National Park Service
U.S. Department of the Interior

Northern Colorado Plateau Inventory and Monitoring Network

Vital Signs Monitoring Plan

Arches National Park

Black Canyon of the Gunnison National Park

Bryce Canyon National Park

Canyonlands National Park

Capitol Reef National Park

Cedar Breaks National Monument

Colorado National Monument

Curecanti National Recreation Area

Dinosaur National Monument

Fossil Butte National Monument

Golden Spike National Historic Site

Hovenweep National Monument

Natural Bridges National Monument

Pipe Spring National Monument

Timpanogos Cave National Monument

Zion National Park

September 2005

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Northern Colorado Plateau Inventory and Monitoring Network

Vital Signs Monitoring Plan

September 2005

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Executive Summary

Chapter 1. Introduction and Background

The Northern Colorado Plateau Network (NCPN) is one of 32 National Park Service (NPS) inventory and monitoring networks that are creating a Vital Signs Monitoring Plan for assessing the condition of park ecosystems. The NCPN consists of 16 parks with diverse cultural and natural resources distributed among four states and three different physiographic regions. Parks in the network range in size from 16 to over 136,000 hectares. Ecosystems encompassed by the NCPN parks include desert grasslands, shrublands and woodlands, forested terrestrial systems, aquatic systems including large rivers, perennial streams, seeps, springs, and cave systems.

The NCPN strives to balance several monitoring goals including understanding natural ecosystem variability and observing known agents of change to provide early warning of abnormal conditions. To do so, the NCPN chose vital signs in each of the following broad categories:

1. **System drivers** that fundamentally affect park ecosystems,
2. **Stressors and their ecological effects,**
3. **Focal resources** of parks, and
4. **Key properties and processes of ecosystem integrity.**

The NCPN effort builds upon existing monitoring programs of network parks. In some cases, the NCPN will augment these existing programs to meet monitoring goals. In other cases, the network will initiate new monitoring.

Water quality monitoring is integrated within the NCPN monitoring program. The water quality monitoring program includes existing park monitoring efforts, and partnerships with the State of Utah, Department of Environmental Quality and the U.S. Geological Survey, Water Resources Division.

Chapter 2. Conceptual Models

The NCPN adopted an interactive-control model as the fundamental framework for system-specific conceptual models. The interactive controls — regional climate, soil resources, major functional groups of organisms, and disturbance regime — govern and respond to ecosystem attributes. Conceptual models were developed for the five major ecosystems: Montane and Subalpine, Dryland, Riparian, Aquatic, and Springs. These are included as appendices.

Chapter 3. Vital Signs

The NCPN identified forty-one vital signs which are presented in the national Vital Signs Framework. Four vital signs refer to air and climate, six refer to geology and soils, four refer to water, 16 refer to biological integrity, three refer to human use, and eight refer to ecosystem pattern and processes. Twenty-three of these will be monitored using NCPN funds, ten are monitored by network parks or other partners, and eight will not be monitored given current funding levels.

Chapter 4. Sampling Design

Five schemes for collecting vital sign measurements were adopted for NCPN monitoring efforts: Grid-based sampling, Network sampling, List-based sampling, Index sites, and Censuses. The NCPN monitoring uses three methods to spatially allocate sample units: simple random, stratified random, and Generalized Random Tessellation Stratified (GRTS). Most sampling designs proposed for the NCPN rotate field sampling efforts through various sets of sample units over time (revisit designs). A summary of sampling designs, spatial allocation of samples, and revisit plans for vital signs monitoring is presented.

Chapter 5. Sampling Protocols

The NCPN is developing 16 monitoring protocols to monitor 30 vital signs. Four protocols are complete and available on the NCPN web site (http://www1.nature.nps.gov/im/units/ncpn/monitoring.cfm). Others will be posted as they become available. Several vital signs will be monitored at co-located sites and are combined into common protocols. Protocol Development Summaries for the vital signs are included as an appendix. The summaries include justification for monitoring, measurable objectives, methods, and a time-line for protocol development.

Chapter 6. Data Management

The goal of the NCPN's data management program is to maintain, in perpetuity, the ecological data and related analyses that result from the network's inventory and monitoring work. The NCPN Data Management Plan describes the resources and processes required to ensure the accuracy, security, longevity, and accessibility of data acquired or managed by the NCPN. The most current version of the plan is available on the NCPN website (http://www.nature.nps.gov/im/units/ncpn/InfoManagement.cfm).

Chapter 7. Data Analysis and Reporting

Disseminating results in a useable format for park managers as well as a wide audience is central to the success of the NCPN monitoring program. Also necessary is adaptive management of the monitoring program. This is accomplished by reviewing the implementation and effectiveness of all monitoring efforts, and revising procedures when necessary. Proposed analyses and reporting for each of these purposes are summarized.

Chapter 8. Administration and Implementation of the Monitoring Program

Administration and implementation includes plans for oversight, staffing, key partnerships, integration with NPS programs, and program review. The NCPN is governed by a board of directors (made up of park superintendents) and advised by a technical committee (made up of park natural resources staff). A staffing plan is included as an appendix. The NCPN partners with the Southern Colorado Plateau Network with whom many vital signs are shared. Conceptual modeling and monitoring protocol development involve active collaborations between the two networks. Other important partners include: NPS Air Resources and Water Resources Divisions; U.S. Geological Survey, Biological Resources Discipline; USGS Water Resources Discipline; USGS Earth Resources Observations Systems data center; Utah Department of Environmental Quality; and the Rocky Mountain Bird Observatory. The NCPN seeks to be a catalyst for integrating natural resource programs among network parks and to link inventory and monitoring efforts with interpretation programs. Program reviews occur every five years and focus on implementation, whether vital signs are being monitored as planned, and effectiveness, whether monitoring data are being communicated to management and are informing decisions.

Chapter 9. Schedule

Not all NCPN monitoring activities begin immediately upon completion of this monitoring plan. A schedule is presented for developing and implementing monitoring protocols through 2008. Monitoring of six vital signs using existing methods began in 2005. Five monitoring protocols, covering fourteen vital signs, will be implemented in 2006. Three monitoring protocols, covering six vital signs, will be implemented in 2007. The final monitoring protocol, covering one vital sign, will be implemented in 2008.

Chapter 10. Budget

NCPN's current base funding is $1,073,500 per year. Fixed costs are 44 percent of base funding. The low proportion of fixed costs maintains flexibility for the network in the early stages of monitoring implementation. Nineteen percent of the budget is allocated to interagency and cooperative agreements to complete protocol development and begin monitoring implementation. Six percent of the budget is allocated to operations costs.

The national program guidelines set a target that 30 percent of the budget is for information management. This includes data quality assurance, archiving, documentation with metadata, as well as analysis and reporting results. About 37 percent of the NCPN funding goes to support these activities.

Chapter 1

Introduction and Background

The Northern Colorado Plateau Network (NCPN) is one of 32 National Park Service (NPS) inventory and monitoring networks nationwide that are creating a Vital Signs Monitoring Plan for assessing the condition of park ecosystems. The network approach facilitates collaboration, information sharing, and economies of scale in natural resource monitoring, and will provide parks with a minimum infrastructure for initiating natural resource monitoring that can be built upon in the future. This plan describes vitals signs monitoring for the NCPN including five parks that make up a prototype cluster in the NPS long-term ecological monitoring program.

1.1. Network Overview

The NCPN consists of 16 parks with diverse cultural and natural resources distributed across four states and three different physiographic regions (Figure 1-1). Ecosystems encompassed by the NCPN parks include desert grasslands, shrublands and woodlands, forested terrestrial systems, aquatic systems including large rivers, perennial streams, seeps, springs, and cave systems. Parks in the network range in size from 16 to over 136,000 hectares, and include one national historic site, one national recreation area, eight national monuments, and six national parks (Table 1-1). Most were established for natural resource protection, but three NCPN parks were created specifically to protect historic or prehistoric cultural resources. The extent of designated wilderness within NCPN parks is limited; Black Canyon of the Gunnison Wilderness is the only congressionally established wilderness within NCPN. However, many network parks include recommended and potential wilderness (Table 1-1). Park Service policy is to manage recommended and potential wilderness lands as if they were designated wilderness. Additional details regarding park resources are in section 1.4 and Appendix A.

A component of the NPS national inventory and monitoring framework is a network of experimental or “prototype” long-term ecological monitoring (LTEM) programs. The tremendous variability among parks in ecological conditions, sizes, and management capabilities represents significant problems for any attempt to institutionalize ecological monitoring throughout the NPS. To develop monitoring expertise throughout this range of ecological and managerial diversity, natural resource park units were grouped into 10 major biogeographic areas or **biomes**. One park unit from each major biome was then selected to serve as a prototype LTEM program for that biome. To address the needs of small parks,

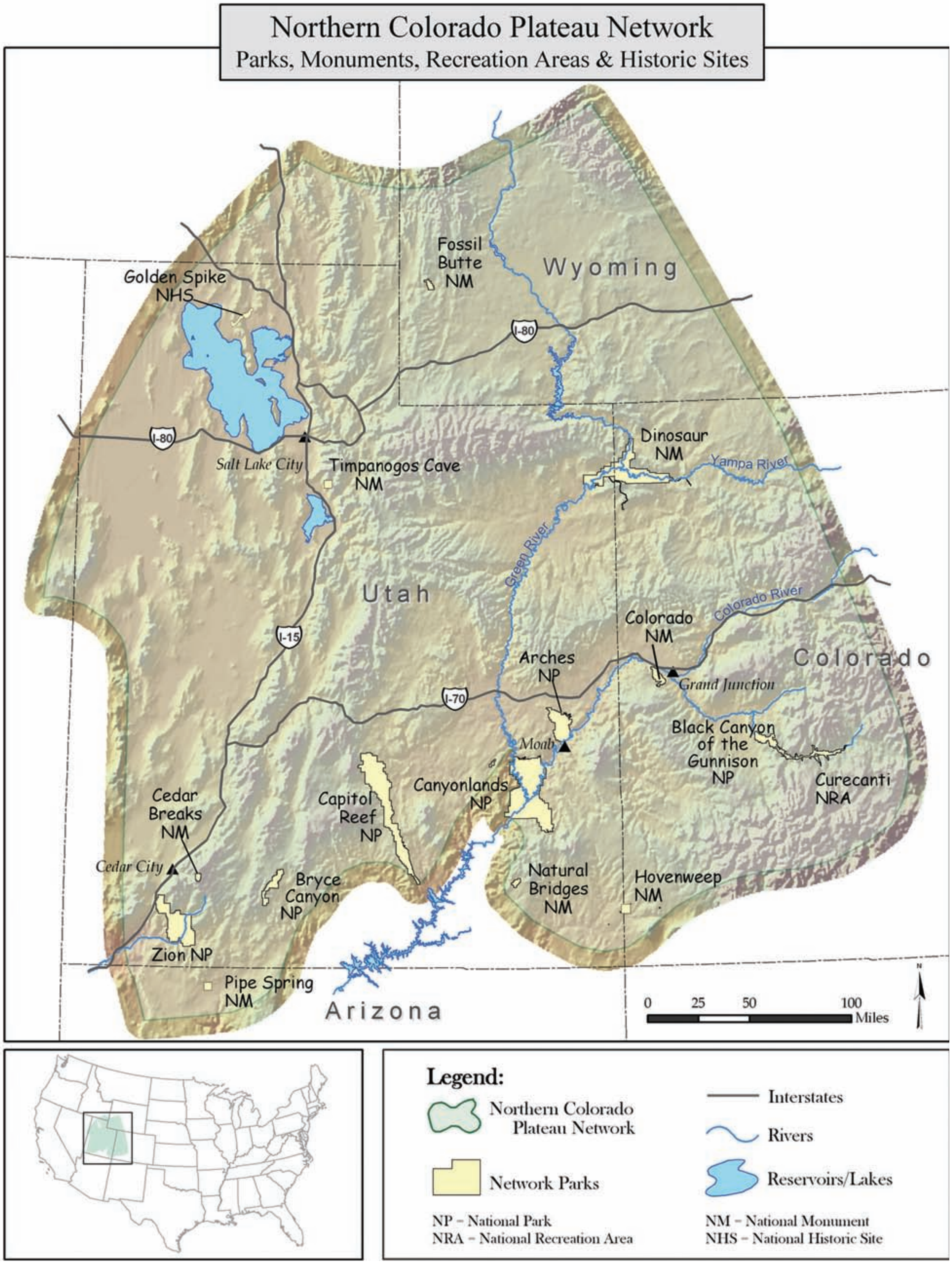

Figure 1-1. Northern Colorado Plateau Parks

Table 1-1. Northern Colorado Plateau Network Units.

Park Name	Park Code	State	Hectares	Designated, recommended & potential Wilderness (ha)	Originally established for	
					Cultural Resources	Natural Resources
Arches National Park *	ARCH	UT	30,966	28,529		x
Black Canyon of the Gunnison National Park	BLCA	CO	12,239	6,313		x
Bryce Canyon National Park	BRCA	UT	14,502	8,422		x
Canyonlands National Park *	CANY	UT	136,610	11,6786	x	x
Capitol Reef National Park *	CARE	UT	97,895	7,4408		x
Cedar Breaks National Monument	CEBR	UT	2,491	1,955		x
Colorado National Monument	COLM	CO	8,310	5,981		x
Curecanti National Recreation Area	CURE	CO	17,433	0		x
Dinosaur National Monument *	DINO	CO/UT	85,097	85,097		x
Fossil Butte National Monument	FOBU	WY	3,318	0		x
Golden Spike National Historic Site	GOSP	UT	1,107	0	x	
Hovenweep National Monument	HOVE	UT/CO	318	0	x	
Natural Bridges National Monument *	NABR	UT	3,009	0		x
Pipe Spring National Monument	PISP	AZ	16	0	x	
Timpanogos Cave National Monument	TICA	UT	101	0		x
Zion National Park	ZION	UT	59,900	53,007	x	x
Total Network Area			**473,312**	**380,498**		

**Prototype parks of the arid lands biogeographic region*

three of the prototype programs were designed as “cluster” programs, i.e, a grouping of four to six small parks, each lacking the full range of staff and resident expertise needed to conduct a long-range monitoring program on its own.

The Northern Colorado Plateau Cluster is the prototype cluster for the Arid Lands biogeographic region. Although several parks now in the NCPN were first proposed as a prototype cluster for long-term monitoring in the Arid Lands biome in 1993, funding for monitoring planning did not commence until the advent of the national I&M program in 2001. Therefore the prototype parks are fully integrated in the NCPN program. They are primarily distinguished as test beds for monitoring-related research and protocol development, some of which has been funded by the U.S. Geological Survey (USGS). The Southern Colorado Plateau Network is working closely with the Northern Colorado Plateau Network during the planning and design phase.

1.2. Integrated Natural Resource Monitoring

1.2.1. Justification for Integrated Natural Resource Monitoring

Understanding the condition of natural resources in national parks is fundamental to managing park resources “unimpaired for the enjoyment of future generations.” National Park managers are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources to make decisions and work with other agencies and the public. The challenge of protecting and managing a park’s natural resources requires a multi-agency, ecosystem-based approach because most parks are open systems, with threats such as air and water pollution, or invasive species, originating outside of the park’s boundaries. An ecosystem-based approach is further needed because no single spatial or temporal scale is appropriate for all system components and processes. The appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level, and in some cases may require a regional, national or international effort to understand and manage the resource. National parks are part of larger ecosystems and must be managed in that context.

The intent of the NPS long-term ecological monitoring program is to track a subset of park resources and processes, known as “vital signs,” that are determined to be the most significant indicators of ecosystem conditions. **Vital Signs** are defined by the NPS monitoring program as a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. 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 acting on those resources. Vital signs may be designated 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). In situations where natural areas have been so highly altered that physical and biological processes no longer operate (e.g., control of fires and floods in developed areas), information obtained through monitoring can help managers understand how to develop the most effective approach to restoration or, in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through long-term natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

1.2.2. Legislation, Policy and Guidance

National Park managers are directed by federal law and National Park Service policies and guidance to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission of conserving parks unimpaired. Congress strengthened the NPS' protective function, and provided language important to recent decisions about resource impairment, when it amended the Organic Act in 1978 to state that *"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."*

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park system. The act charges the Secretary of the Interior to *"continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the National Park System,"* and to *"assure the full and proper utilization of the results of scientific studies for park management decisions."* Section 5934 of the Act requires the Secretary of the Interior to develop a program of *"inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."*

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the Fiscal Year 2000 Appropriations Bill:

"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

The 2001 NPS Management Policies specifically directed the service to inventory and monitor natural systems:

"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."

Further, "The Service will:

- Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.
- Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.
- Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.
- Analyze the resulting information to detect or predict changes, including interrelationships with visitor-carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.
- Use the resulting information to maintain— and, where necessary—restore the integrity of natural systems" (2001 NPS Management Policies).

In addition to the legislation directing the formation and function of the National Park Service, a number of laws protect not only the natural resources within national parks and other federal lands, but they address environmental compliance in the United States. Many of these federal laws require natural resource monitoring within national parks. A summary of legislation, policy, and executive guidance having a direct bearing on natural resource monitoring in the NPS is presented in Appendix B.

Each network park is also mandated to protect certain resources by its enabling legislation. They have identified more detailed goals for resource management, inventory, and monitoring in management plans and related documents. Finally, the Government Performance and Results Act (GPRA) guides the NPS in setting measurable performance goals for the management of national parks and requires annual reporting to Congress on their attainment. Park-enabling legislation, goals for managing resources, and GPRA goals are summarized in Appendix C.

1.2.3. National Park Service Framework for Monitoring

Information from natural resource monitoring and research is essential if the NPS is to meet legislative and policy mandates for sound resource stewardship (Figure 1-2). The Inventory and Monitoring Program was established to help meet those information needs. Under the program, 270 park units have been organized into 32 networks that share funding and professional staff to conduct long-term ecological monitoring. Each network links parks that share similar geographic and natural resource characteristics to improve efficiency and reduce costs. The amount of new funding available for vital signs monitoring would allow most parks to monitor only a few vital signs. To more efficiently and effectively track resource condition and address performance goals, the NPS adopted a strategic approach that leverages the new funding with existing park staffing, funding, and other park service programs, and encourages parks to partner with universities and federal and state agencies to monitor the condition of selected resources. This strategy is intended to maximize the use and relevance of the monitoring data for management decision making and other park operations by allowing each network to determine what they will monitor based on their most critical data needs and local partnership opportunities. Parks are encouraged to use or modify standard protocols and partner with existing programs wherever possible to allow comparability and synthesis of data at multiple scales, but the primary use of the data is at the park level for management decision making and integration with park operations.

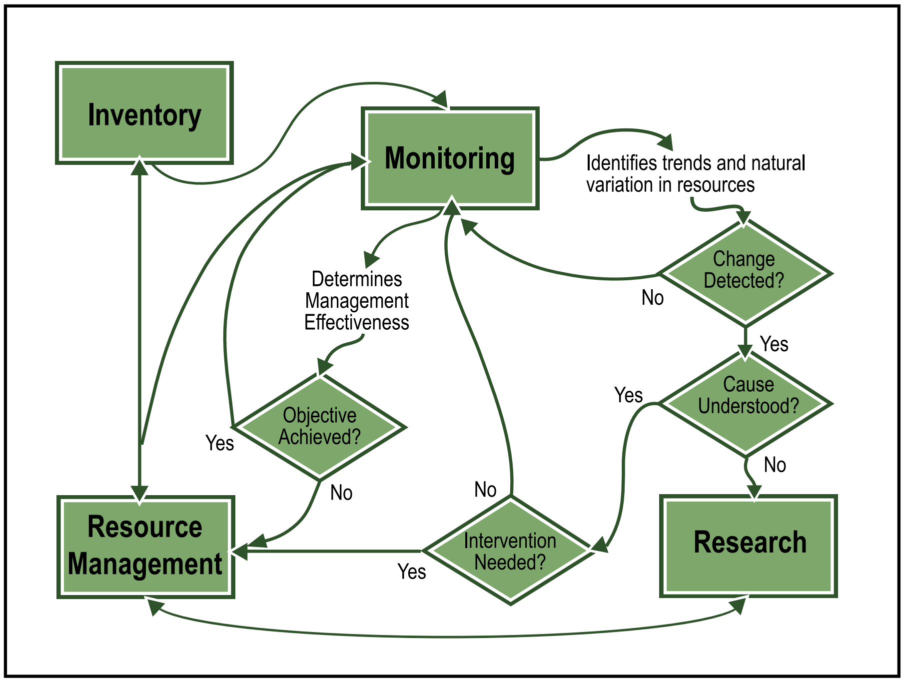

Figure 1-2. Relationships between monitoring, inventories, research, and natural resource management activities in national parks (modified from Jenkins etal., 2002)

The network approach results in some vital signs being monitored at individual parks, others being monitored in multiple parks across a network or networks, and a few vital signs being monitored in most parks nationwide (Figure 1-3). This accommodates the need for park-specific monitoring, such as for rare species that may occur in a single park, while allowing monitoring of other vital signs over a wide geographic area.

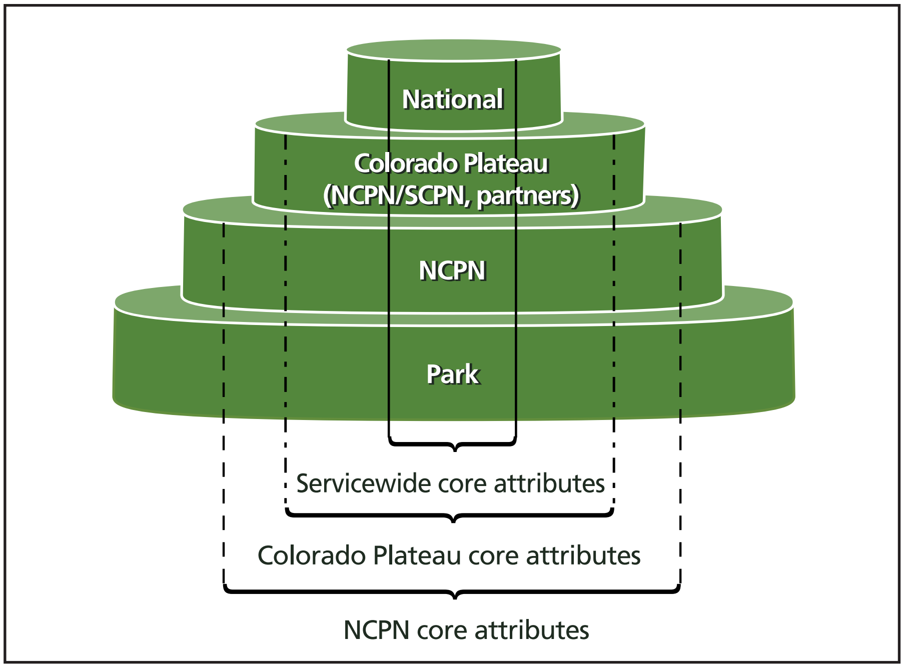

Figure 1-3. Depiction of network monitoring in relation to other efforts throughout the National Park Service (adopted from U.S. Forest Service).

1.2.4. Strategic Approaches to Monitoring

Process for Developing an Integrated Monitoring Program

Developing a network monitoring program requires careful planning and designing to guarantee that monitoring provides critical information needs of each park and scientifically credible results that are clearly understood and accepted by scientists, policy makers, and the public. These front-end investments also ensure that monitoring will build upon existing information and understanding of park ecosystems, and make maximum use of leveraging and partnerships with other agencies and academia.

Each network of parks is required to design an integrated monitoring program that addresses the service-wide goals listed above and that each program be tailored to the high-priority monitoring needs for the parks in that network. Although there will be considerable variability among networks in the final design, the basic approach to designing a monitoring program should follow five steps, which are further discussed in Appendix D:

- Define the purpose and scope of the monitoring program (establish goals and objectives);
- Compile and summarize existing data and understanding of park ecosystems;
- Develop conceptual models of relevant ecosystem components;
- Select vital signs and specific monitoring objectives for each; and
- Determine the appropriate sampling design and sampling protocols.

These steps were incorporated into a three-phase planning and design process that was established for the monitoring program. Phase One involved defining goals and objectives; beginning the process of identifying, evaluating and synthesizing existing data; developing draft conceptual models; and completing other work that was done before the initial selection of vital signs. Each network was required to document these tasks in a Phase One report, which was then peer reviewed and approved at the regional level before the network proceeded to the next phase. Phase Two involved prioritizing and selecting the vital signs that were included in the network's initial integrated monitoring program. The current report is the product of Phase Three, the detailed design work needed to implement monitoring, such as developing specific monitoring objectives for each vital sign, developing sampling protocols and a statistical sampling design, developing a plan for data management and analysis, and determining the type and content of various products of the monitoring effort such as reports and websites.

Planning for water quality monitoring, funded by the NPS Water Resources Division, followed the same steps and proceeded in parallel to the other vital signs planning. Networks were given the options of producing a separate document for water quality monitoring or integrating them into a single plan including all vital signs. NCPN has chosen to create a single integrated monitoring plan.

Strategies for Determining What to Monitor

An overriding objective for natural resource monitoring is to distinguish between normal ecosystem dynamics and conditions that might indicate a need for management attention. Monitoring is an on-going effort to better understand how to sustain or restore ecosystems, and serves as an early warning system to detect declines in ecosystem integrity and species viability before irreversible loss has occurred. One of the key initial decisions in designing a monitoring program is 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.

The current understanding of ecological systems and consequently, the ability to predict how park resources might respond to changes in 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 arise in the future. Ultimately, a vital sign is useful only if it can provide information to support a management decision or quantify the success of past decisions, and a useful ecological indicator must produce results that are clearly understood and accepted by managers, scientists, policy makers, and the public.

Focusing monitoring on the effects of known threats to park resources or on general properties of ecosystem status is a critical decision. Woodley et al., (1993), Woodward et al., (1999), and others have described some of the advantages and disadvantages of alternative monitoring approaches, including a strictly threats-based monitoring program, or a taxonomic, integrative, reductionist, or hypothesis-testing monitoring design (Woodley et al., 1993, Woodward et al., 1999). The method adopted by the NCPN is to achieve a balance among different monitoring approaches, while recognizing that the program will not succeed without also considering political issues. Specifically, the NCPN recommends choosing vital signs in each of the following broad categories:

1. **<u>System</u> drivers** that fundamentally affect park ecosystems,
2. **<u>Stressors</u> and their ecological effects,**
3. **<u>Focal</u> resources** of parks, and
4. **<u>Key</u> properties and processes of ecosystem integrity.**

Natural ecosystem drivers are major external forces like climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events such as earthquakes, droughts, and floods. These can have large-scale influences on natural systems. Trends in ecosystem drivers will suggest what kind of changes to expect and may provide an early warning of changes in the ecosystem. The primary driver in the Colorado Plateau region is climate, particularly precipitation and temperature.

Stressors are physical, chemical, or biological perturbations to a system that are either foreign or natural to the system but applied at an excessive [or deficient] level (Barrett et al., 1976:192). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples of stressors to be monitored in the NCPN are biological invasions, visitor impacts, land-use change, and air pollution. Monitoring of stressors and their effects, where known, will ensure short-term relevance of the monitoring program and provide information useful to managers.

Focal resources, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored to indicate ecosystem integrity. Then NCPN will monitor focal resources including regionally-imperiled ecosystems (e.g., native grasslands), and species that have protected status.

Key properties and processes of ecosystem integrity, when monitored, will provide the long-term baseline needed to judge what constitutes unnatural variation in park resources. They also will provide early warning of unacceptable change. **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. An example of a process to be monitored by the NCPN is **hydrologic function**, the ability of a site to capture, retain, and redistribute water.

1.3. Overview of Network Parks

The NCPN encompasses 16 units managed by the National Park Service in Utah, western Colorado, southwestern Wyoming and northwestern Arizona (Table 1-1, Fig. 1-1, and Appendix E). Most network parks are adjacent to lands managed by the U.S. Department of the Interior, Bureau of Land Management, U.S. Department of Agriculture, Forest Service, and states (Appendix E).

1.3.1. Ecological Context

A major challenge in developing a network-wide strategy for vital signs monitoring is characterizing the tremendous biophysical variation found in a network that spans 480 km from east to west, 560 km from north to south, and over 2130 m of vertical relief. NCPN parks occur in four distinct physiographic regions (Basin and Range, Colorado Plateau, Middle Rocky Mountains, and Southern Rocky Mountains). They are characterized by:

- Large areas of sparsely-vegetated bedrock and soil, along with diverse vegetation zones from grasslands and shrublands to woodlands and forests.
- Gradients of latitude, elevation, and precipitation that are major influences on ecosystem processes and species distributions.
- Soil conditions, particularly parent materials, with profound influences on vegetation such that many **edaphic endemic** species occur.

Significant Resources of the Northern Colorado Plateau Network

Fundamentally, all NCPN resources are significant. From a legal perspective, water, air, and threatened and endangered species are primary. Resources or resource categories are particularly significant from one of three additional perspectives: ecoregional distinctiveness, ecological functionality, and degree of peril on a regional or nationwide basis. In Table 1-2, each resource is considered to include the ecosystems, ecological processes, and conditions required to sustain that resource.

Table 1-2. Categories and examples of significant resources in the NCPN

Significance	Resource examples
Ecoregional distinctiveness	Endemic plants Hanging garden ecosystems
Ecological functionality	Air quality Soil quality Water quality Biological soil crusts Riparian, wetland, and aquatic ecosystems
Critically-imperiled ecosystems of the Intermountain Region (Noss et al. 1995, Christensen et al. 1996)	Native grasslands Sagebrush shrublands and shrub steppe Riparian forests Large streams and rivers

The diversity and abundance of biotic communities varies considerably across the network parks. Major ecosystems occurring in NCPN parks are summarized in Table 1-3 (next page) and detailed in Appendix A.

Table 1-3. (next page) Relative occurrence of major terrestrial, riparian, wetland and aquatic ecosystems with NCPN units. See coding key for explanation of table entries.

Table 1-3. Coding Key

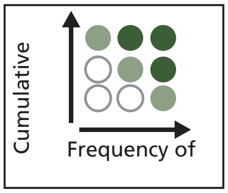

Table 1-3.
Ecosystem category

Ecosystems	**ARCH**	**BLCA**	**BRCA**	**CANY**	**CARE**	**CEBR**	**COLM**	**CURE**	**DINO**	**FOBU**	**GOSP**	**HOVE**	**NABR**	**PISP**	**TICA**	**ZION**
Riparian -wetland and aquatic ecosystems (combined)																
Lotic systems																
Rivers with associated aquatic & riparian systems	◍	●		●	◍			○	●						○	●
Perennial streams with associated aquatic & riparian systems				◍	○		○	◍	◍		○		◍			◍
Intermittent streams with associated aquatic & riparian systems	○		○	○	○		◍		◍	○		○	○			○
Lentic systems																
Reservoirs								●								
Perennial wetlands/marshes/wet meadows	○		○	○	○	○			○	○		○	○			○
Ephemeral playas/wetlands										○						○
Hanging gardens	◍	○		◍	○		○	○	○				◍	○		◍
Springs & seeps (other than hanging gardens)	○	○	◍	○	○	○	○	○	○	○		○	◍	○		○
Slickrock potholes/waterpockets	◍			●	◍		○		○		○		○			◍
Montane shrubland, coniferous woodland, and forest ecosystems																
Subalpine woodlands			○		○	◍										
Spruce=-fir forests		○	◍			●		○							○	
Montane meadows/shrubland parks			◍			●										
Aspen woodlands/forests		○	○	○	○	○		○	○	◍						○
Douglas-fir woodlands/forests		○	◍	○	○	○	○	○	◍	◍			○		○	◍
Ponderosa pine woodlands/forests		○	◍	○	○	○		◍	◍				○			◍
Montane shrub lands		●	○	○	○	○	◍	◍	◍	◍		○	◍		○	◍
Arid-semiarid shrub land, grassland, and woodland ecosystems																
Pinyon-juniper woodlands/savannas	●	●	◍	●	●	○	●	○	●		○	◍	●	○	○	●
Sagebrush shrublands/shrub steppe	○	◍	○	○	○		◍	●	●	●	●	●	○	○		◍
Greasewood shrublands/shrub steppe	○			○	◍		○		◍	○		○				○
Mixed grasslands/shrub steppe	◍			◍	◍		○		●	◍		○		○		◍
Shadescale dwarf- shrublands/shrub steppe	◍			●	●				◍		○	○	○			
Blackbrush shrublands/shrub steppe	●			●	○											○
Mat saltbush dwarf- shrublands/shrub steppe	○			◍	◍				○	○						
Sparsely vegetated terrestrial ecosystems (vascular canopy cover 1-10%)																
Shale-mudstone-siltstone badlands	○	○		○	●				◍	○						○
Caron breaks/limestone barrens			◍			●			○							
Rock-outcrop/slickrock	●			●	●		◍		●	○	○	○	○			◍
Cultural and other unique ecosystems																
Cultivated orchards					○											
Caves and mines				○	○	○	○		○		○				●	

Endangered Species

Twenty-six taxa with federal Endangered Species Act status potentially occur across all NCPN parks combined (Table 1-4).

Outstanding Natural Resource Waters

Although no network parks currently have water bodies with ONRW status, BLCA and CURE are monitoring water quality at several sites to determine whether or not they qualify.

Clean Water Act 303d-Listed Waters in Parks

One of the NCPN's primary goals is to collect, analyze, and interpret data to support management decisions in relation to 303d listings[1] of waters. Currently, three waters (comprised of one or more stream segments) in three parks are 303d-listed (Table 1-5). Additional details regarding 303d listed waters can be found in Appendix F.

Clean Air Act Class I areas

All national parks over 6,000 acres (2430 ha) are designated Class I areas under the Clean Air Act. The Act mandates "...prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution..."

Six NCPN park units are designated Class I areas (ARCH, BLCA, BRCA, CANY, CARE, ZION). Visibility monitoring currently occurs in BRCA, CANY, CARE, and ZION as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. The nearest visibility monitoring to ARCH is at CANY, 35 km to the south; the nearest visibility monitoring to BLCA is at White River National Forest, 65 km to the north. Additional air quality monitoring within NCPN parks is listed in Table 1-6.

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[1] Section 303d of the Clean Water Act of 1977 makes it the states' responsibility to determine whether ambient standards, which are established by the states and subject to federal approval, are being achieved for individual water bodies. Section 303d requires states to identify waters not meeting ambient water quality standards, characterize the pollutants and the sources responsible for the degradation of the listed water(s), create Total Maximum Daily Load (TMDLs) necessary to meet the standards, and assign responsibility to sources for reducing the pollution loads.

Table 1-4. Taxa with federal Endangered Species Act status (i.e., currently listed, candidates for listing, recently delisted, or managed under conservation agreements) known or likely to occur currently in parks, monuments, historic areas or recreation areas of the Northern Colorado Plateau Network.

Taxonomic group **Scientific name**	**Common name**	**Heritage Conservation Status***	**Endangered Species Act Status****	**Parks**
Vascular plants				
Astragalus eremiticus var. *ampullarioides*	Shivwits Milkvetch	G1Q	E	ZION
Cycladenia humilis var. *jonesii*	Jones' cycladenia	G3,G4,T2	T	CARE
Erigeron maguirei	Maguire daisy	G2	T	CARE
Gilia caespitosa	Wonderland Alice-flower	G2	C	CARE
Pediocactus despaini	Despain's cactus	G2	E	CARE
Pediocactus winkleri	Winkler's pin-cushion cactus	G2	T	CARE
Salix arizonica	Arizona willow	G2,G3	M	CEBR
Schoenocrambe barnebyi	Sye's Butte plainsmustard	G1	E	CARE
Sclerocactus glaucus	Uinta Basin Hookless Cactus	G3	T	COLM
Sclerocactus wrightiae	Wright fishhook cactus	G2	E	CARE
Spiranthes diluvialis	Ute ladies' tresses	G2	T	CARE, DINO
Townsendia aprica	Last Chance townsendia	G2	T	CARE
Fish				
Gila cypha	Humpback chub	G1	E	CANY, DINO
Gila elegans	Bonytail chub	G1	E	CANY, DINO
Lepidomeda mollispinis	Virgin spinedace	G1	M	ZION
Ptychocheilus lucius	Colorado pikeminnow	G1	E	CANY, DINO
Xyrauchen texanus	Razorback sucker	G1	E	CANY, DINO
Reptiles				
Gopherus agassizii	Desert tortoise	G4,S1	T	ZION
Birds				
Centrocercus minimus	Gunnison sage grouse	G1	C	BLCA, CURE
Coccyzus americanus	Yellow-billed cuckoo	G5	C	CARE, ZION
Empidonax traillii extimus	Southwestern willow flycatcher	G5,T1,T2	E	BRCA, CARE, ZION
Falco peregrinus anatum	American peregrine falcon	G4,T3	DM	BLCA, BRCA, CARE, COLM, CURE, DINO, ZION
Gymnogyps californianus	California condor	G1	EXPN	ARCH, BRCA
Haliaeetus leucocephalus	Bald eagle	G4	T	ARCH, BLCA, BRCA, CANY, CARE, COLM, CURE, DINO, GOSP, HOVE, ZION
Strix occidentalis lucida	Mexican spotted owl	G3,T3	T	BRCA, CANY, CARE, DINO, ZION
Mammals				
Cynomys parvidens	Utah prairie dog	G1	T	BRCA

*Heritage Conservation Status Codes (http://www.natureserve.org/explorer/ranking.htm)
G1 – Critically imperiled globally; G2 – Imperiled globally; G3 – Vulnerable globally; G4 – Apparently secure globally; G5 – Secure globally; S1 – Critically imperiled within state; S2 – Imperiled within state; T1 – Critically imperiled infraspecific taxon; T2 – Imperiled infraspecific taxon; T3 – Vulnerable infraspecific taxon; Q – Questionable taxonomy that may reduce conservation priority.

**Endangered Species Act Status Codes (http://endangered.fws.gov/)
E – Endangered; T – Threatened; EXPN – Experimental population, non-essential; C – Candidate taxon, ready for proposal; DM – Delisted taxon, recovered, being monitored first five years; AD – Proposed delisting; M – Managed under conservation agreement with U.S. Fish and Wildlife Service.

Table 1-5. Description and status of 303d-listed waters in NCPN park units.

Park	Water Body Description	Beneficial Use Impaired	303d listed constituent(s)	State - Priority
CARE	Upper Fremont River watershed[1]	Cold water fish species	Total Phosphorus (TP) and dissolved oxygen (DO)	UT – high
CARE	Lower Fremont River watershed[2]	Agricultural use	Total dissolved solids (TDS)	UT – high
ZION	North Creek from confluence with Virgin R. to headwaters	Agricultural use	TDS	UT – low[3]
BLCA	Tributaries to Gunnison River, Crystal Reservoir to Colorado River	Aquatic life warm water	Selenium	CO - high

[1] Listed segments for Upper Fremont River watershed include Lower UM Creek from Mill Meadow to Forsythe Reservoir (for low dissolved oxygen; Fremont River near Bicknell to U.S. Forest Service boundary (for total phosphorus and low DO) and the Johnson Valley and Mill Meadow Reservoirs and Forsyth Reservoir (for TP and DO).

[2] Listed segment is the Fremont River and tributaries with confluence of Dirty Devil R. to east boundary of Capitol Reef NP.

