composition (richness and diversity) and community structure (relative abundance, frequency, distribution, ground cover) of remnant, disturbed and/or restored grasslands.	2009
Bird Communities	All SOPN parks	Songbird communities are good indicators of ecosystem health because they respond quickly to changes in resource conditions and comparable regional and national datasets exist. Grassland birds, in particular, respond to management practices such as grazing and fire, as well as landscape-level changes.	Determine occupancy and changes in distribution (i.e., local colonizations and extinctions) of bird communities in grassland and riparian habitats of SOPN parks.	2009
Human Demographics	All SOPN parks	Many SOPN parks are subject to encroaching and changing agricultural, residential, and urban development. These landscape modifications are closely linked to park ecosystem function.	Detect trends in human demographic data in the vicinity of SOPN parks.	2009
Fire and Fuel Dynamics	All SOPN parks	Fire is one of the most influential disturbance processes in Great Plains ecosystems. Fire is important to monitor because it influences vegetative succession and distribution, wildlife habitat, soil parameters, hydrology, water quality, and air quality.	Track the location, extent, timing, and severity of wildland and prescribed fires in SOPN parks. Track successional effects of fire and burn severity on the species composition and structure of vegetation; soil temperature and moisture; and animal community composition.	2009
Landscape Dynamics	All SOPN parks	The landscape dynamics of SOPN parks are particularly important due to the parks small size. The ecological communities within SOPN parks are as influenced by the ecological processes and land use activities occurring outside park boundaries as they are by management decisions within the parks.	Determine the state of the current landscape inside and adjacent to SOPN national parks. Determine long-term trends in land-use change, habitat conversion to urban landscapes, reduction of functional ecosystem size, and elimination of important habitats within and adjacent to SOPN parks.	2009

Chapter 6
Data Management

> ***It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.***
>
> ***~ Sir Arthur Conan Doyle***

6.1 Introduction

Data become information through the process of analysis, synthesis, modeling, or other types of interpretation. Data management provides a means for organizing, documenting, and archiving data so that the potential of the original information is maintained through time. This is particularly important for long-term programs in which the lifespan of a dataset will likely be longer than the careers of those who developed it. A data management system that can effectively produce, maintain, and distribute monitoring results is central to the success of the SOPN program.

This chapter summarizes the general data management standards; expected roles and responsibilities; and data processing, storage, and distribution guidelines for the SOPN. A more detailed description can be found in the SOPN Data Management Plan (DMP), which will be revised periodically. Detailed data management procedures for monitoring projects will be based on the guidelines provided in the the SOPN DMP and the overall principles described in the national-level data management plan.

6.2 Goals and Objectives

The goal of the SOPN data management program is to maintain, in perpetuity, the ecological data and related analyses that result from the network's natural resource inventory and monitoring work. This section describes the objectives, policies, and guidelines that will ensure the highest standards for data acquired or managed by all networks. These standards, established at the national level, include:

- ***Accuracy.*** The quality of the data collected and managed by the SOPN 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 detectability of subtle changes in ecosystem patterns and processes, lead to incorrect interpretations and conclusions, and could greatly compromise the credibility and success of the I&M program. To ensure that the network 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.
- ***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. The network must have proper storage and backup procedures and disaster recovery plans in place. In addition, collaboration with the NPS Museum Management Program enlists the expertise of museum curators and archivists to ensure that related project materials, such as field notes, data forms, specimens, photographs, and reports are properly catalogued, stored, and managed in archival conditions.
- ***Longevity.*** Countless datasets have become unusable over time either because the format is outdated or because metadata is insufficient to determine the data's collection methods, scope and intent, quality assurance procedures, or format. While proper storage conditions, backups, and migration of datasets to current platforms and software standards are basic components of data longevity, comprehensive data documentation is equally important. Networks must ensure that datasets are consistently documented, and in formats

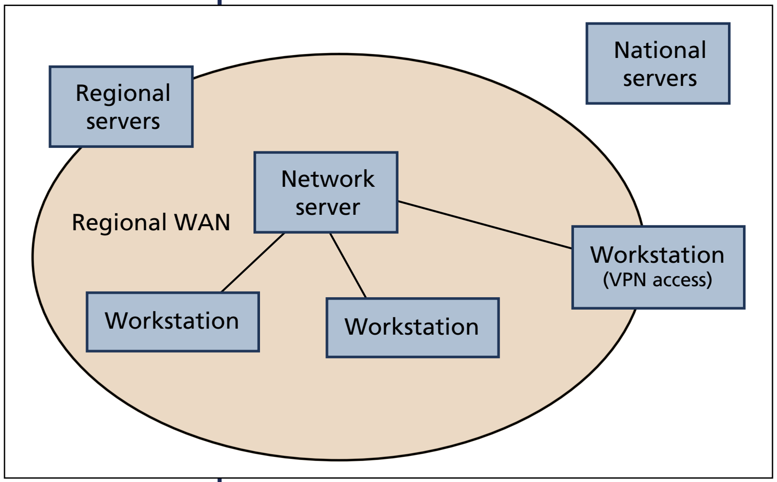
that conform to current federal standards.

- *Usability*. One of the most important responsibilities of the I&M program is to ensure that data collected, developed, or assembled by staff and cooperators are made available for decisionmaking, research, and education. Providing well-documented data in a timely manner to park managers is especially important to the success of the program. Networks must ensure that:
    - o data can be easily found and obtained;
    - o data are subjected to full quality control before release ;
    - o data are accompanied by complete metadata; and
    - o sensitive data are identified and protected from unauthorized access and distribution.

6.3 Infrastructure and System Architecture

A modern data management infrastructure (e.g., staffing, hardware, software) represents the foundation upon which our network information system is built. Infrastructure refers to the system of computers and servers that are functionally or directly linked through computer networking services. Architecture refers to the applications, database systems, repositories, and software tools that make up the framework of an information management system. The SOPN relies on park, network, and national information technology (IT) personnel and resources to maintain a computer systems infrastructure and architecture. This includes, but is not limited to, hardware replacement, software updates and support, security updates, virus protection, telecommunications networking, and server backups. Therefore, communication with park and national personnel is essential to ensure adequate resources and service continuity.

Figure 6.3.1. Digital infrastructure of the Southern Plains Network.



6.3.1 SOPN System Architecture

One important element of an information management program is a reliable, secure network of computers and servers. Our digital infrastructure has three main components: a network-based local area network (LAN), a regional wide-area network (WAN), and servers maintained at the national level (Figure 6.3.1). Each of these components hosts different parts of our natural resource information system. Network workstations either connect directly to this network from inside the regional WAN, or via virtual private network (VPN) connections for offices not located within NPS buildings.

Information technology duties for network programs are provided primarily by the network data manager and, in some cases, the IT staff at LYJO. These include hosting and managing SOPN electronic files being created, managed, and disseminated by network staff and cooperators. The SOPN LAN will be the primary repository for I&M electronic files, with access available to I&M staff. Files will be managed within a standardized electronic directory structure, organized by project. Security will be achieved through electronic file and directory permissions, with administration rights controlled by IT personnel and a limited number of trained program staff.

6.3.2 National System Architecture

The national I&M program provides several repositories for hosting SOPN information products, as well as applications for summarizing park data at a national level. The following applications are available online and allow users to access basic natural resource information for SOPN parks:

- NatureBib: master database for natural resource bibliographic references.

- NPSpecies: master database for species-occurrence records and evidence (voucher specimens, references, observations or datasets) at each park.
- NPS Data Store: master database of metadata for GIS and natural resource datasets and a repository for that data.
- SOPN website: repository for reports and metadata for SOPN projects, certified species lists, search and reporting tools for data, data downloads, and database templates (http://www.nature.nps.gov/im/units/ncpn/index.cfm).

6.4 Data Management Process and Workflow

To better understand the information management needs of the I&M networks, it is useful to understand the information management tasks that are associated with each stage of project development. There are two main types of projects handled by network natural resources staff and the I&M program:

1. Short-term projects, including individual park research projects, inventories, or pilot work done in preparation for long-term monitoring or research; and
2. Long-term projects, including network vital signs monitoring projects central to the I&M program and multi-year research projects and monitoring performed by other park programs, agencies, and cooperators. Long-term projects often require a higher level of documentation, peer review, and program support.

Both short-term and long-term projects share many workflow characteristics, and both generate data products that must be managed and made available. The primary difference between short- and long-term projects is that with long-term projects, there is an increased need to adhere to and maintain standards and to compare data over an extended period of time (i.e., decades, for long-term monitoring).

A project can be divided into a series into five primary stages, each characterized by a particular set of activities carried out by staff involved with the project (Figure 6.4):

1. Planning and Approval. At this stage, many preliminary decisions are made about project scope and objectives, and funding sources. Permits and compliance are also addressed at this time. Primary responsibility rests with project leaders and program administrators. Although there are no specific data management activities during this phase, it is still important that data managers remain informed so as to be able to anticipate data management needs.
2. Design and Testing. Details about how data will be acquired, processed, documented, analyzed, and reported are developed during this stage. Collaboration between the project leader and the data manager is critical during this phase to assure data quality and integrity. Key data management details, such as developing documentation of project databases (e.g., relational diagrams, data dictionaries, business rules, and front-end programming) and formal metadata are worked out during this stage. A joint effort is required to develop and document the project methods, data design, data dictionary, and the database itself.
3. Implementation. At this stage, data are acquired, processed, error-checked and further documented, and products are developed. The project leader oversees all aspects of this stage, with data management staff functioning primarily as facilitators to support database applications, GIS, GPS, data verification, summarization, and analysis. Project staff members work to develop and finalize the deliverables that were identified in the project planning documents (i.e., protocol, study plan, contracts, agreements or permits).
4. Product Integration and Distribution. Here, data are merged from the working database to master databases. Administrative records will be delivered to appropriate park and network staff as specified. All project deliverables will be distributed according to specifications that will be stipulated in all protocols, contracts, agreements, and permits. Products that do not meet program requirements will be returned for revision.
5. Evaluation and Closure. At this final stage, project records are updated in the tracking database to reflect the status of the project.

