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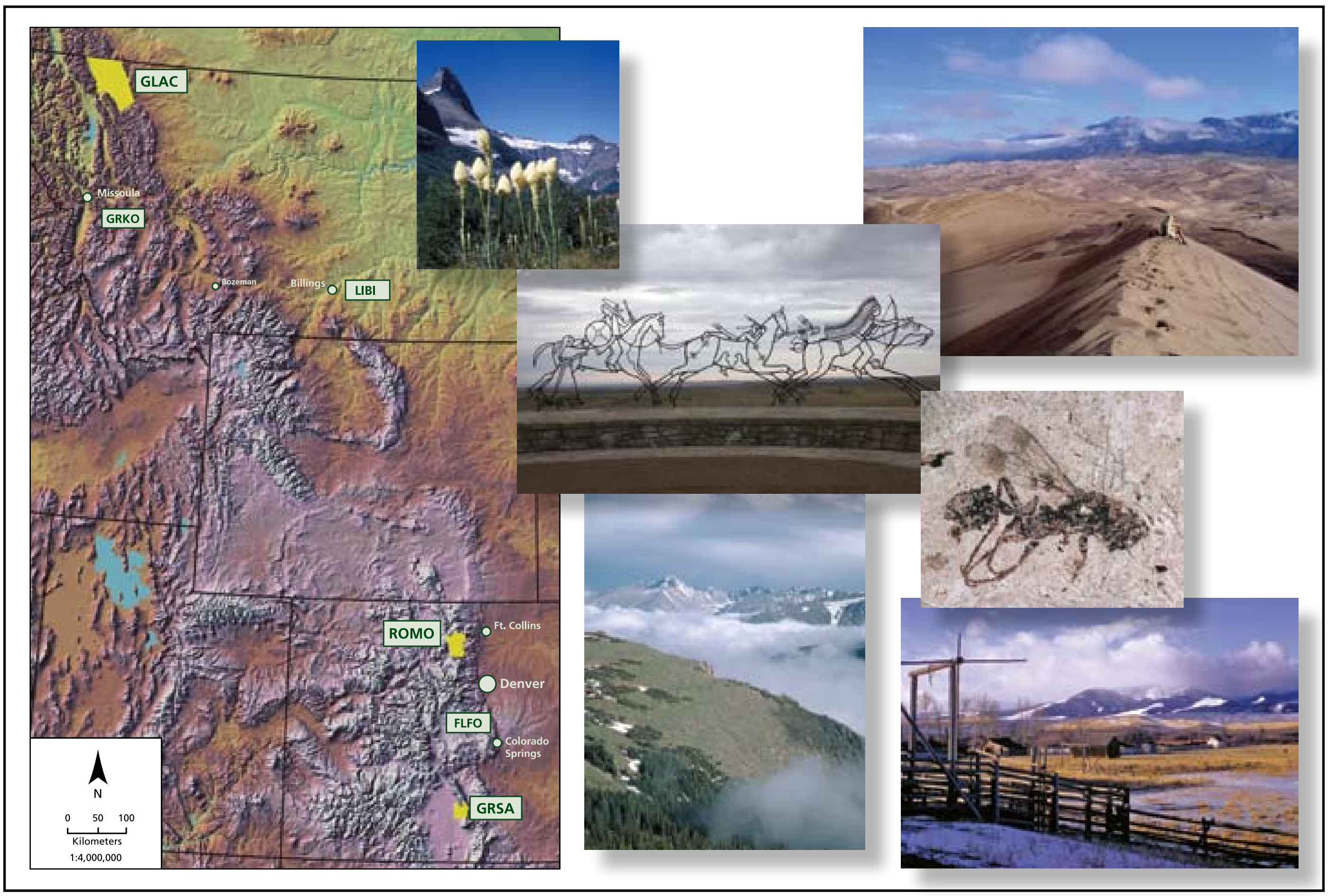
Rocky Mountain Network Vital Signs Monitoring Plan

Natural Resource Report NPS/ROMN/NRR-2007/010



ON THE COVER

Clockwise from top left: Beargrass (*Xerophyllum tenax*), with Mt. Grinnell in the background, Glacier National Park (National Park Service/J. Potter). Indian Memorial, Little Bighorn Battlefield National Monument (NPS). Sand dunes and hiker, Great Sand Dunes National Park and Preserve (NPS). Fossilized wasp, Florissant Fossil Beds National Monument (NPS). Grant-Kohrs Ranch National Historic Site (NPS). Rocky Mountain National Park (NPS).