[3] North Creek's 303d listing is likely from natural discharge from springs in the park, so corrective action would not be desirable from the park's perspective.

Additional details of key network physical and biotic characteristics and detailed biophysical descriptions of individual parks are provided in Appendix A.

1.3.2. Management and Scientific Issues for Network Parks

Early in the monitoring planning process, park staffs were asked about resource-management issues and associated monitoring needs via e-mail. Responses were compiled in a database of specific resource - stressor concerns. Additional park staff input was acquired in an e-mail poll that asked park staff to identify their top five natural resource monitoring priorities. The results are presented in Table 1-8; additional details are provided in Appendix A.

No single resource issue emerged as the top priority. The top stressors identified were: park use (mainly recreation), invasive plants, trampling and grazing by livestock, and adjacent land use activities (particularly housing development). These results were included in the vital signs selection process described in Chapter 3.

A successful monitoring program requires that monitoring and research occur in an adaptive feedback loop (Figure 1-2). Monitoring results can help focus research questions on management issues, and monitoring data are typically collected over longer time periods and broader spatial scales than are research data. This creates an opportunity for researchers to address questions that are not otherwise accessible. Research is necessary to validate hypothesized relationships between agents of change and ecosystem responses. Vital signs selection is based on assumptions about drivers/stressors and responses. As these assumptions are validated or the strength of relationships better understood, the value of the vital sign as an indicator of ecosystem condition increases because it can be used to predict the ecosystem response. Conversely, if original assumptions about relationships prove incorrect, re-evaluating the vital sign may be in order. Other important research issues include understanding the natural range of variability of ecosystem attributes and identifying thresholds of change that trigger management actions. Ecosystems are highly dynamic and much of the variability is normal and contributes to the integrity of the system. However, at some point a threshold may be crossed beyond which the system is in an undesirable, and difficult to recover from, condition. Identifying such thresholds far enough in advance to allow effective mitigation is a fundamental goal of the monitoring program.

1.3.3. Summary of Existing Monitoring for Network Parks

The NCPN I&M effort builds upon existing monitoring programs; every network park has some degree of ongoing natural resource monitoring. In some cases, the NCPN will augment these existing programs to meet vital sign monitoring goals. In other cases, the network will initiate new monitoring. It is not the aim of NCPN to accomplish all of the monitoring needs of network parks, but the network can conduct credible and consistent monitoring of a core set of vital signs. It is expected that parks will continue to conduct additional monitoring with their own resources (Figure 1-3). Current and historic monitoring conducted by NCPN parks is summarized in Table 1-6.

Table 1-6. Historic and current resource monitoring in NCPN parks.

Resource or Stressor of Concern	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION	total
Air Quality:																	
Deposition			C	C													**2**
Ozone			C	C	C											C	**4**
Fine particulates			C	C	C											C	**4**
Visibility			C	C													**2**
Terrestrial Biology																	
Birds	C	C	C	C	C	H	C	C	C	C			C			C	**12**
Invertebrates							H										**1**
Mammals- general	C		C	C	C		H	C	C	C			H			C	**10**

Table 1-6. continued

Resource or Stressor of Concern	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION	total
Mammals- T&E			C		H											C	**3**
Reptiles			H				H						H			C	**4**
Vegetation communities general	C	C	H	C				C				C	C			C	**8**
Rare plants	C		C	H	C				C				C			C	**7**
General soil and soil crust	C		C	C			H					C	C				**6**
Riparian and Aquatic Biology																	
Aquatic ecosystems-general	C	C		C				C		H		C	C			C	**8**
Fish	C			C				H	C							C	**5**
Aquatic invertebrates	C	C	H	C	C			C	H			C	C				**9**
Periphyton		H						H									**2**
Phytoplankton								H									**1**
Zooplankton								H									**1**
Seeps, springs, & hanging gardens			H			C							C	C		C	**5**
Water																	
Water quality	C	C	H	C	H			C	H			C	C		H	C	**11**
Water quantity	C	C		C	H			C	C					C	C	C	**9**
Cave Resources																	
Cave environmental conditions															C		**1**
Cave formations															C		**1**
Sensory resources																	
Night sky	C			C								C	C				**4**
Soundscape	C		C				H		H	H							**5**
Drivers and stressors																	
Climatic conditions	C	C	C	C	C	C	C	C	C	C		C	C		C	C	**14**
Invasive plant species			C	H			C		H	H					C	H	**7**
Invasive animal species			H	H					C								**3**
Grazing and trampling by large mammals			H		C				C								**3**
NPS management actions			C	C					C		C					C	**5**
Fire effects	C		C	C			H		C		C					C	**7**
Adjacent land use activities			H													C	**2**
Natural disturbances	C		C	C			H		C		C					C	**7**

C – data collected within the past five years

H – data collected more than five years ago

1.4. Goals and Objectives for Vital Signs Monitoring

The primary purpose of vital signs monitoring is to provide park managers with scientifically-credible, relevant data on the status and trends of selected park resources as a basis for making decisions, working with other agencies, and communicating with the public to protect park natural systems and native species. Vital signs are defined as "selected physical, chemical, and biological elements and processes of park ecosystems that represent the overall health or condition of the park, known or hypothesized effects of stressors, or elements that have important human values." The program has five goals:

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

The servicewide goals identify the need to balance monitoring priorities between informing park managers and increasing the fundamental understanding of park ecosystem dynamics. Section 1.3 and Chapter 3 provide additional details on the process and criteria used to select potential vital signs based on these goals.

1.4.1. The NCPN Approach To Vital Sign Selection

The approach taken by NCPN in selecting vital signs involved three stages:

1. Identify key resources and stressors.
2. Determine measurable ecosystem attributes associated with resources and stressors.
3. Review and prioritize list of candidate vital signs.

Early in the vital signs selection process, substantial efforts were made to summarize existing information about park resources and ongoing monitoring. An e-mail survey of network park staff was conducted, resulting in development of a database of critical resources and stressors. Topical workshops were held regarding monitoring for geoindicators and water quality. A database capturing historic water quality data for network parks and nearby water bodies was developed to evaluate water quality monitoring needs (Appendix F). Table 1-7 summarizes the schedule of

Table 1-7. Schedule of monitoring planning.

Planning activity	2001		2002		2003		2004		2005	
Data collection, internal scoping	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Conceptual model development	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
E-mail survey to develop resource/stressor database	🟩	🟩								
Monitoring priority questionnaire		🟩								
Geoindicators workshop			🟩							
Delphi round 1					🟩					
Delphi round 2					🟩					
Vital signs workshops					🟩					
Water quality workshop						🟩				
Vital signs reviews with parks						🟩				
Implementation planning and protocol development							🟩	🟩	🟩	🟩
Monitoring plan – phase 1				🟩						
Monitoring plan – phase 2						🟩				
Monitoring plan – phase 3								🟩		

monitoring planning. Table 1-8 provides a summary of key resources identified by park staff.

Two rounds of **Delphi surveys** were conducted via the Internet to solicit wider scientific and resource management input to identify ecosystem attributes as candidate vital signs. The Delphi surveys allowed experts to identify measurable ecosystem attributes related to key resources and stressors (round 1) and evaluate them in relation to standard criteria (round 2). A final evaluation was conducted where vital signs were scored using more specific evaluation criteria. This was followed by a workshop for NPS staff and science partners to review the potential vital signs. A final round of review meetings at each park included identification of park-specific vital signs, not all of which are high priority for the network. All of these efforts proceeded in parallel with conceptual model development, described in Chapter 2; the first round Delphi survey was specifically adapted to the conceptual model framework. Additional details of vital signs selection are in Chapter 3.

1.4.2. Water Quality Monitoring

The monitoring of water quality is approached somewhat differently from other vital signs, focusing on the application of state-mandated standards for water quality. The region has a history of water quality monitoring, and the set of regulatory standards for water quality are already in place. While state water quality standards may have some limitations for protecting natural systems in parks, they do have wide acceptance and regulatory authority that are exceptional among potential vital signs. Additionally, Congress granted funding specifically for water

Table 1-8. Summary of significant resource management concerns by staff in Northern Colorado Plateau Network units.

	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION
Populations / species																
Aquatic																
Native fish	☐	☐		■		☐		☐	☐	☐						☐
TES fish*		☐		○				☐	■							■
Invertebrates	■			☐	☐			☐	☐			■	■			☐
Amphibians	■	☐	☐	☐	☐		○	☐	☐	☐		■	■			■
Terrestrial																
Birds	●	☐	☐	○	☐		☐	☐	☐	☐		◆	●	■		☐
TES birds*	■	●	●	■	☐	☐	☐	●	■	☐		●	■			■
Mammals	○	○	☐	○	☐	◆	○	○	☐	●		○	○	◆	■	■
TES mammals	■	■	◆	■			☐	■	☐			✚	✚		☐	
Plants			☐			☐	☐			☐					☐	☐
TES plants*	●	☐	■	■	◆	■	■	☐	●	☐		✚	●		☐	■
Reptiles		☐					☐					✚	✚			
TES reptiles*																■
Invertebrates	☐		☐	☐		☐			☐			☐	☐			☐
Ecosystems																
Riparian-wetland and aquatic ecosystems	■	■		■	■		■	●	■	☐		●	■			■
Upland ecosystems	■	●	■	■	■		■	■	✚	◆		■	■			☐
Cave ecosystems															◆	
Ecological resources or conditions																
Air quality	☐	■		☐	☐	●	■		☐			☐	☐	◆	☐	●
Climatic conditions		■	☐		☐			■	☐						☐	
Soil resources / soil quality	■	☐	●	■	■	☐	■	☐	☐	○		■	■	☐		■
Water quality	■	■	■	■	○	☐	✚	■	☐	■		■	■	✚	●	☐
Water quantity	■	☐		■	☐			☐	☐	■		■	■	✚	■	■

Table 1-8. continued

	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION
Features and objects																
Paleontological features	□		■	□	□		■		■	■		□	□			□
Geologic features			+				+								□	
Antlers, rocks, other natural objects					□				□							
Sensory resources																
Night sky	□		+	□	□	□	■		■			□	□	■		□
Soundscape	□		■	□	□	■	■		■			□	□	+	□	□

*includes Federally listed Threatened or Endangered species as well as taxa otherwise considered sensitive by NPS staff

Percent of database records by park		high-priority monitoring issue
0		+
1 - 10	□	■
11 - 20	○	●
> 20	◇	◆

quality vital sign monitoring based on an NPS justification that emphasized the need to meet water quality standards under the Clean Water Act.

National Park Service Management Policies for water quality (NPS 2001a: Section 4.6.3) commit the park service to:

1. Work with appropriate governmental bodies to obtain the highest possible standards under the Clean Water Act for the protection of park waters.
2. Take all necessary actions to maintain or restore the quality of surface waters and ground waters within the parks consistent with the Clean Water Act and all other applicable federal, state and local laws and regulations.
3. Enter into agreements with other agencies and governing bodies, as appropriate, to secure their cooperation in maintaining or restoring the quality of park waters.

Vital signs selection for water quality followed a similar process as that for other vital signs. However, scoping was followed by a detailed review and analysis of existing water quality data to identify water bodies in or near NCPN parks with high threats to water quality (exceeding or on a trend to exceed state standards for measured constituents) and important gaps in the existing water quality sampling. This resulted in a prioritized list of sites and attributes for monitoring as described in Chapter 4 and Appendix F.

1.4.3. Monitoring Objectives

To promote collaboration among networks and with other programs and agencies, and to combine results for national reporting, vital signs being monitored by the parks are organized into a hierarchical Vital Signs Monitoring Framework. Analysis and reporting of data will be done at several different scales (park, network, national) depending on the level of detail needed for the intended audiences. For example, the Level 1 categories will be used in a future "Natural Resource Report Card" to describe the condition of park resources nationwide while NCPN will generally report results from Level 3 categories (see Table 3-3). The monitoring objectives developed by the NCPN to track the status and trends in agents of change, ecosystem processes, and focal resources efficiently address the multiple goals of the program. General monitoring objectives for NCPN parks are presented in Table 1-9 in the national framework Level 2 Categories. More specific objectives can be found in Chapter 5, and monitoring methods are summarized in Appendix G.

1.4.4. An Integrative Monitoring Program

Monitoring involves repeated measurements. However, the goals of monitoring, such as increasing understanding of ecosystem variability and providing early warning of abnormal conditions, require that such measurements be assessed in relation to potential drivers and responses. For example, changes in vegetation cover may be compared to climatic trends to distinguish between natural and anthropogenic effects. Such analyses can make monitoring data useful to managers.

Examining interactions among vital signs at multiple spatial and temporal scales also is critical to understanding trends. Interactions among drivers and stressors force change in biotic communities. In turn, interactions among biotic components can change community structure and composition. Many of these interactions occur as same-scale processes. Scale dependencies are also important, where fine-scale processes are mediated by the spatial and temporal heterogeneity of higher-scale patterns and processes (Wiens 1999).

The NCPN monitoring plan is designed to monitor scale-dependent processes and to accommodate integration within and among scales (Figure 1-4). Estimates of climatic parameters derived from regional monitoring networks provide a backdrop for evaluating large-scale changes in abiotic drivers of change. Remotely-sensed information on landscape structure, condition, and land use in and adjacent to park lands, and at multiple scales, provides key measures of spatial pattern and human disturbance. Additionally, public records provide information on critical land-use activities that can't be detected with remote sensing, such as wa-

Table 1-9. NCPN monitoring objectives, organized in the Inventory and Monitoring Program Vital Signs Framework.

Level 1 Category	Level 2 Category	Monitoring goals
Air and Climate	Air quality	Determine status and trends in atmospheric gases, particulates, and deposition.
	Weather and climate	Describe variability in weather patterns across network parks.
Geology and Soils	Geomorphology	Determine status and trends in morphology of selected reaches.
	Soil quality	Determine status and trends in indicators of soil/site stability and hydrologic function.
Water	Hydrology	Determine status and trends in groundwater. Determine status and trends in stream flow.
	Water quality	Determine status and trends in aquatic macroinvertebrate communities. Determine status and trends in selected water quality parameters.
Biological Integrity	Invasive species	Detect incipient populations and new introductions of invasive plant species. Determine status and trends of invasive plant populations.
	Infestations and disease	Determine status and trends of insect and disease outbreaks.
	Focal species or communities	Determine status and trends in composition, structure, and function of focal species and communities.
	At-risk biota	Determine status and trends in populations of species of concern. Quantify habitat conditions for populations of target species.
Human use	Non-point source human effects	Determine status and trends in human demographics and land use statistics.
	Visitor and recreation use	Determine status and trends in spatial and temporal patterns of visitor use.
Ecosystem Pattern and Processes	Fire	Determine long-term changes in fire frequency and extent.
	Landscape dynamics	Determine status and trends of visitor disturbance. Determine status and trends of land-cover types. Determine status and trends in the connectivity of land-cover types. Determine status and trends in cross-boundary land cover contrasts.
	Nutrient dynamics	Determine status and trends in indicators of nutrient cycling.
	Productivity	Determine status and trends in vegetation productivity.

ter diversion and agro-chemical practices. Trends in fine-scale attributes are monitored with ground-based field plots. At each scale, the use of synoptic measures will afford better understanding of trends. The spatial hierarchy of monitored attributes permits understanding of cross-scale interactions; e.g., the effects of regional climatic conditions on patterns and trends in landscape condition, the effects of large-scale climatic conditions and proximate landscape structure on plot-based trends. Additionally, fine-scale data will be used to inform analyses of data collected at coarser scales (e.g., imagery classification, interpretation of land condition), and potentially as the basis for interpolating fine-scale measures to the landscape (e.g., Gradient Nearest Neighbor Imputation [Ohmann and Gregory 2002]).

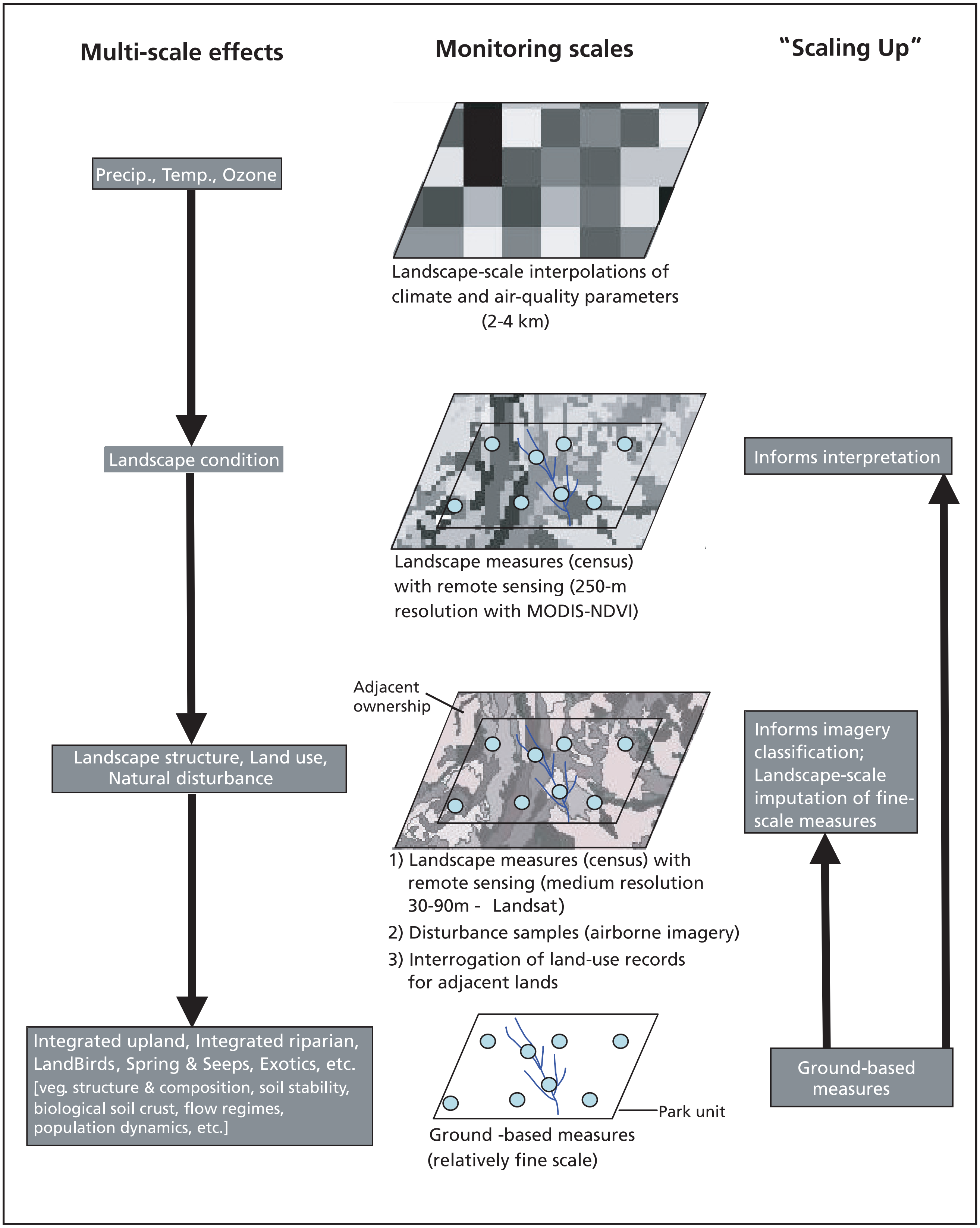

Figure 1-4. Spatial scales of NCPN monitoring and data analysis

Such integration contributes to measuring attributes in ways that facilitate their interpretation; programmatic integration will enhance monitoring in other ways. Programmatic integration requires coordination and communication with other NPS programs including resource management, interpretation, law enforcement and maintenance. Integrating programs will ensure the relevance of monitoring to NPS managers. It also involves working with other federal, state, and non-governmental agencies to increase the scope of and develop constituencies for the monitoring program. Approaches to programmatic integration are discussed in Chapter 8.

Chapter 2

Conceptual Models

2.1. Conceptual Models and the Development of an Ecological Monitoring Program

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

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

Key Terms

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

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

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

Ecological Integrity *– concept that expresses degree to which bio-physical components of an ecosystem are capable of self-renewal.*

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

2.2. Conceptual Model Approach

The NCPN adopted a modified version of the interactive-control model (Chapin et al. 1996; Jenny 1941) as the overarching framework for conceptual model development (Fig. 2-1). This model, also known as the Jenny-Chapin model, defines state factors and interactive controls central to the structure and function of sustainable ecosystems. Jenny (1980, 1941) proposed that soil and ecosystem processes are determined by five *state factors* — global climate, potential biota, relief (topography), parent material, and time since disturbance (Fig. 2-1A). Chapin et al. (1996) extended this framework to define a set of four interactive controls that are regulated by the five state factors. These interactive controls — regional climate, soil resources, major functional groups of organisms, and disturbance regime — govern and respond to ecosystem attributes. (Fig. 2-1B).

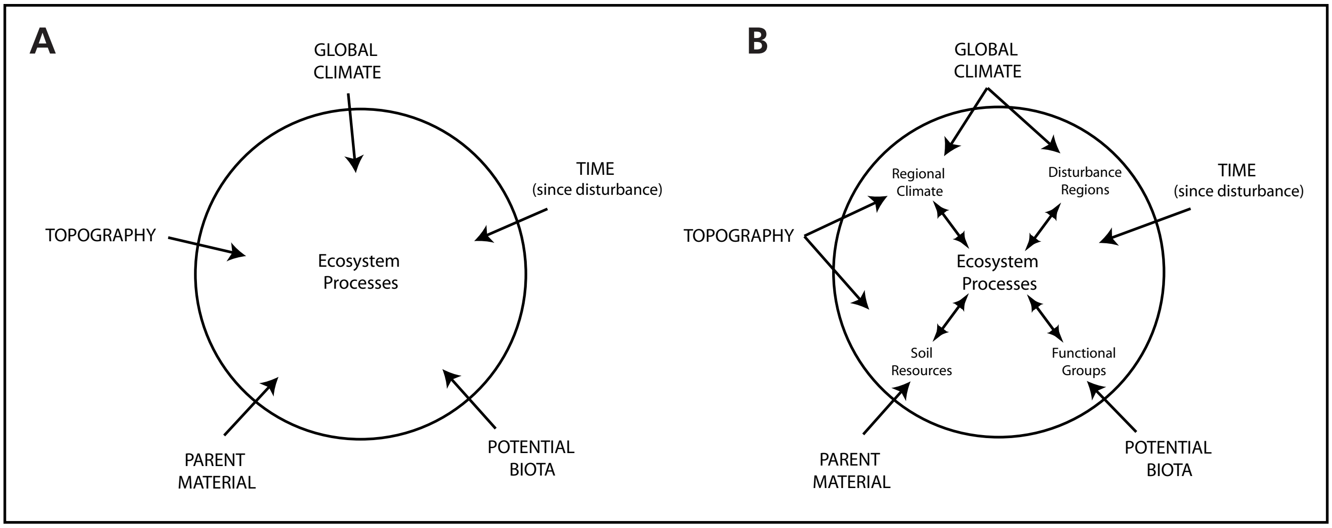

Figure 2-1. Illustration of the Jenny-Chapin model. A – Jenny's (1941) five state factors. B – Relationship among state factors, interactive controls, and ecosystem processes. The circle represents the boundary of the ecosystem (from Chapin et al. 1996).

By substituting water quality and quantity for soil resources, the Jenny-Chapin model can be applied to aquatic as well as terrestrial ecosystems (Chapin et al. 1996). Regional climate and disturbance regimes are external to the system, and are categorized as drivers of ecosystem structure and function. Soil resources and functional groups encompass system states and processes that influence overall system structure and function. Functional-groups pertain to species or species assemblages likely to have profound effects on ecosystem characteristics following their introduction or loss from a system (Chapin et al. 1997; Vitousek 1990).

A key aspect of the Jenny-Chapin model is the associated hypothesis that interactive controls must be conserved for an ecosystem to be sustained. Large changes in any of the four interactive controls are predicted to result in an ecosystem with different characteristics than the original system (Chapin et al. 1996). For example, major changes in soil resources can greatly affect productivity, recruitment, and competitive relations of plants, and result in substantive changes in the structure and function of plant communities and of higher trophic levels.

Using the Jenny-Chapin model as a central theme (Fig. 2-1B), a nested hierarchy of conceptual models (Fig. 2-2) was developed for each of the five major ecosystems in the NCPN. Objectives and details of models varied, from general representation of system structure to hypothesized responses to specific stressors. This nested hierarchy served to identify specific drivers and stressors, plausible stressor-induced degradation pathways and ecosystem responses, and measures and vital signs indicative of the domain of natural conditions and the transition to degraded conditions.

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

Ecosystem Characterization Model (Fig. 2-2A) is a generalized model that includes a list of state variables and forcing functions important to the ecosystem and the focal problem. It also illustrates processes connecting components (Jorgensen 1986). The model provides a framework for organizing information from discussion and literature review around the four interactive controls.

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

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

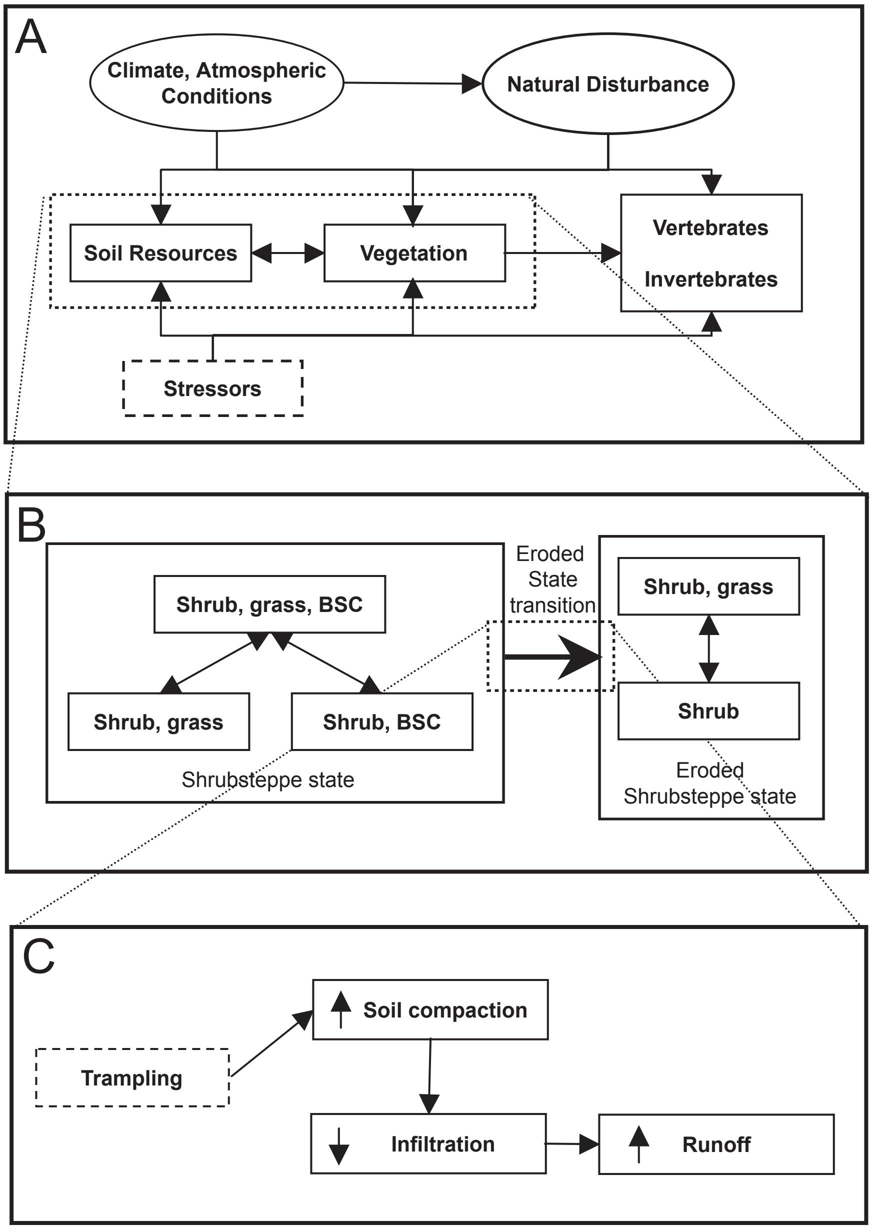

Figure 2-2. Illustration of the hierarchical conceptual model scheme used to identify NCPN vital signs for monitoring. A – ecosystem characterization model showing drivers (ovals), functional components (rectangles), and stressors (dashed rectangles), B – ecosystem dynamics model using a state and transition framework, C – mechanistic model illustrating the degradational process of a stressor (trampling).

2.3. Summary of Conceptual Models for Five NCPN Ecosystems

Conceptual models were developed for the five major ecosystems of the NCPN, and are detailed in appendices. Model development was a joint effort with the Southern Colorado Plateau Network, and conducted by various cooperators and USGS-BRD (Biological Resource Division) The SCPN funded the development of conceptual models for the dryland and montane ecosystems, and the NCPN and SCPN equally funded the development of conceptual models for the riparian-aquatic and spring ecosystems.

A summary conceptual model and narrative for each ecosystem are provided below to illustrate interactive controls (drivers, soil/water resources, functional groups), stressors, key degradational processes, and potential ecosystem measures to characterize natural and degraded system conditions identified from the hierarchical scheme of models. Chapter 3 describes how conceptual models and identified ecosystem measures were used in the selection of the NCPN vital signs.

2.3.1. Dryland Ecosystems (conceptual models are presented in Appendix H)

Dryland systems occur where mean annual precipitation is less than 450 mm, which includes about 90-95% of NCPN parkland area. These systems are characterized by mixtures of pygmy conifers *(Juniperus* and *Pinus spp.)*, shrub and desert grasslands, and biological soil crusts. Additionally, landforms of the dryland systems include deep and sparsely vegetated canyons, lava beds, and slickrock. Limited precipitation, and in many cases limited vegetative cover, imposes a high degree of vulnerability of dryland systems to changes in natural disturbance and climatic regimes, and to human impacts. The summary conceptual model for dryland ecosystems is shown in Fig. 2-3, and discussed below.

Drivers

Regional Climatic and Atmospheric Conditions. Precipitation regime is the most important climatic factor defining the characteristics of dryland ecosystems. Precipitation regulates key water-limited ecological processes, such as primary production, nutrient cycling, and plant reproduction (Noy-Meir 1973, Comstock and Ehleringer 1992, Whitford 2002). Interactions among the seasonality, size, and duration of precipitation events determine ecosystem response to precipitation. Seasonality influences the partitioning of precipitation among evaporation, transpiration, runoff, drainage, and soil-water storage, and determines vegetative dominance (Comstock and Ehleringer 1992).

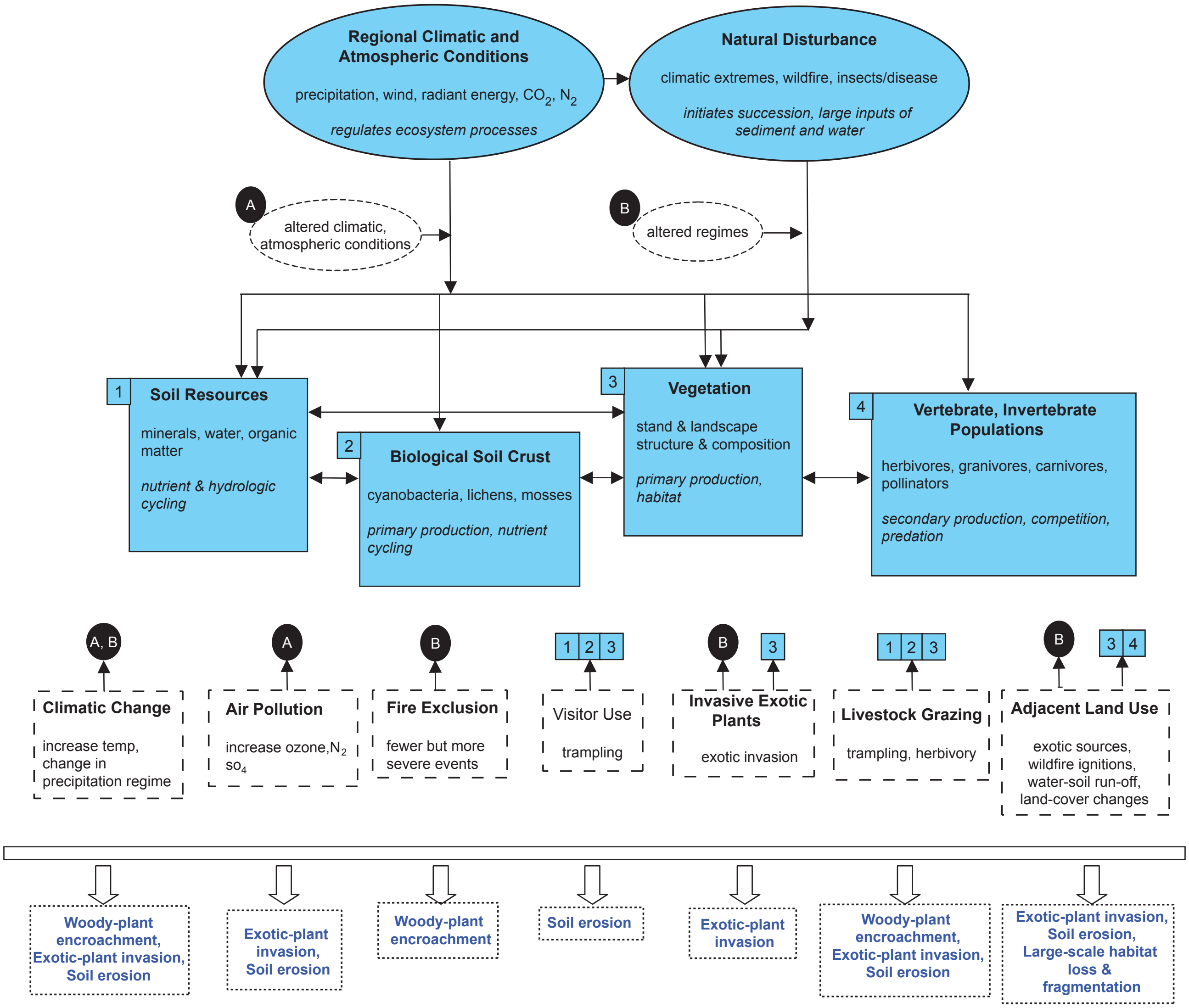

Figure 2-3. Summary conceptual model for dryland ecosystems. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2-1). Text for interactive controls indicates components or structure followed by function. Text for stressors shows proximate effects.

Most (e.g., 70%) precipitation events are small (<5 mm) and drive soil-surface processes such as nutrient mineralization and volatilization. Larger events initiate seed germination and soil-water recharge (Ehleringer et al. 2000). Precipitation intensity, in combination with soil characteristics and soil-surface features, determine infiltration and runoff levels (Whitford 2002, Breshears et al. 2003). **Orographic** effects, rain shadows, and seasonal storm features determine spatial pattern of precipitation which can be highly variable during the summer.

Strong winds are common in dryland systems. Winds modify energy and water balances of plants and soils by affecting evapotranspiration rates (Larcher 1995), redistributing soil resources (Whicker et al. 2002), and interacting with topography to influence wildfire behavior.

Natural Disturbance. Extreme climatic events typify dryland ecosystems (Walker 1993, Whitford 2002) and contribute to the natural spatio-temporal variability of dryland systems. Drought, extreme precipitation events, floods, and wind storms cause widespread mortality or the establishment of long-lived plants, and massive transport and redistribution of soil resources.

The role of wildfire varies among dryland ecosystems, with greater importance in sagebrush shrublands and shrub steppe, productive semidesert grasslands and juniper savannas (Jameson 1962, Johnsen 1962), and piñon-juniper woodlands. Low-intensity surface fires thin or eliminate fire-intolerant woody vegetation, and favor the dominance of fire tolerant graminoids (Jameson 1962, Wright 1980).

Insect and disease outbreaks are linked with climatic conditions that diminish the vigor and insect resistance of host plants, and affect life cycles and dispersal patterns of insect herbivores (Swetnam and Betancourt 1998, Logan et al. 2003). As with fire, insect outbreaks interact with climate to generate long-term changes in vegetation structure.

Soil Resources

The edaphic heterogeneity created by geologic and prehistoric climatic features and the tight coupling between vegetation community pattern and soil resources (Charley and West 1975; Schlesinger et al. 1990, 1996) strongly regulates vegetative patterns across parks. Soil properties and associated biota regulate hydrologic processes and the cycling of mineral nutrients, and sustain the existence and productivity of plant and animal populations. Dynamic attributes defining soil function (i.e., organic matter) vary naturally with temporally variable climatic and disturbance conditions.

Functional Groups

Biological Soil Crusts (BSC). BSC are critical components of dryland systems (Belnap and Lange 2001) and are composed of cyanobacteria, algae, microfungi, mosses, and lichens. BSC occur within the upper few millimeters of the soil surface (Belnap et al. 2001). BSC increase soil stability, reduce raindrop impact and erosivity, and enhance infiltration of precipitation. BSC are primary producers, and associated species of bacteria also fix atmospheric nitrogen.

Vegetation. In addition to conducting photosynthesis, above-ground structures of vascular plants protect soils from erosive raindrops, erosive wind and overland water flow, and enhance the retention of soil resources. Plants also modify the physical environment by shading and litter deposition. Roots stabilize soils, conduct and redistribute resources, and provide organic matter to soil food webs. Vegetation is a key component for vertebrates and invertebrate habitat. Fuel loadings and fuel connectivity, the erosion potential of precipitation, and habitat connectivity for coarse-scale organisms are influenced by the spatial pattern of vegetative conditions.

Vertebrates and invertebrates. Consumption of plant and animal material, trampling of soil and BSC by ungulates, and redistribution of energy and materials are among the key effects and functions of these species.

Stressors

Climatic Change. Increasing levels of atmospheric CO_2, increasing soil and air temperatures, and altered precipitation patterns are likely to affect physiological processes and competitive relations of vascular plants, nutrient cycles, hydrologic processes, and natural disturbance regimes. All of these can greatly alter the structure and functioning of dryland ecosystems (e.g., Alward et al. 1999, Ehleringer et al. 2000, Smith et al. 2000, Weltzin et al. 2003) and the sensitivity of these systems to other anthropogenic stressors.

Air Pollution. Air pollutants including particulates, tropospheric ozone, and nitrogen deposition are concerns at several NCPN parks (Evenden et al. 2002). Acid deposition may be an issue at some parks on the Colorado Plateau (Romme et al. 2003). Nitrogen deposition has potential implications for numerous ecological patterns and processes including ecosystem susceptibility to exotic species invasions (Asner et al. 1997, Galloway et al. 2003, Fenn et al. 2003b). Although current rates of nitrogen deposition generally are low across most of the western United States, modeling indicates potential hot spots of nitrogen deposition in the vicinity of ZION (Fenn et al. 2003a).

Fire Exclusion. Altered fire regimes attributable to past livestock grazing (fuel removal) and fire suppression efforts have caused significant changes in vegetation structure and functioning of associated ecosystem processes. Mediated by changes in vegetation structure, altered fire regimes can result in diminished hydrologic functioning (e.g., Wilcox et al. 1996, Davenport et al. 1998, Jacobs and Gatewood 1999), and increased susceptibility to drought and other disturbances, and to various stressors.