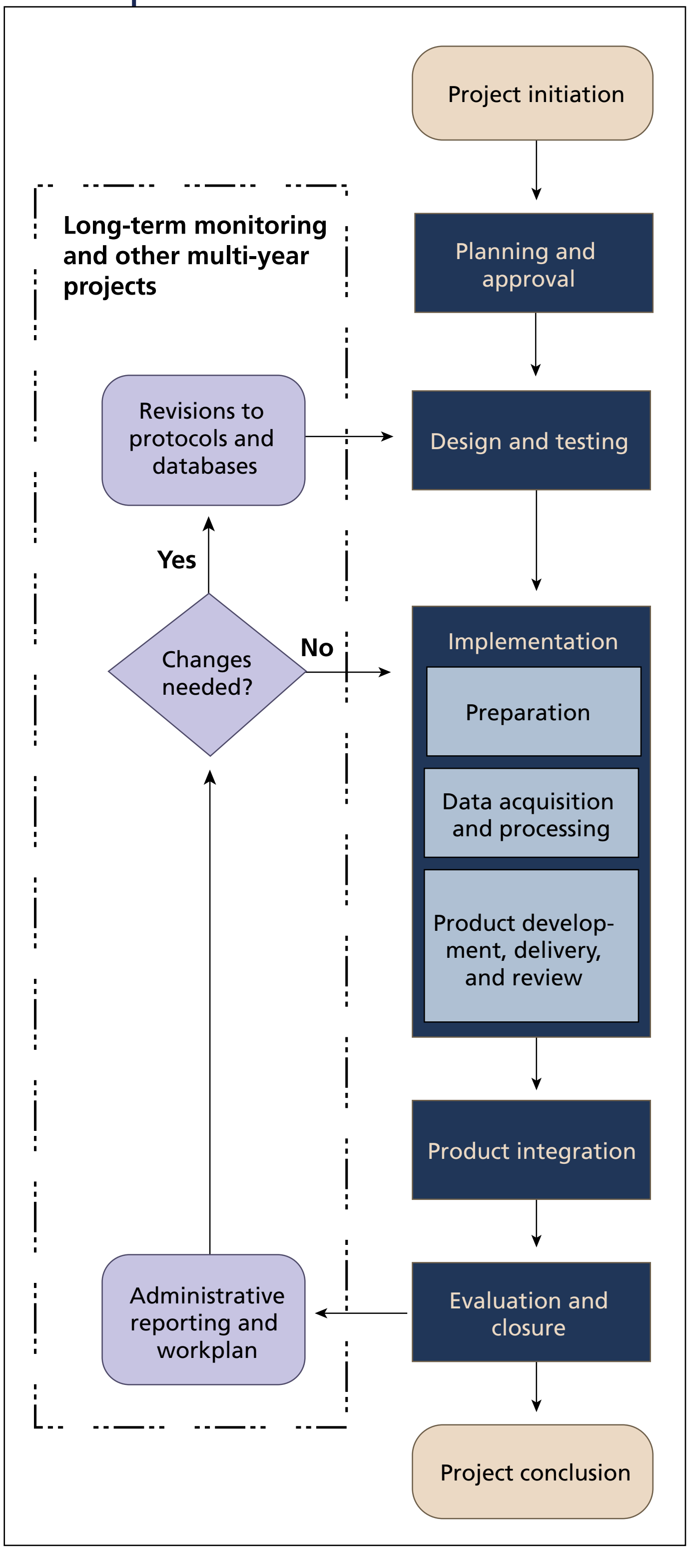


Figure 6.4. Primary project stages.

After products are catalogued and made available, program administrators, project leaders, and data managers will work together to assess how well the project met its objectives, and to determine what might be done to improve various aspects of the methodology, implementation, and formats of the resulting information.

Project data take different forms and are maintained in different places as they are acquired, processed, documented, and archived. These phases can be modeled as a sequence of events and tasks that involve interaction. Key points of this cycle include:

- Archiving all raw data intact.
- Using working databases as the focal point of all modification, processing, and documentation of data collected for a given time period.
- Archiving and posting or integrating data with national archives after all quality assurance, documentation, and certification are complete.
- Uploading data for long-term monitoring projects into master databases.
- Using certified datasets to develop reports and other data products (e.g., maps, checklists). These products are also archived and posted to appropriate national applications and repositories.
- Documenting all subsequent changes to certified datasets in an edit log, which is distributed with the data.

6.5 Roles and Responsibilities

Data management and stewardship are the responsibility of all participants in the SOPN network. I&M activities require true collaboration among many people with a broad range of tasks and responsibilities. Good habits and attitudes are as important as standards and procedures. Although primary responsibility resides with the data manager, project managers, and GIS specialists who make up the core data management team, all SOPN staff and cooperators are responsible for ensuring that data stewardship is practiced throughout the life of a monitor-

Table 6.5. Roles of SOPN network staff and cooperators working on monitoring projects.

Role	Data stewardship responsibilities
Project crew member	Collect, record, verify data; perform data entry; organize field forms, photos, other related materials.
Project crew leader	Supervise crew, communicate regularly with data manager and project leader.
Network data manager	Ensure program data are organized, useful, compliant, safe, and available.
GIS specialist	Oversee GPS data collection, manage spatial data, prepare maps, perform spatial analyses.
IT specialist	Apply database and programming skills to network projects, maintain information systems to support data management.
Project leader	Direct operations, including data management requirements, for network projects.
Resource specialist	Evaluate validity and utility of project data; document, analyze, and publish data and associated information products.
Quantitative ecologist	Determine project objectives and sample design; perform and document data analysis and synthesis; prepare reports.
Network coordinator	Coordinate and oversee all network activities.
Park or regional curator	Ensure project results (e.g., documents, specimens, photographs) are cataloged and stored in NPS or other repositories.
I&M data manager (national level)	Provide servicewide database support and services; provide data management coordination among networks.
End users (managers, scientists, interpreters, public)	Inform and direct the scope of science information needs; interpret information and use to direct or support decisions.

ing project. Table 6.5 summarizes the roles and responsibilities of SOPN staff and cooperators with respect to data stewardship. It should be noted that a single person may take on more than one role in a given project.

6.6 Database Design

The data manager and project manager will collaborate on design of field data sheets, database structure, and database application for each monitoring project. Databases will be standardized, where possible, following the I&M-recommended guidelines for database structure and naming conventions developed in the Natural Resource Database Template and the Recommended Naming Standards. The SOPN will also develop standardized lookup tables for data elements shared across many monitoring projects. The network currently uses Microsoft Access for all project databases. Designing modular databases instead of a central database will allow for greater flexibility to accommodate each project's needs, and sufficient standardization can ensure the ability to aggregate and summarize data across multiple projects. At this time, the SOPN does not plan to move to a client-server relational database management system such as the Microsoft SQL Server. However, all databases will be designed in a way so as to allow upscaling to a client-server relational database system should the need occur.

6.7 Data Acquisition and Quality Control

Data managed and utilized by the network will originate from three types of sources: within the network, other NPS data collection efforts, and outside the NPS altogether, defined as follows:

- Network data: any data produced from projects that are initiated (funded) by the SOPN I&M program or projects that in some way involve the I&M program.
- NPS data: any data produced by the NPS that did not involve the I&M program.
- External data: any data produced by agencies or institutions other than the National Park Service.

Project crew leaders and members are primarily responsible for data collection, data entry, and data verification of data acquired from field data collection. Each monitoring project protocol will detail procedures for these data acquisition steps based on guidelines outlined in this plan. As data are collected and entered into a database, quality control procedures will be used to increase accuracy and check for and correct any transcription mistakes. NPS data acquired from parks, regional offices, and national programs will undergo limited processing. Legacy data from parks will be evaluated and prioritized for digitizing or converting to modern formats. External data necessary for each project will be identified during project planning and protocol development, and will be acquired if documentation and metadata are complete. In come cases, the network will access data that are maintained and archived by other programs (e.g., climate data).

6.8 Quality Assurance and Quality Control

The success of the I&M program will ultimately depend on the quality of the data that are collected, processed, and disseminated. To ensure data of the highest quality, procedures have been established to identify and minimize errors at each project stage associated with the data life cycle. Quality assurance and quality control protocols and execution are joint responsibilities, the results of which are documented to notify end users of the level of data quality. Quality assurance, data summary, and data analysis are the responsibility of the project managers; however, the data manager will provide tools to project managers to facilitate these three activities.

Although some quality control procedures depend upon the nature of a specific project, some general concepts apply to all network projects. To ensure that all SOPN vital signs monitoring projects produce and maintain data of the highest quality, a common set of procedures has been developed to identify and minimize both the frequency and significance of error at all stages in the data life cycle (Figure 6.8).

Examples of quality assurance practices include:

- Field crew training;
- Standardized field data forms with descriptive data dictionaries;
- Use of handheld computers and data loggers with built-in controls;
- Equipment maintenance and calibration;
- Procedures for handling data in the field; and
- Database features to minimize transcription errors, including range limits, pick lists, etc.

Verification and validation, including automated error-checking database routines and quality assurance methods, will be in place at the inception of any project and continue through all project stages to final archiving of the dataset.

6.9 Documentation

Documentation is essential to the longevity and value of project data. Anyone using these data in the future will need to know as much as possible about what, where, how, when, why, and by whom the data were collected, along with appropriate uses, including restrictions on sensitive information, and any known limitations. A good data management system cannot simply attend to the tables, fields, and values that comprise a dataset. It must also provide a process for developing, preserving, and integrating the research context that makes data interpretable and useful. For the SOPN, this will involve the development of formal metadata—a detailed, structured set of information about the content, quality, condition, and other characteristics of project data. The development of formal metadata, which will follow Federal Geographic Data Committee and NPS standards for content and format, will also enable the cataloging of project datasets within Intranet and Internet systems, thereby making them available to a broad range of potential users.

Metadata for all SOPN monitoring projects will be parsed into two nested levels of detail, each with a specific audience in mind. Level 1, or "Manager Level," will present an overview of the product, crafted to quickly convey the essentials needed to understand the context of the data. Level 2, or "Full Metadata," will con-