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All photos in this document are courtesy of the National Park Service unless otherwise noted.

Acronyms

AARWP: Annual Administrative Report and Work Plan

AIC: Akaike's Information Criteria

CASTNET: Clean Air Status and Trends Network

CCRLC: Crown of the Continent Research Learning Center

CDF: Common Data Format

CDRLC: Continental Divide Research Learning Center

CESU: Cooperative Ecosystem Studies Unit

CIRMOUNT: Consortium for Integrated Climate Research in Western Mountains

CNHP: Colorado Natural Heritage Program

CSU: Colorado State University

DOI: U.S. Department of the Interior

EMAP: Environmental Monitoring and Assessment Program

EPA: U.S. Environmental Protection Agency

FGDC: Federal Geographic Data Committee

FLFO: Florissant Fossil Beds National Monument

FTE: full-time equivalent

GLAC: Glacier National Park

GLORIA: Global Observation Research Initiative in Alpine Environments

GPS: Global Positioning System

GRKO: Grant-Kohrs Ranch National Historic Site

GRSA: Great Sand Dunes National Park and Preserve

GRTS: Generalized Random Tessellation Stratified Design

GRYN: Greater Yellowstone Network

HTLN: Heartland Network

I&M: Inventory and Monitoring

IMPROVE: Interagency Monitoring of Protected Visual Environments

IMR: Intermountain Region

INSTAAR: Institute of Alpine and Arctic Research (University of Colorado–Boulder)

KLMN: Klamath Network

LIBI: Little Bighorn Battlefield National Monument

LOADEST: Load Estimator, a FORTRAN program for estimating constituent loads in streams and rivers

LTER: Long-Term Ecological Research site

MMI: multimetric index

MSU: Montana State University

NADP: National Atmospheric Deposition Program

NASA: National Aeronautics and Space Administration

NAWQA: National Water Quality Assessment Program

NCCN: Northwest Coast and Cascades Network

NCPN: Northern Colorado Plateau Network

NDVI: Normalized Difference Vegetation Index

NGO: non-governmental organization

NGPN: Northern Great Plains Network

NLCD: National Land Cover Dataset

NOAA: National Oceanic and Atmospheric Administration

NPS: National Park Service

NPS-ARD: National Park Service Air Resources Division

NPS-WRD: National Park Service Water Resources Division

NRPC: Natural Resource Program Center

NWS: National Weather Service

ONRW: Outstanding Natural Resource Water

PRISM: Parameter-elevation Regressions on Independent Slopes Model

RHESSys: Regional Hydrological Ecosystem Simulation System

RIVPACS: River Invertebrate Prediction and Classification System

RM-CESU: Rocky Mountains Cooperative Ecosystem Studies Unit

ROMN: Rocky Mountain Inventory & Monitoring Network

ROMO: Rocky Mountain National Park

SCPN: Southern Colorado Plateau Network

SIEN: Sierra Nevada Network

SODN: Sonoran Desert Network

SOPN: Southern Plains Network

SPARROW: Spatially Referenced Regressions on Watershed Attributes

SWE: snow–water equivalent

TC: Technical Committee

TMDL: Total Maximum Daily Load

USDA–ARS: U.S. Department of Agriculture–Agricultural Research Service

USFWS: U.S. Fish and Wildlife Service

USGS: U.S. Geological Survey

USGS–WRD: U.S. Geological Survey–Water Resources Division

WASO: Washington-Area Service Office

Executive Summary

The National Park Service (NPS)'s Vital Signs Inventory and Monitoring (I&M) Program was established as part of the Natural Resource Challenge, which called for the NPS to substantially increase the role of science in decision-making, revitalize and expand natural resource programs, gather baseline data on resource conditions, strengthen partnerships with the scientific community, and share knowledge with educational institutions and the public. The purpose of the program is to provide scientifically credible, long-term ecological information for natural resource protection and management through natural resource inventories and monitoring of vital signs of ecosystem health. Having this information will allow park managers and scientists to assess the efficacy of management practices and restoration efforts and receive early warning of impending threats to the resources and systems that the NPS was created to protect. In this way, the I&M program helps the NPS to fulfill its mission "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations."