Visitors. NCPN park units experienced a rapid increase in annual visitors from mid-1980 to mid-1990 (Evenden et al. 2002). The result was greater off-trail trampling of soils and vegetation, direct interactions with and disturbances of wildlife, and increased levels of water and air pollutants. The trampling of soils is of special concern due to the wide-ranging consequences of soil compaction and the destruction of biological soil crusts (BSC). The loss of BSC decreases soil stability and increases wind and water erosion. Additionally, nitrogen fixation by BSC is critical to the productivity of dryland systems.

Invasive Exotic Plants. Exotic invasion can lead to the displacement of native species, and alterations of ecosystem-level properties such as disturbance regimes (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998) and soil-resource regimes (Vitousek 1990, Evans et al. 2001). Current and historic grazing on and around NCPN parks have converted significant portions of native grasslands to cheatgrass *(Bromus tectorum).* Tamarisk *(Tamarix ramosissima)* has replaced native cottonwoods along large portions of the Green and Colorado rivers, which run through several NCPN parks.

Livestock Grazing. Livestock grazing and trailing is permitted in portions of four NCPN parks. Historically, most parks were grazed. Grazing has modified vegetative communities by removing palatable native grasses and shrubs, and trampling soils and vegetation. The reduction of native plants in conjunction with soil disturbance has led to the wide-spread colonization of exotic plants on park lands.

Adjacent Land Use. Livestock grazing, forest management, urban/exurban development, and industrial and agricultural pollutants have the potential to degrade park lands. They increase the transfer of soil and water to park areas by depositing airborne and waterborne pollutants, introducing exotic biota, and can be a source of disturbances such as wildfire. Large-scale habitat loss and reduction of landscape connectivity threaten to increase the insular nature of most NCPN parks.

Degradation Processes

Four key degradation processes are predicted in response to individual and interacting stressors (Fig. 2-3, Table 2-1). These processes can lead to conditions beyond the perceived domain of naturally variable dryland systems, and have important implications for ecosystem sustainability.

1. Woody-plant encroachment can result from fire suppression and the reduction of perennial grasses from grazing, leading to changes in habitat and species composition, and fundamental ecosystem processes.
2. Exotic-plant invasion has occurred on NCPN lands, and continues to be an important threat and concern. Exotic plants exclude native flora,

change soil-vegetation interactions, and increase disturbance frequency (more frequent wildfire).

3. Soil erosion and redistribution can result from numerous stressors. A salient feature is the disruption of natural soil function and distribution due to diminished resource availability, site productivity, and capacity to support characteristic functional groups.

4. Conversion of natural adjacent lands to anthropogenic landscapes can result in large-scale habitat loss and fragmentation. Wildlife that range outside parks can experience critical loss of seasonal habitats. The ingress of species to park lands can be significantly inhibited.

Table 2-1. Key degradation processes in dryland ecosystems, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation Process	Stressors	Ecological Effects	Potential Measures
Woody plant encroachment	Fire suppression and lower fire frequency due to the reduction of perennial grasses from grazing	Altered soil-hydrologic and nutrient cycling and habitat structure; loss of herb species; increased fire severity due to fine-woody branch and leaf litter, increased soil exposure and erosion with high-intensity wildfire	Vegetative composition and structure, grazing intensity, fire-regime attributes
Exotic plant invasion	Livestock grazing, adjacent land-use activities, climatic and atmospheric changes	Altered nutrient dynamics, soil-water dynamics, major shift in functional-group structure, increased fire frequency and extent due to exotic-plant flammability, and spatial continuity	Vegetative composition and structure, grazing intensity, adjacent land-use activities, climatic-atmospheric elements
Soil erosion and redistribution	Trampling by visitors and livestock grazing, air pollution, climatic change, adjacent land-use activities	Erosion and loss of soil function due to reduction of biological soil crusts, soil compaction, soil-surface roughness, soil-aggregate stability, water infiltration; decreased N fixation; changes in vegetative composition and structure	Soil depth and structure, biological soil crust cover and distribution, vegetative composition, structure, and pattern, climatic and atmospheric elements, adjacent land use activities
Large-scale habitat loss and fragmentation	Adjacent land-use activities	Regional-scale habitat loss, reduced connectivity of metapopulations, reduced ingress and egress potential	Land cover, land use, land condition patterns on park and adjacent lands

2.3.2. Montane and Subalpine Ecosystems (conceptual models are presented in Appendix I)

Montane and subalpine ecosystems occur in 13 NCPN parks and occupy significant areas in nine (Table 1-3, Appendix A). Included in this suite of ecosystems are Ponderosa pine forests (1,900-3,100 m elevation), mixed conifer, and subalpine spruce-fir forests and meadows (2,750-3,600 m elevation). Conceptual models for each ecosystem are presented in Appendix I. Common interactive controls, stressors, and key degradation processes are summarized in Fig. 2-4, and discussed below.

Drivers
Regional Climatic and Atmospheric Conditions. The occurrence of forested systems on the Colorado Plateau is directly related to mountainous terrain and elevation-mediated precipitation gradients. A winter snowpack is common in mixed conifer and subalpine systems, and contributes to summer water for plants. A critical weather component in these systems is the high frequency of lightning which provides an abundant source of forest fire ignitions.

Natural Disturbance. Fire is a major disturbance, with regimes and effects varying with elevation. High frequency, low intensity surface fires at lower elevations consume surface fuels and small stems. They rarely result in overstory mortality. Park-like, old-growth Ponderosa forests are maintained by frequent surface fires. Low frequency, high intensity, stand-replacing fires occur at higher elevations, creating over time a patch mosaic of post-fire successional forests. In montane meadows, the natural fire regime inhibits the establishment of trees.

Wind events at scales from microbursts to large storms occasionally result in gap formation. Large windthrow patches notably occur in subalpine forests. Winter winds in combination with ice and snow result in the breakage of branches and large windthrow patches. Downed coarse woody debris resulting from windthrow provides important habitat for ground-dwelling animals and **saprophytic** species, and is important to nutrient cycling.

The major pests and pathogens impacting montane and subalpine systems are native species. Bark beetles—usually present in low numbers and persisting in less productive living trees and in fresh windthrows—occasionally kill trees. Large-scale tree mortality occurs when climate- and pathogen-induced stress weakens tree defenses against beetles.

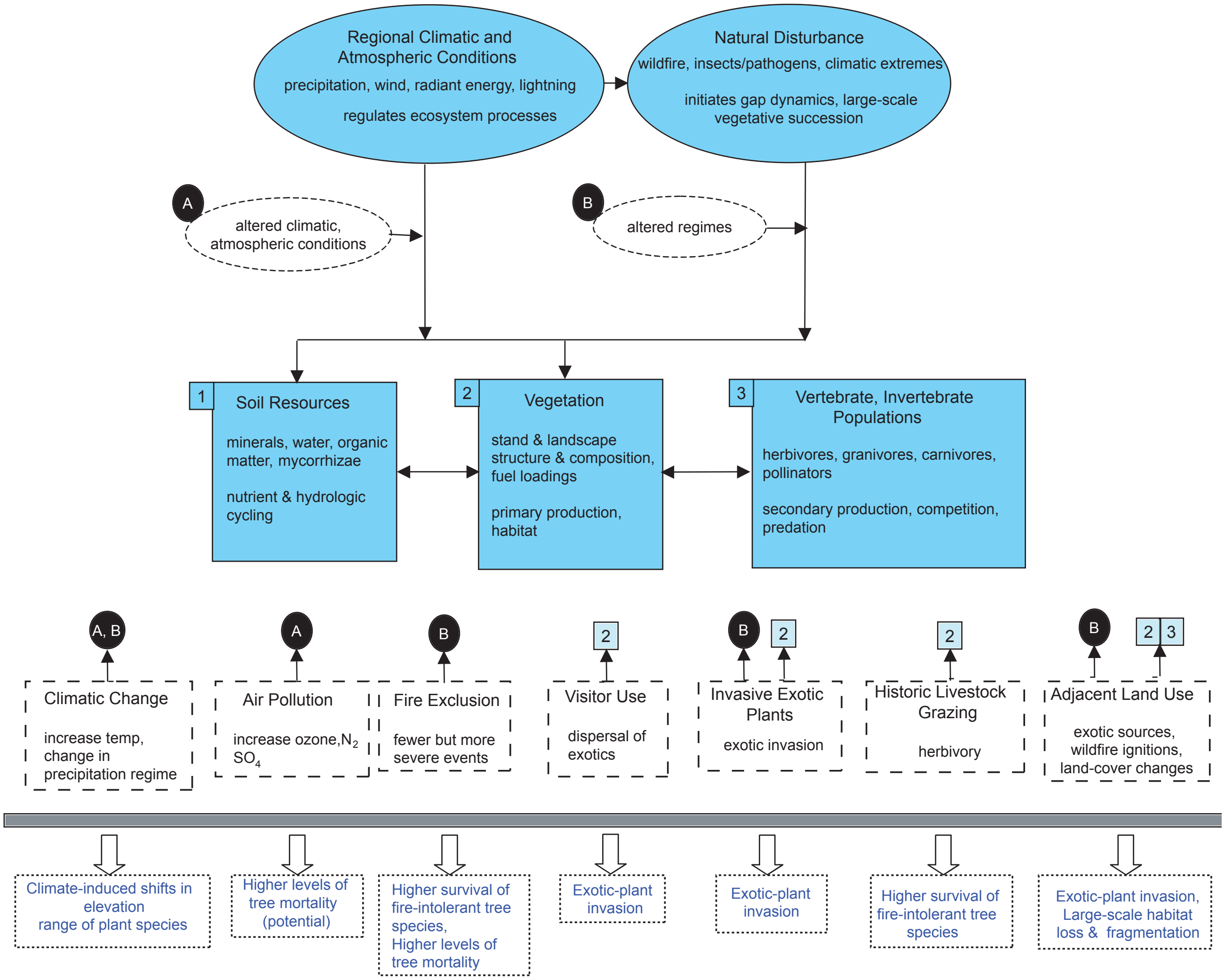

Figure 2-4. Summary conceptual model for montane and subalpine ecosystems. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls (soil resources, functional groups). Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2-2). Text for interactive controls indicates components or structure followed by function. Text for stressors shows proximate effects.

Soil Resources

Soils range from shallow to deep, but are generally permeable and capable of storing snowmelt. This provides available water all or most of the growing season. **Mycorrhizae** are essential components in forested systems, facilitating tree-root uptake of critical nutrients.

Functional Groups

Vegetation. Forests are a significant source of primary production and a unique habitat for numerous plants and animals. At the landscape scale, the spatio-temporal variability of natural disturbances and successional development creates a mosaic of stand conditions and ages, promoting broad-scale diversity of flora and fauna

Vertebrates and Invertebrates. The roles of these species are similar to that of dryland systems.

Stressors

Climatic Change. Predicted increases in temperature can increase physiological stress in trees, leading to greater susceptibility to infestation by insects and pathogens. Increased temperatures can also alter the elevation domain of species, leading to the migration of forest communities farther upslope.

Air Pollution. The air pollutants of greatest concern are ozone, sulfate, and nitrogen-based compounds such as nitrate and ammonium/ammonia. Ozone injures foliage and reduces growth, and may combine with other air pollutants to cause even more damage. Nitrogen may enhance vegetative growth in nitrogen-limited systems, but it can offset that growth with an increased flux of nitrogenous trace gases from soil, decreased diversity of mycorrhizae and lichens, altered carbon cycling and fuel accumulation in forests, and physiological perturbation of overstory trees. Air pollutants potentially can affect patterns of tree mortality and regeneration, and thereby species composition and vegetation dynamics.

Fire Exclusion. Fewer fires can lead to dramatic changes in forest structure and composition, and fuel structure. In general, fire exclusion increases tree densities, and decreases herb and shrub cover. It also leads to increased buildup of fuels, providing conditions for high-intensity fires in systems naturally maintained by low-intensity surface fires.

Visitor Use. Visitor use impacts montane forests through the spread of exotic species and wildfire ignitions, and can contribute to regional levels of air pollution.

Invasive Exotic Plants. Exotic plants compete with and displace native species, resulting in lower biodiversity and altering soil-nutrient cycling. Exotic invasion is most important in Ponderosa pine forests, where exotic plants can comprise 21% of the plant ground cover.

Historic Livestock Grazing. Grazing in high-elevation forests and meadows has greatly reduced the amount of herbaceous cover. This has reduced the amount of fine fuels that once carried surface fires, and has led to increased woody-plant encroachment in meadows and higher understory stem densities in forests.

Adjacent Land Use. Adjacent lands can serve as sources of disturbance, notably fire. Forest harvest and other land use practices can lead to large-scale habitat loss, decrease regional habitat connectivity, and overall, insularization of park lands.

Degradation Processes

Five key degradation processes are predicted for montane and subalpine systems (Fig. 2-4, Table 2-2).

1. Fire exclusion and reduced fire frequency due to historical livestock grazing has differential effects on forest communities. In general, lower fire frequency results in denser stands, altered post-disturbance pathways, and development of old-growth stands with a large component of fire-intolerant species. Grassland meadows are threatened with woody shrub and tree invasion and conversion.
2. In response to higher stand densities, tree mortality can increase and lead to higher dead wood loadings and, in turn, higher fire severity. This can reinforce development of more homogenous landscape patterns and lower landscape-level diversity.
3. Exotic plant invasion can alter species composition and lead to altered disturbance regimes (i.e., wildfire). Visitors and adjacent land-use activities can serve as sources of exotic plant species.
4. Climate-induced changes in elevation domain of plant species can lead to the migration of forest communities up mountain slopes, as well as to novel species-dominance patterns or even communities.
5. Conversion of natural adjacent lands to anthropogenic landscapes can result in large-scale habitat loss and fragmentation. Resident wildlife species that range outside of park lands can experience critical loss of seasonal habitats. Ingress of species to park lands can be significantly inhibited. These and other effects can lead to the insularization of park lands.

Table 2-2. Key degradation processes in montane and subalpine ecosystems, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation Process	Stressors	Ecological Effects	Potential Measures
Higher survival of fire-intolerant tree species (leading to denser stands with large proportion of fire-intolerant species)	Fire exclusion, historical livestock grazing (reduction of fine fuels resulting in lower fire frequencies)	Changes in forest-stand structure and composition result in substantive change in functional groups, with various implications to nutrient cycling and other soil-vegetation processes Ponderosa pine forests: denser tree understory comprised of pine and white fir, reduction of herbaceous cover, stand-replacing crown fires instead of surface fires, post-fire successional stands with a large component of gamble oak and quaking aspen, denser old-growth stands of Ponderosa pine with a large component of fire-intolerant white fir Mixed conifer, subalpine spruce forests: higher stand density, more evenly distributed age classes at landscape level, higher severity fires leading to altered successional stages containing higher hardwood component, old-growth stands denser with a large component of fire-intolerant true-fir species Montane-subalpine grasslands: woody shrub and tree encroachment, eventual displacement of herbaceous species	Fire regime attributes, historical and current livestock grazing intensity, vegetative composition and structure, land cover and land condition patterns
Tree mortality (higher rates in mid, late seral stages due to higher stocking densities)	Insect and disease outbreaks (due to dense stands and homogenous vegetation pattern reinforced by fire exclusion), air pollutants (potentially)	Higher insect/disease mortality due to density-induced physiological stress, higher spatio-temporal frequency of snags and downed, coarse-woody debris; larger contiguous fire patterns due to high fuel loads and fuel connectivity, decreased landscape-scale diversity of forest types (successional stages)	Same as above plus insect/disease mortality, atmospheric conditions
Exotic plant invasion	Exotic invasion, visitor use, adjacent land use	Altered nutrient dynamics, soil-water dynamics, shift in functional-group structure, increased fire frequency and extent due to exotic-plant flammability, and spatial continuity	Vegetative composition and structure, visitor use, adjacent land use
Climate-induced shifts in elevation range of species, leading to changes in elevation range of communities	Climatic change	Displacement of species and communities higher along elevation-moisture gradient, altered landscape structure and attendant processes	Land cover, land condition, climatic elements
Large-scale habitat loss & fragmentation	Adjacent land-use activities	Regional-scale habitat loss, reduced connectivity of metapopulations, reduced ingress and egress potential	Land cover, land use, land condition patterns on park and adjacent lands

2.3.3. Riparian, Aquatic Systems (conceptual models are presented in Appendix J)

Aquatic and riparian systems provide water and unique habitat for numerous plant and animal species in the predominantly dry landscape of the NCPN. Aquatic systems include surface water and channel characteristics of streams. Riparian zones occupy landscape positions transitional between upland and aquatic systems and are physically dynamic and more biologically diverse than surrounding uplands. Seventeen perennial streams occur in the NCPN, and include the larger Colorado, Green, Yampa, and Gunnison rivers. Conceptual models of aquatic and riparian systems encompass perennial, ephemeral, and intermittent streams (Appendix J). A summary conceptual model was developed for the two systems combined given their high degree of overlap (Fig. 2-5) and is discussed below.

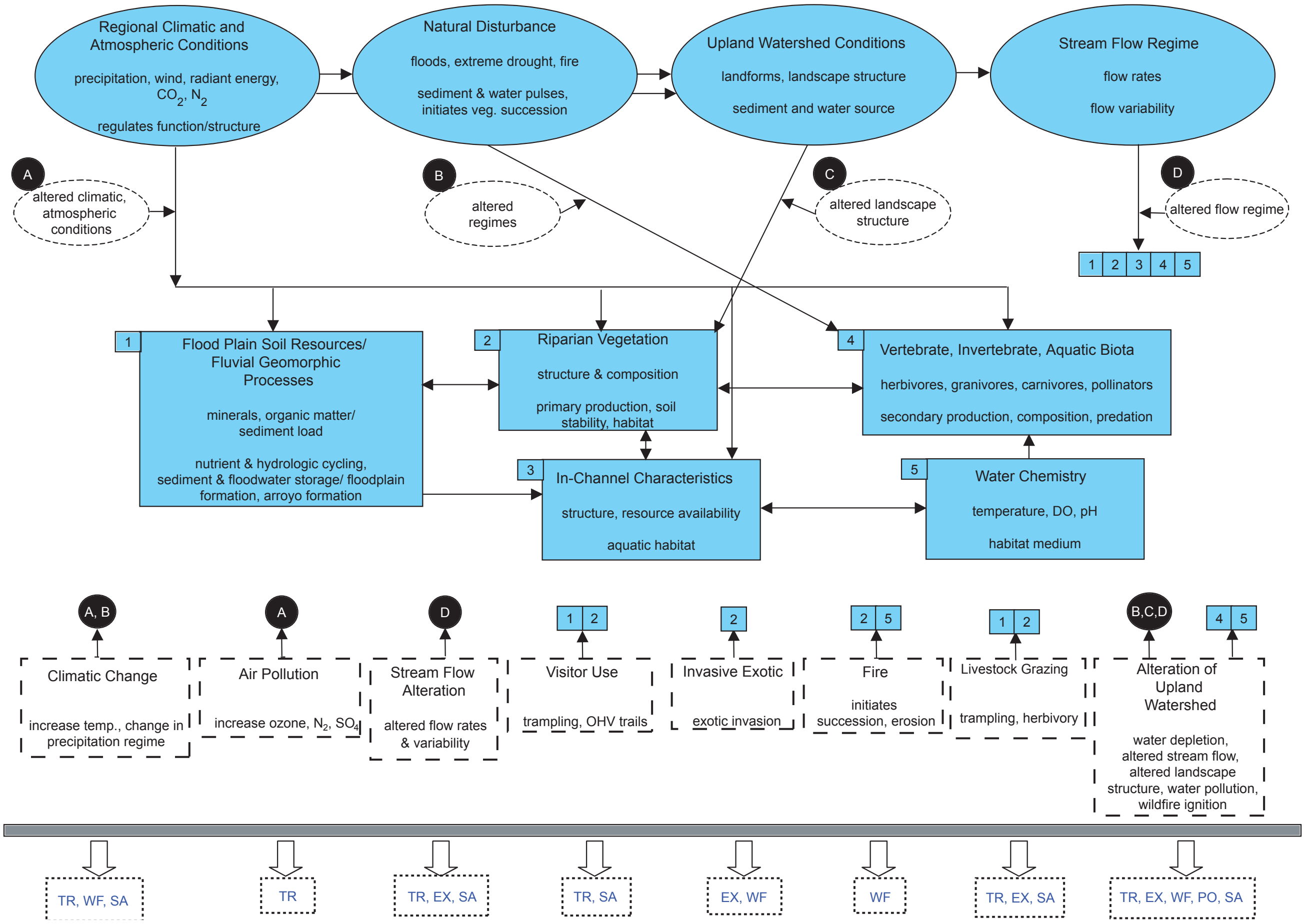

Figure 2-5. Summary conceptual model for riparian and aquatic ecosystems. Solid ovals are drivers and interactive controls, solid rectangles are system components that are interactive controls, dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2-3). Text for interactive controls indicates components or structure followed by function. Text for stressors shows proximate effects. Codes for degradation processes are: EX – exotic-plant invasion, PO – pollution-mediated die-offs, SA – siltation and changes in algae abundance, TR – invasion of riparian zones by upland communities (terrestrilization of riparian habitat), WF – high-severity wildfire in riparian zones.

Drivers

Regional Climatic and Atmospheric Conditions. Precipitation drives fluvial geomorphic processes and water-limited ecological processes, and thus is a key factor shaping aquatic and riparian ecosystems. The general importance of precipitation seasonality, size, and duration are discussed under the dryland conceptual model (2.3.1). Precipitation intensity is especially relevant in terms of runoff and the potential for debris flows and flash floods. Additionally, decadal-scale variations in precipitation patterns are especially important in shaping riparian areas (Mantua and Hare 2002, Hereford et al. 2002). During wet cycles, increased water flow results in erosion of the riparian zone. In subsequent dry periods, channel narrowing, flood plain aggredation, and riparian vegetation establishment on the former channel occurs. The marked shift from wet conditions in 1999 continues to the present and suggests a continued transition to the dry phase for the next two to three decades (Hereford et al. 2002).

Natural Disturbance. Heavy flooding results in widespread geomorphic change and plant mortality as well as the establishment of relatively long-lived, riparian species (Schumm and Lichty 1963). For instance, seeds of *Populus* spp. and *Salix* spp. germinate and grow on moist, freshly deposited alluvial sediments following floods (Auble and Scott 1998, Cooper et al. 2003). Large magnitude floods redistribute sediment in channels and the floodplain and create topographic diversity through large-scale erosion and deposition of sediments. More frequent, low-magnitude floods create hydrologic gradients that control patterns of vegetation establishment and successional processes (Brinson 1990).

Regional drought reduces surface flows and depletes alluvial groundwater aquifers. Mild water stress reduces plant productivity. Under more severe conditions, trees die from water stress or insects, pathogens, and diseases.

Upland Watershed Conditions. The form of channels and floodplains and many attributes of riparian ecosystems are determined by the flux of water and sediment from upland watersheds. Soils, vegetative pattern and composition, initial relief, geology, watershed age, and climate ultimately determine water and sediment inputs to rivers.

Stream Flow Regime. The stream-flow regime determines the mechanical forces that erode, transport, and deposit sediment which influences channel dimensions of aquatic systems. Streamflow variation influences the occurrence of suitable habitat patches and species abundance (Bain et al. 1988, Auble and Scott 1998, Johnson 1992, Poff and Allen 1995). Riparian ecosystems are structured by geomorphic processes and hydrologic conditions found in channels and on associated flood plains.

Reductions in the riparian-zone area result from diminished flow variability. Shallow alluvial groundwater is an important feature of riparian flood plain soils and is tightly linked to surface water dynamics.

Flood Plain Soil Resources, Fluvial Geomorphic Processes, Water Chemistry

Flood Plain Soil Resources. Soil biota contribute to the structure and functioning of riparian ecosystems by mediating nutrient cycling, water infiltration and storage, soil aggregate stability, and water and nutrient uptake by plants (Skujins 1984; Whitford 1996, 2002; Lavelle 1997; Wardle 2002). Functioning of these below-ground processes depends on the amounts and types of organic-matter inputs from vegetation and on soil conditions such as moisture availability, soil structure, soil aeration, and soil temperature (Whitford 1996, 2002; Mitsch and Gosselink 1993). The periodic wetting and drying of riparian soils is critical to the release of nutrients from leaf litter in riparian environments (Mitsch and Gosselink 1993). Soil-water holding characteristics in addition to amount of alluvial groundwater influence occurrence and survival of riparian plants.

Fluvial Geomorphic Processes. Stream channels adjust to variations in the amount and size of the sediments supplied by the watershed. Suspended load influences channel form. Changes in channel patterns parallel changes in stream power, channel gradient, and sediment loads, and occur naturally in response to floods and droughts, and changes in the upland watershed. The vertical accretion of sediments forms flood plains which are critical substrate for riparian vegetation.

Arroyos are steep-walled gullies incised into fine-textured valley fill materials and can form rapidly in response to floods. Arroyos tend to be a self-sustaining, long-term process that can propagate through a drainage network, and can affect riparian vegetation through their influence on alluvial ground water (Scott et al. 2000).

Water Chemistry. Dissolved oxygen, pH, and temperature are critical factors regulating aquatic biota. Aquatic biota are adapted to temporal variations in these factors, but are susceptible to extremes. Conditions outside the normal range of variation can result in the loss of the most sensitive species, substantive shifts in species composition, or at the extreme, the loss of all biota and associated functions. Changes in flow regime, human activities, nutrient loading by livestock, and other stressors can drastically alter water chemistry.

Functional Groups

Vegetation. Vegetation is the dominant functional type in riparian ecosystems, with woody trees and shrubs as the defining elements. In addition to conducting photosynthesis, the above-ground structure of vascular plants protects floodplain soils from erosion and enhances the deposition and retention of nutrient-rich sediments during floods. Litter from plants reduces the erosive impacts of rainfall and adds organic matter for nutrient cycling. Shading and litter deposition by riparian plants affect spatial and temporal patterns of soil-resource availability to other organisms. Roots stabilize soils and stream banks, serve as conduits for resource acquisition and redistribution, and provide organic-matter inputs to soil food webs. Providing habitat for a diverse array of secondary consumer and decomposer communities is an important function of riparian vegetation.

In-channel Characteristics. Variations in channel form such as pools, riffles, wide meander loops, and sand bars create variation in water width and depth, which creates microhabitats for aquatic biota. Water velocity determines the distribution of microhabitats.

Aquatic Biota. **Benthic** macroinvertebrates are a vital link in aquatic and riparian systems. They consume algae and provide food for aquatic and terrestrial vertebrates. Macroinvertebrates respond to physical parameters such as temperature, substrate, and current velocity, and are also influenced by their chemical environment, including pH, oxygen availability, and contaminates. Diversity and abundance of aquatic macroinvertebrates generally increases with substrate stability and the presence of organic detritus (Allan 1995).

Stressors

Climatic Change. Increasing levels of atmospheric CO_2, rising soil and air temperatures, and altered precipitation patterns, including a potential increase in the frequency of extreme events, are likely to affect competitive relations of vascular plants, nutrient cycles, hydrologic and geomorphic processes, and disturbance regimes. Effects on water availability and flow variability have the potential to greatly alter the structure and functioning of riparian ecosystems (e.g., Alward et al. 1999, Ehleringer et al. 2000, Smith et al. 2000, Weltzin et al. 2003) and the sensitivity of these systems to other anthropogenic stressors.

Air Pollutants. Air pollutants including particulates, tropospheric ozone, and nitrogen deposition are concerns at several NCPN parks (Evenden et al. 2002). Nitrogen deposition in particular has potential implications for numerous ecological patterns and processes including ecosystem susceptibility to exotic species invasions (Asner et al. 1997, Galloway et al. 2003, Fenn et al. 2003b).

Streamflow Alteration. Surface and groundwater extractions on lands upstream from NCPN parks largely contribute to stream flow depletion and reduced stream-flow variability. Water extractions can lead to dewatering of the channel and floodplain, resulting in the mortality of riparian vegetation and encroachment of upland vegetation. Decreased bank stability associated with the loss of riparian vegetation increases channel incision and the loss of flood plain soil resources and site conditions. Reduced stream transport leads to channel narrowing, affecting in-stream habitat of aquatic species.

Dams have significantly altered the Green and Colorado River in the NCPN by disrupting water and sediment flows and fragmenting riparian corridors. This disruption has altered habitats and competitive interactions, degrading biotic integrity. Damming modifies stream temperatures and sediment loads, affecting all aquatic biota. In general, flow regulation and depletion leads to widespread loss or ecological simplification of riparian ecosystems (Friedman et al. *in press*).

Stream channel alteration occurs upstream from NCPN park lands to improve drainage or flood-carrying capacity. This results in decreased flow variation, increased **turbidity** and **sedimentation,** and elevated water temperatures in stream segments on park lands. Sedimentation decreases primary productivity. Increased temperatures compromise habitat conditions for species adapted to colder waters.

Visitor Use. Most parks have experienced rapid growth in the number of annual recreational visits between the mid-1980s and the mid-1990s (Evenden et al. 2002). Trails in and adjacent to riparian zones, and hiking in slot canyons can lead to increased erosion and stream channel instability, dispersal of invasive exotic species, increased levels of water and air pollutants, and changes in water chemistry. Recreational Jeep trails often traverse streams. Driving through streams and riparian areas breaches stream banks and levees, increases hydraulic roughness, and removes vegetation. Also, rutted Jeep trails can alter stream flow paths.

Invasive Exotic Plants. Riparian corridors are prone to invasion by exotic plant species (Malanson 1993), and typically host relatively high percentages (25-30%) of non-native species. Ecological effects of exotic species' invasions vary by species, but include major changes in community composition, competitive displacement of native species, and alterations of ecosystem-level properties such as disturbance regimes (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998) and soil-resource regimes (Vitousek 1990). Tamarisk (*Tamarix ramosissima*) and Russian-olive (*Elaeagnus angustifolia*) are invading riparian areas along the Colorado and Green Rivers. Tamarisk may promote fire disturbance by producing large numbers of dead stems. Higher fire frequency can lead to erosion and temperature increases, and altered flow rates. Ash can increase nutrients, ions, turbidity, pH and decrease oxygen levels of aquatic systems.

Fire. Removal or reduction of the forest canopy and surface vegetation by wildfire contribute to accelerated erosion and increase in peak flows, which physically removes riparian vegetation and decreases overall diversity of macro-invertebrates. The frequency of high-severity wildfire in riparian areas is enhanced by the invasion of Tamarisk, which produces more dead fuel than native species.

Livestock Grazing. Livestock grazing in riparian areas is common in NCPN park units with active grazing allotments. Long-term grazing by livestock removes plant biomass, alters plant population age structures, and simplifies plant composition and structure (Schultz and Leininger 1990). These changes reduce abundance and diversity of riparian-dependent species including birds (Dobkin et al. 1998, Scott et al. 2003). Also, trailing, trampling, and wide-spread reductions in vegetation cover by cattle can increase upland runoff, reduce channel stability, and initiate arroyo cutting (Brinson et al. 1981, Cooke and Reeves 1976).

Alteration of Upland Watershed. Activities of concern include livestock grazing, forest management, urban/exurban development, emissions of industrial and agricultural pollutants, and stream flow diversion or regulation. Associated resource issues include increased transfer of soil and water resources, deposition of airborne and waterborne pollutants, introduction of exotic plant and animal species, reduced groundwater recharge, lowered ground water levels, and reduced stream flows. Organic pollutants, such as livestock excretion and pesticide use in urban and agricultural areas can kill in-stream biota and affect potability. Metal contaminants from upstream mines have similar impacts.

Degradation Processes

Five key degradation processes are predicted for aquatic and riparian systems (Fig. 2-5, Table 2-3).

1. Terrestrialization of riparian zones is the encroachment by upland vegetation. The modification of channel and bank forms and reduced flow variability and flow volume allows upland vegetation to establish and out-compete native riparian vegetation. Replacement of riparian with upland vegetation eliminates riparian-zone functions.
2. Exotic invasion of riparian areas is promoted by altered flow variability and has wide consequences for soil-nutrient cycling, habitat, biotic diversity. Tamarisk invasion of riparian zones is prominent in the NCPN region.

3. Increased frequency of high-severity wildfire in riparian areas contributes to accelerated erosion and increased peak flows which physically remove riparian vegetation and decrease overall diversity of macro-invertebrates.
4. Pollution from human activities degrades in-stream structure and function. Also, ash from wildfires can temporarily increase nutrients, ions, turbidity, pH, and alkalinity while decreasing dissolved oxygen levels (Earl and Blinn 2003), especially affecting macro-invertebrate community structure.
5. Altered community structure of macroinvertebrates is precipitated by multiple degradation processes. In general, stressors that increase siltation, and severe drought alter habitat conditions and food resources such as algae, decreasing macro-invertebrate diversity by favoring generalist over specialist species. Notably, invertebrate shredders tend to dominate over grazers as a result of these degradation processes.

Table 2-3. Key degradation processes in riparian and aquatic ecosystems, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation Process	Stressors	Ecological Effects	Potential Measures
Terrestrilization - invasion of riparian zones by upland vegetation	Adjacent land use (streamflow depletion), heavy grazing, visitor use (trampling, road and trail development in riparian areas), global climatic change	Ephemeral stream with stream-side vegetation dominated by upland or xeroriparian species, such as net-leaf hackberry (*Celtis reticulata*), single-leaf ash (*Fraxinus anomala*), Utah serviceberry (*Amelanchier utahensis*), and species of rabbit brush (*Chrysothamnus spp.*); altered structure and function of riparian	Surface and ground water flow rates, grazing intensity, adjacent land-use activities, land cover and land use patterns of the greater park ecosystem, visitor activities, riparian vegetative structure and composition, climatic elements
Exotic plant invasion	Exotic plant invasion, streamflow alteration, livestock grazing, adjacent land use (alteration of upland watershed)	Altered biotic structure, composition, and function, altered ecosystem processes; facilitates channel and flood plain formation	Same as above
High-severity wildfire in riparian zones	Wildfire due to adjacent land use activities and and park-based ignition sources, exotic invasion, climatic change	Increased runoff, sediment transport, erosion of stream bed and banks, reduced density and diversity of macro-invertebrate shredders and scrapers; decreased water quality	Upland fire regime attributes, riparian vegetative structure and composition, climatic elements, aquatic macro-invertebrate structure and composition
Pollution-mediated die-offs	Adjacent land use (alteration of upland watershed)	Altered biotic structure, composition, and function	Land use patterns, water chemistry
Siltation, changes in microflora (changes in habitat and food resources for aquatic macro-invertebrates)	Climatic change, streamflow alteration, visitor use and grazing (trampling)	Altered biotic structure, composition, and function	Composition and structure of macro-invertebrates

2.3.4. Springs (conceptual models are presented in Appendix K)

Springs are important point sources of biodiversity and productivity in otherwise low productive desert landscapes (Stevens and Nabhan 2002 a, b). Aridland springs often function as **keystone ecosystems,** providing the only available water and habitat in the landscape for many plant and animal species. Also, endemism is common due to adaptation to harsh conditions or highly dissolved mineral content of water. Springs occur in 14 of the 16 NCPN parks, and are viewed as a significant resource by park managers. A spring ecosystem includes the aquifer providing groundwater, the spring orifice and associated biota, and the biota supported by the post-orifice surface flow. These features were integrated into the summary conceptual model (Fig. 2-6) and are reviewed collectively below.

Drivers

Regional Climatic and Atmospheric Conditions. Precipitation is critical to the existence of springs. Constrained by geology and geomorphic processes, precipitation sources infiltrate variably permeable or fractured rock strata, and follow groundwater flow paths to surface openings. Size, frequency, and duration of precipitation events are key factors influencing spring water availability.

Natural Disturbance. Flooding, sheetwash, rockfall, seismic disturbance, and other erosional factors moderate groundwater or aquifer dynamics, leading to changes in groundwater flow rates, and shape and size of the opening where the spring emerges above ground. Flooding and rockfall may kill existing plants and rearrange microsite topography, providing colonization opportunities. Heavy precipitation may lead to habitat patches for colonization by long-lived plant species. Subsurface flow paths may become blocked or new paths generated by seismic activities. Drought results in seasonal or erratic desiccation of the springs ecosystem and reduces aquatic and wetland biotic diversity. Fire in surrounding areas can modify water-flow rates and sediment load, resulting in the removal of above-ground vegetative growth, altered soil structure and nutrient spiraling, and altered population dynamics.

Hydrologic Regime

Water flow rates influence the ability of a spring system to maintain biotic components, and the proper functioning of nutrient and hydrologic cycles. Variable flow rates maintain diverse microhabitat conditions critical to spring biota.

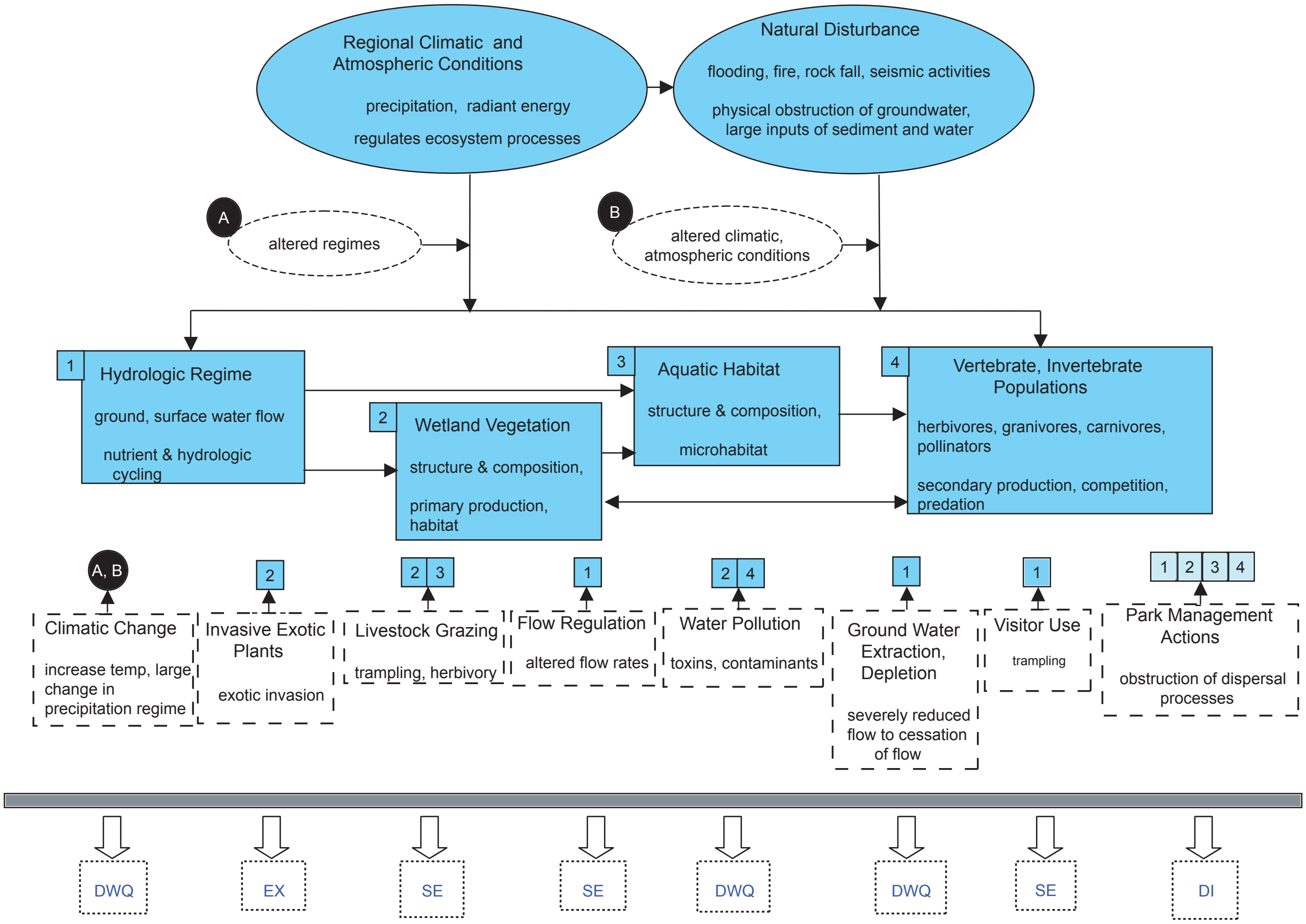

Figure 2-6. Summary conceptual model for spring ecosystems. Solid ovals are drivers and interactive controls. Solid rectangles are system components that are interactive controls. Dashed rectangles are stressors, and dotted rectangles with blue text are key degradation processes associated with each stressor (described in Table 2-4). Text for interactive controls indicates components or structure followed by function. *Text for stressors shows proximate effects. Codes for degradation processes are: DI – declining ingress, DWQ – severe dewatering (loss of most or all water flow) or severely degraded water quality, EX – exotic invasion, SE – soil erosion.*

Functional Groups

Vegetation, Vertebrates and Invertebrates, Aquatic Habitat. Vegetation is critical as animal habitat and for water purification and nutrient cycling. It contributes to the net primary production of aridland systems. Vertebrates and invertebrates occupy various niches in the aquatic and water-mediated terrestrial component of spring systems. Species are key components of **trophic** structures, consuming plant and animal material and providing food for higher-trophic organisms. The microhabitat structure of spring ecosystems determines invertebrate species assemblages. Altering water flow, and terrestrial and aquatic disturbances eliminate or create new microhabitat, and in turn, influence the dynamics of spring biota.