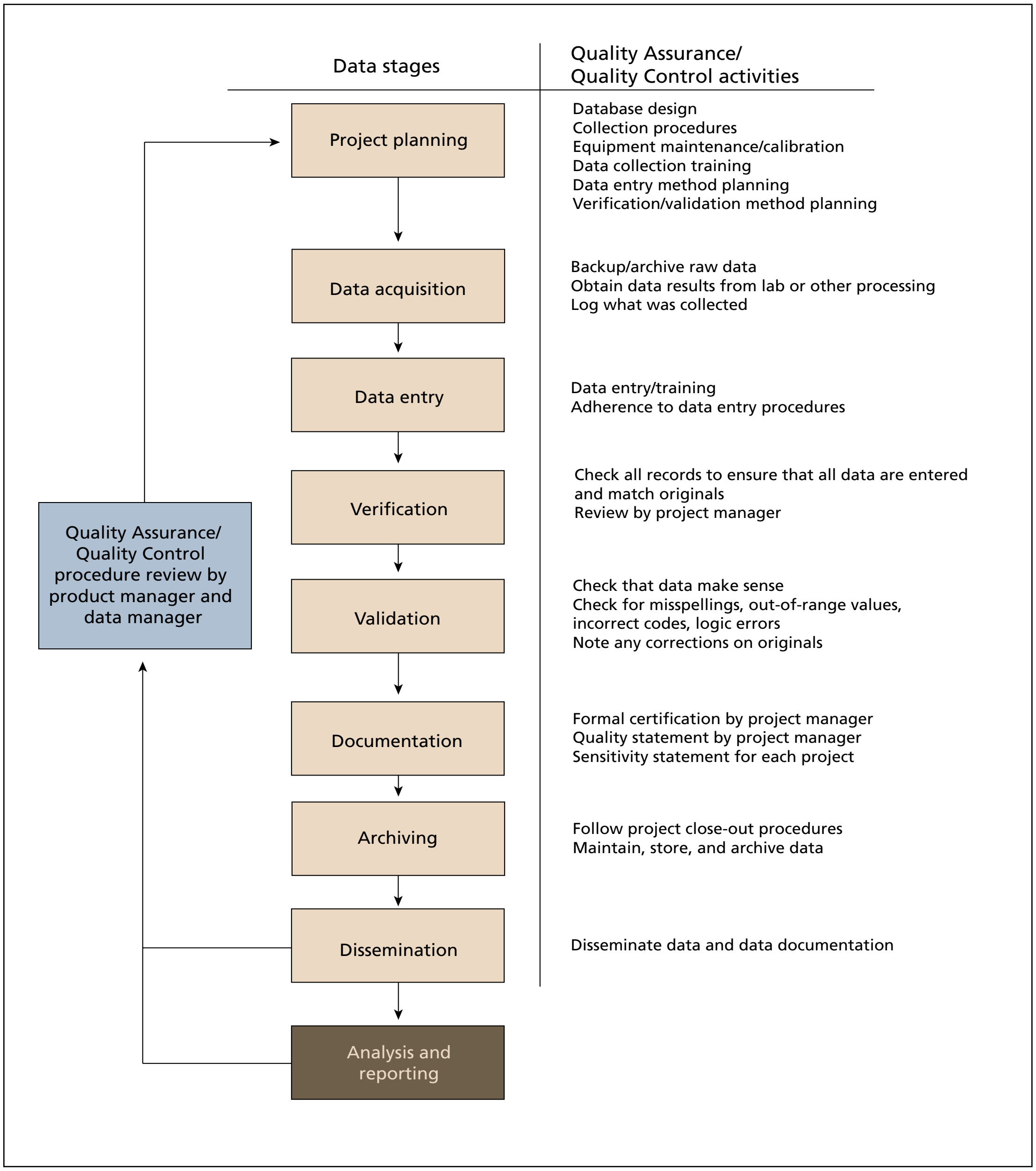


Figure 6.8. General course of data and associated quality assurance/quality control procedures.

tain all components of supporting information such that the data may be confidently manipulated, analyzed, and synthesized.

There are a variety of software tools available for creating and maintaining metadata. The SOPN will use one or more of the following: ESRI's ArcCatalog, NPS Metadata Tools and Editor, and/or the "Metadata in Plain Language" questionnaire. The SOPN data manager will provide training and support in the use of these tools to project leaders and will aid in metadata development where practical. Upon completion, metadata will be posted with project data so that they area available and searchable along with their constituent datasets data and reports via the SOPN Internet web site and the NPS Data Store.

6.10 Ownership and Sharing

SOPN data and information products are considered property of the NPS. However the Freedom of Information Act (FOIA) establishes access by any person to federal agency records that are not protected from disclosure by any exemption or by special law enforcement record exclusions. We will comply with all FOIA strictures regarding sensitive data. If the NPS determines that disclosure of information would be harmful, information may be withheld concerning the nature and specific location of:

- Endangered, threatened, rare, or commercially valuable National Park System resources (species and habitats);
- Mineral or paleontological objects;
- Objects of cultural patrimony; and
- Significant caves.

Each project leader, as the primary data steward, will determine data sensitivity in light of federal law, and will stipulate the conditions for release of the data in the project protocol and metadata. Network staff will classify sensitive data on a case-by-case, project-by-project, basis. They will work closely with investigators for each project to ensure that potentially sensitive park resources are identified, and that information about these resources is tracked throughout the project.

Network staff is also responsible for identifying all potentially sensitive resources to the principal investigator(s) working on each project. Investigators, whether network employees or partners, will develop procedures to flag all potentially sensitive resources in any products that come from the project, including documents, maps, databases, and metadata. When submitting any products or results, investigators will specifically identify all records and other references to potentially sensitive resources. Partners will not release any information in a public forum before consulting with network staff to ensure that the information is not classified as sensitive or protected.

The following guidance for determining whether information will be protected is suggested in the draft Director's Order #66 (the final guidance will be contained in Reference Manual 66):

- Has harm, theft, or destruction occurred to a similar resource on federal, state, or private lands?
- Has harm, theft, or destruction occurred to other types of resources of similar commercial value, cultural importance, rarity, or threatened or endangered status on federal, state, or private lands?
- Is information about locations of the park resource in the park specific enough so that the park resource is likely to be found at these locations at predictable times now or in the future?
- Would information about the nature of the park resource that is otherwise not of concern permit determining locations of the resource if the information were available in conjunction with other specific types or classes of information?
- Even where relatively out-dated, is there information that would reveal locations or characteristics of the park resource such that the information could be used to find the park resource as it exists now or is likely to exist in the future?
- Does NPS have the capacity to protect the park resource if the public knows its specific location?

Natural Resource information that is sensitive or protected requires the following steps:

- Identification of potentially sensitive resources.
- Compilation of all records relating to those resources.
- Determination of what data must not be released to the public.
- Management and archival of those records to avoid their unintentional release.

6.11 Dissemination

The NPS is directed to protect information about the nature and location of sensitive park resources under one Executive Order and four resource confidentiality laws:

- Executive Order No. 13007: Indian Sacred Sites;
- National Parks Omnibus Management Act (NPOMA; 16 U.S.C. 5937);
- National Historic Preservation Act (16

U.S.C. 470w-3);

- Federal Cave Resources Protection Act (16 U.S.C. 4304); and
- Archaeological Resources Protection Act (16 U.S.C. 470hh).

All monitoring information products will be vetted for sensitive data prior to being made available to the general public. Classification of sensitive I&M data will be a shared responsibility that includes network staff, park resource management staff, park superintendents, and investigators working on individual projects. Park managers have ultimate responsibility for deciding which information is sensitive and will not be released to the public. The network has ultimate responsibility for ensuring that sensitive data is not released to the public.

6.11.1 Access

Dissemination of monitoring and information products from SOPN will follow these guidelines:

- Data will be easily located and acquired.
- Only data subjected to full quality control and quality assurance measures will be released.
- Data will be accompanied by complete metadata.
- Sensitive data will be identified and protected from unauthorized access.

Information products will be made available primarily through websites and clearinghouses that will allow users to search for and download reports, summarized data, maps and metadata, and other associated information. Distribution means will include (but may not be limited to) the SOPN public website; NPS Data Store; servicewide databases, such as NPSpecies, NatureBib, and NPSTORET; regional, network, or park data servers protected with read-only access; and FTP sites, email, CDs, DVDs, or hard drives, as appropriate.

6.12 Records Management and Object Curation

Data maintenance, storage, and archiving procedures will ensure that data and related documents and associated physical objects are kept up-to-date relative to content and format (such that the data are easily accessed and their heritage and quality easily learned); and physically secure against environmental hazards, catastrophe, and human malice.

Technological obsolescence is a significant cause of information loss, and data can quickly become inaccessible to users if they are stored in out-of-date software programs or on outmoded media. Effective maintenance of digital files depends on the proper management of a continuously changing infrastructure of hardware, software, file formats, and storage media. Major changes in hardware can be expected every 1–2 years, and in software, every 1–5 years. As software and hardware evolve, datasets must be consistently migrated to new platforms, or they must be saved in formats that are independent of specific platforms or software (e.g., ASCII delimited files). Data maintenance schedules will be developed to ensure that data are migrated and kept up-to-date.

6.12.1 Archiving and storage

Digital and analog information products will be stored, archived, and maintained in a variety of repositories (Table 6.12.1). Digital products resulting from monitoring projects will be archived on the SOPN file server as well as national file and data servers, and protected from catastrophic loss by regular, automated backups to external media and stored off-site. Analog products will be archived to NPS standards by individual park facilities or approved non-NPS institutions. At the termination of a project or at regular milestones, an archival package will be prepared and delivered to the desired location.

6.13 Project Tracking and Documentation

The SOPN will develop and implement a process for tracking I&M projects—including project status, data, and the products of analysis to support program coordination and annual reporting—and to improve accountability for network natural resource inventory and monitoring efforts and products. All projects will be tracked using a database located on the SOPN file server. This will serve as the primary orga-

Table 6.12.1. Repositories for SOPN information products.

Repository	Information Products
SOPN project directories	Working database, metadata, protocols, SOPs, reports, administrative records, digital photos.
SOPN project databases	Certified datasets, comprehensive data for multi-year products.
Park collections and/or National Archives	Administrative records, voucher specimens, raw data forms, hard-copy reports.
Specialized museum facilities (e.g., Botanical Research Institute of Texas)	Voucher specimens.
NPSpecies	Compiled information about species occurrences, abundance, residency, and nativity.
NatureBib	Natural resource documents, I&M reports.
NPSTORET	Water quality data.
NPS Data Store	Metadata and non-sensitive digital datasets.

nizational tool for cataloguing and searching information for ongoing and completed network projects. This database will be used to maintain a list of projects, both ongoing and completed; provide a method of tracking product deliverables; and manage project codes used to tie information to other NPS tracking systems (e.g., RPRS, PMIS, PEPC, RAMS).

Projects will be documented by creating project-specific protocol narratives and standard operating procedures (SOPs). These documents must always accompany the distribution of monitoring data. The network's project-tracking database will track the project narrative and SOPs by version number and will be updated whenever any narrative or SOP document is modified. The protocol narrative and SOPs will not be distributed without a log of changes from the project-tracking database. Long-term monitoring projects may require additional documentation for items such as algorithms, output files, and analytical products that may reside in different systems and formats. Data-use and data-request histories, and information on secondary research or publications resulting from long-term monitoring projects, will also be maintained.

The electronic files for all projects will be stored in a well-organized project directory structure that is clearly understood by all network staff. Network digital directory structures will be organized at the project level, such that most or all digital files associated with a project are filed under a common root directory. Project file names will adhere to the naming conventions established by the network. Physical objects acquired as part of a project will be stored according to the network's specification for records management and object curation.

6.14 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 in them stems from federal law, Executive Orders, Director's Orders, or national I&M program guidance. The data management plans help put these requirements into context, and provide operational guidance for achieving them.

The main body of the national-level data management plan broadly addresses relevant subjects, but directs most of its details into the individual appendices that comprise the network-level data management plans that serve as stand-alone documents for ease of locating and retrieving specific information of greatest value to most users. The network-level data management plan will first be revisited in three years (or by October 1, 2011), and then every five years afterward. Plan appendices, including SOPs, detailed guidelines, reference manuals, and policy statements, will likely 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 network staff, park staff, and cooperators with the tools, procedures, and guidelines outlined in the DMP.