The Rocky Mountain Network (ROMN) is one of 32 vital signs monitoring networks across the NPS. The ROMN comprises six units: Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), and Little Bighorn Battlefield National Monument (LIBI), Montana; and Florissant Fossil Beds National Monument (FLFO), Great Sand Dunes National Park and Preserve (GRSA), and Rocky Mountain National Park (ROMO), Colorado. The six ROMN parks are located in the central and southern Rocky Mountain Cordillera, roughly along a NNW–SSE axis that follows the Continental Divide. Although this is an extremely diverse region, all six ROMN parks share ecological similarities. These units also have a tradition of working together and are within the same NPS region. The ROMN includes core staff who conduct the day-to-day activities of the ROMN, a Technical Committee that makes recommendations and advises the ROMN, a Board of Directors responsible for program accountability, scientific and technical partners, and Intermountain Region (IMR) and Washington Office (WASO) I&M staff.

This ROMN Vital Signs Monitoring Plan is the foundation of the long-term ecological monitoring program for the network's six parks, and describes the rationale and basis for the program. Chapter 1 provides general background on the national and network program as well as on the ecological and geographical setting of the network parks. This chapter also profiles the individual parks, the network operational framework, and our monitoring perspective and approach. General monitoring goals and objectives can also be found in Chapter 1.

The plan was developed during a three-year planning effort that included park staff and scientific partners from numerous organizations (see Chapter 3 for details). We also worked with other networks and utilized guidance and advice from the IMR and WASO, so our results will provide important, comparable information beyond our parks and network. Our long-term ecological monitoring program is designed to complement, not replace, existing park and other agency monitoring programs.

Our planning effort included identifying and evaluating existing monitoring data and programs as well as conceptual modeling (Chapter 2) of key ecosystem drivers, stressors, and responses to help us identify and prioritize vital signs and design our monitoring protocols. In the future, the models will help us to interpret and communicate monitoring results to park management, our scientific partners, park visitors, and the public. The ROMN used this information and worked with park staffs and partners to identify 62 candidate vital signs and, ultimately, 12 high-priority ROMN vital signs: Wet and Dry Deposition; Weather and Climate; Water Chemistry; Surface Water Dynamics; Freshwater Communities; Invasive/Exotic Aquatic Biota; Groundwater Dynamics; Wet-

ROMN High-Priority Vital Signs

- Wet and Dry Deposition
- Weather and Climate
- Water Chemistry
- Surface Water Dynamics
- Freshwater Communities
- Invasive/Exotic Aquatic Biota
- Groundwater Dynamics
- Wetland Communities
- Invasive/Exotic Plants
- Vegetation Composition, Structure, and Soils
- Focal Species (Beaver, Elk, Grizzly Bear, and GRSA Endemic Insects)
- Landscape Dynamics

land Communities; Invasive/Exotic Plants; Vegetation Composition, Structure, and Soils; four Focal Species (Beaver, Elk, Grizzly Bear, and GRSA Endemic Insects); and Landscape Dynamics. The remaining 50 candidate vital signs are important, and the ROMN will continue to explore cost-effective opportunities to monitor them (see Chapter 3).

To monitor these 12 vital signs, we will develop rigorous, peer-reviewed monitoring protocols and sample designs (Chapter 4) that allow valid inference for an entire ROMN park (wherever possible). Our designs will provide a broad distribution of sample points across the parks, combined with more frequent and detailed monitoring at a few "sentinel sites" in the parks. We hope this approach will optimize our understanding of the status and trend in these vital signs across the parks and the region and across time. Sampling for different vital signs will be co-located in space and time to improve efficiency and depth of ecological understanding. Some protocols will be used to monitor more than one vital sign, and one vital sign may be associated with multiple protocols. We will use existing programs and data wherever available and take advantage of regional applications for many vital signs. We will continue to work with scientific and technical cooperators whenever possible to provide the highest-quality monitoring data and information, and to use ROMN resources in the most cost-effective way.

The ROMN is developing five field-based monitoring protocols (Chapter 5): Stream Ecological Integrity; Wetland Ecological Integrity; Vegetation Composition, Structure, and Soils for Alpine and for Grassland/Shrubland ecosystems (two separate protocols); and Alpine Lake Ecological Integrity. These field protocols will use an integrated approach that focuses on ecological integrity and bioassessment and allows efficient characterization of ecological status and trend. We are developing three data-gathering and reporting protocols: Weather and Climate, Snow Chemistry, and National Atmospheric Deposition Program/National Trends Network (NADP/NTN). We will use ecological modeling to develop an Invasive/Exotic Plants–Early Detection protocol. We will also use existing data for monitoring in the Landscapes Dynamics protocol.