Stressors

Climatic Change. Changes in precipitation regime can dramatically alter spring systems. Increased flooding or drought can alter aquifers and thus flow levels and variability, and microhabitat structures, leading to substantive changes in biota.

Exotic Invasion. Invasion by non-native species can greatly compromise ecological functioning at springs. Exotics may displace native species, leading to changes in plant and animal composition, and altering nutrient cycling and trophic dynamics.

Livestock Grazing. Livestock can alter spring ecosystems by removing vegetation cover, altering plant and invertebrate assemblages, increasing erosion, and contaminating surface water (Grand Canyon Wildlands Council 2002).

Ground-water Depletion.[1] Altering spring flows may arise from several anthropogenic impacts on aquifers. Extracting groundwater from the aquifer may partially or wholly empty individual springs or entire complexes of springs resulting in habitat fragmentation, increased isolation of springs ecosystems, and interrupted biogeographic processes at microsite-regional spatial scales. Urbanization leads to an increase in impervious surface area over an aquifer, decreasing the potential for recharge. Also, changes in land use and livestock-grazing intensity can change the role of plant-water use in a watershed and subsequently recharge to the aquifer.

Flow Regulation.[1] The construction of cattle tanks on up-stream sources can affect flow variability at park springs. Flow regulation may stabilize normally highly disturbed streamside spring ecosystems, altering structural, functional, and trophic attributes.

Pollution.[1] Groundwater and surface water pollution strongly affect springs ecosystems. Upstream agricultural groundwater pollution may shift ecosystem nutrient dynamics to entirely novel trajectories, creating conditions to which few native species may be able to adapt.

Park Management Actions. Managers often try to protect springs by closing sites, prohibiting visitors or creating discrete trails to the springs. Such actions may actually damage spring ecosystems. Fencing out livestock may allow excess vegetation to develop, eliminating surface water and threatening aquatic species persistence (Grand Canyon Wildlands Council 2002). Surfaced trails may eliminate leaf litter and prohibit movement of spring-associated land snails and other invertebrate species.

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[1] Stressors associated with adjacent land water use.

Visitor Use. Recreational use at springs leads to trampling around the outflow, degrading native plant communities, and potentially introducing invasive exotic plants.

Degradation Processes

Four key degradation processes are predicted in response to individual and interacting stressors (Fig. 2-6, Table 2-4).

1. Drastic reduction in water flow (dewatering) due to changes in groundwater flow and availability, and compromised water quality can severely reduce microhabitat, biota, and overall ecological function of springs. At the extreme, total loss of water flow eliminates spring ecosystems.
2. Soil erosion due to trampling and livestock grazing can alter the biophysical structure and function of springs, but water flow and some functions may be retained, and restoration is possible.
3. Re-colonization can be critical to maintaining native spring biota. Blocking colonization pathways with physical structures around springs, and by developed roads and trails can decrease ingress of species from external sources, resulting in depauparate spring communities with implications to trophic structure and system function.
4. Springs are vulnerable to exotic establishment due to moist conditions and the attraction of park visitors which can introduce exotic plants and animals. Non-native invasion alters biotic structure, habitat, and ecosystem functions.

Table 2-4. Key degradation processes in spring ecosystems, stressors and ecological effects associated with these processes, and potential measures that would characterize degradation processes and effects.

Degradation Process	Stressors	Ecological Effects	Potential Measures
Severe dewatering (loss of most or all habitat medium) or severe reduction in water quality	Persistent climatic change (decrease in precipitation), groundwater depletion, extraction and diversion from the orifice, water pollution	Decreased or total loss of biotic diversity (extinction of endemic species), decreased or loss of nutrient cycling, primary production, and system functions	Water flow, upstream land use, biotic structure and composition
Soil erosion and compaction	Trampling by humans; trampling and grazing by livestock, flow regulation	Altered soil-hydrologic function (slower turnover, cessation of cycling pathways) due to soil compaction, altered run-off paths, altered biotic composition	Human and livestock trail development near springs, biotic structure and composition
Declining ingress	Park management actions (fencing and road construction blocking immigration from external sources)	Reduced biotic structure and composition	Biotic composition and structure, occurrence of physical structures near, around springs
Exotic invasion	Exotic invasion (due to natural dispersal, visitor use of springs)	Altered habitat structure, population dynamics, species diversity, trophic structure, and nutrient cycling	Biotic structure and composition (native vs. non-native)

Chapter 3

Vital Signs

The list of potential indicators for monitoring ecosystem condition is practically endless. It was therefore necessary to give careful consideration to diverse perspectives in selecting and prioritizing vital signs. The NCPN employed conceptual modeling, electronic surveys, Delphi procedures, workshops and meetings and involved academic and agency scientists along with NPS staff in this process. This chapter describes the approach to choosing the final set of 23 vital signs to be monitored by the NCPN. Additional details regarding vital signs selection are in Appendix L.

3.1. Identifying Potential Vital Signs

Before identifying potential vital signs, information was gathered regarding park resources, resource management concerns, and existing monitoring activities. This included extensive literature review and data mining to locate key datasets (Evenden et al. 2002). An electronic survey was conducted where park staffs listed key resources of concern and stressors thought to impact them (Table 1-8; section 1.3.2). Additionally, workshops were held to identify water quality monitoring priorities (Appendix M), and potential geoindicators (Appendix N), for consideration in vitals signs selection. Conceptual model development for vital signs monitoring proceeded in tandem with and provided a framework for the vital signs selection. Important events in the vital sign selection process are listed in Table 3.1.

Table 3-1. Timeline of key events for identifying NCPN vital signs.

Date	Event	Objective
December 2001	Park staff e-mail survey	Identify key resources and stressors
June 2002	Geoindicators workshop	Develop recommendations for monitoring geoindicators
June 2002	Water quality workshop	Establish priorities for water quality monitoring
January 2003	Delphi survey round 1	Identify measurable ecosystem attributes associated with key resources & stressors
March 2003	Delphi survey round 2	Identify candidate vital signs
March - April 2003	Pre-workshop e-mail survey	Reduce list of vital signs by screening against standard criteria
April 2003	Vital signs workshop	Prioritize vital signs
April 2003	Water quality vital signs workshop	Refine water quality monitoring goals
May – June 2003	Park meetings	Produce approved list of NCPN vital signs, park-specific vital signs

An internet-based Delphi process was used to solicit vital signs input from scientists and resource-management specialists. In the first round of the NCPN Delphi survey, 237 scientists and resource-management specialists (including NPS staff from NCPN and elsewhere) from 13 categories of technical expertise were invited to participate. They discussed measurable ecosystem attributes to be considered as potential indicators for monitoring the health of terrestrial, riparian, wetland and aquatic ecosystems managed by NCPN parks. The organizational framework for the first survey was developed on the basis of the Jenny-Chapin model of ecosystem sustainability. Further details of the Delphi process can be found in Appendix L.

In the second-round Delphi survey the NCPN presented the same participants with 312 candidate vital signs that resulted from the first-round Delphi and a survey of scientific literature. Participants were asked to review the vital signs that fell within the scope of their professional expertise and to evaluate them on the basis of four criteria derived from NPS I&M Program guidance and scientific literature:

1. **Management Significance and Utility.** Vital signs must provide information that is meaningful and useful to park managers.

2. **Ecological Significance and Scientific Validity.** Vital signs must be ecologically significant and clearly justified on the basis of peer-reviewed literature and a scientifically sound conceptual framework.

3. **Feasibility and Cost of Implementation.** Sampling, analysis, and interpretation of vital signs must be technically feasible and cost-effective. For purposes of vital-sign evaluation, a cost-effective vital sign is defined as one with a high benefit:cost ratio – i.e., information benefits are high relative to total costs.

4. **Signal: Noise Ratio (Response Variability).** Vital signs must be characterized by patterns of variability that are well understood and possess a high signal:noise ratio. That is, variability attributable to anthropogenic stressors must be high relative to variability attributable to natural processes or measurement errors.

The NCPN ecologist reviewed the results of the second survey and reduced the candidate set from 312 to 164 candidate vital signs.

Vital-Sign Evaluation

Following the two Delphi surveys, NPS staff and cooperators used 14 criteria to evaluate 164 candidate vital signs through an additional e-mail survey and a workshop (Table 3-2). Participants in the pre-workshop evaluation included NCPN network and park staff, key USGS and academic cooperators, and NCPN science-panel members. Participants evaluated candidate measures by scoring them on a scale of 0-5 for each criterion. They were asked to limit evaluations to those candidate measures and criteria that were within their professional knowledge. NCPN parks submitted single consolidated responses. NCPN network staff, USGS and academic partners, and science-panel members completed the surveys from a network-wide perspective rather than on a park-specific basis. On the basis of overall evaluation scores averaged across all survey participants, candidate vital signs were ranked within categories. This list was the starting point for vital-sign discussions held during the workshop.

Table 3-2. Vital-sign evaluation criteria used by the NCPN during the pre-workshop exercise and the April 2003 vital signs workshop.

1. MANAGEMENT SIGNIFICANCE AND UTILITY	
1.1	Degree of legislative / policy mandate associated with vital sign.
1.2	Vital sign is pertinent to one or more specific management concerns.
1.3	Vital sign reliably predicts adverse changes that can be averted by management actions.
1.4	Vital sign produces results (data & interpretations) that are easily communicated, easily understood, and accepted by scientists, policy makers, managers, and the public, all of whom should recognize implications of vital signs results for protecting and managing park resources.
2. ECOLOGICAL SIGNIFICANCE AND SCIENTIFIC VALIDITY	
2.1	Vital sign reliably reflects status of key ecosystem processes or properties. **OR** if vital sign represents a stressor or natural driver of ecosystem change, then the stressor / driver strongly affects functioning of one or more critical ecosystem processes / properties.
2.2	Vital sign reflects the capacity of critical ecosystem processes to resist or recover from change caused by natural disturbances and/or anthropogenic stressors.
2.3	Vital sign is anticipatory, i.e., reflects an impending change in key components or functions of the ecosystem or other natural resource.
3. FEASIBILITY AND COST OF IMPLEMENTATION	
3.1	Vital sign can be cost-effectively measured.
3.2	Measurement of vital sign is nondestructive.
4. RESPONSE VARIABILITY	
4.1	Measurement of vital sign can repeatedly and reliably sort human-caused changes from natural changes over a wide range of resource conditions.
5. EXISTING DATA AND PROGRAMS	
5.1	Vital sign has been inventoried or is already monitored **within** park (i.e., baseline data are available).
5.2	Vital sign is monitored **outside** of park (e.g., by other agencies or regional/national monitoring programs).
5.3	Data associated with this vital sign are readily available, shared, and/or can be obtained from elsewhere at minimal expense to Inventory & Monitoring Program.
6. PROGRAM INTEGRATION	
6.1	Integrative – the full **SUITE** of vital signs spans key environmental gradients (e.g., soils, elevation, terrestrial > riparian > aquatic), ecological hierarchy (landscapes, ecosystems, populations), spatial scales, and system characteristics / components (including structure, function, and composition).

Vital Signs Workshop

On April 7-9, 2003, a three-day NCPN vital signs workshop was held in Moab, UT to review vital-sign results and identify network-level vital-sign priorities. Participants included park and network staff (including managers and technical staff), USGS and academic cooperators, and NCPN science-panel members (see Appendix L for a list of participants). Water quality vital signs, though included in the Delphi and pre-workshop surveys, were addressed separately during a subsequent two-day workshop on April 10-11, 2003 (see Appendix M for details for of the water quality vital signs workshop and Appendix F for park-specific water quality vital signs).

Participants discussed average evaluation scores associated with particular measures and evaluation criteria. Numerous evaluation scores were revised to reflect group decisions. After the group reached consensus regarding evaluation scores, they discussed relative weighting schemes. This discussion focused on whether the five criteria categories should receive equal or different weights, and whether individual criteria should be eliminated or emphasized. To develop a final overall ranking of candidate attributes and measures, the group decided to apply the following relative weights:

Management Significance and Utility	35%
Ecological Significance and Scientific Validity	35%
Feasibility and Implementation Cost	20%
Response Variability	10%
Existing Data and Programs	0%

No weight was given to the Existing Data and Programs category because the group decided that candidate vital signs should not be "penalized" for the absence of monitoring in the past. Weights were applied to the consensus evaluation scores, and the resulting overall evaluation scores were used to produce a final ranking of candidate vital signs (see Table 11 in Appendix L).

Participants then discussed and adjusted rankings resulting from the above process. The purpose of the discussion was to agree upon network-level vital-sign priorities. Very few candidate vital signs were dropped from consideration during group discussion. In fact, some candidate vital signs previously trimmed from the list (e.g., following the second Delphi survey) were restored. Appendix L, Table 11 indicates vital signs retained after the workshop.

After the April 2003 workshop, the NCPN ecologist visited all NCPN parks during May-June 2003 to identify their monitoring needs and increase network familiarity with park resources and issues. Park visits, coordination with SCPN, and reconsideration of input received during various phases of the vital signs evaluation process facilitated reorganization of candidate attributes and measures retained after the April workshop. These measures were aggregated into a shorter list of vital-sign candidates that is broadly applicable across the NCPN. This list was subsequently reviewed and accepted by park staff, and is presented in the national vital signs framework in Table 3-3. Potential measures associated with these vital signs are presented in Appendix O; park-specific vital signs are presented in Appendix P.

The NCPN has identified 23 vital signs for long-term monitoring (Table 3-3). For some of the 10 additional vital signs currently monitored by others (e.g., climate, air quality), the NCPN will develop protocols, and manage, analyze and report on the data. Seven vital signs have been identified that will not be monitored in the foreseeable future. Monitoring of the selected vital signs will not provide a comprehensive view of park ecosystems. What is proposed is an efficient approach to achieve a limited set of monitoring objectives.

The first years of monitoring will likely see some changes in the program. Priorities may be adjusted as additional data become available. For example, improved understanding of attribute variability may justify increased replication in order to meet a particular sampling objective. Monitoring objectives may be revised based on the need to monitor a particular vital sign more extensively than is currently planned. Also, the cost of monitoring a particular vital sign may differ from current projections, requiring adjustments to the sampling of multiple vital signs. Changes will be deliberate, well documented, and kept to a minimum.

Table 3-3. National Vital Signs framework levels 1 – 3 and NCPN Vital Signs.

Level 1 Vital Sign	Level 2 Vital Sign	Level 3 Vital Sign	Network Vital Sign	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION
Air and climate	Air quality	Ozone	Ozone	◆	●	●	●	●	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	●
		Wet and dry deposition	Wet and dry deposition	◆	◆	●	●	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
		Visibility and particulate matter	Visibility and particulate matter	◆	◆	●	●	●	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	●
	Weather and climate	Weather and climate	Climate	●	●	●	●	●	◆	●	●	●	●	◆	●	●	●	●	●
Geology and soils	Geomorphology	Hillslope features and processes	Hillslope erosional processes	-	-	◆	-	-	◆	-	-	-	-	-	-	-	-	-	-
		Stream / river channel characteristics	**Stream / wetland hydrologic function**	+	+	◆	+	+	-	◆	+	+	◆	-	◆	+	-	◆	+
	Paleontology	Paleontology	Status of paleontological resources	◆	-	◆	◆	◆	-	-	◆	◆	◆	-	-	-	-	-	◆
	Soil quality	Soil function and dynamics	**Biological soil crusts**	+	+	◆	+	+	◆	◆	◆	+	◆	◆	◆	◆	◆	◆	+
			Upland hydrologic function	+	+	◆	+	+	◆	◆	◆	+	◆	◆	◆	◆	◆	◆	+
			Upland soil/site stability	+	+	◆	+	+	◆	◆	◆	+	◆	◆	◆	◆	◆	◆	+
Water	Hydrology	Groundwater dynamics	**Groundwater dynamics**	+	+	+	+	+	◆	◆	+	+	◆	◆	●	●	◆	◆	+
		Surface water dynamics	**Surface water dynamics**	+	+	+	+	+	-	◆	+	+	◆	-	●	●	◆	◆	+
	Water quality	Water chemistry	**Water chemistry**	+	+	+	+	+	◆	◆	+	+	◆	◆	●	●	◆	◆	+
		Aquatic macroinvertebrates and algae	**Aquatic macroinvertebrates**	+	+	◆	+	+	-	◆	+	+	◆	-	◆	+	-	◆	+
Biological integrity	Invasive species	Invasive/Exotic plants	**Invasive plants**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Infestations and disease	Insect pests	**Insect/disease outbreaks**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		Animal diseases	Novel diseases/pathogens	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Focal species or communities	Riparian communities	**Riparian plant communities**	+	+	◆	+	+	-	◆	+	+	◆	-	◆	+	-	◆	+
			Springs, seeps and hanging garden communities	+	+	◆	+	+	◆	◆	+	+	◆	-	●	●	◆	-	+
		Freshwater communities	Other aquatic communities	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
		Grassland vegetation	**Native grassland communities**	+	-	-	+	+	-	◆	◆	+	◆	-	-	-	◆	-	+
		Shrubland vegetation	**Shrubland communities**	+	+	◆	+	+	◆	◆	◆	+	◆	◆	◆	◆	◆	◆	+

Table 3-3. Cont.

Level 1 Vital Sign	Level 2 Vital Sign	Level 3 Vital Sign	Network Vital Sign	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION
Biological integrity	Focal species or communities	Cave biota	Cave biota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	•	-
		Fishes	Native fish communities	◆	◆	◆	◆	◆	-	-	◆	◆	◆	◆	-	-	-	◆	◆
		Amphibians & reptiles	Amphibians	◆	◆	◆	•	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
		Birds	**Landbird communities**	+	+	+	+	+	◆	+	+	+	+	◆	◆	+	◆	◆	+
		Mammals	Bats	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
		Vegetation communities	**Predominant plant communities**	+	+	◆	+	+	◆	◆	◆	+	◆	◆	◆	◆	◆	◆	+
	At-risk biota	T&E species and communities	TES plant populations	•	-	-	-	•	-	◆	-	•	-	-	-	-	-	-	•
			Peregrine falcon	•	•	•	•	•	•	◆	•	•	◆	◆	◆	-	-	-	•
Human use	Consumptive use	Consumptive use	Permitted consumptive/ extractive uses	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Non-point source human effects	Non-point source human effects	**Human demographics and developments**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Visitor and recreation use	Visitor usage	Visitor use patterns	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Ecosystem pattern and processes	Fire	Fire and fuel dynamics	**Fire dynamics**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Landscape dynamics	Land cover and use	**Fine scale disturbance**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
			Land cover	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
			Landscape connectivity and fragmentation	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Night sky	Night Sky	Natural night sky	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Soundscape	Soundscape	Natural soundscape	•	◆	•	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Nutrient dynamics	Nutrient dynamics	**Upland nutrient cycling**	+	◆	◆	+	+	◆	◆	+	+	◆	◆	◆	◆	◆	◆	+
	Productivity	Productivity	**Land condition**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

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

• Vital signs that are monitored by a network park, another NPS program, or by another federal or state agency using other funding. The network will collaborate with these other monitoring efforts.

◆ High-priority vital signs for which monitoring will likely be done in the future, but which cannot currently be implemented because of limited staff and funding.

- Vital sign does not apply to park, or for which there are no foreseeable plans to conduct monitoring.

Chapter 4

Sampling Design

4.1 Introduction

Providing information on the status and trends of selected vital signs is the overarching goal of the Northern Colorado Plateau Network Inventory and Monitoring program. Time and budgetary constraints will dictate the use of sampling instead of enumeration to monitor most vital signs. The development of statistical sampling designs that provide unbiased and defensible inference from sample observations to the intended target population is thus essential. This chapter provides a brief overview of sampling definitions and concepts, followed by the statistical sampling designs the NCPN will employ for vital signs monitoring. The sampling-design narratives describe how spatial locations are chosen for sampling and how sampling effort will be rotated among them.

4.2 Sampling Concepts and Definitions

The monitoring plans for the NCPN rely heavily on the use of **survey sampling.** Survey designs have fewer assumptions and provide more reliable and legally defensible parameter estimates than other approaches, such as those designed to sample from infinite populations (Schreuder et al. 2004; Edwards 1998; Nusser et al. 1998). Two critical features of survey sampling are the delineation of the surveyed, finite population and the use of probability sampling (Cochran 1977). A finite population is delineated by treating the target population as a finite list of non-overlapping elements. This list of elements, commonly referred to as a **sampling frame,** is used in selecting samples representative of elements, and serves as the basis for making inference from samples to the population. Inference in survey-based designs only can be made to the elements of a population that can be included in a sample (Schreuder et al. 2004). **Probability sampling** is where each element in the finite population has a known probability of being included in a sample (i.e., selection probability). The selection probability can be uniform or vary among groups of elements (i.e., unequal probability sampling). Additionally, selection probabilities can vary in subsequent additions of sampling sites. Proper estimation of population parameters requires maintaining a record of the selection probability for each element for each sample-site selection event.

Most sampling designs proposed for the NCPN rotate field sampling efforts through various sets of sample units over time. A group of sample units that are always sampled during the 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 pattern of visits through time to all panels is the **revisit design.** Revisit designs specify the temporal sampling schedule. Proposed notation for revisit designs is represented by a pair of digits. The first is the number of consecutive occasions a panel is sampled. The second is the number of consecutive occasions that a panel is not sampled (McDonald 2003). For instance, if a single panel is visited every sample occasion, its revisit design would be [1-0]. The notation [1-0, 1-5] means that units in one panel are visited every occasion, while units in the other are visited once every six years. The way in which units in the population become members of a panel is called the **membership design** (McDonald 2003).

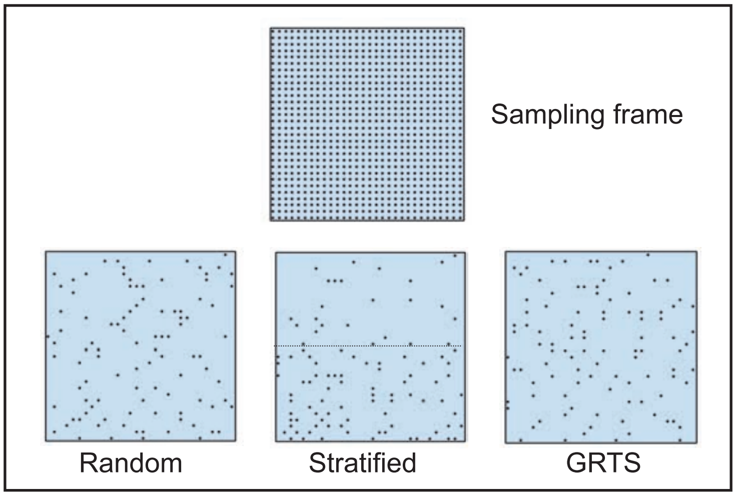


Figure 4-1. Illustration of the three methods used to spatially allocate sample units in the NCPN monitoring program. In each method, 100 sampling locations were selected from the 900-element sampling frame. In the stratified example, strata were the upper and lower half of the box, with the latter receiving three-times the number of samples as the upper half.

The NCPN monitoring uses three methods to spatially allocate sample units (Fig. 4-1). A **simple random** sample selects the desired number of elements from a known population without regard to spatial location. A **stratified random** design is where the sampling frame is divided into mutually exclusive strata. Stratification affords increased precision and efficiency, and greater information about subpopulations (Lohr 1999). Strata are typically selected such that variation within a stratum is less than among strata. Sampled elements within strata are randomly selected. The **Generalized Random Tessellation Stratified (GRTS)** scheme is relatively new and is designed to produce a spatially-balanced random sample (Stevens and Olsen 2004). This method maps two-dimensional space into one-dimensional space and uses a restricted randomization algorithm to select spatially-balanced, random samples. Spatial balance means that sampled areas are spread out approximately uniformly. Inherent in the GRTS scheme is the ability to assign selected sampling units to panels so each panel is spatially balanced. There are various benefits and limitations to each of the three allocation methods. However, the benefits of spatially balanced samples among panels motivated the use of the GRTS scheme to monitor most NCPN vital signs.

Sample size needs, and the spatial and temporal allocation of samples are dictated by **sampling objectives.** Sampling objectives include the detectable level of change, acceptable levels of error, and a reference time frame. The detectable level of change for an indicator depends on factors such as the ecological implication of change and the level of change that will elicit management action (i.e., management trigger). The probability of concluding a change when in fact one did not occur (Type I error), and the power to detect a change influences sample size requirements (Steidl and Thomas 2001). Additionally, sample size is dictated by the desired time frame for detecting change. All things being equal, more samples will allow detection of change sooner. By extending the reference time for change detection, however, fewer samples per sampling event are required.

The NCPN monitoring program emphasizes co-location of vital-sign monitoring locations and co-visitation. **Co-location** refers to monitoring multiple vital signs at the same physical locations. **Co-visitation** refers to recording observations on multiple vital signs during a sampling occasion. An obvious benefit of both is operational efficiency. Overall time and costs for plot set-up and sampling are reduced when measuring multiple vital signs at the same place and time. Also, synoptic measures can provide important insights into ecological processes which have direct application to management:
1. Monitoring drivers and responses aids in interpreting reasons for observed changes. This leads to the identification of resource conditions for which mitigation actions would be effective (e.g., change due to human disturbance vs. climate-driven change);
2. Related to this, synoptic measures enhance the understanding of causes and consequences of interactive behaviors. Interactions among ecological attributes will manifest as one of two primary behaviors. Additive behaviors are expressed as opposing or parallel trends among indicators. Complex behaviors vary from non-linear to chaotic and occur in response to exceeding thresholds and for particular combinations of state conditions (Michener et al. 2001). Synoptic observations are essential to unravel the pathways and factors leading to these behaviors. Understanding this guides mitigation actions that can effectively achieve management objectives without promoting undesired consequences; and
3. Where the lack of precision masks statistically significant change, consistency in trends among vital signs can serve as weight of evidence of change. Synoptic measures minimize confounding factors and enhance assessments of such subtle, but possibly important trends.

4.2.1. Accessibility and Travel Costs

Identifying inaccessible elements and delineating travel costs to the remaining elements in the sampling frame is necessary in the NCPN. Steep and rugged terrain severely limits access to many canyon bottoms and mesas. Expense and safety issues prohibit the use of helicopter transport and mountaineering practices, such as rock climbing, to reach these isolated sites. Additionally, the larger park units have considerable amounts of backcountry with limited trail access. Sampling front- and back-country equally is cost prohibitive.

For each park unit in the NCPN, spatial data layers of accessibility and travel costs have been generated and are used to select sampling locations. These layers are created with the Landscape Access Model (LAM), developed specifically for the NCPN (http://www.nature.nps.gov/im/units/ncpn/Tools.cfm). Areas in a park that can not be reached without traversing steep slopes (e.g., >50%) are categorized as inaccessible, and excluded from monitoring. Using existing spatial layers for roads (primary and 4-WD) and trails, LAM derives the slope-corrected hiking distance to every point on the accessible landscape. Travel costs (i.e., distance) can be translated to selection probabilities of frame elements in two ways. Selection probabilities can vary by discrete travel-cost classes, such as front and back country (e.g., $\leq$ 2 km, >2km). Alternatively, a continuous selection probability can be derived using the actual distance estimate of each element (e.g., $\sqrt{(\text{travel distance})^{-1}}$).

4.2.2. Tracking Selection Probabilities

Most of the NCPN vital signs will be monitored using probability sampling. Factors considered in deriving a selection probability vary among vital signs, with the most common being accessibility and travel costs (see section 4.2.1). Formal stratification is avoided in most cases. Instead, unequal probability sampling is employed. This approach provides the same benefits of stratification but without the restriction of permanent strata. The NCPN is well aware of the potential for monitoring goals and objectives to change over time. As time and budget allows, additional sites may be established to enhance status and trend assessments, or to expand the number and types of areas sampled. With probability sampling, the selection probability of elements can be modified to reflect changes in objectives, and new sampling sites added through re-sampling with replacement. Maintaining a record of selection probabilities in the original and subsequent sampling-site lotteries will be essential for statistical and inferential integrity. Thus, properties of the sampling frame for each vital sign (e.g., location of elements, accessible/inaccessible designation, travel distance) and selection probability of elements will be documented for each park unit. Metadata will include the numbers and types of selected sampling units, selection procedures and outcomes, and reasons for re-sampling events. Documentation will follow National Biological Information Infrastructure Biological Profile guidelines, and be implemented using the USDA Forest Service Metavist package. Accommodating the potential for change in the initial monitoring design is essential for the long-term viability of the NCPN monitoring program.

4.3. Sampling Designs

Five fundamentally different schemes for collecting vital sign measurements were adopted for NCPN monitoring efforts. **Grid-base sampling** uses a grid of points to represent elements of a target population and draws a probability sample. Riparian and aquatic vital signs are sampled using a **Network-based sampling** method that delineates elements of the target population as equal-distance elements located on network segments, and draws a probability sample. **List-based sampling** constructs a list of sample units and either draws a probability sample or attempts to census all units. **Index sites** are used to collect information on areas or at points that were hand-picked to yield adequate data on a particular vital sign. Certain vital signs can be monitored at the full spatial extent of a park, thus, sampling is not required. For these vital signs, a **Census** is employed to observe status and trends. The remainder of this chapter contains one main section for each of the five sampling schemes. A summary of sampling designs, spatial allocation of samples, and revisit plan for vital signs monitoring is presented in Table 4-1.

Table 4-1. Summary of sampling design, spatial allocation of samples, and revisit plan for NCPN vital signs monitoring. Levels 1-3 pertain to the NPS National Vital Sign Framework.

Level 1	Level 2	Level 3	Network Vital Sign Name	Sample Design	Spatial Allocation	Revisit Plan
Air and climate	Air quality	Ozone	Ozone[1]	Index sites	NA	Continuous
		Wet and dry Deposition	Wet and dry deposition[1]	Index sites	NA	Continuous
		Visibility and particulate matter	Visibility and particulate matter[1]	Index sites	NA	Continuous
	Weather and climate	Weather and climate	Climate	Index sites	NA	Continuous
Geology and soils	Geomorphology	Stream / river channel characteristics	Stream / wetland hydrologic function[2]	Network based	GRTS	TBD
	Soil quality	Soil function and dynamics	Biological soil crusts[3]	Grid based	GRTS	[2-7,1-8]
			Upland hydrologic function[3]	Grid based	GRTS	[2-7,1-8]
			Upland soil / site stability[3]	Grid based	GRTS	[2-7,1-8]
Water	Hydrology	Groundwater dynamics	Groundwater dynamics[2]	Network based	GRTS	TBD
		Surface water dynamics	Surface water dynamics[2]	Network based	GRTS	TBD
	Water Quality	Water chemistry	Water chemistry	List based	Judgment	[2-2, 1-0]
		Aquatic macroinvertebrates and algae	Aquatic macroinvertebrates[2]	Network based	GRTS	TBD

Table 4-1. cont.

Level 1	Level 2	Level 3	Network Vital Sign Name	Sample Design	Spatial Allocation	Revisit Plan
Biological integrity	Invasive Species	Invasive / exotic plants	Invasive plants	Index sites	NA	Annual to periodic
	Infestations and Disease	Insect pests	Insect / disease outbreak	Census	NA	[1-4]
	Focal species or communities	Riparian communities	Riparian plant communities[2]	Network based	GRTS	TBD
		Riparian communities	Springs, seeps, and hanging garden communities	List based	GRTS	TBD
		Grassland vegetation	Native grassland communities[3]	Grid based	GRTS	[2-7,1-8]
		Shrubland vegetation	Shrubland communities [3]	Grid based	GRTS	[2-7,1-8]
		Birds	Landbird communities	Grid based	Random	Annual
		Vegetation communities	Predominant plant communities[3]	Grid based	GRTS	[2-7,1-8]
	At-risk biota	T&E species and communities	TES plant populations	List based	Stratified Random	Annual
			Peregrine falcon	Index sites	NA	Annual
Human Use	Non-point source human effects	Non-point source human effects	Human demographics and developments	List based	NA	Commensurate with public-record updates
	Visitor and recreation use	Visitor usage	Visitor use patterns	List based (or census)	GRTS	TBD
Ecosystem Patterns and Processes	Fire	Fire and fuel dynamics	Fire dynamics	Census	NA	[1-4]
	Landscape dynamics	Land cover and use	Fine-scale disturbance	List based	NA	TBD
			Land cover	Census	NA	[1-4]
			Landscape connectivity and fragmentation	Census	NA	[1-4]
	Nutrient dynamics	Nutrient dynamics	Upland nutrient cycling[3]	Grid based	GRTS	[2-7,1-8]
	Productivity	Productivity	Land condition	Census	NA	Annual

[1] *Co-located, co-visited as part of the Air Quality Protocol*
[2] *Co-located, co-visited as part of the Integrated Riparian Protocol*
[3] *Co-located, co-visited as part of the Integrated Upland Protocol*

4.4. Grid-based Sampling

Grid-based sampling is the primary spatial sampling method for vital signs associated with upland, terrestrial systems and landbird monitoring. The sampling frame is constructed as a randomly oriented grid of points (elements), with each point corresponding to an equal extent. The entire accessible target population of a vital sign is represented by unique, non-overlapping elements. Specifics of grid-based sampling are described below for each vital sign.

4.4.1. Upland Vital Signs

The monitoring of upland vital signs is one of the two highly integrative efforts of the NCPN monitoring program. Seven vital signs will be recorded concurrently at the same ground-based sampling plots. These include upland nutrient cycling, biological soil crusts, upland hydrologic function, upland soil/site stability, and native grassland, shrubland, and predominant plant communities. Additionally, to support interpreting observed trends, micro-climate stations will be located in the vicinity of upland monitoring plots. Stations will consist of battery-operated Hobo rain and temperature gauges (http://www.onsetcomp.com/Products/outdoor_guide.html) with a recording frequency of approximately every 15 minutes to an hour. The frame consists of a systematic grid of points with 50 m spacing (e.g., Fig. 4-2A). Upland vital signs are measured on three parallel transects that cover a 50 x 50 m area. Thus, the 50 m frame spacing ensures that the target population is delineated by unique, non-overlapping elements.

Monitoring upland vital signs on the basis of ecological-site type is critical in the sparsely vegetated dryland systems of the NCPN. An ecological site is attributed from climate, soil, and geology (SRM 1989, 1995). The soil and geologic attributes of ecological sites are relatively static and constrain patterns and processes. For these reasons, ecological sites have variable resistance to natural and anthropogenic disturbances, and motivate alternative pathways of disturbance-induced successional development. Limiting monitoring to specific site types ensures interpretable status and trend observations of key combinations of above-below ground processes.

The proposed sampling objective for each upland vital sign is the detection of a 7% change per year over nine years with a Type I error rate of 0.10 and an 80% chance of detecting a change. This objective represents an initial estimate of desirable change detection for current management concerns. At the outset, this objective applies to all ecological-site types, but park-specific objectives are likely as management concerns evolve. Given this objective, initial rotation and panel designs are proposed below based on variance information from previous upland studies from multiple ecological sites in the NCPN (Schelz 2002a-d). Rotation and panel designs will be refined during the initial implementation phase of the upland vital signs monitoring as variance estimates of NCPN field methods are ascertained.