These efforts will begin in 2008, and be led by SOPN data management staff. Goals for the first three years include the following:

- All staff of targeted programs and their cooperators will understand the fundamentals of data and information management, including file management, documentation, quality assurance and quality control, electronic storage, and archive storage.
- Data management practices will be improved by implementing:
    - 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;
- Common SOPs and guidance documents for multiple protocols;
- Detailed specifications for data management consistent with the DMP, included in every vital signs monitoring protocol; and
- Procedures and outlets for communication within and among network parks and with the public.

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

- Procedures to facilitate the summarization and reporting of monitoring data;
- A framework and gateway for integrating monitoring data with that of other agencies or networks; and
- Methods for improving file management (e.g., a content management system), database administration and security (e.g., migration to SQL Server), integration into the network of off-site users, and 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 encouraged broadly within the SOPN and, in time, within all SOPN park programs.

Chapter 7
Analysis and Reporting

Essentially, all models are wrong, but some are useful.

~ George Box

7.1 Introduction

One of the guiding principles of the National Park Service's FY2001–2005 Strategic Plan (NPS 2001b) was "applying scientific information to park management decisions to preserve park resources." This goal was also emphasized in the Natural Resource Challenge (NPS 1999) and during the development of the I&M program (NPS 2004a). To effectively accomplish this, the goal of the SOPN can be stated, quite simply, as follows: the SOPN will strive to get the "right" information to the "right" people at the "right" time, and in the "right" form.

Getting the "right" information entails making sure that the information we collect is relevant to the information needs of SOPN parks, and is scientifically credible and defensible. We have attempted to ensure relevancy through the extensive vital signs selection process described in Chapter 3. Using the sampling designs described in Chapter 4 will ensure that the network collects data in a way that meets the highest standards of scientific quality, and this chapter describes how the SOPN will implement reliable analyses to complement our sampling designs. Fulfilling the rest of the stated goal requires careful consideration of target audiences, so that those who make resource decisions in SOPN parks have the information they need readily available to them when they need it, and in a form they can use. Through the analyses and reporting approaches described here, the SOPN will communicate valid inferences about the resources being monitored and ensure that our monitoring results are effectively distributed.

7.1.1 Target audiences

Park managers are the primary audience for the results of vital signs monitoring. Our goal is to provide superintendents and resource managers with the data they need to make and defend management decisions and to work with others for the benefit of park resources. Other key audiences for general SOPN products include park planners, interpreters, researchers and other scientific collaborators, and the general public. Key audiences for administrative reports include the Department of the Interior (including NPS), Office of Management and Budget, and the United States Congress.

7.2 Data Analysis

The following sections outline the guiding principles used to determine the appropriate analysis in a given context. Due to the detailed nature of analysis techniques, the specific analyses used for each vital sign will be found in the associated monitoring protocol; this chapter serves as a conceptual overview of the analytical methods the SOPN plans to use. General categories of analysis for SOPN vital signs are presented in Table 7.2.

To conduct an appropriate analysis of monitoring data, one must consider the monitoring objectives, the sampling design used, the intended audiences, and the management uses of these data. Selection of specific analytical methods should occur after determination of monitoring objectives and sampling design, and before sampling.

In general, the principal investigator for a particular project will collaborate with a quantitative ecologist or statistician (for the SOPN, this will be the network coordinator at the current time, and/or in consultation with other network ecologists or statisticians) on selection

Table 7.2. Tentative types of primary analyses expected for each SOPN vital sign.

SOPN Vital Sign	Parameter Estimation	Hypothesis Testing	Model Selection	Bayesian Approches	Spatial Analysis*	Primary Responsibility
Soil Structure and Chemistry	X			?		Principal Investigator in collaboration with SOPN ecologist.
Ground Water Levels	X					Principal Investigator in collaboration with SOPN ecologist.
Water Quantity–Surface	X	X				Principal Investigator in collaboration with SOPN ecologist.
Water Quality–Core Parameters	X	X				Principal Investigator in collaboration with SOPN ecologist.
Exotic Plants	X		X	?	X	Principal Investigator in collaboration with SOPN ecologist.
Riparian Vegetation Communities	X		X	?		Principal Investigator in collaboration with SOPN ecologist.
Grassland Vegetation Communities	X		X	?	X	Principal Investigator in collaboration with SOPN ecologist.
Bird Communities	X		X	?	X	Principal Investigator in collaboration with SOPN ecologist.
Human Demographics	X			?	X	Principal Investigator in collaboration with SOPN ecologist.
Fire Dynamics	X			?	X	Principal Investigator in collaboration with SOPN ecologist.
Landscape Dynamics	X			?	X	Principal Investigator in collaboration with SOPN ecologist. 1
Climate	X					see Frakes

*The exact nature of our spatial analyses will be determined as part of the development of individual protocols.

of analytic approaches for status and trends analyses. Responsibilities for conducting and reporting the analyses will also be shard. Integrated analyses that examine patterns across vital signs will require a team approach, in which multiple principal investigators will collaborate with the quantitative ecologist. Air quality vital signs pose an exception to these analytical activities; analyses and reports of air quality are produced by the NPS-ARD and other agencies (EPA-CASTNET and IMPROVE). To provide a context for data analysis, a brief conceptual overview of five types of analyses is presented below.

7.2.1 Parameter estimation

Because one of the primary goals of the I&M program is to determine the status and trends of selected vital signs, parameter estimation will certainly be one, if not the, most common type of analysis in our program. This can involve either the estimation of the state or condition of a given resource (status) or the change in that resource state over time (trend). This analysis focuses on measuring and describing the attributes of a population in terms of its distribution and structural features. Parameter estimation requires an understanding of the distribution from which the samples are drawn, such as the central tendency and the precision or variability in the data. Thus, parameter estimation will almost always include estimates of precision in the form of confidence intervals.

We will be concerned about bias and precision in our estimates. If the expected value of the estimate (e.g., the mean from repeated samples) is equal to the true value of the parameter, then the estimator is considered unbiased (Figure 7.2.1).

If, however, the parameter estimate differs systematically from the true value (e.g., repeated samples are always greater than the true value), then the estimator is biased. Precision reflects variation in the data; the greater the precision (or tendency of the samples to be close to the true value), the less variation in the data.

7.2.2 Hypothesis testing

The second general category of analysis is hypothesis testing, which will likely be more limited in use within the network protocols than parameter estimation. This method of analysis will be used when the state (status) of a given resource needs to be tested against a specified reference, such as a legal threshold or desired condition. That is, the SOPN does not plan to test scientific hypotheses—an activity that might be better suited to a research program using an experimental approach. Rather, the SOPN will use this approach to test whether uncertainty about parameter estimates warrants conclusions about the relationship between a given resource state and the reference to which it is being compared. This method is considered to be a type of statistical hypothesis testing, primarily because it will be extended to include comparisons with a priori reference values. In the context of I&M program goals, hypothesis testing will likely be used for determining whether certain legal or congressional mandates have been met or performance targets achieved. However, the focus of the network will be on estimating parameters to ensure that biological and statistical significance are appropriately distinguished, following Yoccoz (1991).

7.2.3 Model selection

The third general class of analyses that the SOPN will use is model selection, which helps us to better understand the dynamic nature and condition of park resources. To grasp these dynamics, it is necessary to move beyond parameter estimation (although parameter estimation will likely be included in the context of specified models) to include the relationships among ecosystem resources, drivers, and stressors. In contrast to a hypothesis testing framework, which seeks to determine "the" correct alternative hypothesis, a model-selection approach considers the evidence within the data in support of a suite of candidate models that represent multiple hypotheses.

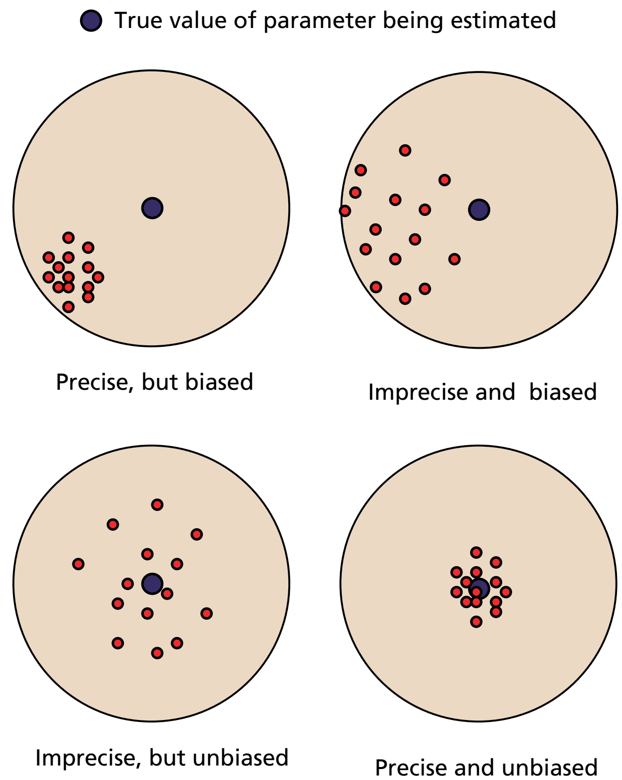


Figure 7.2.1. Conceptual diagram illustrating the difference between bias and precision for a given parameter estimate.

7.2.3.1 Principle of parsimony

Our model selection is based on the principle of parsimony: the notion that an appropriate model should contain just enough parameters to adequately account for the variation in the data, because adding and deleting parameters has important consequences (Burnham and Anderson 2002). Underfitting (i.e., having too few parameters) can result in a model that does not adequately represent the information contained within the data. In contrast, overfitting (i.e., having too many parameters) may improve the fit of the model to the data at a cost of reducing the precision of the parameter estimates, sometimes to the point of rendering them of little value. Thus, the goal of the principle of parsimony is to find the right balance between under- and overfitting the model.