For the Focal Species vital signs, monitoring will be described in other protocols. For example, the GLAC Landscape Dynamics protocol will detail methods for monitoring important aspects of grizzly bear habitat such as road density and land cover, and how the ROMN will relate this work to existing population monitoring. The Vegetation Composition, Structure, and Soils protocol for ROMO will include methods for monitoring elk herbivory and other aspects of elk habitat, and how the ROMN will relate this information to park-based population monitoring. ROMN protocols for Stream and Wetland Ecological Integrity and Landscape Dynamics will include methods for monitoring presence/absence of beaver and status and trend in beaver-built structures such as dams, canals, and lodges. Because little is known about the species, habitat, and populations of the seven GRSA endemic insects, the ROMN is working with the park on research and development for a possible monitoring protocol.

The ROMN will implement its vital signs monitoring program in 2008 (see Chapter 9 for the implementation schedule). The network began to develop protocols and gather pilot monitoring data in 2006. In 2007, we continued pilot monitoring as a necessary step in preparing scientifically credible monitoring protocols. As we complete pilot projects, we will draft and submit detailed monitoring protocols to the IMR I&M coordinator for peer review and approval. Protocols will be submitted on approximately the following schedule:

- 2008: Grassland/Shrubland Vegetation Composition, Structure and Soils; Snow Chemistry; and NADP/NTN Reporting.
- 2009: Weather and Climate; Stream Ecological Integrity; Wetland Ecological Integrity; and Alpine Vegetation Composition, Structure, and Soils.
- 2010: Landscape Dynamics; Invasive/Exotic Plants–Early Detection; Alpine Lake Ecological Integrity; and Focal Species–GRSA Endemic Insects.

The ROMN program and protocols will evolve as we learn from earlier pilot efforts (especially as we better understand costs). Adjustments will likely include changes to monitoring objectives, elimination of some costly objectives, and reducing the scope of inference.

Data and information management is central to the ROMN I&M program (Chapter 6), and a key to the network's success. In partnerships with ROMN parks and the WASO I&M program, we drafted a detailed Data and Information Management Plan to guide these efforts. Our ultimate goal is for the data and information we generate to be readily available and used for resource management decision support.

ROMN analysis and reporting (Chapter 7) will ensure that monitoring data and information will be scientifically defensible and rigorously quality-assured; match analytical methods to the objectives and sample design used; accurately and precisely establish status and trend; aid in interpretation of results for various constituents; identify possible warning signals of abnormal conditions; synthesize the strengths and weaknesses of the monitoring effort in meeting I&M program goals; provide information that will help with assessments of the I&M program and the parks with respect to legal mandates; report information in a usable format for park staffs; and provide analyses and reports to ROMN parks in a timely manner. Assessment of ROMN results, scientific journal articles, and other reports will be produced on a variable schedule, with at least basic data summaries accomplished annually. The Internet will be an important method of communicating ROMN results.

The ROMN has a limited amount of funds with which to accomplish vital signs monitoring (Chapter 10) and program administration (Chapter 8). The ROMN will make these funds go as far as possible by analyzing and reporting existing high-quality and appropriate data and information whenever available, partnering with parks, other agencies, and organizations, and carefully evaluating options for implementing monitoring.

Acknowledgements

The Rocky Mountain Network Vital Signs Monitoring Plan was prepared by Rocky Mountain Network (ROMN) staff based on input and information from many people. Errors are the responsibility of ROMN staff.

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Chapter 1
Introduction and Background

1.1 Who We Are

The Rocky Mountain Network (ROMN) is one of 32 vital signs monitoring networks established by the National Park Service (NPS) as part of a servicewide strategy to institutionalize scientifically credible natural resource inventory and monitoring as a means to meet the mandate of the NPS Organic Act and other federal legislation. This effort will ensure that the 270 park units identified as having significant natural resources possess the information needed for effective, science-based resource protection and management.

The ROMN is comprised of six national park units and their professional staffs, affiliated scientists, and resource managers who are involved in and responsible for managing, preserving, and protecting ROMN park ecosystems. This includes ROMN staff hired to help develop and implement the ROMN inventory and monitoring program.