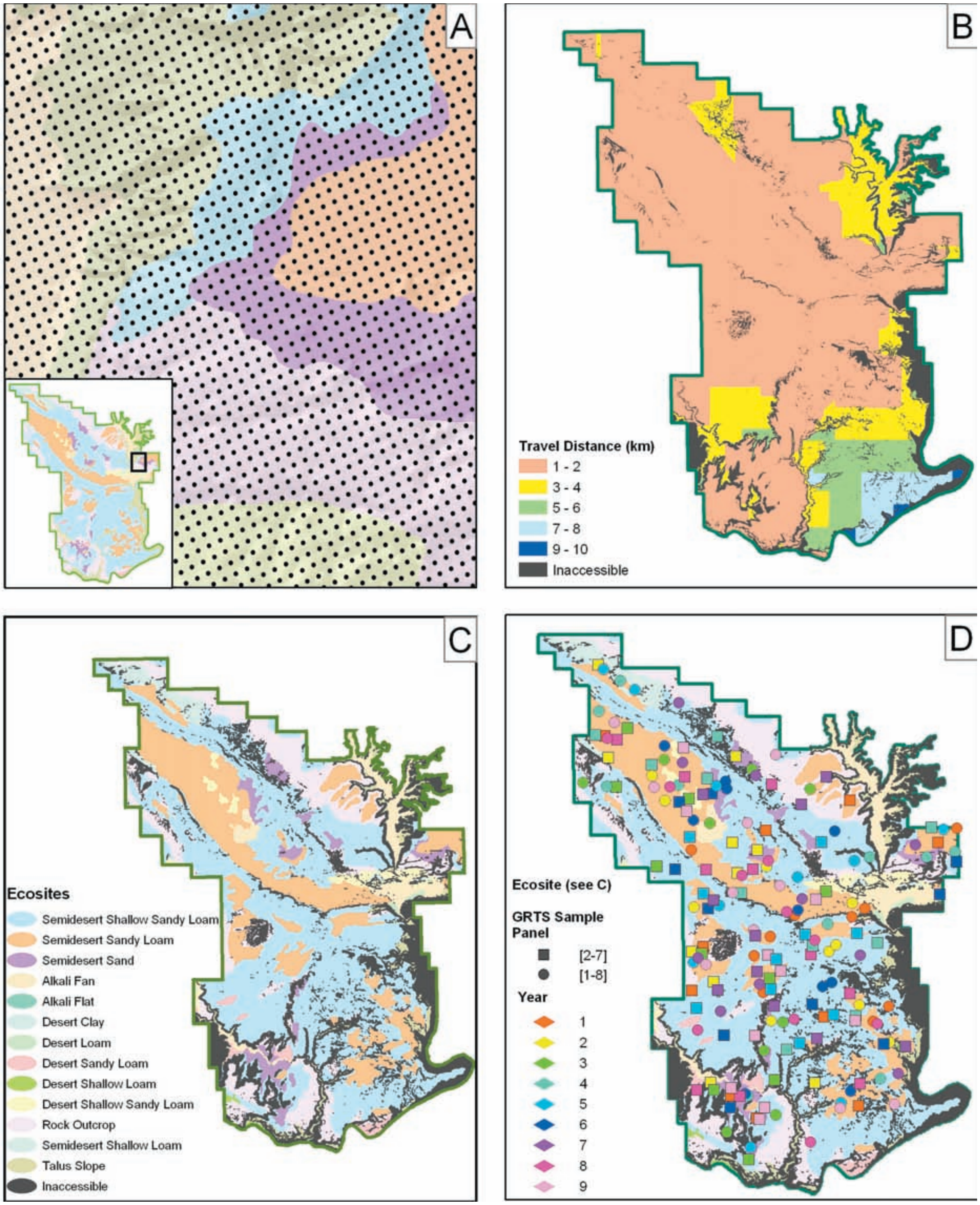


Figure 4-2. Illustration of spatial data layers used to generate a GRTS sample for monitoring upland vital signs in Arches National Park. A – a randomly orientated, grid sampling frame with 50 m spacing between elements derived with the NCPN Frame model (Garman, unpubl.); B – estimates of accessibility and travel-costs from the NCPN Landscape Access Model (Garman, unpubl.); C- ecological site map showing inaccessible areas; D – a GRTS sample of 180 sampling locations for monitoring three ecological sites (Semidesert Sand, Semidesert Sandy Loam, Semidesert Shallow Sandy Loam). The split-panel revisit design illustrated by panel and year corresponds to Table 4-2.

Sampling objectives, variance estimates, and the budgetary limitation of 180 plots per year were employed in determining sample-size needs and panel designs. Sample-size assessments using the Trend (Gerrodette 1987) program indicated that about 60 plots per ecological site are required to satisfy the sampling objective. Given the affordable number of sampling plots (i.e., 180), only three ecological sites can be monitored effectively in a park unit. Ecological sites considered for monitoring will be park specific and based on spatial extent, perceived sensitivity to disturbance, association with key focal vegetative communities, or otherwise of special management concern. Additionally, monitoring is affordable for only six of the NCPN park units. Park units included in upland monitoring largely will be selected on the basis of land area and geographic location.

An initial estimate of the temporal allocation is a split-panel design with a revisit design of [2-7,1-8] (Table 4-2). This design provides the ability to evaluate inter-annual variability and balances the ability to assess trends and status. Each selected park will have a total of 180 unique sampling plots with plots distributed equally among three ecological sites. Ninety plots will be sampled for two consecutive years every eight years, and the remaining plots sampled once every nine years. Within each of the six parks, 30 plots will be sampled each year, for a total of 180 sampled plots per year across the NCPN. An unequal probability GRTS sample will allocate the 180 sampling plots within a park unit (e.g., Fig. 4-2D). Using the sequential list of the 180 selected plots, park-level panel membership will be generated by assigning sequential sets of 10 plots to a panel of the [2-7] revisit design then to a panel of the [1-8] design, starting with the first panel of each revisit design and ending with the last panel. Plots in each panel will be about equally distributed among the selected ecological sites.

Selection probability of elements within will be based on accessibility (e.g, Fig. 4-2B) and ecological site (e.g., Fig. 4-2C). Following standard sampling procedures, inaccessible elements are retained in the sampling frame, but assigned a selection probability of zero. For all other elements, the selection probability is first derived as the inverse of the square root of travel distance. This probability is then adjusted by the proportion of area of the ecological site containing the element. This joint selection probability ensures the selection of 60 sampling plots per ecological site, with the number of elements decreasing with increasing travel cost in each of the ecological sites.

Table 4-2. Proposed split-panel design for monitoring upland vital signs. "X" indicates 10 sampling plots about equally distributed among three ecological sites and spatially distributed across a park landscape. This design is employed in each of six parks simultaneously. See text for details.

Year/ Panel	1	2	3	4	5	6	7	8	9	10
1	X	X								X
2		X	X							
3			X	X						
4				X	X					
5					X	X				
6						X	X			
7							X	X		
8								X	X	
9	X								X	X
1	X									X
2		X								
3			X							
4				X						
5					X					
6						X				
7							X			
8								X		
9									X	

4.4.2. Landbird Monitoring

The NCPN is collaborating with the Rocky Mountain Bird Observatory (RMBO) to monitor land birds. This collaboration complements RMBO's existing 1,000-site network that ranges from South Dakota to northern New Mexico. The goal of the NCPN landbird monitoring effort is to contribute to the regional perspective of status and trends in landbirds in two upland habitat types – sagebrush and pinyon-juniper woodlands - and in riparian habitat. Park-based inference is not an objective of this monitoring effort. RMBO's sampling objective guided sample sizes for the NCPN monitoring. The sampling objective of detecting a -3% change in species' density over 30 years, given a Type I error rate of 0.1 and 90% power required 15 sampling locations per habitat type and two surveys of a transect each year.

Methods for selecting sampling locations differed between the upland habitats and riparian areas. For upland habitats, a gridded sampling frame with an inter-point spacing of 100 m was generated for each of the 16 parks in the NCPN. Inaccessible areas were delineated and eliminated from consideration. Travel costs were not considered; thus, each point in the frame within accessible areas had the same selection probability. For each habitat type, points falling within a habitat patch were pooled across all parks. Following RMBO protocol, the points were randomly ordered, and evaluated sequentially using GIS. The evaluation criterion was the ability to locate a 15-point transect with at least a 250 m inter-point interval (minimum of a 3.5 km transect) within a habitat patch starting at the selected point. Where habitat patches were too small, the point was discarded and the next point was evaluated. Additionally, a point was discarded if it would result in a transect that overlapped a previously selected point and its transect. The first 15 suitable locations in each habitat type were selected for monitoring. Perennial streams in the NCPN are limited. Thus, the 15 riparian areas included in landbird monitoring were selected based on availability. To determine the starting locations of the transects, the accessible extent of a riparian corridor was ascertained and measured. For riparian strips longer than the 3.5 km transect, the starting location was randomly determined, but constrained to accommodate the full length of the transect. The rotation design is [1-0] with no membership design since all locations are monitored annually.

At each of the 15 transect points, a five-minute survey is performed. Observations of birds by sight or call are recorded along with the distance from point center to the first detection of an individual. The histogram of detection distances allows a function to be estimated which will adjust overall counts for decreased probability of detection at large distances. Estimation of the detection function and of density for each species will be performed using the Distance program (Buckland et al. 2001). Observations of target species also are recorded along the transect while walking between point locations. Target species are those that are uncommon or of special concern, and that typically are under-represented on point-count surveys. Detection distances are recorded for target species. Given the tendency for a limited number of observations of these species, however, transect observations generally provide status rather than trend information.

4.5. Network-based Sampling

4.5.1. Riparian and Aquatic Vital Signs

The monitoring of riparian and aquatic vital signs is one of the two highly integrative efforts of the NCPN monitoring program. Five vital signs will be monitored concurrently at the same sampling locations. They will include riparian vegetation structure and composition, stream hydrologic function, ground water dynamics, surface water dynamics, and aquatic macro-invertebrates.

The sampling design relies on a stream classification scheme. River systems in the NCPN are highly variable, ranging from large rivers such as the Green and Colorado River to small intermittent streams. A hierarchical process-based classification system similar to that described by Montgomery and Buffington (1998) will be applied to all perennial and intermittent streams in each park. The objective of this classification system is to identify streams by their potential response to a range of drivers and stressors. Using spatial data layers of geology and valley slope, and derived estimates of channel confinement, reach types will be identified for all suitable streams within each watershed in a park. A watershed defines the bounds of a target population. Reaches, however, serve as the basic inferential unit; that is, inference will be made from sampled to unsampled reaches of similar types. The stream length monitored at each sampling location will depend on the pattern of channel units. Channel units, such as fan-eddy complexes and flood-plain meanders, reflect the fundamental geomorphic organization of a stream at the reach scale, and also serves as a sampling template for measurements of related biotic response variables (riparian vegetation and aquatic macro-invertebrates). The first repeating sequence of channel units starting at the selected sampling location is monitored. For each channel unit, measures of channel width and depth, flood plain width, riparian vegetative conditions, ground water, surface flow, and aquatic macro-invertebrates are recorded.

The sampling frame will consist of equal-distance elements in each segment of a reach type (e.g., Fig. 4-3A). Sampling locations will be an unequal probability GRTS sample (e.g., Fig. 4-3B). Selection probabilities will be based on reach type, with reaches in high-order streams having higher probabilities. The revisit design will depend on finalized estimates of sample variance and sample-size needs, but likely will involve a split-panel design similar to that of the upland vital signs. Similarly, panel membership will be determined by the sequential allocation of the ordered GRTS sample.

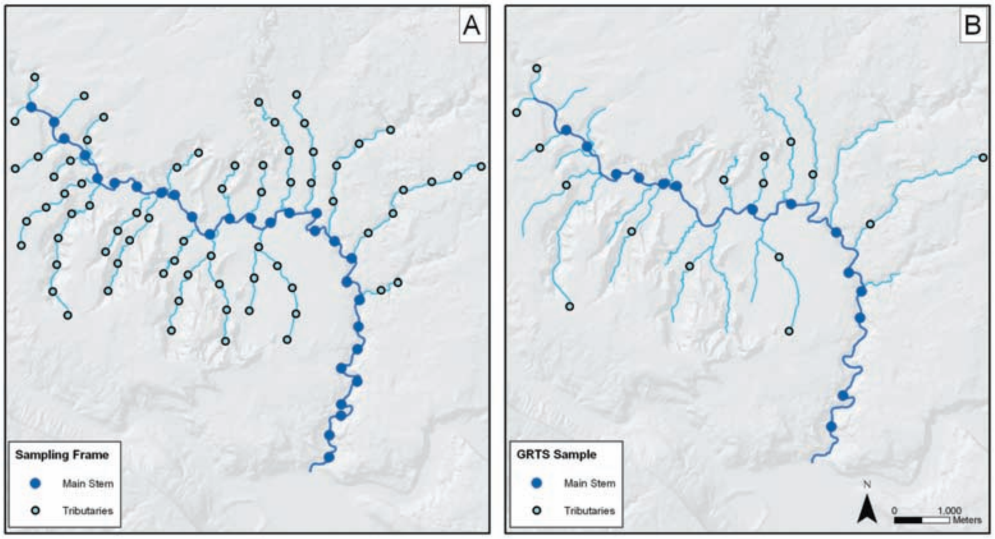


Figure 4-3. Illustration of a GRTS sample for monitoring riparian and aquatic vital signs. A – sampling frame for the two reach types (main stem, tributaries) of Courthouse Wash, Arches National Park. All tributaries are classified as the same reach type in this example. Frame elements are spaced ca. 500 m on each reach segment. B – a GRTS sample of 30 sampling locations.

4.6. List-based Sampling

A list-based scheme is used for monitoring Threatened and Endangered plants, springs/seeps/hanging gardens, non-point source human land-use activities, visitor patterns, and fine-scale disturbance vital signs. For all vital signs, the location and extent of target populations are derived from inventories, which are organized as lists. The spatial and temporal allocation of samples, however, vary by vital sign.

4.6.1. Threatened and Endangered Plants (T&E)

The number of monitored T&E species will depend on park-based funding levels and topical management concerns. Specific field measures will vary among species, but common observations will include spatial dispersion within and among metapopulations, growth and reproductive performance at the individual stem level and at the metapopulation level, and habitat conditions.

Lists of the known locations of populations of a species will be determined from inventories. Many T&E species in park units also occur in adjacent ownerships, which has motivated the development of multi-agency monitoring protocols. A stratified random design will be used to determine sampling locations, with strata defined by ownership. Within an ownership, populations or patches will be arrayed by size classes, and random samples selected from each size category.

A proposed revisit scheme is annual monitoring until a species population is determined to be stable, followed by monitoring every three to five years. Thus, the revisit design is species specific. There is no membership design since all selected populations of a species will be monitored concurrently.

4.6.2. Springs, Seeps, and Hanging Gardens

The extent of monitoring of this vital sign will depend on park-based funding levels and topical management concerns. Field measures for springs and seeps include channel attributes (if applicable), flow volume and rate, water quality, aquatic invertebrates, and associated terrestrial and aquatic vegetation. Vegetative composition and structure, and aerial extent of hanging gardens will be monitored. Additionally, measures of anthropogenic disturbance in and around these features will be recorded.

Lists of the known locations of these hydrologic features will be determined from inventories. Features, such as hanging gardens, can occur on sheer cliffs and are too dangerous to monitor. The ability to record detailed field measures will be ascertained from inventory records, and unsuitable sites will be eliminated from the sampling lists. For each hydrologic feature, the adjusted list of known locations will constitute the target population. The overall sample design for each feature will select an unequal probability GRTS sample, with selection probabilities based on spatial extent of the feature, estimated water-volume potential, and travel costs (distance from roads). Where necessary, panel membership will be assigned by the sequential allocation of the ordered GRTS sample.

4.6.3. Human Demographics and Developments

This vital sign pertains to human activities on adjacent and distant lands that have the potential to affect park lands. Monitoring will determine status and trend changes in local human demographics, building permits, water diversion and allocations, well-drilling permits, and other land uses documented in public records. Certain information will be available at the county or state level, while other information will pertain to specific locations (e.g., dam-water release). A list of human activities known or suspected to affect park-land patterns and processes will be assembled, and determine monitoring information needs. For each listed activity, a complete interrogation of all available public records will be conducted and summarized whenever information sources are updated.

4.6.4. Visitor Use Patterns

The monitoring of this vital sign provides measures on the status and trends of park-visitor use at pre-defined locations. Field surveys, trail-use monitoring instrumentation, and other methods are proposed for recording visitor use. Locations of concern will be identified by individual parks, and form the basis of the list-based sampling frame. Areas may include trial heads, trails to signature features, and designated backcountry campsites. The sampling design will depend on funding levels and topical management concerns of the individual parks. Where visitor use of specific locations is of interest, the sample design will be annual monitoring of all locations without a membership design. Where park-wide status and trend information are desired, the list of locations will be organized by categories (trail heads, campgrounds, etc.), selection probabilities will be generated based on park-defined criteria, and monitored areas will be selected as a GRTS sample. Where applicable, panel membership will be determined by the sequential allocation of the ordered GRTS sample.

4.6.5. Fine-scale Disturbances

The NCPN will monitor the unauthorized expansion of social trails and campsites, and backcountry roads in upland and riparian areas using a fine-scale (<5 m) airborne remote-sensing platform. Roads, trails, campgrounds, and riparian areas of concern will form the list-based sampling frame for a park unit. Flight lines will be constructed to overlap the sampling frame of a park. All areas will be monitored in each sampling occasion. There is no membership design. The revisit design will be determined by final cost estimates. It is likely that this vital sign will be monitored once every three to five years in a park. Multiple parks will be on the same rotation schedule, and include, for budgetary reasons, combinations of small and large park units.

4.6.6. Water Chemistry

The NCPN approach to water quality monitoring focuses on collecting and interpreting data to support management in relation to water source threats, and 303(d) listings relative to state standards. For each park, an assessment of historical water-quality data and vital signs was completed by USGS-WRD (Water Resources Division) to inform the monitoring design (Appendix F). A list of water sources representing the range of water-quality conditions among the significant surface-water sources was identified during the vital-sign scoping phase (Appendix F). This list was based on a combination of:

1. knowledge of historical water-quality conditions and issues;
2. natural and human factors affecting water quality;
3. applicable state water-quality standards;
4. accessibility of candidate sites;
5. surrounding land-use;
6. gaps in available data and;
7. professional judgment. Monitoring focuses on waters within park boundaries, but samples will be collected outside of parks because of access issues or specific data needs.

Forty-two sites are recommended for water-quality monitoring (Table 4-3, and Figs. 4-4 – 4-8). Criteria for including each site were the value of the site in meeting NCPN vital signs monitoring goals, and for providing data to meet park resource management needs. To guide NCPN monitoring efforts in the next few years, the 42 recommended sites were ranked according to current condition and management needs (see “Priority” column in Table 4-3). Monitoring these sites will provide representative data at site and network levels because most of the significant surface-water sources identified in the scoping phase of vital-sign selection are included in this sample, and many of the parameters will be sampled over a wide range of hydrologic conditions.

Twenty-nine sites are planned for monitoring (priority 1) by the NPS and other agencies. Of those, 16 require full or partial NCPN support, and 13 are currently monitored and supported by external programs for the foreseeable future. The 16 sites NCPN will support are marked with an “X” in the “Planned NCPN Supported Site” column in Table 4-3. Extensive water-quality monitoring that directly meets NCPN vital signs goals is being conducted by the State of Utah, NPS (SEUG and BLCA/CURE staff), and the USGS for significant water sources throughout the network. Monitoring that partially addresses critical data needs is ongoing in ARCH, BLCA, CANY, CARE, CURE, DINO, GOSP, HOVE, NABR, and ZION. Specific details regarding the scope and utility of these monitoring efforts are presented in Appendix F, and were used to prioritize new monitoring that should be directly managed and funded by the NCPN.

Table 4-3. Recommended water-quality monitoring sites.

Recommended Site ID	Park***	NCPN Database Site No	Site Name	Latitude (nn°nn’nn”)/ Longitude (nnn°nn’nn”)	Panel: Long-Term (L) or Rotation (R)	Current Monitoring Agency/Group	Priority*	Current NPS Sample Site	Current Sample Site by others	Planned NCPN Supported Site	Streamflow Gage	Sample Frequency	Sample Parameters**	Priority Constituents**	Consideration
M-0	ARCH	225	Courthouse Wash near Moab, UT	38°36’46” 109°34’45”	L	SEUG	1	X		X		12/yr	C, MI, N, T, TSS, B	FC	Status and trends
M-1	ARCH	263	Salt Wash at Wolfe Ranch Road	38°44’14” 109°31’09”	L	SEUG	1	X		X		12/yr	C, MI, N, T, TSS, B		Status and trends
M-2	ARCH		Upper Courthouse Wash at park boundary	38°41’00” 109°39’26”	R	SEUG	1	X				12/yr	C, MI, N, T, TSS, B		Status and trends; reference site
M-3	BLCA	570	Gunnison River below Gunnison Tunnel	38°31’45” 107°38’54”	L	BLCA USGS	1	X			09128000	12/yr	C, MI, N, T		Status and trends
M-4	BLCA	4528	Red Rock Canyon near NPS boundary near Montrose, CO	38°34’18” 107°47’14”	L	BLCA	1	X		X		7-12/yr	C, MI, N, T	Se, nutrients	Se, Un-ionized ammonia, irrigation return flow; reference site
M-5	BRCA		Sheep Creek below spring	Near park bound.	R		1			X		8/yr	C, MI, N, T, B, Tu	FC	Water source for hikers, grazing/ wildlife
M-6	BRCA		Yellow Creek below spring	Near park bound.	R		1			X		8/yr	C, MI, N, T, B, Tu	FC	Water source for hikers, grazing/ wildlife
M-7	CANY	1039	Colorado River above Green River	38°11’33” 109°53’02”	L	SEUG	1	X				12/yr	C, MI, N, T, TSS, B	Se, Phosphorus	Status and trends
M-8	CANY	1055	Green River above Colorado River	38°11’24” 109°53’21”	L	SEUG	1	X				12/yr	C, MI, N, T, TSS, B	Se	Status and trends
M-9	CANY	1083	Salt Creek at Crescent Arch	38°05’06” 109°45’59”	L	SEUG	1	X		X	09187650 (upstrm)	12/yr	C, MI, N, T, TSS, B		Status and trends
M-10	CANY	1072	Little Spring Canyon	38°11’03” 109°47’59”	R	SEUG	2					12/yr	C, MI, N, T, B	Se	Status and trends

Table 4-3. Cont.

Recommended Site ID	Park***	NCPN Database Site No	Site Name	Latitude (nn°nn’nn”)/ Longitude (nnn°nn’nn”)	Panel: Long-Term (L) or Rotation (R)	Current Monitoring Agency/Group	Priority*	Current NPS Sample Site	Current Sample Site by others	Planned NCPN Supported Site	Streamflow Gage	Sample Frequency	Sample Parameters**	Priority Constituents**	Consideration
M-11	CARE	1423	Fremont River at Hickman Bridge	38°17’19” 111°14’03”	L	UTDWQ	1		X			12/yr	C, MI, N, T	nutrients	Total phosphorus
M-12	CARE	1450	Halls Creek below the Narrows	37°36’54” 110°52’15”	R		1			X		12/yr	C, MI, N, T, TSS, B	bacteria, nutrients	Few data, FC, hiker impact
M-13	CARE	1461	Oak Creek above Diversion	38°04’57” 111°08’12”	R		2					12/yr	C, MI, N, T, TSS, B	bacteria	Few data, status and trends
M-14	CARE	1473	Pleasant Creek South of Sleeping Rainbow Ranch	38°10’48” 111°10’50”	R		2					12/yr	C, MI, N, T, TSS, B	bacteria, Phosphorus	Total phosphorus, ammonia, pH, FC; research station planned for site in future
M-15	CARE	1481	Sulphur Creek at mouth at Fruita, UT	38°17’33” 111°15’43”	R		2					12/yr	C, MI, N, T, B	Phosphorus, bacteria	Nutrients; near Fremont R. site (UTDWQ co-op potential)
M-16	CURE	2362	Blue Mesa Reservoir above Soap Creek	38°28’31” 107°26’00”	L	CURE	1	X		X		7/yr	C, MI, N, T, SD		Status and trends
M-17	CURE	2446	Cimarron River below Squaw Creek	38°26’47” 107°33’18”	L	CURE	1	X		X	09126500	7/yr	C, MI, N, T,B	bacteria	Ag. and silviculture, status and trends; *E. coli* (potential 303(d) listing)
M-18	CURE	2462	Crystal Reservoir near dam	38°29’24” 107°35’23”	L	CURE	1	X				7/yr	C, MI, N, T, SD		Trophic status, status and trends
M-19	CURE	2492	Gunnison River at 32 Road	38°31’03” 106°59’42”	L	USGS	1		X			7/yr	C, MI, N, T		Status and trends
M-20	CURE	2436	Cebolla Creek at Powderhorn	38°16’33” 107°05’47”	R	CURE	1	X			09122000	7/yr	C, MI, N, T		Status and trends
M-21	CURE	2509	Lake Fork Gunnison River below Gateview	38°19’34” 107°33’50”	R	CURE	1	X				7/yr	C, MI, N, T		Status and trends

Table 4-3. Cont.

Recommended Site ID	Park***	NCPN Database Site No	Site Name	Latitude (nn°nn'nn")/ Longitude (nnn°nn'nn")	Panel: Long-Term (L) or Rotation (R)	Current Monitoring Agency/Group	Priority*	Current NPS Sample Site	Current Sample Site by others	Planned NCPN Supported Site	Streamflow Gage	Sample Frequency	Sample Parameters**	Priority Constituents**	Consideration
M-22	CURE	2547	Steuben Creek near mouth	38°31′37″ 107°18′36″	R	CURE	1	X				7/yr	C, MI, N, T		Status and trends
M-23	CURE	2550	West Elk Creek below Forest boundary	38°30′28″ 107°16′22″	R	CURE	1	X		X		7/yr	C, MI, N, T		Status and trends; reference site
M-24	CURE	2349	Blue Creek at Hwy 50	38°24′18″ 107°24′26″	R	CURE	2					7/yr	C, MI, N, T		Trophic status, status and trends
M-25	CURE	2361	Blue Mesa Reservoir above Cebolla Creek	38°28′29″ 107°12′22″	R	CURE	2					7/yr	C, MI, N, T, SD		Trophic status, status and trends
M-26	CURE	2466	Curecanti Creek near Sapinero	38°29′16″ 107°24′52″	R	CURE	2					7/yr	C, MI, N, T		Status and trends
M-27	CURE	2518	Morrow Point Reservoir near dam	38°27′02″ 107°31′54″	R	CURE	2					7/yr	C, MI, N, T, SD		Trophic status, status and trends
M-28	CURE	2540	Soap Creek above Chance Creek	38°31′37″ 107°18′36″	R	CURE	2					7/yr	C, MI, N, T		Status and trends
M-29	DINO	3341	Green River near Jensen	40°24′34″ 109°14′05″	L	USGS	1		X		09261000	8-12/yr	C, MI, N, T		Status and trends
M-30	DINO	3478	Yampa River at Deerlodge Park	40°27′06″ 108°31′28″	L	USGS	1		X	X	09260050	4/yr (USGS) 8/yr (NCPN)	C, MI, N, T, Se, B, TDS	pH, nutrients	Increasing pH effects on biota
M-31	DINO	3369	Green River above Gates of Lodore	40°44′17″ 108°52′49″	R		1			X		8-12/yr	C, MI, N, T		Status and trends
M-32	DINO	3416	Jones Hole Creek below Fish Hatchery	40°35′15″ 109°03′24″	R		1			X	09260500	8/12/yr	C, MI, N, T, B, Tu	nutrients	Effects of fish hatchery upstream on creek
M-33	DINO	3326	Cub Creek at mouth	40°25′13″ 109°14′28″	R		2					8-12/yr	C, MI, N, T		Status and trends; very low flow

Table 4-3. Cont.

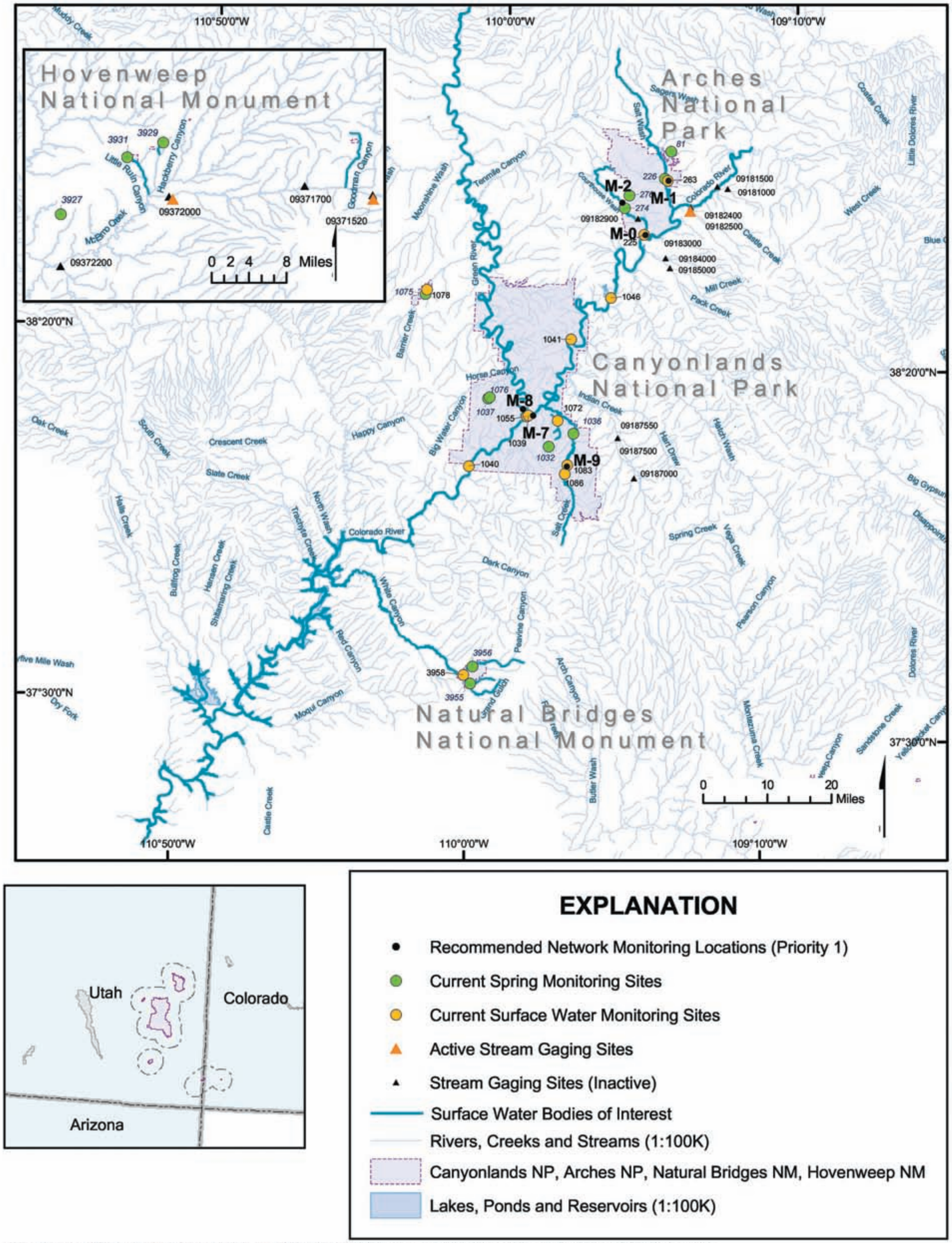
Recommended Site ID	Park***	NCPN Database Site No	Site Name	Latitude (nn°nn'nn")/ Longitude (nnn°nn'nn")	Panel: Long-Term (L) or Rotation (R)	Current Monitoring Agency/Group	Priority*	Current NPS Sample Site	Current Sample Site by others	Planned NCPN Supported Site	Streamflow Gage	Sample Frequency	Sample Parameters**	Priority Constituents**	Consideration
M-34	TICA		Cave Pools		R		2								Critical resource
M-35	ZION	4493	North Fork Virgin River above confluence	37°09'48" 113°00'44"	L	UTDWQ	1		X			12/yr	C, MI, N, T, Tu		Total phosphorus
M-36	ZION	4511	North Fork Virgin River at Narrows Trailhead	37°22'59" 112°50'16"	L		1			X		12/yr	C, MI, N, T, Tu	bacteria	FC, source tracking, trends
M-37	ZION	4454	East Fork Virgin River above confluence	37°09'47" 113°00'38"	R	UTDWQ	1		X			12/yr	C, MI, N, T, Tu		Total phosphorus, source tracking, trends
M-38	ZION	4478	La Verkin Creek at Lee Pass Trail	37°24'26" 113°10'30"	R		1			X		12/yr	C, MI, N, T		Total phosphorus, ammonia
M-39	ZION	4486	North Creek at planned gage in park	37°15'45" 113°06'08"	R		1			X	Planned	12/yr	C, MI, N, T		Total phosphorus
M-40	ZION		East Fork Virgin River at upper park boundary	Best access point	R		2					12/yr	C, MI, N, T, Tu		Source tracking, trends; reference site
M-41	ZION	4485	North Creek above confluence of Virgin River	37°12'09" 113°02'90"	R	UTDWQ	2					12/yr	C, MI, N, T	TDS	TDS 303(d) listing

*Priority is the relative importance of the site to meet NCPN needs.
1. indicates NCPN will monitor the site with planned network resources or the site is otherwise receiving stable, long-term support through other NPS or outside agency programs;
2. indicates site is lower priority and will not be monitored with NCPN resources in the near term unless additional funding support become available to support inclusion of the site.

**B, bacteria; C, core field parameters; FC, fecal coliform bacteria; MI, major ions; N, Nutrients; SD, secchi depth; Se, selenium; T, trace elements; TDS, total dissolved solids; TSS, total suspended solids; Tu, turbidity.

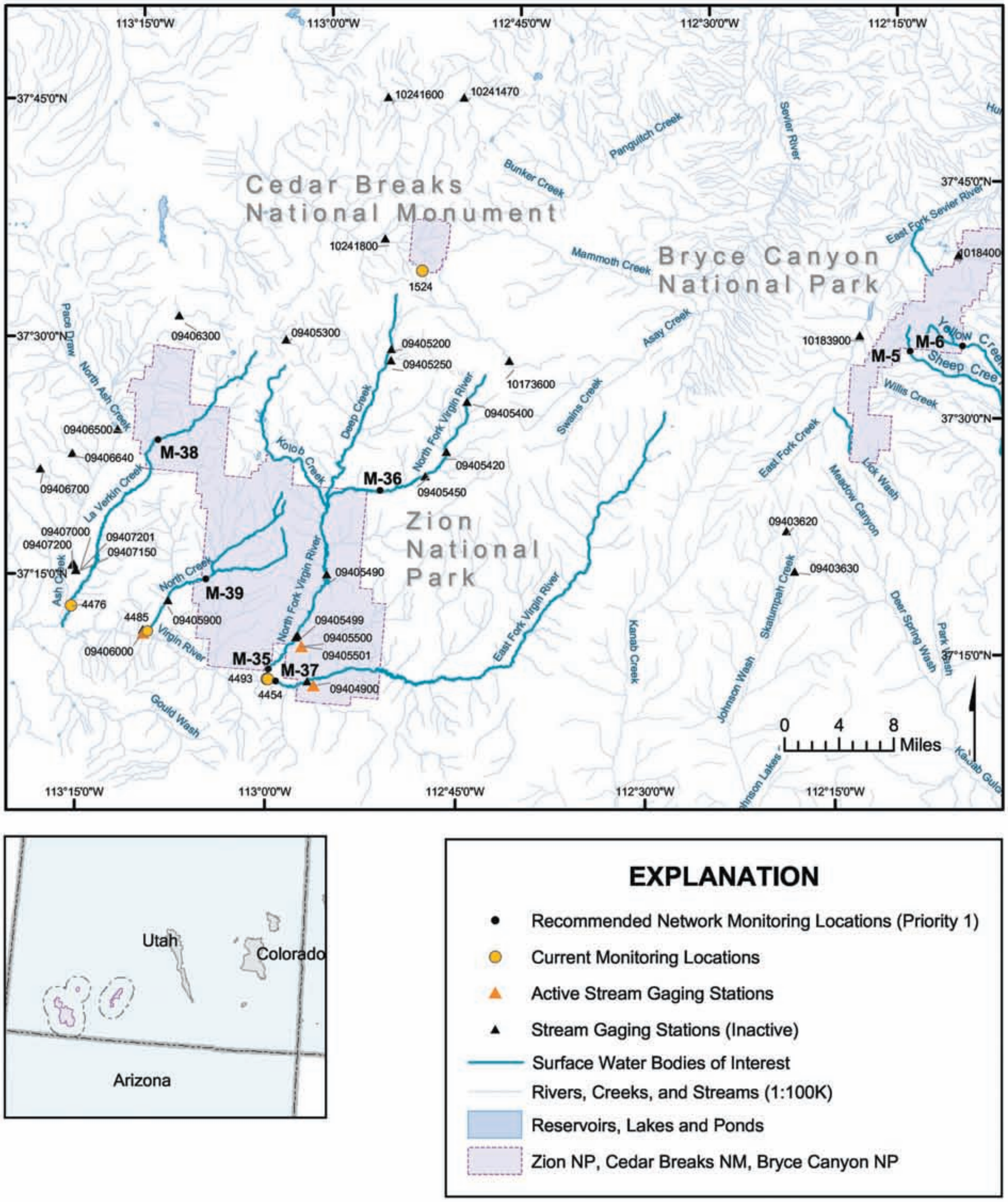
*** FOBU, GOSP, HOVE, NABR and PISP do not have recommended sites for monitoring at this time.

Figure 4-4. Recommended water-quality monitoring sites for ARCH, CANY, HOVE, and NABR.



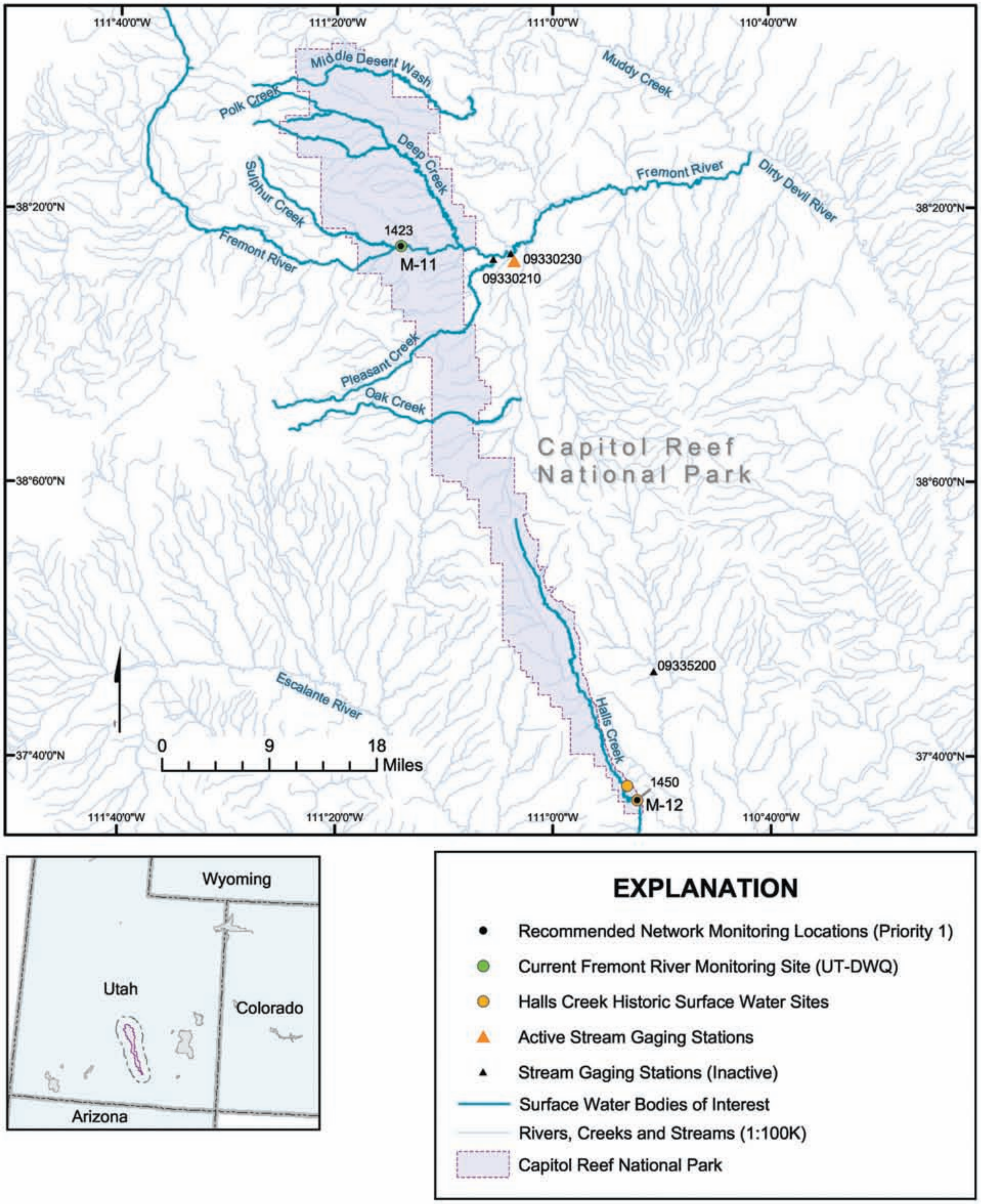
Map layers from the National Atlas of the United States and National Park Service GIS Datasets.