This balance can be expressed in terms of a trade-off between bias (i.e., systematic lack of fit) and precision (i.e., the confidence of our parameter estimates) (Figure 7.2.3.1). The addition of parameters in a model reduces bias, but decreases precision. Likewise, reducing the number of parameters increases the precision of parameter estimation, but increases bias. Model selection does not seek to find the

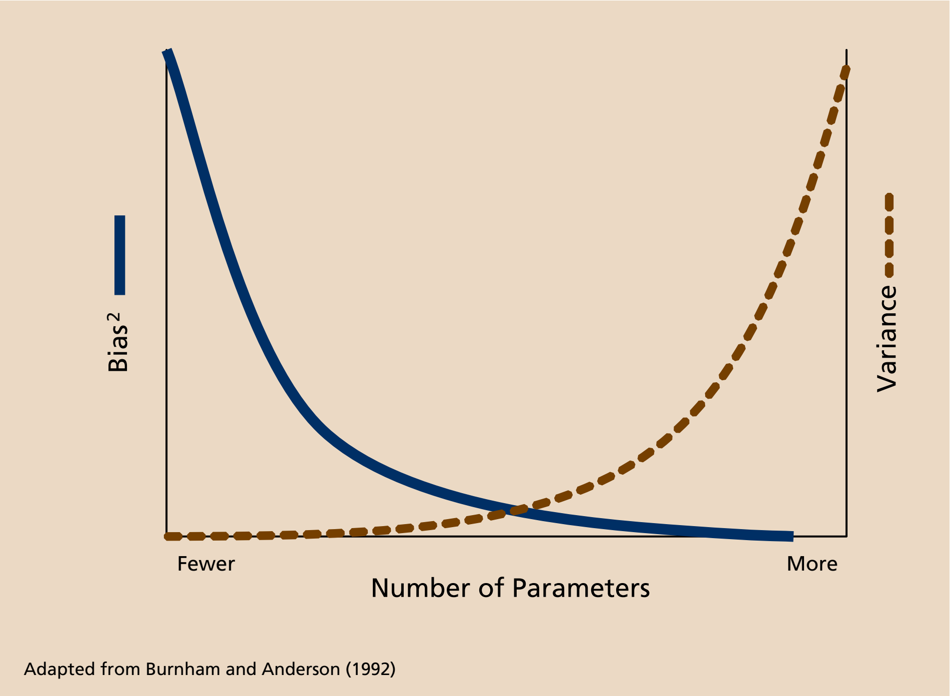


Figure 7.2.3.1. Conceptual diagram illustrating the tradeoff between bias and precision imposed by the number of parameters included in a given model (adapted from Burnham and Anderson 1992).

"true" model (Burnham and Anderson 2002); rather, it seeks to find the best approximation of the information contained within the data by summarizing the major systematic effects together with the nature and magnitude of the unexplained (random) variation (McCullagh and Nelder 1989).

7.2.3.2 Akaike's Information Criterion

Considerable attention has emerged in recent years regarding the use of information theoretic approaches such as Akaike's Information Criterion (AIC) (Akaike 1973) as a basis for model selection (e.g., Burnham and Anderson 2002). In contrast to treating steps of the model-selection process as a series of hypothesis tests, AIC treats the model-selection process as a problem in optimization of the balance between model fit and precision (Spendelow et al. 1995). AIC optimizes the fit of a model balanced against the cost of adding excessive parameters. The SOPN will use AIC as a primary tool for model selection; however, we recognize that this approach is not a panacea for all cases (i.e., AIC does not work equally well for all model types and situations), although it does embody the principal elements that are sought for model selection. Thus, AIC will be an essential tool for model selection, but in some cases, when the situation is not conducive to AIC, the network may depart from this approach. These will be considered on an individual basis as they arise.

7.2.3.3 Model averaging

When deriving inference about the dynamics and condition of park resources using model selection, we must recognize that there is uncertainty associated model selection, itself. Buckland et al. (1997) proposed a procedure to better account for the uncertainty of model selection by deriving parameter estimates based on an average of several plausible models, rather than a single, "chosen" one. This approach weights the models according to AIC values; thus, the most-plausible models receive the highest weight, while the least-plausible models receive little or no weight. The SOPN will use model averaging to estimate parameters of interest when the parameters are derived from a selected model for which alternative models exist.

7.2.4 Sampling Error vs. Process Variation

One of the key components of the I&M program is assessing how particular vital signs change over time. However, it is important to note that it is seldom possible to estimate parameters without some sampling error. Consequently, when looking at changes over time, it is necessary to consider that, in addition to real environmental variation that occurs over space and time in the population (and is thereby reflected in our measurements), there is also a sampling error associated with the measurement. Distinguishing these real changes in the population from measurement error is sometimes difficult. The traditional "sampling variance" that is estimated from the data typically includes an element of both types of error, which are highly confounded. Burnham et al. (1987) provide a theoretical framework for partitioning the variance into error that is attributable to sampling and parameter (process) variation. Where feasible, the SOPN will use this, or alternative approaches as they are developed, to estimate the true variation in the populations of interest over time.

7.2.5 Bayesian Approaches

The SOPN will consider use of Bayesian statistical methods as an alternative to traditional, frequentist statistics. In general, Bayesian approaches allow for the incorporation of previous evidence (data), along with new information, to estimate the probability of a particular outcome. This technique may be useful during model selection. These statistical methods are based on Bayes's theorem (Bayes 1763). More specifically, Bayesian methods use observed data to calculate the probability of the value of a parameter. With additional data, Bayesian techniques draw on this prior (a priori) distribution to derive a new (posterior) distribution that incorporates the likelihood of the data given the prior distribution. This approach is appealing because it accounts for all of the accumulated information and enables an assessment about the probability of a given hypothesis being true, rather than rejection or acceptance based on a specified threshold (e.g., the p-value of traditional statistics). A Bayesian approach may be well-suited for selecting models that relate the dynamic nature of park resources over the long term because of its ability to continually incorporate updates to parameter estimates as data accumulate.

7.3 Reporting

SOPN reporting will be hierarchical and intended for multiple audiences and media. The primary delivery system will be the Internet, via the the Learning Center of the American Southwest (LCAS), http://www.soutwestlearning.org. However, the individual products available on the web site will also be available in a format (pdf) that will facilitate easy printing or enable us to deliver a printed version to appropriate audiences.

The LCAS is a partnership between four networks (SOPN, Sonoran Desert Network, Southern Colorado Plateau Network, and Chihuahuan Desert Network), the Sonoran Institute, and the Desert Southwest Cooperative Ecosystem Studies Unit. Its purpose is to build stronger relationships between national parks and scientists and better communicate science results to interested park audiences. The hub of the Learning Center is a web page that gathers information about a number of resource topics in one place (Figure 7.3-1). The web-enabled Learning Center concept is founded in the belief that all Internet-using members of the public, from university researchers to primary school students, should be able to access the vast amounts of scientific information that exist about SOPN's natural and cultural resources, appropriate to their level of technical sophistication. The LCAS is designed around resources, rather than institutionally driven, to faciliate ease of use: in this way, users can find the maximum amount of scientific information

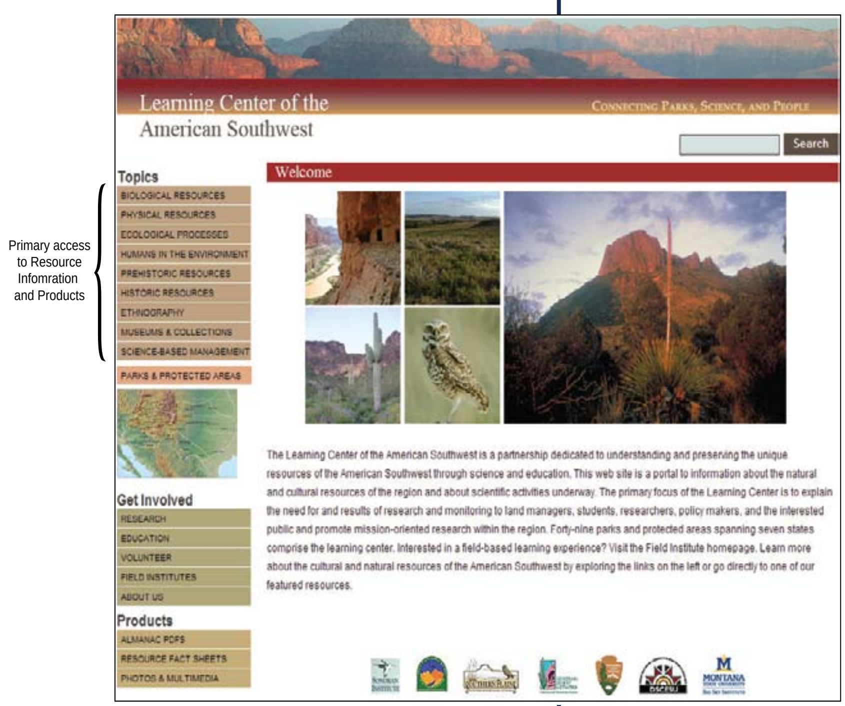


Figure 7.3-1. The home page of the Learning Center of the American Southwest enables navigation via a given resource or via a given park unit or network.

Figure 7.3-2. A pull down menu or interactive map will enable the user to navigate to a particular park unit, from which they can access the natural or cultural resources of that unit.

about a given resource in one place, rather than having to conduct multiple searches according to the institutional unit with which the information originated. However, the LCAS offers a dual-navigation approach that also enables users to quickly access the information for a given park unit (Figure 7.3-2).

Our information will be organized hierarchically, as a series of products (Table 7.3) within two major levels, the resource level and the project level. Resource-level products report on the condition of the resource, regardless of the source of information. This is the level that best synthesizes the available information regarding the status and trends of the resource. In contrast, project-level products report the available information from a given project, whether it be monitoring, research, etc. Thus, someone looking for the most comprehensive information about status and trend of a resource would find it at the resource level, while someone looking for the specific results from a given project would find it at the project level. I&M monitoring data will contribute to, and sometimes be the only source of information for, resource-level products, and will also be reported at the project level.

7.3.1 Resource level

The home page for a given resource (Figure 7.3.1) will provide background information for that resource, as well as a series of products at the resource level. The resource-level products may include an overview, fact sheet(s), resource briefs, references, links, and scientist list, each of which is explained below:

7.3.1.1 Overview

For natural resources, the overview provides an in-depth description (typically 7-10 pages) of natural history and ecological function. For cultural resources, the overview provides an in-depth description of the resource and its place in time. The overview also explains how the resource is monitored and managed, and includes the following topics:

- *Distribution.* For natural resources, this section describes where the species is present within a given area of interest and within its entire range. If appropriate, it may also include information about the historic range of the species. For cultural resources, this section describes where similar resources are found.

Table 7.3. Core products of the Learning Center for the American Southwest, including their level of application, purpose, updating frequency, and responsible party.