The six ROMN parks are Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), and Little Bighorn Battlefield National Monument (LIBI), Montana; and Florissant Fossil Beds National Monument (FLFO), Great Sand Dunes National Park and Preserve (GRSA), and Rocky Mountain National Park (ROMO), Colorado. These units are relatively close to each other, have a tradition of working together, share natural resource characteristics and issues, and are within the same NPS region (Intermountain) (see Table 1.1).

Rocky Mountain Network parks share funding and professional staff for the planning, design, and implementation of an integrated, long-term vital signs monitoring program. The network facilitates this collaboration, coordination, communication, and information sharing. The ROMN also works with other NPS networks, the Intermountain Region, the Natural Resource Program Center, and the Office of Inventory, Monitoring, and Evaluation to achieve its inventory and monitoring goals.

Rocky Mountain Network staff work under the direction of and in cooperation with several groups. The ROMN Board of Directors has ultimate responsibility for program accountability. The Technical Committee works closely with network staff to develop ROMN inventory and monitoring plans and strategies, and will have an increasing, important role in developing and communicating alternatives for park management based on monitoring results and information. Network staff also cooperate with park professional staff, other NPS natural resource staff (e.g., from the servicewide divisions of air, water, geologic, and biological resource management), and external scientific and technical experts to prepare ROMN plans and products and to carry out inventory and monitoring. The NPS Office of Inventory, Monitoring, and Evaluation and the Intermountain Region Inventory & Monitoring coordinator provide program vision and guidance as well as administrative, technical, and scientific review. Chapter 8 presents the ROMN organization and administrative plan in detail.

Table 1.1. Rocky Mountain Network park acronyms and acreage.

Park name	Park acronym	Area in acres*
Florissant Fossil Beds National Monument	FLFO	5,998
Glacier National Park	GLAC	1,013,322
Grant-Kohrs Ranch National Historic Site	GRKO	1,618
Great Sand Dunes National Park and Preserve	GRSA	Park: 44,246 Preserve: 41,686
Little Bighorn Battlefield National Monument	LIBI	765
Rocky Mountain National Park	ROMO	265,828
Total ROMN acreage		**1,373,463**

*Areas calculated using the Lands Office dataset from 4/30/2007 (http://science.nature.nps.gov/nrdata/datastore.cfm?ID=44049).

1.2 Introduction to Inventory and Monitoring

1.2.1 Purpose of the NPS Inventory & Monitoring Program

For years, national park managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas in order to assess the efficacy of management practices and restoration efforts and provide early warning of impending threats (see Sellars 1997). The purpose of the NPS Inventory & Monitoring (I&M) Program, established through the NPS Natural Resource Challenge, is to provide scientifically credible, long-term ecological information for natural resource protection and management through natural resource inventories and monitoring of vital signs.

The challenge of protecting and managing natural resources in the national parks requires a multi-agency, ecosystem approach, because most parks are open systems with threats, such as air and water pollution or invasive species, often originating outside their boundaries. An ecosystem approach is also needed because no single spatial or temporal scale is appropriate for all system components and processes. The appropriate scale for effectively managing a resource might be population, species, community, or landscape; in some cases, a regional, national, or international effort may be required to understand and manage the resource.

Table 1.2.1.1. Elements of the NPS I&M inventory program.

Dataset	Responsible organization
Natural resource bibliography	NPS regions, now maintained by parks/networks
Base cartographic data	WASO I&M program–Geographic Information Systems group
Geology map and report	WASO Geologic Resource Division
Soils map and report	WASO Geologic Resource Division
Weather data	WASO I&M program
Air quality	WASO Air Resources Division
Location of air quality monitoring stations	WASO Air Resources Division
Water body location and classification	WASO Water Resources Division
Water quality data	WASO Water Resources Division
Vegetation map and report	WASO Biological Resources Management Division/Vegetation Mapping Program and USGS–Biological Resources Division
Documented species list of vertebrates and vascular plants	Networks
Species distribution and status of vertebrates and vascular plants	Networks

1.2.1.1 Natural resource inventories

Natural resource inventories are extensive, point-in-time efforts to determine the location or condition of resources, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Inventories with at least a minimal complement of information allow more effective park management. The required data for a suite of resources in all parks identified as having significant natural resources have been defined in terms of 12 datasets to be developed at the federal, regional, network, and park levels (Table 1.2.1.1).

1.2.1.2 Natural resource monitoring

Natural resource monitoring, defined by Elzinga et al. (1998) as "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective," is a central component of natural resource stewardship in the NPS. In conjunction with natural resource inventories, management, and research, monitoring provides the information needed for effective, science-based managerial decisionmaking and resource protection. Monitoring differs from inventories by adding the dimension of time.

Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate threats to these systems (Roman and Barrett 1999). Natural resource monitoring provides information needed to define the normal limits of natural variation in park resources; to observe and identify change in complex, variable, and imperfectly understood natural systems; and to determine whether that change is within natural levels of variability or may indicate unwanted human influence—that is, to determine whether the change is meaningful.

Detection of a change or trend may trigger a management action or generate a new line of inquiry. Monitoring results may also be used to determine what constitutes impairment and to identify the need for modifications to management practices. In addition, the broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for research, education, and promoting public understanding of park resources.

1.2.1.3 Vital signs

Vital signs, as defined by the NPS, are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (e.g., harvested or charismatic species). 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 features, plants, animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may be designated at any level of organization, including landscape, community, population, or genetics, 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).

1.2.2 Legislation and policy

Knowing the status and trends in the condition of park resources is fundamental to the NPS mission of managing resources in a manner that leaves them "unimpaired for the enjoyment of future generations," as required under federal law. Thereby, a variety of federal laws, as well as NPS policies and guidance, direct national park managers to conduct natural resource monitoring. The mission of the NPS, set out in the National Park Service Organic Act of 1916, is:

> . . . to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations . . . by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

Congress strengthened the NPS's 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 (NPOMA) 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 NPOMA 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 NPOMA's message in its FY2000 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 *2006 NPS Management Policies* updated previous policy and specifically directed the NPS 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.

The *2006 NPS Management Policies* further direct park managers to:

- 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; and
- Use the resulting information to maintain—and, where necessary, restore—the integrity of natural systems.

Table 1.2.2 presents a summary of relevant legislation, policy, and executive guidance intended not only to protect the natural resources of national parks and other federal lands, but also to address concerns over environmental quality in the United States generally. These laws have a direct bearing on the development and implementation of natural resource monitoring in the national parks; many of them require it. As NPS units are among some of the most secure areas for numerous threatened, endangered, or otherwise compromised natural resources in the country, the particular guidance offered by federal environmental legislation and policy is an important component to the development and administration of a natural resource inventory and monitoring system in the national parks.

Additional statutes that provide legal direction for expending funds to determine the condition of natural resources in parks and specifically guide the natural resource management of network parks include:

- Taylor Grazing Act (1934);
- Fish and Wildlife Coordination Acts (1958 and 1980);
- Migratory Bird Treaty Act (1974);
- Forest and Rangeland Renewable Resources Planning Acts (1974 and 1976);
- Mining in the Parks Act (1976);
- American Indian Religious Freedom Act (1978);
- Archaeological Resources Protection Act (1979); and
- Federal Cave Resources Protection Act (1988).

Table 1.2.2. Summary of federal legislation and policy related to inventory and monitoring.