Figure 4-5. Recommended water-quality monitoring sites for BRCA, CEBR, and ZION.



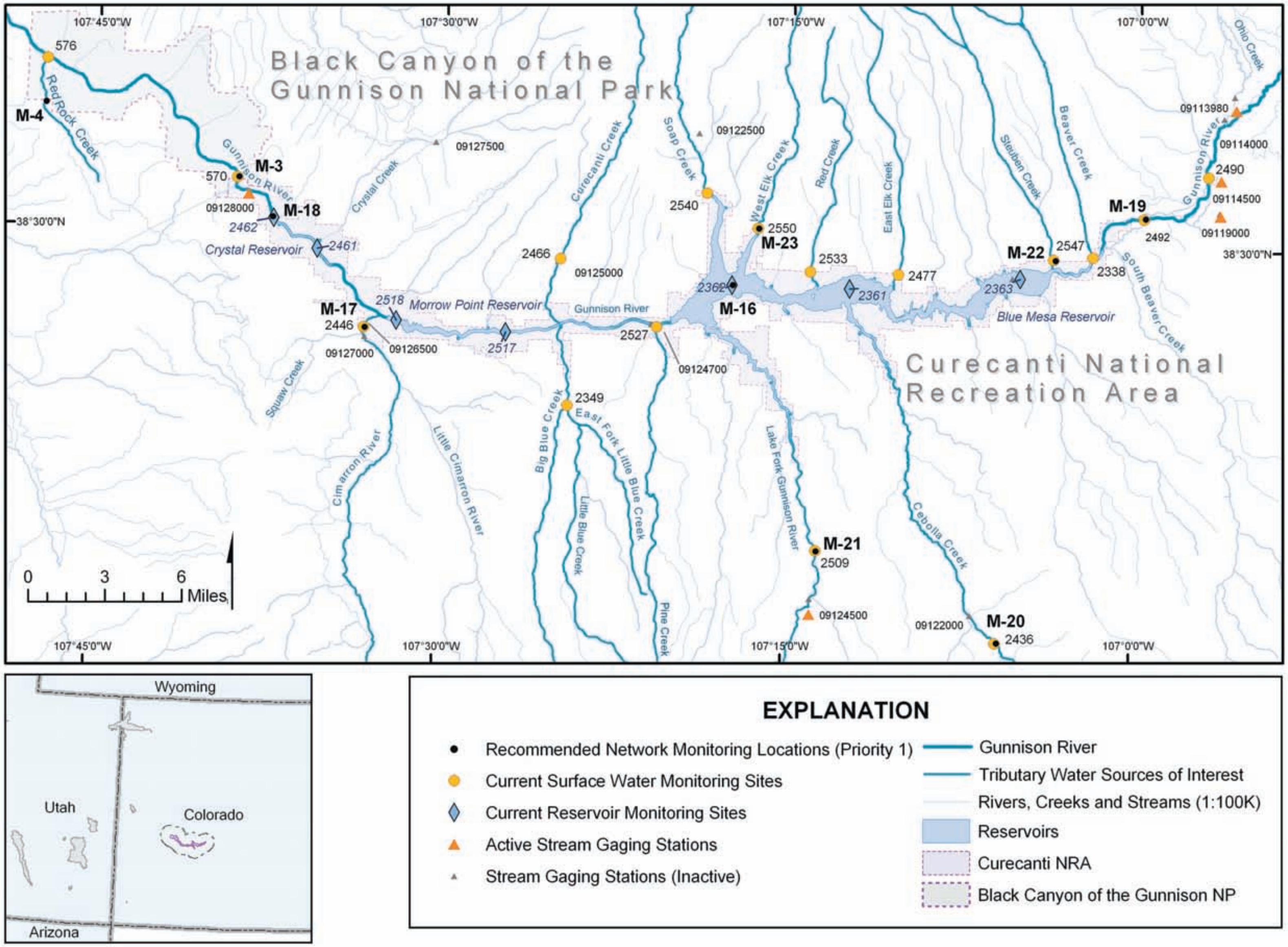
Map layers from the National Atlas of the United States and National Park Service GIS Datasets.

Figure 4-6. Recommended water-quality monitoring sites for CARE.



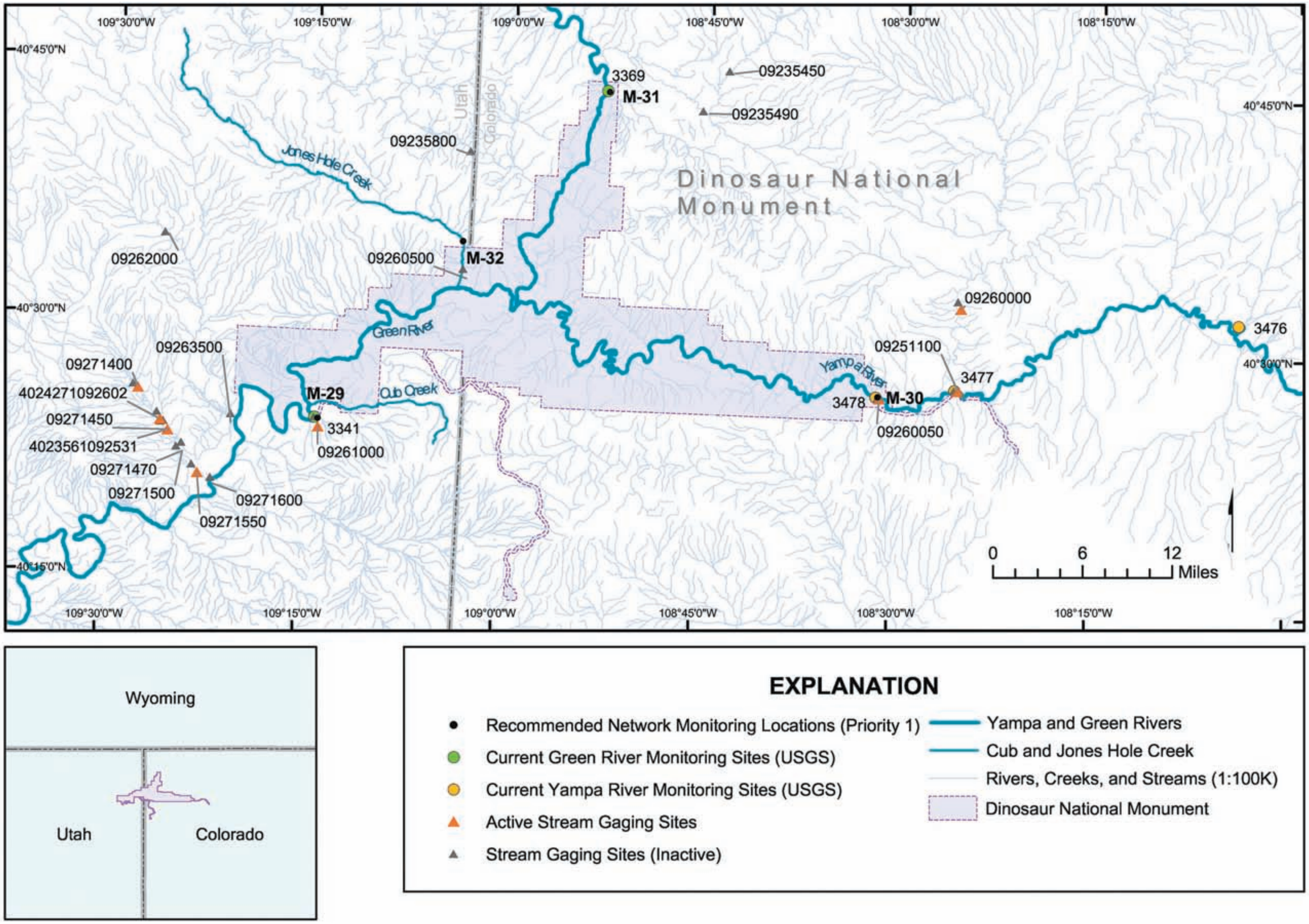
Map layers from the National Atlas of the United States and National Park Service GIS Datasets.

Figure 4-7. Recommended water-quality monitoring sites for BLCA, CURE.



Map layers from the National Atlas of the United States and National Park Service GIS Datasets.

Figure 4-8. Recommended water-quality monitoring sites for DINO.



Map layers from the National Atlas of the United States and National Park Service GIS Datasets.

A split-panel design is proposed for the 16 monitored sites funded by the NCPN, with a revisit design of [2-2,1-0]. The split panel design balances the need to sample every site with budget constraints. In Table 4-3, the Long-Term/Rotation column indicates the panel for each site. "L"sites will be visited annually and "R" sites will be sampled in rotation. Of the 16 sites requiring NCPN support, eight are long-term and eight are rotation sites (Table 4-4). "L" sites were in streams of special concern, where annual measures were deemed critical to management. "R" sites were about equally distributed between Utah and Colorado. The final panel design for all monitored streams will be largely contingent on schedules and budgets of other monitoring efforts and partnerships that can be developed.

Table 4-4. Proposed panel design for the 16 sites monitored directly by the NCPN.

Schedule	Rotation Panel (8 sites total)	Long -Term Panel (8 sites total)
2006	Sites 1-4[a]	Sites 1-8[b]
2007	Sites 1-4	Sites 1-8
2008	Sites 5-8[c]	Sites 1-8
2009	Sites 5-8	Sites 1-8
2010	Restart rotation	Sites 1-8
….	….	….

[a] 1 site in Colorado, 3 sites in Utah.
[b] 4 sites in Colorado, 4 sites in Utah.
[c] 1 site in Colorado, 3 sites in Utah.

Core parameters to be collected at each stream site include dissolved oxygen, pH, specific conductance, water temperature, and streamflow. Core parameters for lake/reservoir monitoring will include dissolved oxygen, pH, specific conductance, water temperature, and **secchi depth.** Recommended parameter groups and specific parameters of concern are listed for each recommended site in Table 4-5. Parameters were restricted to constituents most likely to produce a data set useful for assessment of status and trends in park water-quality conditions, and early warning of threats to water quality. Additional parameters were selected at certain sites to track known or suspected water-quality issues. For most sites, recommended parameters are a broad suite of major ions, nutrients, and trace elements, and occasionally bacteria (Table 4-5).

Table 4-5. Water-quality attributes analyzed by sample type.

Sample type	Attributes
Major ion	Calcium, magnesium, chloride, fluoride, potassium, sodium, sulfate, alkalinity, and total dissolved solids
Nutrients	Ammonia, un-ionized ammonia (calculated), nitrite, nitrate, organic nitrogen, total phosphorus
Trace elements	Aluminum, cadmium, copper, lead, selenium, and zinc.
Bacteria	Fecal coliform, E. coli in selected samples

4.7. Index Sites

Six vital signs will be monitored using index sites. These include vital signs associated with air quality (ozone, wet/dry deposition, visibility and particulate matter), and climate, invasive plants, and peregrine falcon. The use of index sites is justified due to the high costs of the surveys or equipment involved in the measurements (e.g., air quality and climate). Also, the limited distribution of index sites are specific points or locations that are hand-picked by lead investigators and monitored to yield adequate data on a particular vital sign. Statistical inference to a larger area is not possible because of the lack of a probability sample. However, the use of index sites is appropriate when it contains the majority of the population of monitored subjects, or the spatial fluctuation in measures across a larger area is inconsequential for long-term monitoring purposes.

4.7.1. Air Quality and Climate

Air quality (ozone, wet and dry deposition, visibility and particulate matter), and climate vital signs will continue to be monitored at existing air quality and weather stations, respectively. Programs external to the NCPN I&M effort currently are monitoring these vital signs (Table 4-6). NCPN monitoring efforts consist of acquiring and archiving data from existing stations, and analyzing data specific to park units. Station locations have been determined by the external programs according to program-specific objectives and sampling frames. Target populations of these programs are regional in scope. Within a park unit, the number and dispersion of existing stations are insufficient for park-level inference. Many of the climate stations are located, for convenience, next to visitor centers. Also, it is common for climate stations of different programs to be co-located. Many of the climate stations, however, have a long period of record, with some dating back to the 1950-60's. This temporal sample provides a useful context for delineating future, broad-scale climatic extremes and change.

Table 4-6. Climate and air quality monitoring programs in the NPCN.

Climate			Air Quality		
Program	No. of stations	No. of parks	Program	No. of stations	No. of parks
NOAA - National Weather Service Cooperative Observing Program (NWS-Coop)	17	14	IMPROVE	4	4
National Interagency Wildfire Program – Remote Automated Weather Station (RAWS)	6	4	Interagency - National Atmospheric Deposition Program (NADP)	2	2
National Resources Conservation Service (NRCS) - SNOwpackTELemetry (SNOTEL)	1	1	EPA/NPS - Clean Air Status and Trends Network (CASTNET)	1	1
NRCS - Snow Survey	1	1			
SNOWNET (Univ. of Utah)	3	3			
NOAA - Climate Reference Network (CRN)	2	2			
USGS Climate Meteorology (CLIM-MET)	2	1			

4.7.2. Invasive Plants

There are two components to this vital sign: early detection and status and trends. The early detection portion involves monitoring of:
1. key vectors and pathways for invasive species and their propagules,
2. park areas most vulnerable to exotic invasion,
3. park areas exposed to major disturbances, and
4. likely habitat for targeted groups of invasive species.

Literature review of life-history traits of invasive species, inventory results, expert opinion, and predictive modeling will determine targeted areas for early-detection monitoring. All identified sites will be monitored for the occurrence of invasive species. The intended revisit design is [1-0] with no membership design since all sites will be monitored annually. Status and trends monitoring will focus on target populations of management interest, including some treated for eradication. Populations to be monitored will be selected on a park basis in consultation with park management. Areas selected to receive chemical or mechanical treatments will be monitored before and after treatment. Post-treatment monitoring will occur annually for the first one to three years depending on the species and treatment, followed by periodic monitoring. As the number of treated sites increases, the revisit and membership design will be updated to accommodate the monitoring work load.

4.7.3. Peregrine Falcon Surveys

Suitable nesting areas have been identified for seven parks in the NCPN with known or historical occupancy. Accessible portions will be surveyed using a modified version of the protocol established by the U.S. Fish and Wildlife Service (USFWS 2003). Park-based funding will determine the number of parks implementing peregrine falcon monitoring. Surveys will record territory occupancy, nesting success, and productivity. Suitable but currently unoccupied nesting areas are included in the survey to determine future occupancy.

The peregrine falcon survey in a park contains a single index site consisting of all surveyable areas. Statistical inferences about peregrine falcon parameters are not possible to beyond the surveyed area. However, data from park surveys will be distributed to state and regional agencies, and used by these agencies in regional assessments of peregrine falcon populations. The rotation design will be [1-0]. No membership design exists because the single index site will be surveyed each year.

4.8. Census

Satellite imagery is used to monitor vital signs associated with landscape dynamics. These include land cover, land condition, landscape-scale disturbances such as fire and insect/disease outbreaks, and landscape connectivity and fragmentation. Imagery is acquired for the full extent of the Greater Park Ecosystem (GPE), thus monitoring employs a census rather than sampling. The GPE includes the park and surrounding land that could influence the park. The GPE is defined by criteria related to gravitational flows (potential for erosion into a park), movement corridors and home ranges of highly vagile animal species, and potential corridors for exotic plant and animal invasion.

4.8.1. Land Condition

This vital sign pertains to vegetative productivity of the landscape. The Normalized Difference Vegetation Index (NDVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) platform is used as a surrogate for productivity. Seasonal NDVI curves illustrate green-up times, production levels, and senescence periods. Among-year comparisons of NDVI curves for each 250 m pixel on the landscape will identify changes in vegetative conditions. Understanding reasons for changes requires consideration of abiotic factors (e.g., climatic trends) as well as on-site inspection of vegetative conditions. The NCPN will acquire the 16 d (composite NDVI data for the GPE of every park unit for at least 10 months of the year (excluding January and December). Land condition of all GPEs will be monitored annually, thus the revisit design is [1-0] and there is no membership design.

4.8.2. Land Cover, Landscape Connectivity and Fragmentation, Fire Dynamics, Insect/Disease Outbreak

Status and trends of these vital signs are monitored with medium-resolution satellite imagery. A base-line classified map of the GPE is generated using a combination of Landsat (or a similar platform) and field measures from the NCPN vegetation mapping effort. In subsequent monitoring events, the magnitude of spectral change at the pixel level indicates the degree of change. A vector-change assessment method assigns spectral change to a land cover designation. Classified maps from the most recent and previous monitoring occasions are used to determine status and trends in land cover, and connectivity and fragmentation. Fire and insect/disease disturbances are monitored indirectly. Where relatively rapid and large-scale changes in spectral properties of sequential imagery are detected, field investigation is initiated to identify the occurrence and type of disturbance. The expense of imagery acquisition and processing requires a minimum revisit design of at least [1-4], or once every five years. There is no membership design given the census of a GPE. However, monitoring occasions will be distributed among the 16 park units of the NCPN so four parks will be monitored every year. For budgetary reasons, the parks monitored in the same year will be based on size (i.e., two large and two small parks).

Chapter 5

Sampling Protocols

5.1. Introduction

Following the selection of vital signs and sampling designs, methods must be specified to monitor each vital sign. These methods are documented in a monitoring protocol which describes the background, approach, and detailed methods for conducting the monitoring presented in a standard format (Oakley et al., 2003). For efficiency and to enhance interpretation, some vital signs are monitored at the same time and place (co-visited and co-located). The NCPN is developing 16 monitoring protocols to monitor 30 vital signs. Four of these are complete and available at the NCPN web site (http://www1.nature.nps.gov/im/units/ncpn/index.cfm). The rest will be posted when they become available.

The key to a successful long-term monitoring program is ensuring that monitoring protocols are thoroughly documented, periodically reviewed, updated as necessary, and archived. This chapter presents a synopsis of the monitoring protocols that will be implemented over the next four years. Each protocol is summarized in Appendix G. The fully documented protocols are stand-alone documents and included as supplements to this monitoring plan.

The NCPN began its monitoring program in the spring of 2005 using protocols adapted from existing programs. This included using existing protocols for land bird and water quality monitoring at new sites in the NCPN. Summarizing and reporting climate and air-quality monitoring data collected by other national programs, and monitoring with new NCPN protocols will begin in 2006.

Table 5-1 lists vital signs, the protocols by which they will be monitored, the parks where they will be implemented, and their scheduled implementation along with justifications and specific objectives.

Table 5-1. National Vital Signs framework level 3, NCPN Vital Signs, monitoring protocols, and development schedule.

Level 3 Vital Sign	NCPN Vital Sign	Protocol (year beginning)	Justification	Objectives	Parks for implementation
Ozone	Ozone	Air quality (2005)	Supports evaluation of compliance with legislative requirements of Clean Air Act, Regional Haze Guidelines. Facilitates interpretation of plot-based vegetation and water quality measurements.	Determine the annual status and trends in ozone concentration at BLCA, BRCA, CANY, CARE, and ZION. When identified thresholds are exceeded, determine the seasonal change (e.g., foliar damage resulting from ozone pollution) in ozone sensitive vegetation species.	BLCA, BRCA, CANY, CARE, ZION
Wet and dry deposition	Wet and dry deposition			Determine the annual status and trends in: • concentrations of N- and S-containing, and other selected ions, from wet deposition at BRCA and CANY • dry deposition chemistry at CANY	BRCA, CANY
Visibility and particulate matter	Visibility and particulate matter			Determine the annual status and trends in concentrations of visibility-reducing pollutants at BRCA, CANY, CARE, and ZION.	BRCA, CANY, CARE, ZION
Weather and cimate	Climate	Climate (2005)	Key driver for change in most other measures. Facilitates interpretation of plot-based and remotely-sensed measures of vegetation cover, condition, integrated upland, and integrated riparian measures.	Provide monthly and annual summaries of climatic parameters in NCPN park units. Common climatic parameters include air temperature and precipitation. Additional parameters include wind speed and direction, solar radiation, fuel temperature and moisture. Identify extremes of climatic conditions for common parameters (precipitation and air temperature), and other parameters where sufficient data are available (e.g., wind speed and direction, solar radiation, fuel temperature and moisture).	ARCH, BLCA, BRCA, CANY, CARE, COLM, CURE, DINO, FOBU, HOVE, NABR, PISP, TICA, ZION
Birds	Land bird communities	Land birds (2005)	Indicators of habitat quality. Participation in regional program allows broad inference and comparison of areas with differing levels of habitat alteration.	Determine status and trends in breeding-bird species' density in sagebrush, pinyon-juniper, and riparian habitats.	ARCH, BLCA, BRCA, CANY, CARE, COLM, CURE, DINO, FOBU, NABR, TICA, ZION

Table 5-1. Cont.

Level 3 Vital Sign	NCPN Vital Sign	Protocol (year beginning)	Justification	Objectives	Parks for implementation
Grassland vegetation	Native grassland communities	Integrated upland (2006)	Feedbacks between soil, water and vegetation condition are central to conceptual models. Site ability to retain soil, water and nutrients is critical to ecosystem resilience in the semiarid West. Facilitates interpretation of remotely-sensed measures of land cover and condition. Increases understanding of dynamics and condition of predominant ecosystems and ecosystems of high management concern.	Determine annual status and trends in: • live vegetation (trees, shrubs, forbs, grasses) species composition and structure • cover of biological soil crusts by species or morphological group • cover of exotic plants in upland areas • ground cover (live vegetation, litter, rock, biological soil crust, bare ground), soil aggregate stability, and compaction as indicators of soil/site stability, hydrologic function, and nutrient cycling	ARCH, BLCA, CANY, CARE, DINO, ZION
Shrubland Vegetation	Shrubland communities				
Vegetation communities	Predominant plant communities				
Nutrient dynamics	Upland nutrient cycling				
Soil function and dynamics	Biological soil crusts				
	Upland hydrologic function				
	Upland soil/site stability				
T&E species and communities	TES plant populations	TES plants (2006)	Supports evaluation of compliance with legislative requirements of Endangered Species Act.	Determine the population status and trend of selected listed Threatened, Endangered, or other plant species of concern. Document habitat conditions (vegetation composition and cover, disturbances) for selected populations of target species. Determine demographic properties of management interest (e.g., longevity, recruitment) and key life cycle stages where species are most vulnerable to threats for selected target species.	CARE, DINO, ZION
	Peregrine falcon	Peregrine falcon (2005)	Supports evaluation of compliance with legislative requirements of Endangered Species Act.	Determine annual status and trends in territory occupancy, nest success, and productivity of peregrine falcons.	ARCH, BLCA, BRCA, CURE, DINO, ZION

Table 5-1. Cont.

Level 3 Vital Sign	NCPN Vital Sign	Protocol (year beginning)	Justification	Objectives	Parks for implementation
Riparian communities	Riparian plant communities	Integrated riparian (2006)	Critical landscape elements harboring regional biodiversity disproportionate to extent of the ecosystems. Facilitates interpretation of remotely-sensed measures of land cover and condition. Increases understanding of dynamics and condition of ecosystems of high management concern.	For selected reaches of perennial rivers and streams determine annual status and trends in: • areal extent, cover, species composition and spatial structure of riparian vegetation (trees, shrubs, forbs, grasses) • cover of exotic plants • continuous stream flow/discharge • bank stability, stream channel morphology (of surveyed cross sections)	ARCH, BLCA, CANY, CARE, CURE, DINO, NABR, ZION
Surface water dynamics	Surface water dynamics				
Groundwater dynamics	Groundwater dynamics				
Stream/River channel characteristics	Stream / wetland hydrologic function				
Riparian communities	Springs, seeps and hanging garden communities	Springs, seeps and hanging garden communities (2008)	Critical landscape elements harboring regional biodiversity disproportionate to extent of the ecosystems. Increases understanding of dynamics and condition of ecosystems of high management concern.	For selected springs, seeps and hanging gardens, determine long-term trends in: • discharge • core and site-specific water chemistry parameters • habitat area • vegetation composition and structure • diversity and abundance of aquatic and riparian invertebrates Determine impacts of human-related activities to structure and function of selected springs, seeps and hanging gardens	ARCH, BLCA, CANY, CARE, CURE, DINO, NABR, ZION
Invasive/Exotic plants	Invasive plants	Invasive plants (2006)	Important drivers of ecosystem change, nationally recognized stressor. Efficient management of the problem requires early detection.	Detect incipient populations and new introductions of invasive plant species before they become established in areas of management significance Determine status and trends of selected populations of invasive plants of management significance	All NCPN park units

Table 5-1. Cont.

Level 3 Vital Sign	NCPN Vital Sign	Protocol (year beginning)	Justification	Objectives	Parks for implementation
Land cover and use	Fine-scale disturbance	Fine-scale disturbance (2007)	Major stressor of upland and riparian ecosystems in the region. Provides a basis for management to mitigate visitor impacts.	Determine status and trends in the composition (types and amounts) and configuration (spatial pattern) of visitor-use footprints in selected high-use areas (trails, trailheads, campgrounds, roads and riparian areas).	All NCPN park units
Insect pests	Insect/disease outbreaks	Land cover (2007)	Composition, configuration, and connectivity of landscape elements determine habitat availability, the movements of organisms, and energy and material flows on a landscape.	Determine long-term changes in fire frequency and extent, insect and disease outbreaks. Determine annual status and trends in: • areal extent and configuration of land-cover types on park and adjacent lands • cross-boundary land cover contrasts • connectivity of land-cover types within parks, and for park and adjacent lands combined	All NCPN park units
Fire and fuel dynamics	Fire dynamics				
Land cover and use	Land cover				
Land cover and use	Landscape connectivity and fragmentation				
Productivity	Land condition	Land condition (2007)	Broad -scale measure of how ecosystem resistance and resilience are impacted by anthropogenic and natural factors. Can be monitored regionally at low cost.	Determine annual status and trends in: • the seasonally integrated Normalized Difference Vegetation Index (NDVI) for NCPN park lands Where anomalous departures from previous trends are evident, investigate changes in vegetation and land cover likely to be responsible • the seasonally integrated NDVI for lands adjacent to park boundaries. Where anomalous departures from previous trends are evident, investigate changes in vegetation and land cover likely to be responsible	All NCPN park units

Table 5-1. Cont.

Level 3 Vital Sign	NCPN Vital Sign	Protocol (year beginning)	Justification	Objectives	Parks for implementation
Non-point source human effects	Human demography and development	Human demographics and developments (2006)	Allows comprehensive understanding of forcing agents of change. Monitoring extra-local activities will provide information that may help explain changes in park lands.	Determine changes in local human demographics, building permits, water diversion/allocations, well-drilling permits, and other land uses documented in public records.	All NCPN park units
Visitor usage	Visitor use patterns	Visitor use patterns (2006)	Information about changes in the numbers and distribution of visitors among areas of a park will support analysis of fine-scale disturbance data and aid managers.	Determine status and trends in numbers, and spatial and temporal distribution of visitors in selected NCPN parks.	All NCPN park units
Aquatic macroinvertebrates and algae	Aquatic macroinvertebrates	Aquatic macroinvertebrates (2006)	Focal communities, indicative of biotic integrity of aquatic systems.	Determine annual status and trends in abundance of selected aquatic macroinvertebrates in selected reaches of perennial rivers and streams.	ARCH, BLCA, CANY, CARE, CURE, DINO, NABR, ZION
Water chemistry	Water chemistry	Water quality (2005)	Supports evaluation of compliance with legislative requirements of Clean Water Act.	Determine status and trends in core parameters and selected constituents of selected water bodies.	ARCH, BLCA, BRCA, CANY, CARE, CURE, DINO, ZION

Chapter 6

Data Management

Information is the common currency among the activities and staff involved in natural resource management in the NPS. The central mission of the NPS' Inventory and Monitoring Program is to acquire, manage, analyze, and distribute scientific information on the status and trends of specific park natural resources. Intended users of this information include park managers, cooperators, researchers, and the general public.

A cornerstone of the I&M Program is the strong emphasis placed on data management. The NCPN expects to invest at least 30 percent of its available resources in data management, analysis, and reporting activities.

Because of the size and complexity of the elements comprising network data management, a separate Data Management Plan has been developed and is included in this report as Appendix Q.

6.1. The NCPN Data Management Plan

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

6.1.1. Data Accuracy

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

6.1.2. Data Security

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

6.1.3. Data Longevity

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

6.1.4. Data Accessibility

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

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

The NCPN's main mechanism for distributing the network's I&M data will be the Internet, which will allow data and information to reach a broad community of users. As part of the national I&M Program, web-based applications and repositories have been developed to store a variety of park natural resource information (Table 6-1).

Table 6-1. Data that are provided on the NCPN and national I&M websites.

Web Application Name	Data available at site
NPSpecies	Database of vascular plant and vertebrate species known or suspected to occur on NPS park units (**http://science.nature.nps.gov/im/apps/npspp/index.htm)**
NatureBib	Bibliography of park-related natural resource information **(http://www.nature.nps.gov/nrbib/index.htm)**
NPSFocus	Portal to a variety of NPS information sources; will include NatureBib and NR/GIS Data Store links
Biodiversity Data Store	Digital archive of documents, GIS datasets and non-GIS dataset files that document the presence/absence, distribution and/or abundance of taxa in NPS units **(http://science.nature.nps.gov/im/inventory/biology/index.htm)**
NR-GIS Data Store	Park-related metadata and selected data sets (spatial and non-spatial) **(http://science.nature.nps.gov/nrdata/)**
NCPN Website	Reports and metadata for the NCPN projects,certified species lists,search and reporting tools for data, data downloads, database templates **(http://www.nature.nps.gov/im/units/ncpn/index.cfm)**

The NCPN's information acquires its real value when it reaches those who can apply it. If web portals do not meet a specific user's requirements, NCPN data management staff will work with users on an individual basis to make sure they receive the desired information in the requested format.

6.2. Data Management Roles and Responsibilities

Data management involves many people with a broad range of expertise and abilities. All network staff have a role in data stewardship, and project data sets and products reflect all who have contributed.

Table 6-2 lists data-related roles and primary responsibilities, from field-based data collection, to final distribution and archiving. The network manager coordinates these tasks.

Table 6-2. Roles and primary responsibilities related to network data management.

Role	Primary responsibilities related to data management
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
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, publish data and associated information products
Network data manager	Ensure program data are organized, useful, compliant, safe, and available
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 (documents, specimens, photographs, etc.) are cataloged and stored in NPS or other repositories
I&M data manager (national level)	Provide service-wide 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

6.3. Data Sources and Priorities

There are multiple sources of significant data related to natural resources in the NCPN parks. The types of work that may generate these data include:

- Inventories
- Monitoring
- Protocol development pilot studies

- Special-focus studies performed by internal staff, contractors or cooperators
- External research projects
- Studies performed by other agencies on park or adjacent lands
- Resource impact evaluations related to park planning and compliance
- Resource management and restoration work

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

For example, all natural resource parks need a basic suite of resource inventory data in order to manage their resources and support a successful monitoring program. The national Inventory and Monitoring Program has determined that a minimum of 12 inventory data sets, including both biotic and abiotic components, should be acquired by all parks. The NCPN is working with individual parks and national NPS programs to acquire and standardize these basic resource data sets, and make them widely available.

Prioritizing data management efforts in a sea of unmanaged data

- *Highest priority is to produce and curate high-quality, well-documented data originating with the Inventory and Monitoring Program*
- *As time and resources permit, assist with data management for current projects, legacy data, and data originating outside the Inventory and Monitoring Program that complement program objectives*
- *In addition, help ensure good data management practices for park-based natural resource projects that are just beginning to be developed and implemented*

The data sets are:
- Natural resource bibliography
- Base cartographic data
- Geology map
- Soils map
- Weather data
- Air quality data
- Location of air quality monitoring stations
- Water body location and classification
- Water quality data
- Vegetation map
- Species distribution and status of vertebrates and vascular plants
- Documented species list of vertebrates and vascular plants.

6.4. Data Management Categories

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

1. Data managed in service-wide databases.
The NCPN uses three databases developed by the I&M Washington Office (WASO). NatureBib is a bibliographic tool for cataloging reports, publications, or other documents that relate to natural resources in park units. Dataset Catalog is used to document primarily non-spatial natural resource-related databases or other data

assemblages. NPSpecies is used by the network to develop and maintain lists of vertebrates and vascular plants in network parks, along with associated supporting evidence.

2. **Data developed or acquired directly by the network as a result of inventory, monitoring, or other projects, and managed by the NCPN.**
   This category includes project-related protocols, field data, reports, spatial data, and associated materials such as field forms and photographs provided to the NCPN by contractors or developed by NCPN staff. Projects can be short-term (one to three years long) or long-term (ongoing monitoring).

3. **Data that, while not developed or maintained by the NCPN, are used as primary data sources or provide context to other data sets.**
   Examples include: GIS data developed by parks, other agencies or organizations; national or international taxonomic or other classification systems; climate, air quality, or hydrologic data collected or assembled by regional or national entities.

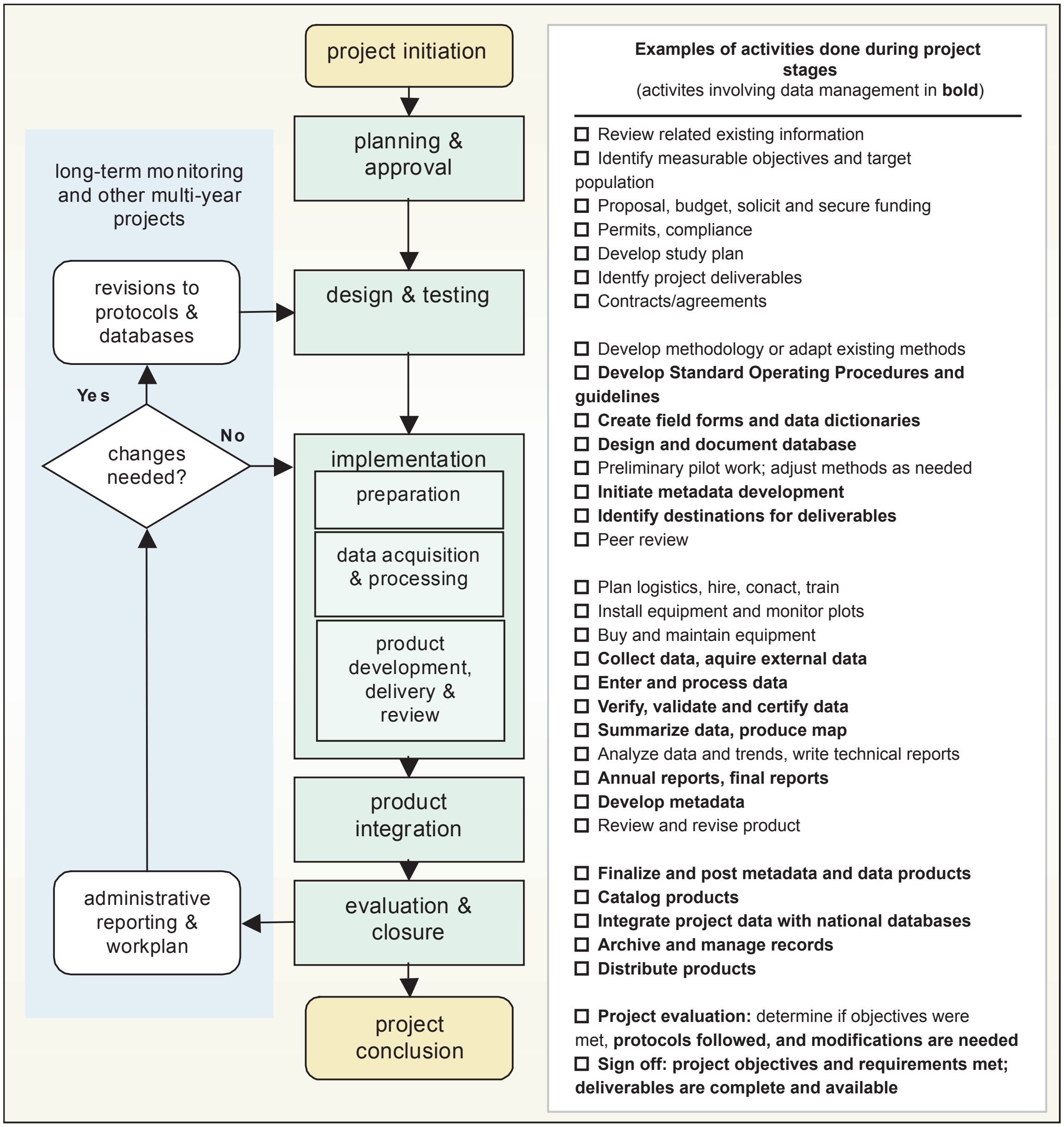
4. **Data acquired and maintained by network parks that the NCPN helps manage.**
   Because of the lack of data management expertise in many network parks, the NCPN provides data management assistance for high-priority data sets or those that may benefit from standardized procedures. Examples include a multi-park database for rare plant data, data sets of legacy natural resource monitoring data, and data on exotic invasive plants.

These above categories can contain one or more of the following data formats:
- Hard-copy documents (e.g., reports, field notes, survey forms, maps, references, administrative documents)
- Physical objects (e.g., specimens, samples, photographs, slides)
- Electronic text files (e.g., Word files, e-mail, websites)
- Electronic tabular data (e.g., databases, spreadsheets, tables, delimited files)
- Spatial data (e.g., shapefiles, coverages, remote-sensing data)
- Miscellaneous electronic files (images, sounds, other files with proprietary formats)

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

6.5. Data Management and the Project Life Cycle

Inventory and monitoring projects are typically divided into seven broad stages: initiation, planning and approval, design and testing, implementation, product integration, evaluation and closure, and conclusion (Fig. 6-1). During all stages, data management staff collaborate closely with project leaders and participants.



Examples of activities done during project stages
(activites involving data management in **bold**)

☐ Review related existing information
☐ Identify measurable objectives and target population
☐ Proposal, budget, solicit and secure funding
☐ Permits, compliance
☐ Develop study plan
☐ Identfy project deliverables
☐ Contracts/agreements

☐ Develop methodology or adapt existing methods
☐ **Develop Standard Operating Procedures and guidelines**
☐ **Create field forms and data dictionaries**
☐ **Design and document database**
☐ Preliminary pilot work; adjust methods as needed
☐ **Initiate metadata development**
☐ **Identify destinations for deliverables**
☐ Peer review

☐ Plan logistics, hire, conact, train
☐ Install equipment and monitor plots
☐ Buy and maintain equipment
☐ **Collect data, aquire external data**
☐ **Enter and process data**
☐ **Verify, validate and certify data**
☐ **Summarize data, produce map**
☐ Analyze data and trends, write technical reports
☐ **Annual reports, final reports**
☐ **Develop metadata**
☐ Review and revise product

☐ **Finalize and post metadata and data products**
☐ **Catalog products**
☐ **Integrate project data with national databases**
☐ **Archive and manage records**
☐ **Distribute products**

☐ **Project evaluation:** determine if objectives were met, **protocols followed, and modifications are needed**
☐ **Sign off: project objectives and requirements met; deliverables are complete and available**

Figure 6-1. Model of data lifecycle stages and associated activities for the Northern Colorado Plateau Network

Specific data management procedures correspond to these stages and are fully detailed in the chapters of the Data Management Plan (Appendix Q). Building upon the data management framework presented in Chapters 1 through 4 of the Data Management Plan, Chapter 5 is devoted to data acquisition and processing. Chapter 6 provides a framework for verifying and validating data that have been collected and entered into databases. Dataset documentation is the subject of Chapter 7, reporting in Chapter 8, and data dissemination, including issues such as data ownership, data sensitivity, and compliance with the Freedom of Information Act, are addressed in Chapter 9. Chapter 10 provides a framework for the long-term maintenance, storage, and security of NCPN data.