Scope	Summary (1-2 Page) Version	Full (> 2 page) Version	Primary Purpose	Update Frequency	Who Does It?
Resource	Fact Sheet	Overview	To provide background context for a given resource	Revised as needed	Shared responsibility among Networks and Parks of the LCAS
Resource	Almanac	--	To report status and trends of the resource	Annual	Project P.I. and/or SOPN Project Leader
Resource	--	Resource Synthesis Reports	To report status and trends of the resource	Approx 5 yrs	Shared responsibility among SOPN and Project P.I.s
Project	Project Summary	Project Report	To report status and findings of a given project	Annual	Project P.I.
Resource	Quick Reference	Various reports	To provide a useful excerpt of a longer report when only a subset may be needed for some audiences	Revised as needed	SOPN Staff
Project	Protocol Summary	Protocol or Study Plan	To provide documentation of the methods and procedures used to collect data to ensure repeatability an reliability	Revised as needed	Project P.I. and/or SOPN Project Leader
Resource	--	References	To provide or point to the key references for that topic	Revised as needed	SOPN Staff
Resource	--	Links	To provide links to other sources of information for that topic	Revised as needed	SOPN Staff

- *Physical description*. For natural resources, this section describes the physical characteristics of the resource and explains how to identify the resource. For cultural resources, this section gives a historic or prehistoric physical description of the resource.
- *Ecology*. For natural resources, this section includes topics such as habitat (a description of what the species needs in its environment to survive and how it affects its environment; what it eats and what eats it) and life cycle (how the species reproduces, life stages, life span, what causes or contributes to its death). Other topics may be more specific to a particular species. For cultural resources, this section describes the interactions between the resource and the environment, where appropriate.
- *Status and Threats*. For both cultural and natural resources, if applicable, this includes an explanation of any legal status and what, if any, special protections apply. This section also describes the threats that exist to the resource.
- *Management activities*. For both cultural and natural resources, this section includes information on current and past management practices and policies. It also includes a description of how long current practices and policies have been in place.

7.3.1.2 Fact sheet

The fact sheet is a 1-2 page document, (in pdf format) which provides context for the resource. A fact sheet often contains a subset of information provided in the overview that provides the reader with important background information to better understand the resource. Relevant photos, maps, and/or graphs complement the text. An information summary that explicitly focuses on the status and trend of a resource is a special case of background information with specific value to park managers that will be reported as a Resource Brief (below) rather that a fact sheet.

7.3.1.3 Resource Briefs

The resource brief is a one-page synthesis document, downloadable in pdf format, that explains the importance of a resource, describes its status and trend, and discusses its stressors and drivers. Relevant photos, maps, and/or graphs complement the text. The resource brief page contains three parts:

- *Importance*. A one-paragraph description of why the resource is important that may include information on the ecological role or historical significance of the resource.
- *Status and Trends*. A one-paragraph summary of the status of the resource and how the resource has changed over a specified period of time.
- *Discussion*. A one-paragraph discussion of the key drivers and stressors for a resource. If this is not applicable or unknown, describe the issues faced in managing this resource.

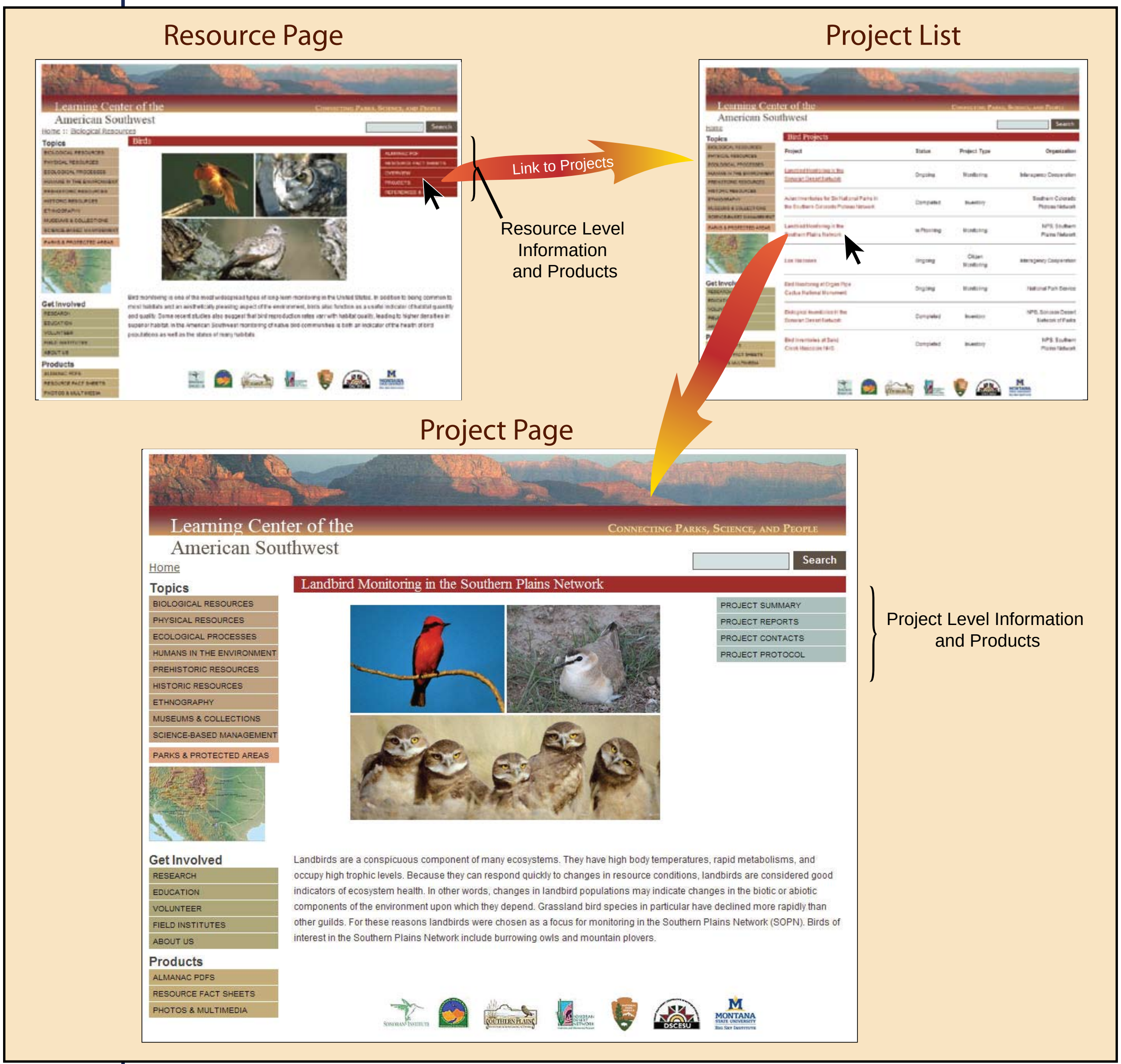


Figure 7.3.1. From the home page of a given resource, the user can access products for the resource or navigate to any project pages related to that resource via a project list. Additional products related to a specific project are then available.

7.3.1.4 References

The references include key references for a given resource, with documents available as links or pdfs, when possible. Also included are agency documents related to management of the resource. Internet links to agencies or organizations associated with the resource are also listed.

7.3.1.5 Scientists

The scientists page provides links to scientists studying a given resource. In the future, this page might provide profiles of (willing) scientists to make the science seem more personal to the user.

7.3.2 Project level

From a given resource page, there would also be a link to any projects associated with that resource (see Figure 7.3.1). These projects would not be limited to monitoring projects, but would include such things as inventories, research, and management projects. At the project level, there would be an additional set of products, including project summaries, project reports, any study plans or protocols, and project contacts.

7.3.2.1 Project summary

The project summary is a two-page synthesis of the current status and results, if applicable, of a given project. The pdf provides the user with a summary of a project and includes an introduction as well as sections on methods, results, and project contacts. Relevant graphs, photos, and/or maps complement the text.

7.3.2.2 Project reports

Project reports will be produced annually or as appropriate, and will synthesize the results of a given period's effort for that project. The two-page project report provides additional detail not included within the project summary, and includes the following sections:

- *Introduction*. Explains the purpose and background of the project.
- *Methods*. A brief description of the methods with reference to the full monitoring protocol.
- *Results*. The results of the current period's effort and trend information where appropriate.
- *Discussion*. A short narrative putting the current years results into context, a discussion of patterns or trends, and a description of possible implications to management.

7.3.2.3 Project study plans or protocols

This would include any documents describing design, filed methods, etc. If the project is a NPS I&M effort, this page provides a link to the most up-to-date monitoring protocol used by the network. For other projects (e.g., research), a project proposal or study plan might be available.

Chapter 8
Administration

We can lick gravity, but sometimes the paperwork is overwhelming."

~ Werner von Braun

This chapter provides information on the administrative organization of the Southern Plains Network, including staffing, operations, and partnerships.

8.1 Network Organization

A multi-level organizational structure has been identified as the best way to ensure that an effective I&M program is created and implemented for the SOPN (Appendix N: SOPN Charter). This organizational structure comprises a Board of Directors, Technical Committee, Scientific Panel, and SOPN staff.

8.1.1 Board of Directors

The SOPN Board of Directors (BOD) provides guidance, oversight, and advocacy toward development and implementation of the I&M program for 11 park units within the network. The BOD has six voting members: three superintendents serving three-year terms, a resource manager serving a two-year term, the SOPN network coordinator, and the IMR I&M coordinator (Table 8.1.1). The unit leaders from the Great Plains and Gulf Coast CESUs are non-voting members. A superintendent serves as chair and is elected by the BOD for a one-year term. Responsibilities of the BOD include:

- Providing guidance, oversight, and advocacy toward development and implementation of the I&M Program;
- Promoting accountability by reviewing progress and quality control for the network;
- Reviewing and approving the strategic plan, network charter, program budgets, hiring, and annual work plans;
- Advocating an active and effective I&M program in the network;
- Deciding on strategies for leveraging network funds and personnel to best accomplish the natural resource inventories, long-term monitoring, and other needs of network parks;
- Providing input to the supervisor of the Technical Committee Chairperson for performance appraisals;
- Promoting collaboration with Cooperative

Table 8.1.1. Southern Plains Network Board of Directors as of August 2008.

Name	Title	Affiliation
Christopher Moos (Chair)	Superintendent	CAVO
Kevin McMurry	Superintendent	FOLS
Cindy Ott-Jones	Superintendent	LAMR/ALFL
Steve Burrough	Chief, Resource Management	CHIC
Robert Bennetts	Network Coordinator	SOPN
Bruce Bingham	I&M Coordinator	IMR
Gary Willson (non-voting member)	CESU Coordinator	GP-CESU
	CESU Coordinator	GC-CESU

Ecosystem Studies Units;

- Ensuring that network work is integrated with park resource management programs and other NPS natural resource funding initiatives;
- Facilitating communication and coordination about network activities with park managers in the network and region, and serving as liaison to Cluster Leadership Councils and Natural Resource Communication Advisory Team; and
- Identifying and developing internal and external partnerships to further the goals of the Natural Resource Challenge and I&M program.

8.1.2 Technical Committee

The SOPN Technical Committee is responsible for developing the specific I&M program plans, budgets, and hiring proposals that are presented to the BOD for review and approval. The TC is also responsible for the detailed technical formulation and execution of the SOPN program. The TC is accountable to the BOD for all activities and products. The TC is comprised of a representative from each of the 11 parks in the SOPN, plus the SOPN network coordinator (Table 8.1.2). Each park superintendent appoints a representative who serves until the appointing official designates a new member. The resource manager currently serving on the Board of Directors chairs the TC for a two-year term. Responsibilities of the TC include:

Table 8.1.2. Southern Plains Network Technical Committee membership.