Public law	Significance to inventory and monitoring
National Park Service Organic Act (16 USC 1 et seq. [1988], Aug. 25, 1916)	The NPS Organic Act is the core of National Park Service authority and the definitive statement of the purposes of the parks and of the NPS mission: ". . . to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."
General Authorities Act of 1970 (16 USC 1a-1—1a-8 (1988), 84 Stat. 825, Pub. L. 91-383	The General Authorities Act amends the Organic Act to unite individual parks into the "National Park System." The act states that areas of the National Park System, "though distinct in character, are united through their inter-related purposes and resources into one national park system as cumulative expressions of a single national heritage; that individually and collectively, these areas derive increased national dignity and recognition of their superb environmental quality through their inclusion jointly with each other in one national park system preserved and managed for the benefit and inspiration of all the people of the United States. . . ."
National Parks Omnibus Management Act (NPOMA), 1998 (P.L. 105-391)	NPOMA requires the secretary of the interior to continually improve the NPS's ability to provide state-of-the-art management, protection, and research on NPS resources. Section 5939 states that the purpose of legislation is to: (1) Enhance management and protection of national park resources by providing clear authority and direction for the conduct of scientific study in the National Park System and to use the information gathered for management purposes; (2) Ensure appropriate documentation of resource conditions in the National Park System; (3) Encourage others to use the National Park System for study to the benefit of park management as well as broader scientific value; and (4) Encourage the publication and dissemination of information derived from studies in the NPS.
National Historic Preservation Act of 1966, as amended (16 USC 470 et seq.)	The directives Congress set forth in NHPA include preserving "the historical and cultural foundations of the Nation" and preserving irreplaceable examples important to our national heritage in order to maintain "cultural, educational, aesthetic, inspirational, economic, and energy benefits." NHPA established the National Register of Historic Places, composed of places and objects "significant in American history, architecture, archeology, engineering, and culture." NHPA requires federal agencies to account for effects of actions on historic (state and federal) properties.
National Environmental Policy Act of 1969 (42 USC 4321-4370)	The purposes of NEPA include encouraging "harmony between [humans] and their environment, . . . promot[ing] efforts which will prevent or eliminate damage to the environment, . . . and stimulat[ing] the health and welfare of [humanity]." NEPA requires a systematic analysis of major federal actions that includes a consideration of all reasonable alternatives as well as an analysis of short-term and long-term, irretrievable, irreversible, and unavoidable impacts. Within NEPA, the environment includes natural, historical, cultural, and human dimensions. Within the NPS, emphasis is on minimizing negative impacts and preventing "impairment" of park resources as described and interpreted in the NPS Organic Act. The results of evaluations conducted under NEPA are presented to the public, federal agencies, and public officials in document format for consideration prior to taking official action or making official decisions.
Clean Water Act (33 USC 1251-1376)	The Clean Water Act, passed in 1972 as amendments to the Federal Water Pollution Control Act, and significantly amended in 1977 and 1987, was designed to restore and maintain the integrity of the nation's water. It furthers the objectives of restoring and maintaining the chemical, physical and biological integrity of the nation's waters and of eliminating the discharge of pollutants into navigable waters by 1985. It also establishes effluent limitation for new and existing industrial discharge into U.S. waters, provides an enforcement procedure for water pollution abatement, and requires conformance to permit required under §404 for actions that may result in discharge of dredged or fill material into a tributary to, wetland of, or associated water source for a navigable river.
Clean Air Act (42 USC 74017671q, as amended in 1990)	The Clean Air Act establishes a nationwide program for the prevention and control of air pollution and establishes National Ambient Air Quality Standards. Under the Prevention of Significant Deterioration provisions, the act requires federal officials responsible for the management of Class I areas (some national parks and wilderness areas) to protect the air quality-related values of each area and to consult with permitting authorities regarding possible adverse impacts from new or modified emitting facilities. The act establishes specific programs that provide special protection for air resources and air quality-related values associated with NPS units. The Environmental Protection Agency is charged with implementing this act.

Table 1.2.2. Summary of federal legislation and policy related to inventory and monitoring, cont.

Public law	Significance to inventory and monitoring
Wilderness Act of 1964 (16 USC 1131 et seq.)	The Wilderness Act establishes the National Wilderness Preservation System. Wilderness areas designated by Congress are made of existing federal lands that have retained a wilderness character and meet the criteria found in the act. Federal officials are required to manage wilderness areas in a manner conducive to retention of their wilderness character and must consider the effects upon wilderness attributes from management activities on adjacent lands.
Federal Advisory Committee Act	FACA creates a formal process for federal agencies to seek advice and assistance from citizens. Any council, panel, conference, task force, or similar group used by federal officials to obtain consensus advice or recommendations on issues or policies falls under the purview of FACA.
Government Performance and Results Act (GPRA)	Requires the NPS to set goals (strategic and annual performance plans) and report results (annual performance reports). The NPS Strategic Plan contains four GPRA goal categories: park resources, park visitors, external partnership programs, and organizational effectiveness, all focused on measurable outcomes.
Other related public laws and executive orders	Redwood National Park Act (16 USC 79a-79q (1988), 82 Stat. 931, Pub. L. 90545; Environmental Quality Improvement Act of 1970 (42 U.S.C. 56 § 4371); Executive Orders 11644 and 11989 (Off-Road Vehicle Use); Executive Order 11988 (Floodplain Management); Executive Order 11990 (Protection of Wetlands); and Executive Order 13112 (Invasive Species).

1.2.2.1 GPRA goals

The Government Performance and Results Act (GPRA), passed by Congress in 1993, directs federal agencies to ensure that daily actions and expenditures are guided by long- and short-term goal-setting in pursuit of accomplishing an organization's primary mission, followed by performance measurement and evaluation. GPRA requires federal agencies to develop and use three primary documents in conducting business: a strategic plan, an annual performance plan, and an annual performance report.