For monitoring projects, extensive protocol Standard Operating Procedures (SOPs) provide detailed guidance on all stages of a project's data lifecycle. These SOPs are specific to each project, yet all fall within the guidelines established in the Data Management Plan.

6.6. Water Quality Data

The water quality component of the Natural Resource Challenge requires that networks archive all water quality data collected as part of the monitoring program in a STORET (STOrage and RETrieval) database maintained by the NPS Water Resources Division (WRD). NCPN has developed an MS-Access database (NCPN H_2O) that consolidates water quality data collected in and near the 16 NCPN park units. Associated with this database are water quality standards assessment tools that allow comparisons of historical and current data with applicable state standards. NCPN will maintain this database and integrate new data so it can serve as an ongoing tool for the network's long-term water quality monitoring and analysis needs.

On an annual basis, the NCPN will compile and format new water quality data from NCPN H_2O into an electronic data deliverable (EDD) that is compatible with WRD-STORET. WRD will ensure that content is transferred to the Environmental Protection Agency's STORET database (Figure 6-2).

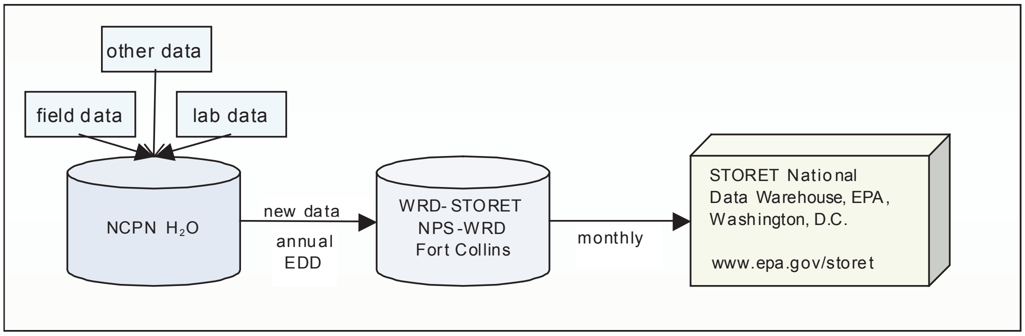


Figure 6-2. Simplified data flow diagram for water quality data.

6.7. Data Management Plan Maintenance

The NCPN approach is to maintain a Data Management Plan that is useful to a broad audience and can provide guidance on data management practices at a number of levels. The NCPN will keep the plan simple, flexible, and evolving, and include data users in the decision-making process whenever possible.

The document has undergone an initial prescribed review process that included both an internal network review (i.e., by members of the technical committee and network staff), and a service-wide review that involves the regional data/GIS coordinator and data management staff from the WASO I&M Program. External reviewers from other agencies are also sought to provide a more balanced and comprehensive review.

The NCPN will update the plan to ensure that it reflects accurately the network's current standards and practices. Recommendations for changes can be forwarded to the network data manager by any interested party or user of network inventory and monitoring data (e.g., park resource managers, project leaders, technicians, superintendents, external users). These recommendations will be discussed by data management and network staff who will decide what actions to take. Simple changes can be made immediately in the document, while substantive changes will be made during updates. Plan updates will be distributed to members of the network Technical Committee before implementation. Otherwise, the plan will be scheduled for a full revision and review at a minimum of every five years.

The most current version of the plan is available on the NCPN website (www.nature.nps.gov/im/units/ncpn/).

Chapter 7

Data Analysis and Reporting

Disseminating results in a useable format for managers and a wide audience is central to the success of the Northern Colorado Plateau Network (NCPN) monitoring program. Proposed reports of the NCPN monitoring program are listed in Table 7-1, and summarized below.

7.1. Administrative and Protocol Development Reports

An annual Administrative Report & Work Plan addresses aspects of program implementation, and is required to satisfy national reporting requirements (Table 7-1, I). Protocol development and pilot testing by cooperators will continue for at least two more years. Their reports will serve as a record of decision for protocol design (Table 7-1, II).

7.2. Protocol Review and Program Review Reports

The efficacy of monitoring procedures and overall program effectiveness will be assessed throughout the monitoring program and documented in two types of reports. Reviews of each protocol are documented in the Protocol Review Report (Table 7-1, III). Reviews of protocol design early in the program are important to correct initial design flaws. Reviews over time will ensure continued refinement of protocols. A protocol review emphasizes implementation, effectiveness, and data management. The Program Review Report (Table 7-1, IV) documents operations and program effectiveness. Program operations will be assessed on adherence to the monitoring schedule and budgetary allocations, meeting reporting requirements, and maintaining productive relationships with NCPN park units and regional network staff, among other factors. Program effectiveness is measured in terms of how well monitoring results are communicated to target audiences and how useful the results are to decision makers. The program review motivates adjustments to better satisfy overall program goals and objectives. Criteria used in protocol reviews, and the effectiveness portion of the program review are summarized in Table 7-2. The NCPN envisions distributing the criteria for protocol reviews as a checklist to NCPN staff for recording issues or problems as they arise. The Protocol Review Report will be based on the annual summary of checklist entries. Information on program effectiveness will be determined by responses to questionnaires sent to park superintendents and resource-management staff. Both types of reports provide a general record of protocol and program evolution, and key information on monitoring and program performance.

7.3. Annual Protocol Reports and Comprehensive Analysis and Synthesis Reports

Two reports document monitoring data collection, analyses, and interpretation. Annual reports for each protocol provide a general accounting of yearly monitoring activities, issues and problems as they arise, and a status summary of measured indicators (Table 7-1, V, VI). Detailed trend analyses and syntheses will be conducted every three to five years, and reported in the Comprehensive Analysis and Synthesis Reports (Table 7-1, VII, VIII). The comprehensive reports will include park- and network-level assessments. Park-level assessments will emphasize detecting and interpreting trends in individual vital-sign measures, and in interactions among drivers/stressors and responses measured at similar scales and across multiple scales. The latter, for example, will consider the role of broad-scale landscape pattern or coarse-scale air quality measures on plot-based measures such as upland vegetative structure. Where evidence of resource degradation exists, mitigation measures will be recommended. Network-level assessments will compare status (e.g., number of species and visitors, areal extent of patch types per time unit) and trends of vital-sign measures among NCPN park units with qualitative summaries and quantitative (where possible) methods. Comparisons with regional networks also will be considered. The latter will depend on the availability of commensurate measures. Currently, the NCPN and the Southern Colorado Plateau Network (SCPN) are coordinating the development and use of several protocols. Status and trend comparisons with at least the SCPN are anticipated. A summary of proposed data analyses by vital sign is provided in Table 7-3.

The annual and comprehensive reports will be written at a general level, but will be thorough. To communicate results to a wider audience, the reports will be rendered to brief narratives highlighting key findings, and where applicable, management recommendations (Table 7-1, VI, VIII). The abbreviated versions will target park superintendents and interpretation staff. Further rendering of the abbreviated reports will provide information suitable for dissemination to the general public (e.g., one- to two-page pamphlets). All versions of these reports will be readily available to accommodate different levels of information needs.

7.4. Presentations, Workshops, Publications

Monitoring results, methods, and topical issues will be communicated to resource managers from various agencies and to external scientists through presentations at management-oriented meetings, professional meetings, and in scientific publications (Table 7-1, IX, X). Meeting participation affords the opportunity to openly discuss results and issues of the monitoring program and fosters productive interactions with others involved in monitoring. The publication of proceedings and scientific articles contributes to quality assurance of the program in the form of peer review of methods and data interpretation, and aid in validating program rigor.

7.5. Other

The State of The Parks report card (Table 7-1, XI) is an initiative of the National I&M Program. Monitoring data from the NCPN will contribute to this effort.

The NCPN website will serve as a centralized repository for all finalized, reviewed reports (Table 7-1, XII).

Table 7-1. Summary of proposed reports, NCPN.

Type of report	Purpose of Report	Primary Audience	Frequency	Initiator	Review Process
I. Annual Administrative Report & Work Plan	Account for funds and FTEs expended. Describes objectives, tasks, accomplishments, products of the monitoring effort. Improves communication within park, network, and region.	Superintendents, technical committee, network staff, regional coordinators, and service-wide program managers; Admin. Report used for annual report to Congress	Annual, due to WASO (Washington Office) by Nov. 8	Network coordinator	Reviewed and approved by I&M Regional Coordinator and service-wide Program Manager
II. Reports for Specific Protocol Development and Pilot Projects	Provides background and methods of protocol development and enhancements. Provides record of decision for protocol design. Documents pilot study results.	Network staff	Annual reports from FY05-07 with project-specific due dates, thereafter variable depending on needs	Network coordinator and ecologist	Peer reviewed at network level
III. Protocol Review Reports	Documents efficacy of protocols: 1. Implementation: Documents what is actually feasible to implement compared to what was specified. 2. Effectiveness: Documents minimum change detection levels, and compares to expected detection levels. 3. Data Management: Documents compliance with standards for data entry, QA/QC, retrieval, and archiving. Documents: 1. where actual procedures fall short of stated expectations; 2. recommendations for necessary changes and; 3.) changes to protocols that were implemented since the last Protocol Review Report.	Superintendents, park resource managers, network staff, service-wide program managers, external scientists	Within 1-3 years of protocol implementation, thereafter every 5 years by February	Network coordinator, ecologist, data manager	Peer reviewed at network and regional level

Table 7-1. continued

Type of report	Purpose of Report	Primary Audience	Frequency	Initiator	Review Process
IV. Program Review Report	Documents formal review of operations and products, including: 1. the effectiveness of reports and other network venues in communicating results to all audiences . 2. the use of results in management decision making; and 3. the ability to engage external scientists in data sharing or designing complementary resource-monitoring studies.	Superintendents, park resource managers, network staff, service-wide program managers, external scientists	5-year intervals	Network coordinator, ecologist, data manager	Peer reviewed at regional or national level, NCPN Board of Directors, Technical Committee
V. Annual Reports for specific protocols	Documents monitoring activities for the year including: 1. numbers of samples by park and relevant attributes (e.g., ecological sites or riparian types); 2. related data management activities (data base updates, QA/QC); and 3. changes in monitoring protocols. Describes status of the resource. Communicates monitoring efforts and results to resource managers.	Park resource managers, network staff; external scientists	Annual, distributed to park resource managers by February	Network coordinator, ecologist, data manager	Peer reviewed at network level
VI. Summary of Annual Reports for specific protocols.	Same as Annual Reports, but summarized to highlight key points.	Park superintendents, general public	Annual, distributed by February	Network coordinator	Peer reviewed at network level
VII. Comprehensive Analysis and Synthesis Reports	Park Level: Describes and interprets trends of individual vital-sign measures. Describes and interprets relationships among vital-sign measures, including relationships between drivers/stressors and responses measured at commensurate scales and measured at multiple scales. Network Level: Describes and interprets trends in vital-sign measures in the context of the Network and of the region (using information from other networks). Highlights resources in need of management action, and documents recommended types of actions.	Park resource managers, network staff, external scientists	Every 3-5 yrs for all monitored vital signs, due by March	Network coordinator and ecologist	Peer reviewed at the network level

Table 7-1. continued

Type of report	Purpose of Report	Primary Audience	Frequency	Initiator	Review Process
VIII. Summary of Comprehensive Analysis and Synthesis Reports	Same as Comprehensive Analysis and Synthesis Reports, but summarized to highlight key findings and recommendations.	Park superintendents, Interpretation staff, general public	Commensurate with reporting frequency of Comprehensive Report (OK as was)	Network Coordinator and Ecologist	Peer reviewed at the network level
IX. Symposia, workshops, and conferences	Reviews and summarizes information on a specific topic or subject area. Communicates latest findings to peers. Identifies emerging issues and generates new ideas.	Resource managers of National Park Service and other federal and state agencies, network staff, external scientists	Variable, opportunities include: Bi-annual at the Colorado Plateau Science Conference; every 3-5 yrs at the Colorado Plateau Cluster superintendent's meeting, and professional meetings	Network coordinator, ecologist, data manager	May be peer reviewed by editor if written papers are published
X. Scientific journal articles and book chapters	Documents and communicates advances in knowledge.	External scientists, park resource managers, network staff	Variable	Network coordinator, ecologist, data manager	Peer reviewed by journal or book editor
XI. State of the Parks Report	Describes current conditions of park resources. Reports interesting trends and highlights of monitoring activities. Identifies situations of concern. Explores future issues and directions.	Congress, budget office, NPS leadership, superintendents, general public	Annual	Compiled by WASO from data provided by networks	Peer reviewed at national level
XII. Web	Centralized repository of all final reports in I-XI to ensure products are easily accessible in commonly-used electronic formats.	Park superintendents, resource managers and biologists, network staff, service-wide program managers, external scientists, general public	After a report is reviewed	Network coordinator, ecologist, data manager	Only reviewed, finalized products will be posted

Table 7-2. Summary of analyses for protocol and program reviews.

Review	Analyses	Analyst
Protocol Reviews	Reviews will be driven by the following questions which will be answered using empirical results and from operational experience. Implementation: 1) Is the protocol clear? 2) Are data collection methods as efficient as possible? 3) Do data forms capture all of the measurements? 4) Is requisitioned equipment sufficient? 5) Were as many samples measured as planned? 6) Do all sampled plots satisfy the sampling frame and design specifications? Effectiveness: 1) Is the number of sample sizes sufficient to satisfy the minimum detectable change levels (i.e., is actual and expected variance the same? Were errors made when deriving sample-size needs?). 2) Are measures at spatial and temporal resolutions sufficient for proposed assessments among indicators? 3) Is "early warning of abnormal conditions" provided (i.e., is the minimum detectable change sufficient to alert management before substantive degradation of a natural resource)? 4) Do external data help interpret status and trends? If so, can these observations be included in the monitoring program? Data Management: 1) Are data management procedures followed? 2) Do QA/QC procedures ensure error-free, quality data? 3) Are electronic data secure from loss or corruption? 4) Are electronic data stored in current versions of commonly-used software? 5) Are data archived on a regular and appropriate schedule? 6) Are archived data easily accessible? 7) Does documentation ensure proper interpretation of data by a broad range of users?	Network staff
Program Review-effectiveness	The effectiveness of the monitoring program will be ascertained from questionnaire responses sent to park superintendents and resource managers. At a minimum, the following questions will be included: 1) Are monitoring results summarized and communicated in a useful fashion? 2) Are managers learning about the status and trends of indicators in a way that helps them make better decisions? 3) Are minimum change detection levels sufficient to meet park-management needs?	Network staff

Table 7-3. Summary of data analyses by vital sign.

Vital Sign	Proposed Analyses	Analyst
Air Quality Vital Signs (ozone, wet and dry deposition, visibility and particulate matter)	Status: Monthly and annual means of air quality parameters for each station in a park. Comprehensive Analysis and Syntheses: Trend analyses of major ions (wet dep.), particulates (P_{10}, $P_{2.5}$), (b_{ext}),N_{100}, and number of days with exceedances for O_3; qualitative comparisons of trends among NCPN park units, and with regional trends.	Network ecologist designs summary procedures. Data management staff implement procedures and generate report. Network ecologist implements comparison procedures, interprets results, and produces report.
Aquatic Macroinvertebrates	Status: Mean and variance of measured attributes; park-level inference of monitored attributes. Comprehensive Analysis and Syntheses: Regression-based trend analysis of each measure using frequentist and Bayesian methods; correlative analyses of trend slopes of measures with those of riparian and water-quality measures, and with broader-scale measures such as localized landscape structure, and climate (2-4 km grain) measures; qualitative and quantitative comparisons of status and trends among streams or among NCPN park units, and among other regional networks.	Network ecologist designs and implements summaries and analyses, interprets results, and produces reports.
Climate	Status: Monthly and annual means of climatic parameters for each climate station in a park; number of days above 95th percentile and below 5th percentile of air temperature and precipitation, number of days below freezing. Comprehensive Analysis and Syntheses: Identification of climatic extremes by descriptive comparisons of current-year climatic parameters with historical trends and distributions on a yearly, monthly, and daily basis; qualitative and quantitative comparisons of annual conditions and trends, and climatic extremes among NCPN park units and with regional trends.	Network ecologist designs status procedures. Data management staff implements procedures, generates report. Network ecologist designs and implements comparison procedures, interprets results, and produces report. Comparison procedures also codified by IT specialist as a NCPN web-based application that allows park staff to perform custom analyses.
Fine-scale disturbance –airborne remote sensing	Status: Summary of land area with recent disturbance, by disturbance type (trampling, trail, and campsite) if possible. Comprehensive Analysis and Syntheses: Regression-based trend analysis of percent disturbed land area; correlation of trends with broader-scale landscape structure, proximity to developed areas; qualitative and quantitative comparisons of status and trends among NCPN park units and among other regional networks.	Remote-sensing cooperator performs interpretation of imagery. Network ecologist designs and implements summaries and analyses, interprets results, and produces reports.
Riparian Vital Signs (stream/wetland hydrologic function, groundwater dynamics, surface water dynamics, riparian plant communities)	Status: Mean and variance of measured attributes; park-level inferences of monitored attributes. Comprehensive Analysis and Syntheses: Regression-based trend analysis of each vital-sign measure using frequentist and Bayesian methods; correlative analyses of trend slopes among riparian vital-sign measures (incl. micro-climate), and with broader-scale measures such as localized landscape structure, interpolated climate (2-4 km grain) measures; qualitative and quantitative comparisons of status and trends among NCPN park units, and among other regional networks.	Network ecologist designs and implements summaries and analyses, interprets results, and produces reports.

Table 7-3. continued

Vital Sign	Proposed Analyses	Analyst
Upland Vital Signs (biological soil crust, upland soil/site stability, upland hydrologic function, upland nutrient cycling, native grassland communities, shrubland communities, predominant plant communities)	Status: Mean and variance of vital-sign measures; park-level inferences of monitored attributes Comprehensive Analysis and Syntheses: Regression-based trend analysis for each vital-sign measure using frequentist and Bayesian methods; correlative analyses of trend slopes among upland vital-signs measures (incl. micro-climate), and with broader-scale measures such as localized landscape structure, interpolated air-quality and climate (2-4 km grain) measures; qualitative and quantitative comparisons of status and trends among NCPN park units, and among other regional networks.	Network ecologist designs and implements summaries and analyses, interprets results, and produces reports.
Invasive Plants	Status: numbers of newly detected exotic plants (or patch size) and locations; summaries (no. of stems or patch size) by species; annual trend in extent or population size of target populations Comprehensive Analysis and Syntheses: Spatial pattern analysis of early detections (correlative analyses with bio-physical features, regression analysis using similar factors and interpreted using AIC criterion [Information-Theoretic methods]); Regression-based trend analysis in area or number of detections of newly detected/established exotic plants, where possible; qualitative and quantitative comparisons of trends among NCPN park units and among other regional networks, where possible.	Status and trend analyses performed by park staff. Network Ecologist assembles results and produces Network- and region-wide summary reports, where applicable.
Land Birds - collaboration with Rocky Mt. Bird Observatory	Status: Number of observations and density by species, by habitat type Comprehensive Analysis and Syntheses: Regression-based trend analysis of breeding-bird density, and comparison of trends among ecological regions, management units (NCPN park units vs. others), and habitats; correlation of NCPN trends with habitat conditions and climatic parameters.	Rocky Mt. Bird Observatory (RMBO) analyst
Land Condition – coarse scale using MODIS-NDVI	Status: Annual trend in MODIS-NDVI and seasonally integrated NDVI Comprehensive Analysis and Syntheses: Quantitative comparisons of seasonally-integrated NDVI of landscape parcels among years (ANOVA, regression-based trend analyses); quantitative comparisons of changes in integrated NDVI among NCPN park units and other regional networks.	Network ecologist designs and implements summaries and comparison methods, interprets results, and produces reports.

Table 7-3. continued

Vital Sign	Proposed Analyses	Analyst
Land Cover, Landscape Connectivity and Fragmentation, Fire Dynamics, Insect/Disease Outbreaks – medium scale census using satellite imagery (e.g., Landsat, Aster)	Status: Measures of landscape structure (composition, configuration, and connectivity) on the basis of land-cover types (from classified satellite imagery) and derived with FRAGSTATS (McGarigal and Marks 1995). Landscape-structure components resulting from fire and insect/disease highlighted to track status of disturbance-regime attributes. Comprehensive Analysis and Syntheses: Change detection among years using spectral comparison methods; quantitative comparison (possibly repeated-measures ANOVA, regression-based trend analysis) of changes in landscape-structure metrics (for land-cover classes) within and adjacent to park units; correlation of adjacent-land changes with proximate changes in park units; correlation of broad-scale climate and air quality with changes in landscape structure; qualitative and quantitative comparisons of landscape-structure status and trends among NCPN park units and among other regional networks.	Remote-sensing cooperator performs change detection and classification of imagery. Network ecologist generates landscape metrics, designs and implements summaries and comparison procedures, interprets results, and produces reports.
Land Use	Status: Amount of area affected by land-use activity, by ownership, by distance from park boundary; for non-point source information, tallies of activity levels (e.g., number of well-drilling permits by county). Comprehensive Analysis and Syntheses: Quantitative or qualitative assessment of trends for individual land-use activities, where applicable; spatial-pattern assessment of land-use activities, where possible; correlation analyses between land-use and vital-sign measures logically responsive to specific land-use activities; qualitative and quantitative comparisons of status and trends in land-use activities among NCPN park units or sub-regional extents within the NCPN, and among other regional networks.	Network ecologist designs and implements summaries and analyses, interprets results, and produces reports.
Springs, Seeps, and Hanging Gardens	Status: Mean and variance of measures (spring discharge, water chemistry, vegetative conditions, diversity and abundance of aquatic inverts, measures of human impact). Comprehensive Analysis and Syntheses: Regression-based trend analysis of individual measures with frequentist and Bayesian methods; correlative analyses of trends with measures of human impact, flow regimes, climatic conditions, and broader-scale measures such as localized landscape structure; qualitative and quantitative comparisons of status and trends among NCPN park units and among other regional networks, where possible.	Network ecologist and Vegetation Program manager design and implement summaries and analyses, interpret results, and produce reports.
Threatened & Endangered, Sensitive Plant Species	Status: Summary of demographic and habitat-related measures, by species. Comprehensive Analysis and Syntheses: Regression-based trend analysis of demographic parameters and habitat occupancy at the park unit, network, or regional level; network-wide summary and qualitative comparison of status and trends by species, where applicable.	Status and trend analyses performed by park staff. Network ecologist assembles results and produces network-wide summary report, where applicable.

Table 7-3. continued

Vital Sign	Proposed Analyses	Analyst
Threatened & Endangered, Sensitive (TES) - Peregrine Falcon	Status: Summary of annual or periodic demographic parameters and habitat-related measures, by species. Comprehensive Analysis and Syntheses: Regression-based trend analysis of demographic parameters and habitat occupancy at the park unit, network, or regional level; network-wide summary and qualitative comparison of status and trends by species, where applicable.	Status and trend analyses performed by park staff or analyst of external agency. Network ecologist assembles results and produces network-wide summary, where applicable.
Visitation	Status: Summary of number of visitors by park area Comprehensive Analysis and Syntheses: Regression-based trend analysis of continuous measures of visitation; spatial-pattern assessment of location measures of visitor-use (proximity assessments [spatial correlations with bio-physical features], spatial auto-correlation of trends); network-wide summary and qualitative comparison of trends, where applicable.	Status and trend analyses performed by park staff. Network ecologist assembles results and produces network-wide summary, where applicable.
Water Chemistry	Monthly data review: Quality assurance and control; identify anomalous values indicating need for re-analyzing samples; censor values below method detection limits; flag values exceeding state standards and report to parks. Status (annual summary): Summarize site data by season and tabulate values exceeding, and approaching exceedance of standards (20% or less below the applicable standard); summary tables, histograms, and box and whisker plots to show frequency distribution, median and interquartile ranges (for non-normally distributed data), mean and standard deviation (for normally distributed data), and 95% confidence intervals for means and medians of parameters at each site. Comprehensive analysis and synthesis: Site level trend analysis adjusted for season and flow for individual constituents. Statistical tests include Seasonal Kendall tests for monotonic trends and Seasonal Rank Sum tests for step trends.	Data reviews, annual summaries, and status and trend analysis performed by NCPN hydrologist.

Chapter 8

Administration / Implementation of the Monitoring Program

8.1. Introduction

This section explains the operation and administration of the Northern Colorado Plateau Network (NCPN) monitoring program. It also describes staff and personnel management, oversight committees, key cooperators and review procedures. Staffing discussed below is restricted to those who implement monitoring and associated operations; staff associated with special projects (e.g. vegetation mapping) are not included. The program is in transition from conducting inventories and planning monitoring to the actual implementation of monitoring. Therefore, some of the following discussion is tentative, focusing on proposed alternatives and possibilities rather than final decisions. The NCPN anticipates a major program review in four to five years to resolve some of these uncertainties.

8.2. NCPN Inventory and Monitoring Program Overview

8.2.1. Network Program Location

The NCPN Inventory and Monitoring Program is based at the Southeast Utah Group (SEUG) headquarters in Moab, UT. The program combines prototype and network components of the NPS Service-wide Inventory and Monitoring Program. Some staff are located at Colorado National Monument and Bryce Canyon National Park. It is envisioned that additional staff will be located at other NCPN parks in the future.

The SEUG has been a gracious host to the network, offering much-appreciated administrative, contracting, and personnel support. An additional benefit of this location has been proximity to the USGS - Canyonlands Field Station.

8.2.2. Relationship of NPS Organizational Structure to NCPN I&M

NCPN shares boundaries with five other networks: Southern Colorado Plateau, Mojave Desert, Upper Columbia Basin, Greater Yellowstone, and Rocky Mountain (Fig. 8-1). This creates opportunities for cross-network coordination discussed below in more detail.

The network lies within the Intermountain Region (IMR) of the National Park Service, with headquarters in Denver. Several years ago, IMR organized into three separate administrative clusters to facilitate closer working relationships among parks (Fig. 8-1). The NCPN is primarily located within the Colorado Plateau Cluster and has two parks (BLCA, CURE) within the Rocky Mountain Cluster. Superintendents within these clusters meet periodically and conduct group business meetings.

Figure 8-1. Map showing boundaries of Vital Signs networks, NPS Intermountain Region, and Intermountain Region park clusters.

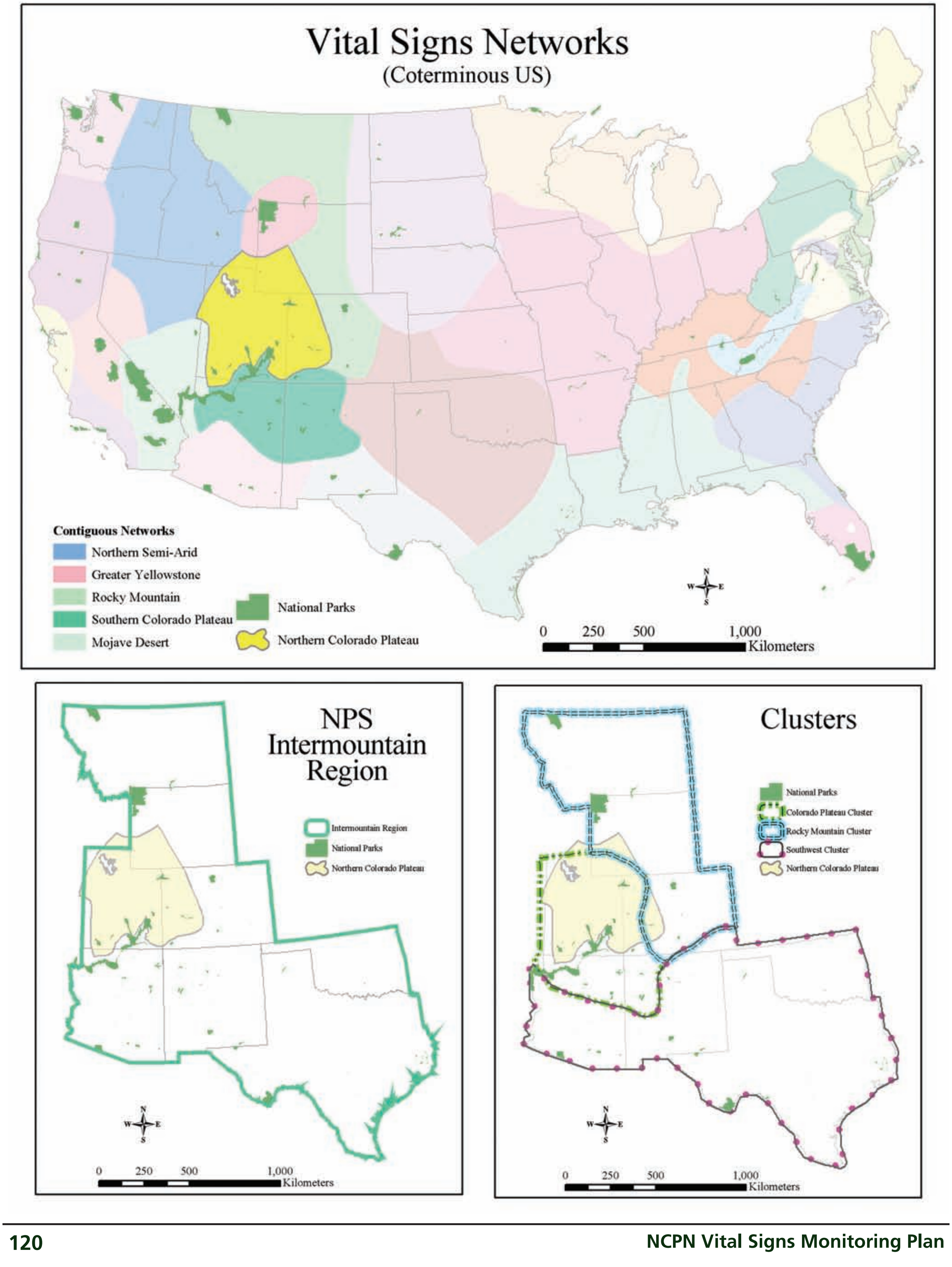


Table 8-1. Membership and responsibilities of the Northern Colorado Plateau Network Board of Directors, Technical Committee and Science Panel.

NCPN Board of Directors

MEMBERSHIP	RESPONSIBILITIES
Five superintendents, chosen by a vote of all network superintendents Chair of NCPN Technical Committee Non-voting: NCPN I&M Program Manager *Ex officio:* Colorado Plateau CESU Leader Rocky Mountain CESU Leader IMR I&M Coordinator	Strategic guidance. Review and approve program budgets, hiring and plans. Ensure accountability of funds. Oversee NEPA compliance & research permits. Serve as program advocates. Help create opportunities to leverage funding. Assist with program integration across other NPS programs. Facilitate internal NPS communication about I&M Program, at all levels. Cultivate external partnerships.

OPERATIONS: One superintendent is elected chair. Members serve in staggered two-year terms. BOD meets in person one or two times a year. Meetings are supplemented by conference calls as needed.

NCPN Technical Committee

MEMBERSHIP	RESPONSIBILITIES
Eight natural resource professionals from the following units: DINO, BLCA/CURE, COLM, SEUG, CARE, BRCA, ZION/CEBR/PISP, and FOBU/GOSP/TICA. NCPN I&M Program Manager. Committee members will be appointed by park superintendents. *Ex officio:* IMR I&M Coordinator	Develop inventory program plans, budgets and hiring proposals. Compile & summarize existing information about park resources. Host scoping workshops. Solicit professional guidance as needed. Prepare annual network reports and work plans. Formulate and prepare network/prototype monitoring plan. Review program periodically. Ensure compliance with federal laws & NPS policy. Work within individual park to develop support for & integration of I&M. Ensure that NCPN I&M program is fully integrated w/individual park resource programs.

OPERATIONS: One member is elected chair for a two-year term. In-person meetings are held two to three times annually.

NCPN Science Panel

MEMBERSHIP	RESPONSIBILITIES
Six members representing a variety of ecological disciplines from academia, federal agencies and non-governmental organizations.	Assist with design and implementation of I&M program. Review network monitoring plans and activities.

OPERATIONS: Meet annually as needed.

8.2.3. Network Organization and Operation

In 2001, superintendents across the NCPN approved a network charter defining the program organization and operational procedures. The charter was revised in 2003 (Appendix R). The charter provides for the establishment of a Board of Directors, Technical Committee, and Science Panel. Responsibilities and composition of these committees are described in Table 8-1 and in the charter.

8.2.4. Staffing

Current staff (not including positions specifically devoted to vegetation mapping) includes six permanent and four term positions (Table 8-2). The NCPN's long-term staffing needs will be indeterminate for several years as it learns more about costs and personnel requirements. A staffing plan describes the duties of three slightly different positions of various tenures (Appendix S). It is important to note that new staff positions are not yet approved. Any new position must be approved by the Board of Directors.

As monitoring is implemented, the NCPN needs to consider options for additional personnel. These will include field data collection personnel and data management personnel.

Location and organization options for positions include:

1. I&M network staff based centrally or in parks
2. NCPN park staff
3. Cooperators or contractors

Several needs must be balanced in choosing how to meet monitoring data collection goals. A more centralized staff model employs dedicated teams to collect data for one or a few vital signs across all parks. This model may lead to more efficient and consistent data collection because the same people collect all data for particular measures. A decentralized model uses park staff to collect data for many vital signs. Some efficiency is gained from reduced travel time. Basing staff in parks increases local awareness and ownership of the monitoring program. Sharing staff positions with NCPN parks might be feasible in other instances. It may increase the value of monitoring data (by using a single team to gather data over a wide geographic area for instance) or be more cost effective to have cooperators conduct monitoring activities. In all but the third option, choices must be made between seasonal or other temporary appointments, term or permanent appointments, and part-time or full-time positions.

NCPN staffing will include a mixture of the options listed above. Cooperators will monitor birds. Water quality monitoring employs a network position located in BRCA, NPS staff at BLCA/CURE and SEUG, plus

USGS WRD cooperators. Initial riparian monitoring will be conducted by USGS BRD. Staffing options for other protocols will be determined later.

Table 8-2. Northern Colorado Plateau Inventory and Monitoring Program staff (As of 6/05)[1].

Northern Colorado Plateau I&M Staff	Location	Appointment
Program Manager GS-13	SEUG	Permanent
Program Ecologist GS-12	SEUG	Permanent
Vegetation Program Manager GS-12	SEUG	Permanent (STF[2])
Data Manager IT-11	COLM	Permanent
Administrative Technician GS-6	SEUG	Permanent
Hydrologist GS-11	BRCA	Term (PT[3])
Cartographic Technician GS-9	SEUG	Permanent (STF)
Biologist GS-9	SEUG	Term
IT Specialist IT-7	COLM	Term
Biological Technician GS-6	COLM	Term

1. *Positions specifically devoted to vegetation mapping are not included.*
2. *Subject to furlough.*
3. *Part time.*

8.2.5. Internal and External Partnerships

Efficient monitoring of natural resources involves internal and external partnerships. Numerous partners have been and continue to be involved in inventorying NCPN park resources and developing monitoring protocols. Below is a list of partners and their roles.

8.2.5.1. Federal

National Park Service

Air Resources Division (ARD)

The ARD coordinates air quality monitoring (ozone, particulates, visibility) for the NPS. The NCPN will rely on ARD data collection and will regularly retrieve and summarize these data for NCPN parks. No agreement is envisioned for this within-NPS arrangement.

U.S. Geologic Survey

Biological Resources Discipline

Canyonlands Field Station (CFS) conducts research to support vital signs monitoring. Investigations of potential ecological indicators, their measurement, and their relationship to ecological processes may continue for several years in prototype parks.

USGS-BRD staff from the Fort Collins Science Center are developing riparian monitoring protocols and will conduct initial monitoring via interagency agreement IAF 1341040004.

Amphibian Research and Monitoring Initiative (ARMI)

Canyonlands Field Station of the USGS-BRD is conducting amphibian monitoring in CANY. NCPN is supporting its effort to adapt the national amphibian monitoring protocol to arid environments.

Water Resources Discipline (WRD)

The NCPN is working with the USGS WRD to develop the water quality monitoring program. The WRD will assist and train network personnel to collect samples and manage data during the first three years of water quality monitoring. Additionally the WRD collects water samples for DINO and analyzes samples for DINO and BLCA/CURE. This work is being done via interagency agreement IA238099002.

USGS-WRD staff from the Utah District Office are developing aquatic invertebrate monitoring protocols via interagency agreement IA F134040005.

Earth Resources Observations Systems (EROS) data center

The USGS EROS data center provides NCPN with MODIS NDVI data for monitoring land condition. It also provides technical assistance to analyze this information.

National Oceanic and Atmospheric Administration, Interagency Fire Center, Natural Resources Conservation Service, MesoWest

NCPN relies on multiple agencies for data from their weather station networks. These networks include the NOAA National Weather Service Cooperative Observing Program and Climate Research Network (CRN), the Remote Automated Weather Stations (RAWS) network supported by the Interagency Fire Center, the SNOpack TELemetry (SNOTEL) and Snow Course network administered by the Natural Resources Conservation Service, and the SNOWNET network (data archived and provided by the Utah State Climatology Center-MesoWest).

8.2.5.2. State

Utah Department of Environmental Quality

Division of Water Quality

In return for NPS commitments to collecting water samples, the Utah Division of Water Quality (DWQ) has agreed to support NCPN water quality monitoring. DWQ will provide training and supplies for sampling, and pay for laboratory analysis of the samples. In return, NCPN agrees to collect monthly samples and follow DWQ procedures.

8.2.5.3. Non-Governmental Organizations

Rocky Mountain Bird Observatory

NCPN has an agreement with Rocky Mountain Bird Observatory (RMBO) to monitor birds in NCPN parks. Using NCPN funding, RMBO has expanded its regional bird monitoring adding 48 sites in three habitats in NCPN parks. This work is being done via cooperative agreement H1341050203.

8.2.6. Integration

8.2.6.4. Integration with the Southern Colorado Plateau Network (SCPN)

The NCPN is working closely with the SCPN to monitor vital signs. Conceptual model development has specifically attempted to integrate both networks. Both networks share many vital signs, and they are collaborating on developing protocols for riparian, uplands, aquatic invertebrates, springs, seeps and hanging gardens, and remote sensing related vital signs.