Park	TC-member job title
ALFL	None
BEOL	Chief, Natural Resources
CAVO	Chief Park Ranger
CHIC	Chief, Resource Management
FOLS	Supervisory Park Ranger
FOUN	Supervisory Park Ranger
LAMR	Chief, Resource Management
LYJO	Integrated Resources Program Manager
PECO	Park Ranger
SAND	Superintendent
WABA	Chief, Facilities and Resources

- Preparing a five-year strategic plan for BOD review and approval;
- Compiling and summarizing existing information about park resources;
- Hosting workshops and other outreach efforts as needed to develop and implement the SOPN I&M program;
- Soliciting professional guidance from Scientific Panel members, individuals, and other organizations as needed;
- Reviewing proposals for hiring network staff prior to BOD approval;
- Reviewing, in detail, annual network accomplishment reports, annual work plans, and long-term monitoring plans prior to BOD approval;
- Developing and fostering partnerships that support overall I&M objectives;
- Organizing and facilitating periodic program reviews;
- Integrating environmental compliance activities, as required by federal law and NPS policy, into the development of study plans and the park project approval process;
- Working with park staff in areas such as cultural resources or interpretation to build support for an integrated I&M program; and
- Ensuring that the network's work is fully integrated with park resource management programs and other NPS natural resource funding initiatives.

8.1.3 Scientific Panel

Scientific panels assist the network with planning for vital signs monitoring and provide scientific peer review. Panels will be appointed as needed and configured to address scientific topics and issues. Scientific panel members represent key disciplines and may be affiliated with federal agencies, academic institutions, and other relevant organizations. Panel members should have knowledge of sampling procedures, monitoring techniques, and statistical methods in order to evaluate conceptual designs, monitoring strategies, and the ecological relevance of monitoring proposals.

8.2 Staffing

The SOPN TC and BOD will develop an operational staffing plan for the SOPN during FY08. The staffing plan will reflect the shared belief that the network requires a core staff of highly qualified NPS scientists to implement this important, long-term program (Figure 8.2). Due to funding restraints, it is anticipated that the BOD will recommend a conservative strategy toward allocating funds for permanent personnel and other fixed costs. These costs are currently maintained at below 60% of the program's operational base. The staffing plan will also maintain a commitment to continuing partnerships with our CESU partners. Most data collected in support of the network will be done under the direction of network staff. Approximately one-third of the program's budget will be directed toward accomplishing monitoring objectives through cooperative relationships. Short-term, technical, and field data collection positions will be filled by cooperative agreements with other state and federal agencies and universities and by students, interns, and volunteers from the Student Conservation Association. Table 8.2 describes SOPN positions and their responsibilities.

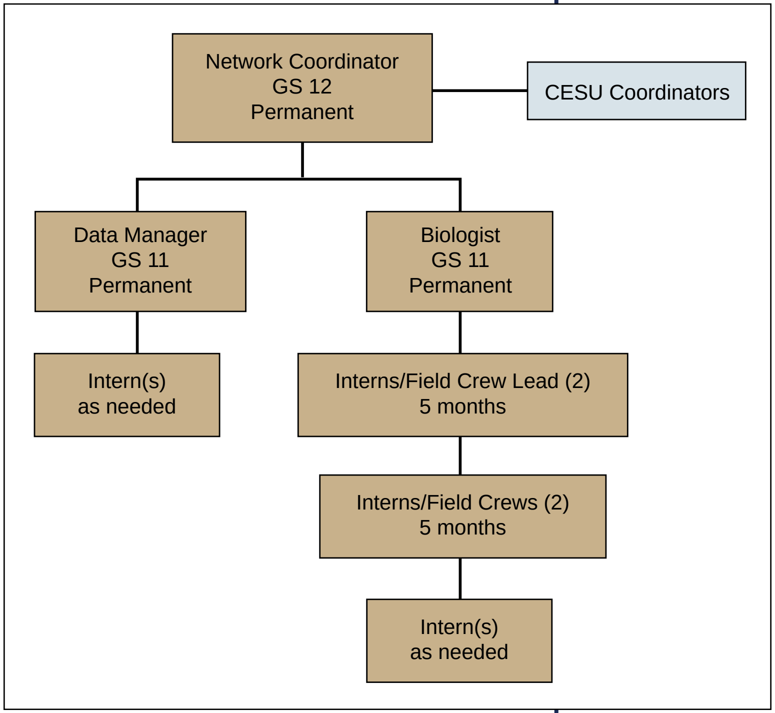


Figure 8.2. Southern Plains Network organizational chart.

8.3 Operations

The SOPN covers a far reaching area which consists of 11 parks across five states. As such, effectively administering the monitoring program will require careful and efficient planning in order to implement cost-effective visits to these parks.

8.3.1 Facilities

The SOPN is primarily housed on the campus of New Mexico Highlands University (NMHU) at Las Vegas, New Mexico. In addition to being centrally located, NMHU has a special emphasis on the rich heritage of Hispanic and Native American cultures that are distinctive to the state of New Mexico and throughout the SOPN. This partnership provides an opportu-

Table 8.2. Roles and responsibilities of network staff positions.

Position	Roles and responsibilities
Network Coordinator	• Responsible for the overall management and supervision of the program. • Develops process for selecting indicators • Oversees the development and testing of monitoring protocols, hiring and supervising network staff, managing the implementation of monitoring projects, and ensuring the resulting data are appropriately analyzed and reported.
Data Manager	• Responsible for the information and data stewardship of the program. • Designs databases for monitoring projects • Writes data management plans and protocols • Works with network and park staff, cooperating scientists, and others to ensure that datasets are fully documented and validated.
Biologist	• Responsible for developing and implementing monitoring projects relating to vegetation-oriented vital signs. • Performs overall integration, analysis, and reporting of monitoring results.

nity for the SOPN to contribute to, as well as benefit from, a diverse university by integrating education, research, public service, and employment opportunities. To date, the university has provided office space as in-kind support to the program.

The SOPN data manager continues to be housed at the network's original location at Lyndon B. Johnson NHP. The network benefits by having data-related activities at a location directly connected to NPS computer networks. It was also deemed unnecessary to relocate the position to New Mexico in that data management activities can easily be coordinated remotely with the New Mexico office.

8.3.2 In-house Monitoring Crews

We plan to use our cooperative relationship with NMHU and the Lady Bird Johnson Wildflower Center to staff two field crews to collect data for the Grassland Vegetation Communities, Riparian Vegetation Communities, Exotic Plants, and Soil Structure and Chemistry vital signs. Water quality and quantity will be monitored by park staff following in-depth training by cooperative partners.

8.3.2.1 Training

The quality of data resulting from long-term monitoring is only as good as the field crews who collect the data. Routine training prior to the field season is essential to ensure that high-quality, consistent data are collected over the years. During the training period, the SOPN biologist will provide crew members with review and/or training for all standard operating procedures included in the monitoring protocols. This period will also allow the biologist to evaluate the skills and experience level of new crew members.

8.3.2.2 Safety

Field work can involve exposure to harsh conditions, hazardous plants and animals, and extreme weather conditions. Worker safety is of paramount concern in conducting a field-based monitoring program. The SOPN monitoring program will be operated in accordance with safety laws, regulations, and policies, and appropriate training will be provided.

8.3.2.3 Equipment

The network will supply the equipment and supplies necessary to conduct in-house monitoring projects. Property and equipment will be managed according to Director's Order #44: Property Management. Sensitive property (e.g., cameras, computers) and property sensitive to theft, loss, or damage (GPS units, radios, and binoculars) will be managed as accountable property. Purchasing of equipment likely to depreciate will be scheduled over time to reduce the impact of replacing substantial amounts of equipment in any given year. Calibration of equipment will follow manufacturer directions and will be included in an appendix to the appropriate monitoring protocol. Vehicles will normally be leased through the U.S. General Services Administration.

8.4 Partnerships

We have initiated a number of cooperative agreements to develop monitoring protocols and complete projects in support of the monitoring program. We anticipate forming additional partnerships as we move into implementation of the monitoring program. A few key relationships are described below.

8.4.1 Gulf Coast, Great Plains, Desert Southwest, and Rocky Mountain Cooperative Ecosystems Studies Units

Organizationally, the SOPN is a participant in the Gulf Coast, Great Plains, Desert Southwest, and Rocky Mountains Cooperative Ecosystem Studies Units (GC-CESU, GP-CESU, DS-CESU, RM-CESU). The CESU mission is to improve access to scientific research and technical assistance within the federal land management agencies and to create effective partnerships among federal agencies and universities. The CESUs listed above will provide the SOPN with ready access to university and non-profit members for technical assistance needed to develop and implement the monitoring program.

8.4.2 National Park Service

8.4.2.1 Fire Effects Monitoring Program

Table 8.5. Monitoring program review.

Review	Timing	Reviewers	Purpose
Annual Administrative Report and Work Plan	Annual	Network TC and BOD, IMR I&M coordinator, servicewide program manager	To provide a simple means to track accomplishmnents, planned activities, and budgets for network inventory and monitoring efforts.
Monitoring Protocols	Initially as completed; thereafter, as needed or at least every five years	External review by at least three subject-area experts, including a statistician	To provide peer review of the proposed sampling design, methods, and analysis/reporting, ensuring that the data produced through this protocol will meet the stated monitoring objectives and be scientifically credible and relevant to management.
Integrated Analysis Reports	As needed	External review by at least three subject-area experts, including a statistician	To provide peer review of long-term trend reports and integrative reports, ensuring that the analytic procedures are valid and the interpretation supportable.
Program Review	Every 10 years	External review by at least three subject-area experts, including a statistician	To evaluate the program's overall performance in providing high-quality, scientifically credible information that is useful to park management, and to offer recommendations for improving the monitoring program.

The NPS Fire Effects Monitoring Program documents basic information for wildland fires and monitors prescribed fire effects on vegetation. The SOPN and Fire Effects Monitoring Program are currently working together to develop a method to achieve common monitoring objectives.

8.4.2.2 Water Resources Division

The NPS Water Resources Division (WRD) provides technical support for hydrologic monitoring (water quantity and quality) in SOPN parks. The water quality component of the Natural Resource Challenge (NRC) requires vital signs networks to archive all physical, chemical, and biological water quality data collected with NRC water quality funds in the National Park Service's STORET database, maintained by WRD.

8.4.3 Other Cooperators and Partners

The network relies on the following agencies and organizations for data, protocol development and review, and monitoring related to a number of vital signs:

- Botanical Research Institute of Texas
- U.S. Bureau of Reclamation
- Colorado Natural Heritage Program
- Colorado State University
- Emporia State University
- Kansas Natural Heritage Inventory
- Lady Bird Johnson Wildflower Center
- Natural Heritage New Mexico
- NatureServe
- Rocky Mountain Bird Observatory
- Texas A&M University
- Texas State University
- U.S. Geological Survey

8.5 Review Process

An essential element of any science program is periodic review. Peer review of proposals,

Chapter 9
Schedule

Be not afraid of growing slowly, be afraid only of standing still.

~ Chinese Proverb

This chapter presents SOPN efforts to develop monitoring protocols for core vital signs and to implement those protocols across network parks. Additionally, a summary is presented of the frequency and seasonality of monitoring for each core vital sign.

9.1 Protocol Development

The expected timeline for completion of protocol development and implementation of the SOPN's integrated monitoring protocols is shown in Table 9.1. We have employed a phased approach when preparing these documents. Creation of three protocols was begun in FY2006 (in conjunction with Texas A&M University and Colorado State University), integrating 6 of the 12 SOPN core vital signs. A fourth protocol was begun in FY2007, by Texas State University. The remaining three vital signs will enter protocol development during FY2008.

Monitoring plots will be co-located for vegetation-oriented protocols whenever practical, allowing for minimal cumulative impact and efficient use of time and energy. Previously completed vegetation maps will inform the stratification process for riparian and grassland community identification. The Soil Structure and Chemistry and Fire and Fuel Dynamics vital signs will be monitored in conjunction with vegetation community plots. Exotic Plants monitoring will also take place within these plots, in addition to other high-priority areas. Due to the small acreage found in the majority of SOPN parks, Bird Communities monitoring will take place only in designated habitats of interest. Water quality/quantity monitoring will integrate previous locations of data collection whenever possible to extend the temporal range of sampling efforts.

9.2 Sampling Frequency and Revisit Rates

Vital signs monitoring will be performed on various temporal schedules (see Table 9.2) and by different entities. Sampling within designated seasons can minimize between-year variability due to natural events and optimize the accessibility of the target community or attribute. Monitoring for groundwater and surface water quantity and quality will generally be carried out by the individual parks, following training of key personnel. Water quality will be monitored monthly throughout the year, while surface and groundwater readings will be taken quarterly. Vegetation monitoring for Riparian Vegetation Communities, Grassland Vegetation Communities, Fire and Fuel Dynamics and Exotic Plants (as well as Soil Structure and Chemistry) will be carried out by SOPN teams. The teams will visit one-half of the SOPN parks twice each year, thus enabling early detection of exotic plants to be effectively carried out at either end of the growing season. There are many benefits to this approach, including ease of training, co-location of plots, efficient travel, and the opportunity to obtain a bi-annual snapshot of park vegetation.

9.3 Program Development Schedule

9.3.1 Continual Improvement

Quality assurance and control has been addressed in the context of data management in Chapter 6. However, quality assurance goes beyond data management and must be an integral component of all aspects of the SOPN program. In the context of the overall program,

Table 9-1. Implementation schedule for core vital signs of SOPN.

Ecological Monitoring Framework								
Level 1	**Level 2**	**Level 3**	**Vital sign**	**2008**	**2009**	**2010**	**2011**	**2012**
Geology and Soils	Soil Quality	Soil Function and Dynamics	Soil Structure and Chemistry	FT	SS/FI	FI	FI	FI
Water	Hydrology	Ground Water Dynamics	Ground Water Levels	PP/SS	FI/Park	FI/Park	FI/Park	FI/Park
		Surface Water Dynamics	Water Quantity–Surface	PP/SS	FI/Park	FI/Park	FI/Park	FI/Park
	Water Quality	Water Chemistry	Water Quality–Core Parameters	PP/SS	FI/Park	FI/Park	FI/Park	FI/Park
Biological Integrity	Invasive Species	Invasive/Exotic Plants	Exotic Plants	FT	SS/FI	FI	FI	FI
	Focal Species or Communities	Wetland Community	Riparian Vegetation Communities	PP	PP	SS/FI	FI	FI
		Grassland/Herbaceous Communities	Grassland Vegetation Communities	FT	SS/FI	FI	FI	FI
		Birds	Bird Communities	PP	SS/FI	FI	FI	FI
Human Use	Non-Point Source Human Effects	Non-Point Source Human Effects	Human Demographics	PP/SS	FI	FI	FI	FI
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire and Fuel Dynamics	FT	SS/FI	FI	FI	FI
	Landscape Dynamics	Land Cover and Use	Landscape Dynamics	PP/SS	FI	FI	FI	FI
Air and Climate	Air and Climate	Weather and Climate	Climate	AE	AE	AE	AE	AE

PP = Protocol planning or development (without field effort)

FT = Field trials to evaluate and refine protocol

SS = Site selection and establishment

FI = Full implementation of monitoring by SOPN

Park = Monitoring done by park

AE = Currently being monitored by another entity

prevention is addressed through sound development of sampling design, data management and analysis. These have been addressed in greater detail in other chapters and in the corresponding sections of each protocol; however, we will also be evaluating the effectiveness and efficienc of our monitoring as an ongoing process and through periodic program reviews (below).

9.3.2 Program Reviews

The SOPN will undergo an initial program review three years after its approved monitoring plan (scheduled in 2011) to evaluate how well sample designs of individual protocols are achieving the monitoring objectives, and whether the overall program represents the best compromise between the information needs of the parks and the corresponding costs. This overall review will compliment the individual protocol reviews and focus on the full suite of our monitoring program toward achieving the overall program goals.

The program will also be formally reviewed by WASO at least once every five years. A formal report is generated from this periodic review, making specific suggestions for changes and revisions in the monitoring program.

Table 9-2. Sampling Season and Revisit Design

Ecological Monitoring Framework				
Level 1	**Levels 2 and 3**	**Vital sign**	**Sampling season**	**Revisit design[1]**
Geology and Soils	Soil Quality: Soil Function and Dynamics	Soil Structure and Chemistry	May–September	[1-9]
Water	Hydrology: Ground Water Dynamics	Ground Water Levels	All [Quarterly]	[1-0]
	Hydrology: Surface Water Dynamics	Water Quantity–Surface	All [Quarterly]	[1-0]
	Water Quality: Water Chemistry	Water Quality–Core Parameters	All [Weekly]]	[1-0]
Biological Integrity	Invasive Species: Invasive/Exotic Plants	Exotic Plants	May–September	[1-1]
	Focal Species or Communities: Wetland Community	Riparian Vegetation Communities	May–September	[1-1]
	Focal Species or Communities: Grassland/Herbaceous Communities	Grassland Vegetation Communities	May–September	[1-1]
	Focal Species or Communities: Birds	Bird Communities	April–July	[1-0]
Human Use	Non-Point Source Human Effects: Non-Point Source Human Effects	Human Demographics	All	[1-0]
Landscapes	Fire and Fuel Dynamics: Fire and Fuel Dynamics	Fire and Fuel Dynamics	May–September	[1-1]
	Landscape Dynamics: Land Cover and Use	Landscape Dynamics	All	[1-0]
Air and Climate	Air and Climate: Weather and Climate	Climate	All	[1-0]

[1] The revisit design specifies the sampling frequency (see Chapter 4).

Chapter 10
Budget

"We didn't actually overspend our budget. The allocation simply fell short of our expenditure."

~ Keith Davis

In this chapter, we present the budget of the SOPN monitoring program for the first year of operation after review and approval of this plan (anticipated to be FY2009). We first show the network budget according to the expense categories used in preparing the Annual Administrative Report and Work Plans submitted to Congress (Table 10.1). In Table 10.2, we show the same budget, but with more detail, including our projections for network resources devoted to information management.

The SOPN receives $391,325 from the NPS Servicewide Inventory and Monitoring Vital Signs Program, and $29,100 from the NPS Water Resources Division annually. We anticipate spending approximately 60% of the budget on Personnel, including permanent staff and seasonal technicians and/or interns. A core of professional, permanent staff will oversee and coordinate the program. Technician-level assistance will be largely accomplished through Cooperative Ecosystem Studies Unit (CESU) agreements for student interns and assistance from the Student Conservation Association (SCA). The bulk of the program's data collection will be accomplished through cooperative and interagency agreements. Because of the distances involved in traveling to network parks from the network offices, we will avoid creating a centralized technical staff and the associated budgetary and logistical difficulties. Agreements with regional universities, as well as other federal and state agencies, will give us access to local technical assistance while network staff oversees the program's implementation across the network.

Guidelines for developing a monitoring program suggest that approximately 30% of the budget should be allocated to information and data management activities so that information is not lost, results are communicated, and adequate reporting takes place. In Table 10.2, we provide the percentage of time that each network position devotes to information and data management. Note that many protocols are still under development and several will be completed in FY2008. Staff and strategies for implementing those protocols are difficult to finalize prior to completion of the protocols; we provide the best estimates currently possible.

Table 10.1. Southern Plains Network budget for 2008 according to the expense categories used in preparing Annual Administrative Report and Work Plans.

Income		Amount	% of total
NPS Servicewide Inventory and Monitoring Vital Signs Program		$391,325	93%
NPS Water Resources Division		$29,100	7%
	Total	**$420,425**	**100%**
Expenditures			
Personnel		$249,000	59%
Cooperative agreements		$120,000	29%
Operations/Equipment		$25,000	6%
Travel		$25,000	6%
Other		$1,425	0%
	Total	**$420,425**	**100%**

*Some changes in budget and expenses are anticipated and will be addressed in concert with the SOPN Board of Directors as they arise.

Table 10.2. Southern Plains Network budget for 2008 including projections for resources devoted to information management.

Income		Amount		
NPS Servicewide Inventory and Monitoring Vital Signs Program		$391,325		
Water Resources Division		$29,100		
	Total	**$420,425**		
Expenditures		**Amount**	**% Data & Info Mgmt**	**$ Data & Info Mgmt**
Personnel	GS Level			
Network Coordinator	12	$100,000	20%	$20,000
Biologist	9/11	$55,000	30%	$16,500
Data Manager	11	$71,000	95%	$67,450
IMR Administration Support	9	$12,000	0%	$0
Writer-Editor	11	$5,000	100%	$5,000
Interns/SCAs	-	$6,000	30%	$1,800
Cooperative agreements		$120,000	29%	$34,251
Operations/Equipment		$25,000	6%	$1,487
Travel		$25,000	6%	$1,487
Other		$1,425	0%	$0
	Total	**$420,425**	**35%**	**$147,979**

*Some changes in budget and expenses are anticipated and will be addressed in concert with the SOPN Board of Directors as they arise.

Chapter 11
Literature Cited

Somewhere, something incredible is waiting to be known.

~ Carl Sagan

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Glossary

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

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

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

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

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

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

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

Indicators are a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 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.

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

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

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

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