Two major benefits result from this close relationship. First, the two networks are able to share costs and workload for conceptual model and monitoring protocol development. Second, where the same measures are used, monitoring data will have broader inference than would otherwise be the case. Opportunities are also being sought to collaborate with other adjoining networks.

8.2.6.5. Integration with Other Federal and State Agency Monitoring Programs

NCPN recognizes the importance of developing the monitoring program in cooperation with other federal and state agencies and universities. NCPN will continue to look for ways to partner with the USDA Forest Service (USFS), USDI Bureau of Land Management (BLM), Fish and Wildlife Service (USFWS), USGS and state water quality and natural resource programs.

8.2.6.6. Integration with Other NPS Park Operations

It is a goal of NCPN to serve as a catalyst in linking individual park natural resource programs in a successful integrated Inventory and Monitoring program. Presently, most parks manage their natural resource programs independently and prepare annual proposals to develop their programs. The same or similar resource inventory, monitoring and management work is regularly proposed across network parks, in competing proposals. Evaluating existing and future needs at a network level presents a significant opportunity for parks to begin working together while sharing limited resources. Already NCPN has demonstrated the benefit of leveraging network and park funding to obtain additional financial support for large projects (e.g., vegetation mapping).

NCPN is interested in fostering internal NPS cross-program coordination. Board members are charged with helping facilitate these relationships. Significant opportunity exists to link efforts with interpretation programs in the parks. The NCPN is committed to educating all park staff about the natural resource I&M program. The NCPN developed an internal communications plan in 2002 to address these linkages.

Some examples of how the NCPN will integrate with other park programs include:

1. It will participate in seasonal interpreter training by giving an overview of the I&M program. It will provide specific ways for interpreters and the public to participate; for example, provide information for species needing documentation, locations of invasive plants, etc.
2. It will produce an interpretative program on the state of the ecosystem.
3. It will meet annually with park staff to update them on network activities and opportunities for collaboration.
4. It will produce a quarterly newsletter on network activities.

8.2.6.7. Network (National Environmental Policy Act) NEPA Compliance and Research Permitting

NCPN uses a network-wide approach to conducting NEPA compliance and issuing research permits for network I&M projects. The board of directors drafted an agreement describing procedures for a coordinated research permits process (Appendix T). All 16 NCPN superintendents signed this agreement. This procedure is used for multi-park projects.

8.2.7. Periodic review

Review of the monitoring program will allow adaptive management of its components. Reviews will focus on the program's implementation and its effectiveness in achieving goals. Implementation includes collection, management, quality assurance and quality control, analysis, summarization and reporting of data. The program will be effective when data lead to improved understanding of resource conditions and better-informed management decisions.

Certain types of reviews are part of the annual reporting requirements. For example, the annual administrative report addresses some aspects of implementation. Other reviews, such as those for Standard Operating Procedures for collecting and managing monitoring data, will be incorporated in Protocol Review Reports. Program reviews will occur every five years. Examples of review timing, participants, and purposes were given in Chapter 7, Tables 7.1-2.

8.2.8. Adaptive Management of the Monitoring Plan

The NCPN monitoring plan is subject to change based on monitoring results, budget, program reviews and other factors. Monitoring protocols are still being developed. Monitoring costs are coarse estimates, and decisions have yet to be made regarding numbers and locations of permanent plots and other critical issues. Once finished, these protocols may be revised to accommodate new methods or new understanding based on monitoring results. For example, if a measure is much less variable than originally thought, fewer samples are necessary to reach a desired statistical power. This might save money, which could then be spent on other monitoring activities.

While long-term monitoring is most valuable when it is consistent, the early years of this program should be seen as a time to make adjustments. In the current schedule (Chapter 9), a program benchmark will be reached in 2008 when the final monitoring protocols are implemented. A program review is planned for 2009, providing a major opportunity for course-correction, should one be necessary.

Chapter 9

Schedule

9.1. Schedule for NCPN Monitoring 2005 – 2016

Not all NCPN monitoring activities begin immediately upon completion of this monitoring plan. Development and testing of monitoring protocols will continue through 2007. The schedule below and Table 9-1 portray the NCPN's phased approach.

Monitoring with well-established protocols began in 2005. These include air quality, land birds, climate, and water quality. Vital signs requiring protocol development will take up to two years before implementation. Protocols will continue to be refined during the first several years of implementation.

Some protocol development and testing will be scheduled at the discretion of NCPN parks. For example, some additional monitoring protocols for Threatened and Endangered Species may be developed based on park needs. Implementation of visitation monitoring depends on park funding and management priorities.

Monitoring results also will be reported in phases. As the NCPN collects data, it will prepare annual reports for each monitoring protocol. As data accumulate, reporting will be expanded to include comprehensive analysis and synthesis reports. After the fourth year of monitoring, reports will include trend assessments within park units and network-level summaries and comparisons. Additional details of planned reports were given in Chapter 7.

9.2. NCPN Schedule for Monitoring Implementation

2005 Begin monitoring air quality, climate, land birds.

Begin water quality monitoring at some locations; assess additional sites.

Develop and test methods and sampling approaches for integrated upland, integrated riparian, aquatic macroinvertebrates, land cover, land condition, human demographics and developments, TES plants, invasive plants, and visitor use patterns. Draft monitoring protocols for all of these except land condition and land cover.

2006 Continue monitoring climate, air quality, land birds, water quality.

Begin annual reports.

Develop and test methods and sampling approaches fine-scale disturbance.

Begin monitoring upland, riparian, aquatic macroinvertebrates, human demographics and developments, and invasive plants.

Draft monitoring protocols for land cover, land condition, and fine-scale disturbance.

2007 Develop and test methods and sampling approaches for spring, seep and hanging garden monitoring. Draft monitoring protocol.

Continue monitoring climate, air quality, birds, water quality, upland, riparian, and aquatic invertebrates.

Begin monitoring land condition, land cover and fine-scale disturbance; begin annual reports for upland, aquatic macroinvertebrates, demographics and development, and invasive plants.

2008 Begin monitoring springs, seeps, and hanging gardens.

Continue using all protocols. Begin annual reports for land cover.

2009 Five-year program review.

Continue monitoring all vital signs. Begin annual reports for springs, seeps, and hanging gardens.

First complete network sample for riparian, aquatic macroinvertebrates, fine-scale disturbance monitoring (assuming three-year rotation).

2010 Continue monitoring all vital signs.

First complete network sample for SSHG garden monitoring (assuming three-year rotation).

2011 Continue monitoring all vital signs.

2012 Continue monitoring all vital signs.

Second complete network sample for riparian, aquatic macroinvertebrates, and fine-scale disturbance monitoring.

2013 Continue monitoring all vital signs.

First complete network sample for upland monitoring (assuming a maximum eight year re-sampling interval for integrated upland).

2014 Five-year program review.

Continue monitoring all vital signs.

Table 9-1. Monitoring protocol development and implementation schedule

Level 3	Network Vital Sign	Monitoring protocols	Winter 2004	Spring 2005	Summer 2005	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2008	Spring 2009	Summer 2009	Fall 2009	Winter 2009	Spring 2010	Summer 2010	Fall 2010	Winter 2010	Spring 2011	Summer 2011	Fall 2011	Winter 2011	Spring 2012	Summer 2012	Fall 2012	Winter 2012
Air Quality																																			
Ozone **Wet and dry deposition** **Visibility and particulate matter**	Ozone Wet and dry deposition Visibility and particulate matter	Data collection (continuous)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Climate																																			
Weather and Climate	Climate	Data collection (continuous)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
		Land Birds																																	
Birds	Land bird communities	Plot installation		🟩																															
		Data collection		🟩				🟩				🟩				🟩				🟩				🟩				🟩				🟩			
		Complete network sample		🟩				🟩				🟩				🟩				🟩				🟩				🟩				🟩			
Water Quality																																			
Water Chemistry	Water chemistry	Protocol development																																	
		draft protocol	🟩	🟩																															
		Plot installation			🟩								🟩																						
		Data collection (monthly)			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
		Complete network sample																		🟩															
Integrated Upland																																			
Grassland Vegetation **Shrubland Vegetation** **Vegetation Communities** **Nutrient Dynamics** **Soil Function and Dynamics**	Native grassland communities Shrubland communities Predominant plant communities Upland nutrient cycling Biological soil crusts Upland hydrologic function Upland soil/site stability	Protocol development																																	
		test methods		🟩	🟩																														
		draft protocol					🟩	🟩																											
		Plot installation (complete 2013)						🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Data collection						🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample (2013)																																	

Table 9-1. continued

Level 3	Network Vital Sign	Monitoring protocols	Winter 2004	Spring 2005	Summer 2005	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2008	Spring 2009	Summer 2009	Fall 2009	Winter 2009	Spring 2010	Summer 2010	Fall 2010	Winter 2010	Spring 2011	Summer 2011	Fall 2011	Winter 2011	Spring 2012	Summer 2012	Fall 2012	Winter 2012
Integrated Riparian																																			
Riparian Communities **Surface water dynamics** **Groundwater dynamics** **Stream/River Channel Characteristics**	Riparian plant communities Surface water dynamics Groundwater dynamics Stream / wetland hydrologic function	Protocol development																																	
		test methods		🟩	🟩																														
		draft protocol				🟩	🟩																												
		Plot installation						🟩	🟩			🟩	🟩			🟩	🟩																		
		Data collection						🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample																🟩												🟩					
Aquatic macroinvertebrates																																			
Aquatic	Aquatic macroinvertebrates	Protocol development																																	
		test methods		🟩	🟩																														
		draft protocol				🟩	🟩																												
		Plot installation						🟩	🟩			🟩	🟩			🟩	🟩																		
		Data collection						🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample															🟩												🟩						
Land cover																																			
Insect Pests **Fire and Fuel Dynamics** **Land Cover and Use**	Insect/disease outbreaks Fire dynamics Land cover Landscape connectivity and fragmentation	Protocol development																																	
		develop methods		🟩	🟩	🟩	🟩	🟩	🟩	🟩																									
		draft protocol									🟩	🟩																							
		Data collection											🟩				🟩				🟩				🟩				🟩				🟩		
		Complete network sample																											🟩						
Land condition																																			
Productivity	Land condition	Protocol development																																	
		Develop methods		🟩	🟩	🟩	🟩	🟩	🟩	🟩																									
		Draft protocol								🟩	🟩																								
		Data collection										🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample							🟩				🟩				🟩				🟩				🟩				🟩				🟩		

Table 9-1. continued

Level 3	Network Vital Sign	Monitoring protocols	Winter 2004	Spring 2005	Summer 2005	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2008	Spring 2009	Summer 2009	Fall 2009	Winter 2009	Spring 2010	Summer 2010	Fall 2010	Winter 2010	Spring 2011	Summer 2011	Fall 2011	Winter 2011	Spring 2012	Summer 2012	Fall 2012	Winter 2012
Human Demography and Development																																			
Non-point source human effects	Demographics and development	Protocol development																																	
		draft protocol				🟩	🟩																												
		Data collection						🟩	🟩																			🟩	🟩						
		Complete network sample							🟩																				🟩						
Fine-scale disturbance																																			
Land Cover and Use	Fine-scale disturbance	Protocol development																																	
		test methods						🟩	🟩																										
		draft protocol								🟩	🟩																								
		Data collection										🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample																							🟩										
Springs, Seeps and Hanging Garden Communities																																			
Riparian Communities	Springs, seeps and hanging garden communities	Protocol development																																	
		test methods										🟩	🟩																						
		draft protocol												🟩	🟩																				
		Plot installation														🟩	🟩			🟩	🟩			🟩	🟩										
		Data collection														🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample																						🟩	🟩										
TES plants																																			
T&E Species and Communities	TES plant populations	Protocol development																																	
		draft protocol	🟩	🟩																															
		Pilot data collection			🟩																														
Invasive plants																																			
Invasive/Exotic Plants	Invasive plants	Protocol development																																	
		draft protocol				🟩	🟩	🟩																											
		Plot installation							🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩	
		Data collection							🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩	
		Complete network sample																								🟩									

Table 9-1. continued

Level 3	Network Vital Sign	Monitoring protocols	Winter 2004	Spring 2005	Summer 2005	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007	Spring 2008	Summer 2008	Fall 2008	Winter 2008	Spring 2009	Summer 2009	Fall 2009	Winter 2009	Spring 2010	Summer 2010	Fall 2010	Winter 2010	Spring 2011	Summer 2011	Fall 2011	Winter 2011	Spring 2012	Summer 2012	Fall 2012	Winter 2012
Visitor use patterns																																			
Visitor Usage	Visitor use patterns	Protocol development																																	
		Develop methods			🟩																														
		draft protocol				🟩	🟩																												
		Data collection							🟩	🟩		🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩			🟩	🟩		
		Complete network sample																			🟩														

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Chapter 11

Literature Cited

Allan, J. D. 1995. Stream ecology: Structure and function of running waters. Chapman & Hall, London.

Alward, R. D., J. K. Detling, and D. G. Milchunas. 1999. Grassland vegetation changes and nocturnal global warming. Science **283**:229-231.

Asner, G. P., T. R. Seastedt, and A. R. Townsend. 1997. The decoupling of terrestrial carbon and nitrogen cycles. BioScience **47**:226-234.

Auble, G. T., and M. L. Scott. 1998. Fluvial disturbance patches and cottonwood recruitment along the upper Missouri River, Montana. Wetlands **18**:546-556.

Bain, M. B., J. T. Finn, and H. E. Booke. 1988. Streamflow regulation and fish community structure. Ecology **69**:382-392.

Barrett, W. G., G. M. VanDyne, and E. P. Odum. 1976. Stress ecology. BioScience **26**:192-194.

Belnap, J., and O. L. Lange, eds. 2001. Biological soil crusts: Structure, function, and management. Springer-Verlag, Berlin.

Belnap, J., B. Büdel, and O. L. Lange. 2001. Biological soil crusts: Characteristics and distribution. Pages 3-30 in J. Belnap and O. L. Lange, editors. Biological soil crusts: Structure, function, and management. Springer-Verlag, Berlin.

Bestelmeyer, B.T., J.R. Brown, K.M. Havstad, R. Alexander, G. Chavez and J.E. Herrick. 2003. Viewpoint: issues in the development and use of state and transition models for rangeland management. Journal of Range Management.

Breshears, D. D., J. J. Whicker, M. P. Johansen, and J. E. Pinder, III. 2003. Wind and water erosion and transport in semi-arid shrubland, grassland and forest ecosystems: Quantifying dominance of horizontal wind-driven transport. Earth Surface Processes and Landforms **28**:1189-1209.

Brinson, M. M. 1990. Riverine forests. Pages 87-141 in A. E. Lugo, M. M. Brinson, and S. Brown, editors. Forested wetlands. Elsevier, Amsterdam.

Brinson, M. M., B. L. Swift, R. C. Plantico and J. S. Barclay. 1981. Riparian ecosystems: their ecology and status. U.S. Fish and Wildlife Service Biological Report 81. 155 p.

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake, D. L. Borchers, and L. Thomas. 2001. Distance Sampling, Oxford University Press, Oxford.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. The American Naturalist **148**:1016-1037.

Chapin, F. S., III, B. H. Walker, R. J. Hobbs, D. U. Hooper, J. H. Lawton, O. E. Sala, and D. Tilman. 1997. Biotic control over the functioning of ecosystems. Science **277**:500-504.

Charley, J. L., and N. E. West. 1975. Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems of Utah. Journal of Ecology **63**:945-963.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons and others. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications **6**:665-691.

Cochran, W. G. 1977. Sampling techniques. John Wiley & Sons, N.Y.

Comstock, J. P., and J. R. Ehleringer. 1992. Plant adaptation in the Great Basin and Colorado Plateau. The Great Basin Naturalist **52**:195-215.

Cooke, R.U., and R.W. Reeves. 1976. *Arroyos and environmental change in the American southwest.* Clarendon Press, Oxford, England. 213 p.

Cooper, D.J., D.R. D'Amico, and M.L. Scott. 2003. Physiological and morphological response patterns of *Populus deltoides* to alluvial groundwater declines. Environmental Management **31**:215-226.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics **23**:63-87.

Davenport, D. W., D. D. Breshears, B. P. Wilcox, and C. D. Allen. 1998. Viewpoint: Sustainability of pinyon-juniper ecosystems--a unifying perspective of soil erosion thresholds. Journal of Range Management **51**:231-240.

Dobkin, D. S., A. C. Rich, and W. H. Pyle. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. Conservation Biology **12**:209-221.

Earl, S.R., and D.W. Blinn. 2003. Effects of wildfire ash on water chemistry and biota in South-Western U.S.A. streams. Freshwater Biology **48**:1015-1030.

Edwards, D. 1998. Issues and themes for natural resource trends and change detection. Ecological Applications **8**:323-325.

Ehleringer, J. R., S. Schwinning, and R. Gebauer. 2000. Water use in arid land ecosystems. Pages 347-365 *in* M. C. Press, J. D. Scholes, and M. G. Barker, eds. Physiological Plant Ecology. Proceedings of the 39th Symposium of the British Ecological Society, 7-9 September 1998, University of York. Blackwell Science, Boston.

Evans, R. D., R. Rimer, L. Sperry, and J. Belnap. 2001. Exotic plant invasion alters nitrogen dynamics in an arid grassland. Ecological Applications **11**:1301-1310.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. Northern Colorado Plateau Vital Signs Network and Prototype Cluster, Plan for Natural Resources Monitoring: Phase I Report, October 1, 2002. [Two volumes]. National Park Service, Northern Colorado Plateau Network, Moab, UT. 138 p. plus appendices.

Fenn, M. E., R. A. Haeuber, G. S. Tonnesen, J. S. Baron, S. Grossman-Clarke, D. Hope, D. A. Jaffe, S. Copeland, L. Geiser, H. M. Rueth, and J. O. Sickman. 2003a. Nitrogen emissions, deposition, and monitoring in the western United States. BioScience **53**:391-403.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003b. Ecological effects of nitrogen deposition in the western United States. BioScience **53**:404-420.

Friedman, J.M., G.T. Auble, P.B. Shafroth, M.L. Scott, M.F. Merligiano, M.D. Freehling, and E.R. Griffin. *In press*. Dominance of non-native riparian trees in western USA. Biological Invasions 00:00.

Galloway, J. N., J. D. Aber, J. W. Erisman, S. P. Seitzinger, R. W. Howarth, E. B. Cowling, and B. J. Cosby. 2003. The nitrogen cascade. BioScience **53**:341-356.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology **68**:1364-1372.

Grand Canyon Wildlands Council, Inc. 2002. Inventory of 100 Arizona Strip springs, seeps, and natural ponds: Final Project Report. Arizona Water Protection Fund, Phoenix.

Hereford, R., R. H. Webb, and S. Graham. 2002. Precipitation history of the Colorado Plateau Region, 1900-2000. USGS Fact Sheet 119-02. U.S. Department of Interior, U.S. Geological Survey. (http://geopubs.wr.usgs.gov/fact-sheet/fs119-02/) Accessed 21 November 2004.

Holling, C. S., L. H. Gunderson, and D. Ludwig. 2002. In quest of a theory of adaptive change. Pages 3-22 *in* L. H. Gunderson and C. S. Holling, eds. Panarchy: Understanding transformations in human and natural systems. Island Press, Washington, D.C.

Jackson, R. D., J. W. Bartolome, and B. H. Allen-Diaz. 2002. State and transition models: Response to an ESA symposium. Bulletin of the Ecological Society of America **83**:194-196.

Jacobs, B. F., and R. G. Gatewood. 1999. Restoration studies in degraded pinyon-juniper woodlands of north-central New Mexico.Proceedings: Ecology and management of pinyon-juniper communities within the Interior West. Provo, UT, Proc. RMRS-P-9, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT, 15-18 September 1997.

Jameson, D. A. 1962. Effects of burning on a galleta-black grama range invaded by juniper. Ecology **43**:760-763.

Jenny, H. 1941. Factors of soil formation: a system of quantitative pedology. McGraw-Hill, New York. 281 p.

Jenny, H. 1980. The soil resource: origin and behavior. Springer-Verlag, New York. 377p.

Johnsen, T. N., Jr. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecological Monographs **32**:187-207.

Johnson, W. C. 1992. Dams and riparian forests: case study from the upper Missouri River. Rivers **3**:229-242.

Jorgensen, S. E. 1986. Fundamentals of ecological modeling. Elsevier. New York, New York.

Larcher, W. 1995. Physiological plant ecology. 3rd edition. Springer-Verlag, Berlin.

Lavelle, P. 1997. Faunal activities and soil processes: adaptive strategies that determine ecosystem function. Advances in Ecological Research **27**: 93-132.

Logan, J. A., J. Régnière, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment **1**:130-137.

Lohr, S. L. 1999. Sampling: design and analysis. Duxbury Press, NY.

Mack, M. N., and C. M. D'Antonio. 1998. Impacts of biological invasions on disturbance regimes. Trends in Ecology and Evolution **13**:195-198.

Malanson, G.P. 1993. *Riparian Landscapes*. Cambridge University Press, Cambridge, England.

Mantua, N. J., and S. R. Hare. 2002. The Pacific decadal oscillation. Journal of Oceanography **58**:35-42.

McDonald, T. L. 2003. Environmental trend detection: a review. Environmental Monitoring and Assessment **85**:277-292.

McGarigal, K. and B. J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Dept. Of Agriculture, Forest Service, Pacific Northwest Research Station. 122p.

Michener, W. K., T. J. Baerwald, P. Firth, M. A. Palmer, J. L. Rosenberger, E. A. Sandlin, and H. Zimmerman. 2001. Defining and unraveling biocomplexity. BioScience **51**:1018-1023.

Mitsch, W.J., and J.G. Gosselink. 1993. Wetlands. Second edition. Van Nostrand Reinhold. New York, NY.

Montogmery, D.R and J.M. Buffington. 1998. Channel processes, classification and response. Pages 13-42 in R. J Naiman and B.E. Bilby (eds.), River Ecology and Management, Springer, New York, NY.

Nusser, S. M., F. J. Breidt, and W. A. Fuller. 1998. Design and estimation for investigating the dynamics of natural resources. Ecological Applications **8**:234-245.

Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 *in* D. E. Busch and J. C. Trexler, eds. Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, D.C.

Noss, R. F., E. T. LaRoe, III, and J. M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28. National Biological Service, Washington, D.C. (http://biology.usgs.gov/pubs/ecosys.htm). Accessed December 2004.

Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. Annual Review of Ecology and Systematics **4**:25-51.

NPS. 2001a. Water Quality, Contaminants, and Aquatic Biology Vital Signs Monitoring & Other Park Service Long-Term Aquatic Monitoring Projects. Part A: Identification of priority impaired and pristine waters for the water quality vital signs monitoring component. 11/13/01 DRAFT contribution to the Handbook for Vital Signs Monitoring in National Parks. (Available on-line at http://www1.nature.nps.gov/im/monitor/index.htm). Accessed Dec. 9, 2004.

NPS. 2001b. Management policies, 2001. Department of Interior, National Park Service, Washington, D.C. (http://data2.itc.nps.gov/npspolicy/index.cfm.) Accessed Dec. 9, 2004.

Oakley, K., L. Thomas, S. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin **31**(4): 1000-1003.

Ohmann, J. L. and M. J. Gregory. 2002. Predictive mapping of forest composition and structure with gradient analysis and nearest neighbor imputation in coastal Oregon, USA. Canadian Journal of Forest Research **32**:725-741.

Poff, N. L., and J. D. Allen. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology **76**:606-627.

Romme, W. H., S. Oliva, and M. L. Floyd. 2003. Threats to the piñon-juniper woodlands. Pages 339-360 *in* M. L. Floyd, D. D. Hanna, W. H. Romme, and M. Colyer, editors. Ancient piñon-juniper woodlands: A natural history of Mesa Verde country. University Press of Colorado, Boulder.

Schelz, C. 2002a. Vegetation long-term monitoring – Arches National Park 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT. 216 pp.

Schelz, C. 2002b. Vegetation long-term monitoring – Canyonlands National Park 2002 Annual report, Vol. I-III. Southeast Utah Group, National Park Service, Moab, UT. 216 pp.

Schelz, C. 2002c. Vegetation long-term monitoring – Hovenweep National Monument 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT. 216 pp.

Schelz, C. 2002d. Vegetation long-term monitoring – Natural Bridges National Monument 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT. 216 pp.

Schlesinger, W. H., J. A. Raikes, A. E. Hartley, and A. F. Cross. 1996. On the spatial pattern of soil nutrients in desert ecosystems. Ecology **77**:364-374.

Schlesinger, W. H., J. F. Reynolds, G. L. Cunningham, L. F. Huenneke, W. M. Jarrell, R. A. Virginia, and W. G. Whitford. 1990. Biological feedbacks in global desertification. Science **247**:1043-1048.

Schreuder, H. T., R. Ernst, and H. Ramirez-Maldonado. 2004. Statistical techniques for sampling and monitoring natural resources. USDA Forest Service, Rocky Mountain Research Stn., RMRS-GTR-126.

Schultz, T. T., and W. C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and exclosures. Journal of Range Management **43**:295-299.

Schumm, S.A., and R.W. Lichty. 1963. Channel widening and floodplain construction along Cimarron River in southwestern Kansas. U.S. Geological Survey Professional Paper 352-D.

Scott, M.L., G.C. Lines, and G.T. Auble. 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments **44**:399-414.

Scott, M.L., S.K. Skagen, and M.F. Merligiano. 2003. Relating breeding bird diversity to geomorphic change and grazing in riparian forests. Conservation Biology **17**:284-296.

Skujins, J. 1984. Microbial ecology of desert soils. Advances in Microbial Ecology **7**:49-91.

Smith, S. D., T. E. Huxman, S. F. Zitzer, T. N. Charlet, D. C. Housman, J. S. Coleman, L. K. Fenstermaker, J. R. Seemann, and R. S. Nowak. 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. Nature **408**:79-82.

SRM (Society for Range Management). 1989. Glossary of terms used in range management. 3rd edition, Society for Range Management, Denver.

SRM (Society for Range Management). 1995. New concepts for assessment of rangeland condition. Journal of Range Management **48**:271-282.

Steidl, R., and L. Thomas. 2001. Power analysis and experimental design. Pages. 14-36 *in* Scheiner, S. M. and J. Gurevitch (eds). Design and Analysis of Ecological Experiments. Oxford University Press, NY.

Stevens, L. E., and G. P. Nabhan. 2002a. Hydrological diversity: water's role in shaping natural and cultural diversity on the Colorado Plateau. Pages 33-40 *in* Center for Sustainable Environments, Terralingua, and Grand Canyon Wildlands Council, editors. Safeguarding the uniqueness of the Colorado Plateau: an ecoregional assessment of biocultural diversity. Center for Sustainable Environments, Northern Arizona University, Flagstaff, AZ.

Stevens, L. E., and G. P. Nabhan. 2002b. Biodiversity: plant and animal endemism, biotic associations, and unique habitat mosaics in living landscapes. pp. 41-48 *in* Center for Sustainable Environments, Terralingua, and Grand Canyon Wildlands Council, editors. Safeguarding the uniqueness of the Colorado Plateau: an ecoregional assessment of biocultural diversity. Center for Sustainable Environments, Northern Arizona University, Flagstaff, AZ.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Stringham, T.K., W.C. Krueger, D. R. Thomas. 2001. Application of non-equilibrium ecology to rangeland riparian zones. J. Range Management 54:210–217.

Swetnam, T. W., and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate 11:3128-3147.

U.S. Fish and Wildlife Service. 2003. Monitoring Plan for the American Peregrine Falcon, A Species Recovered Under the Endangered Species Act. U.S. Fish and Wildlife Service, Divisions of Endangered Species and Migratory Birds and State Programs, Pacific Region, Portland, OR.

Vitousek, P. M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos **57**:7-13.

Walker, B. H. 1993. Rangeland ecology: understanding and managing change. Ambio **22**:80-87.

Wardle, D. A. 2002. *Communities and ecosystems: Linking the aboveground and belowground components.* Princeton University Press, Princeton, NJ. 392 pp.

Weltzin, J. F., M. E. Loik, S. Schwinning, D. G. Williams, P. A. Fay, B. M. Haddad, J. Harte, T. E. Huxman, A. K. Knapp, G. Lin, W. T. Pockman, M. R. Shaw, E. E. Small, M. D. Smith, S. D. Smith, D. T. Tissue, and J. C. Zak. 2003. Assessing the response of terrestrial ecosystems to potential changes in precipitation. BioScience **53**:941-952.

Whicker, J.J., D.D. Breshears, P.T. Wasiolek, T.B. Kirchner, R.A. Tavani, D.A. Schoep, and J.C. Rodgers. 2002. Temporal and spatial variation of episodic wind erosion in unburned and burned semiarid shrubland. Journal of Environmental Quality **31**:599-612.

Whitford, W. G. 1996. The importance of the biodiversity of soil biota in arid ecosystems. Biodiversity and Conservation **5**:185-195.

Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego.

Wiens, J. A. 1999. The science and practice of landscape ecology. Pgs. 371-383 in J. M. Klopatek and R. H. Gardner, eds. Landscape Ecological Analysis – Issues and Applications. Springer-Verlag, NY.

Wilcox, B. P., J. Pitlick, C. D. Allen, and D. W. Davenport. 1996. Runoff and erosion from a rapidly eroding pinyon-juniper hillslope. Pages 61-77 *in* M. G. Anderson and S. M. Brooks, editors. Advances in hillslope processes. John Wiley & Sons, NY.

Woodley, S., J. Kay, and G. Francis. 1993. Ecological Integrity and the Management of Ecosystems. St. Lucie Press.

Woodward, A., K. J. Jenkins, and E. G. Shreiner. 1999. The role of ecological theory in longterm ecological monitoring: Report on a workshop. Natural Areas Journal **19**:223-233.

Wright, H. A. 1980. The role and use of fire in the semidesert grass-shrub type. Gen. Tech. Rep. INT-85. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Glossary

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

Attribute: 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.

Biological Significance: An important finding from a biological point of view that may or may not pass a test of statistical significance.

Benthic: occurring at the bottom of a body of water.

Co-location: Sampling of the same physical units in multiple monitoring protocols

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

Degradation: an anthropogenic reduction in the capacity of a particular ecosystem or ecosystem component to perform desired ecosystem functions (e.g., degraded capacity for conserving soil and water resources). Human actions may degrade desired ecosystem functions directly, or they may do so indirectly by damaging the capacity of ecosystem functions to resist or recover from natural disturbances and/or anthropogenic stressors (derived from concepts of Herrick et al. 1995, Ludwig et al. 1997, Whisenant 1999, Archer and Stokes 2000, and Whitford 2002).

Delphi survey: a structured process for collecting and distilling knowledge from a group of experts by means of a series of questionnaires interspersed with controlled opinion feedback.

Disturbance: "...any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985:7). In relation to monitoring, disturbances are considered to be ecological factors that are within the evolutionary history of the ecosystem (e.g., drought). These are differentiated from anthropogenic factors (*stressors,* below) that are outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

Driver: a natural agent responsible for causing temporal changes or variability in quantitative measures of structural and functional attributes of ecosystems.

Ecological indicator: see *indicator.*

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

Ecological site: a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management (Society for Range Management Task Group on Unity in Concepts and Terminology 1995:279).

Ecological sustainability: the tendency of a system or process to be maintained or preserved over time without loss or decline (Dale et al. 2000:642).

Ecosystem: 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: 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 functioning: the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem. Includes many ecosystem processes such as primary production, trophic transfer from plants to animals, nutrient cycling, water dynamics and heat transfer. In a broad sense, ecosystem functioning includes two components: ecosystem resource dynamics and ecosystem stability (Díaz and Cabido 2001).

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

Ecosystem integrity: see *ecological integrity.*

Ecosystem management: 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.

Ecosystem sustainability: see *sustainable ecosystem.*

Edaphic endemic species: species restricted to a particular soil type.

Focal ecosystems: ecosystems that play significant functional roles in landscapes by their disproportionate contribution to the transfer of matter and energy, or by their disproportionate contribution to landscape-level biodiversity (Miller; adapted from definition of *focal species*).

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

Focal species/organisms: species/organisms that play significant functional roles in ecological systems by their disproportionate contribution to the transfer of matter and energy, by structuring the environment and creating opportunities for additional species / organisms, or by exercising control over competitive dominants and thereby promoting increased biological diversity (derived from Noon 2003:37). [Encompasses concepts of keystone species, umbrella species, and ecosystem engineers.]

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

Functional types: sets of organisms sharing similar responses to environmental factors such as temperature, resource availability, and disturbance (= functional *response* types) and/or similar effects on ecosystem functions such as productivity, nutrient cycling, flammability, and resistance / resilience (= functional *effect* types) (Díaz and Cabido 2001).

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

Indicators: a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Inventory: An extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource.

Keystone ecosystems: see *focal ecosystems*.

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

Lentic: relating to, or living in still waters (as lakes, ponds, or swamps).

Lotic: relating to, or living in actively moving water.

Measures: specific feature(s) used to quantify an indicator, as specified in a sampling protocol. For example, pH, temperature, dissolved oxygen, and specific conductivity are all measures of water chemistry.

Metadata: Data about data. Metadata describes the content, quality, condition, and other characteristics of data. It's purpose it to help organize and maintain a organization's internal investment in spatial data, provide information about an organization's data holdings to data catalogues, clearinghouses, and brokerages, and provide information to process and interpret data received through a transfer from an external source.

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

Mycorrhizae: the symbiotic association of the mycelium of a fungus with the roots of a plant.

Orographic: associated with or induced by the presence of mountains.

Protocols: as used by this program, are detailed study plans that explain how data are to be collected, managed, analyzed and reported and are a key component of quality assurance for natural resource monitoring programs (Oakley et al. 2003).

Resilience: the capacity of a particular ecological attribute or process to recover to its former reference state or dynamic after exposure to a temporary disturbance and/or stressor (adapted from Grimm and Wissel 1997). Resilience is a dynamic property that varies in relation to environmental conditions.

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

Saprophytic: obtaining nourishment from the products of organic breakdown and decay.

Secchi: depth depth of visibility as determined by viewing a secchi disc.

Sedimentation: the process of settling.

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

Soil degradation: a decline in soil quality (i.e., decline in a soil's capacity to perform desired ecological functions)

Soil quality: the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al. 1997:6). From an NPS perspective, soil quality is defined by a soil's capacity to perform the following ecological functions: (a) regulate hydrologic processes; (b) capture, retain, and cycle mineral nutrients; (c) support characteristic native communities of plants and animals. Soil quality can be regarded as having (1) an inherent component defined by the soil's inherent soil properties as determined by the five factors of soil formation, and (2) a dynamic component defined by the change in soil function that is influenced by human use and management of the soil (Seybold et al. 1999).

State: as applied to state-and-transition models, a *state* is defined as "a recognizable, resistant and resilient complex of two components, the soil [or geomorphic] base and the vegetation structure" (Stringham et al. 2003:109). These two ecosystem components interactively determine the functional status of the primary ecosystem processes of energy flow, nutrient cycling, and hydrology. States are dynamic and "... are distinguished from other states by relatively large differences in plant functional groups and ecosystem processes [including disturbance and hydrologic regimes] and, consequently, in vegetation structure, biodiversity, and management requirements" (Bestelmeyer et al. 2003:116). (Also see *threshold* and *transition.*)

Stressors: 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.

Sustainable ecosystem: an ecosystem "...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).

Threshold: as applied to state-and-transition models, a *threshold* is a point "...in space and time at which one or more of the primary ecological processes responsible for maintaining the sustained [dynamic] equilibrium of the state degrades beyond the point of self-repair. These processes must be actively restored before the return to the previous state is possible. In the absence of active restoration, a new state ... is formed" (Stringham et al. 2003:109). Thresholds are defined in terms of the functional status of key ecosystem processes and are crossed when capacities for resistance and resilience are exceeded. (Also see *state* and *transition.*)

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

Trend: as used by this program, refers to directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units).

Trophic: of or relating to nutrition.

Turbidity: a measure of opacity.

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

Literature Cited

Archer, S., and C. Stokes. 2000. Stress, disturbance and change in rangeland ecosystems. Pages 17-38 in O. Arnalds and S. Archer, eds. *Rangeland desertification.* Kluwer, Dordrecht.

Barrett, G. W., G. M. Van Dyne, and E. P. Odum. 1976. Stress ecology. *BioScience* 26:192-194.

Bestelmeyer, B. T., J. R. Brown, K. M. Havstad, R. Alexander, G. Chavez, and J. E. Herrick. 2003. Development and use of state-and-transition models for rangelands. *Journal of Range Management* 56: 114-126.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148: 1016-1037.

Costanza, R., M. Mageau, B. Norton, and B. C. Patten. 1998. What is sustainability? Pages 231-239 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health.* Blackwell Science, Malden, MA.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10: 639-670.

Díaz, S., and M. Cabido. 2001. Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution* 16: 646-655.

Elzinga, Caryl L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. BLM Tech. Reference 1730-1. BLM/RS/ST-98/005+1730.

Frid, A., and L. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology* 6: 11. [online] URL: http://www.consecol.org/vol6/iss1/art11

Grimm, V., and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. *Oecologia* 109: 323-334.

Harwell, M. A., V. Myers, T. Young, A. Bartuska, N. Gassman, J. H. Gentile, C. C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. *BioSicence* 49: 543-556.

Herrick, J. E., and M. M. Wander. 1998. Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition and soil biological activity. Pages 405-425 in R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, eds. *Soil Processes and the Carbon Cycle.* CRC Press, Boca Raton.

Karlen, D. L., M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. *Soil Science Society of America Journal* 61: 4-10.

Likens, G. 1992. An ecosystem approach: its use and abuse. *Excellence in ecology, book 3.* Ecology Institute, Oldendorf/Luhe, Germany.

Ludwig, J. A., D. J. Tongway, D. O. Freudenberger, J. C. Noble, and K. C. Hodgkinson, eds. 1997. *Landscape ecology, function and management: principles from Australia's rangelands.* CSIRO Publishing, Collingwood, VIC, Australia.

Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 in D. E. Busch and J. C. Trexler, eds. *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives.* Island Press, Washington, D.C.

Oakley, K. L., L. P. Thomas and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31: 1000-1002.

Pellant, M., P. L. Shaver, D. A. Pyke, and J. E. Herrick. 2000. I*nterpreting indicators of rangeland health.* Version 3. Interagency technical reference TR-1734-6. U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. 188 pp.

Rapport, D. J. 1998. Defining ecosystem health. Pages 18-33 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health.* Blackwell Science, Malden, MA.

Seybold, C. A., J. E. Herrick, and J. J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. *Soil Science* 164: 224-234.

Society for Range Management. 1999. *A glossary of terms used in range management.* Society for Range Management, Denver, CO. 20 pp.

Stringham, T. K., W. C. Krueger, and P. L. Shaver. 2003. State and transition modeling: An ecological process approach. *Journal of Range Management* 56: 106-113.

Whisenant, S. G. 1999. *Repairing damaged wildlands: a process-oriented, landscape-scale approach.* Cambridge University Press, Cambridge.

White, P. S., and S. T. A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. Pages 3-13 in S. T. A. Pickett and P. S. White, eds. *The ecology of natural disturbance and patch dynamics.* Academic Press, San Diego.

Whitford, W. G. 2002. *Ecology of desert systems.* Academic Press, San Diego. 343 pp.