This monitoring plan represents a significant, specific step toward fulfilling GPRA Goal Category I (Preserve Park Resources) for network parks. The servicewide goal pertaining to Natural Resource Inventories specifically identifies the strategic objective of inventorying the resources of the parks as an initial step in protecting and preserving park resources (GPRA Goal Ib1). This goal tracks the basic natural resources information that is available to parks; performance is measured by which datasets are obtained. The servicewide long-term goal is to "acquire or develop 87% of the outstanding datasets identified in 1999 of basic natural resource inventories for all parks" based on the I&M program's 12 basic datasets. This plan also presents a strategy for long-term monitoring to detect trends in resource condition (GPRA Goal Ib3).

1.2.2.2 Servicewide monitoring goals

All 32 networks in the NPS I&M program share a common set of overarching goals developed to comply with legal mandates, fully implement NPS policy, and provide park managers with the information they need in order to understand, manage, and protect park resources. They are:

1. To determine the 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. To provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
3. To provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, al-

tered environments.

4. To provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
5. To provide a means of measuring progress towards performance goals.

To be effective, a monitoring program must be relevant to current management issues and anticipate future issues based on current and potential threats to park resources. The program must be scientifically credible, produce data of known quality that are accessible to managers and researchers in a timely manner, and be linked explicitly to management decisionmaking processes.

1.3 Rocky Mountain Network Parks and Resources

This section provides a synthesis of the important similarities and differences among ROMN parks, then presents brief summaries of each park, including key resources (Table 1.3.2-1), threats to these resources (Table 1.3.2-2), and existing or past monitoring (Table 1.3.2-3).

1.3.1 Ecological and geographic context

The six ROMN parks are located in the central and southern portion of the Rocky Mountain Cordillera, which extends from the Ogilvie Mountains of eastern Alaska southeast through western Canada, through the states of Montana, Idaho, Wyoming, Utah, and Colorado, and into the Jemez Mountains of north-central New Mexico (Figure 1.3.1). The parks are roughly located along a NNW–SSE axis that follows the Continental Divide. The one exception to this is LIBI, which lies about 300 km to the east of the Divide, on the northern Great Plains. Although this is an extremely diverse region, with pronounced gradients in topography, climate, soils, land cover, and human usage, all six ROMN parks share some ecological similarities.

1.3.1.1 Geology

The central Rocky Mountains are primarily granitic intrusions, with associated metamorphic rocks forming uplifted domes with fractured sedimentary rocks in roughly elliptical or circular patterns surrounding the central igneous and metamorphic core (Cairns et al. 2002). In the northern Rockies especially, sedimentary units are heavily deformed by faulting, local intense folding, and overthrusting. Glacial activity has strongly influenced the landforms and ecosystems of the Rocky Mountains. Current glaciers in GLAC and ROMO are small and are retreating rapidly, due in part to anthropogenic warming (McCarthy and Smith 1994).

1.3.1.2 Topography

The ROMN parks range in maximum elevation from 933 m in LIBI to 4,343 m in ROMO. LIBI, GRKO, and FLFO have narrow elevation ranges, on the order of 200 m, while GLAC, GRSA, and ROMO have broad elevation ranges, on the order of 2,000 m. The Continental Divide runs along the Rocky Mountain Cordillera and through GLAC and ROMO. GRKO lies approximately 25 km west of the divide; LIBI lies nearly 300 km east of it. FLFO and GRSA are approximately 65 km east and 80 km southeast of the divide, respectively. For ROMN parks, important component mountain ranges include the Lewis and Livingston ranges for GLAC, the Front Range (including the Mummy and Never Summer Ranges) for ROMO and FLFO, and the Sangre de Cristo Range for GRSA.

1.3.1.3 Climate

The Rocky Mountains encompass a wide range of climatic settings, from relatively cold, dry, continental settings (e.g., LIBI) to a cool, moist, maritime setting (the west side of GLAC) and the warmer, temperate setting of the American Southwest (e.g., the lower elevations of GRSA). Winter storms approaching GLAC and GRKO from the west are laden with moisture, whereas those approaching the southern Rockies lose much moisture crossing the Sierra Nevada and Intermountain West. On the east side of the cordillera, both polar continental cold air from boreal regions and warmer maritime tropical moist air from the Gulf of Mexico are blocked by the mountain front from Alberta to New Mexico. As these winter air masses collide with the mountain front, they move upslope and generate precipitation along the eastern ranges of the Rockies. In summer, the southern

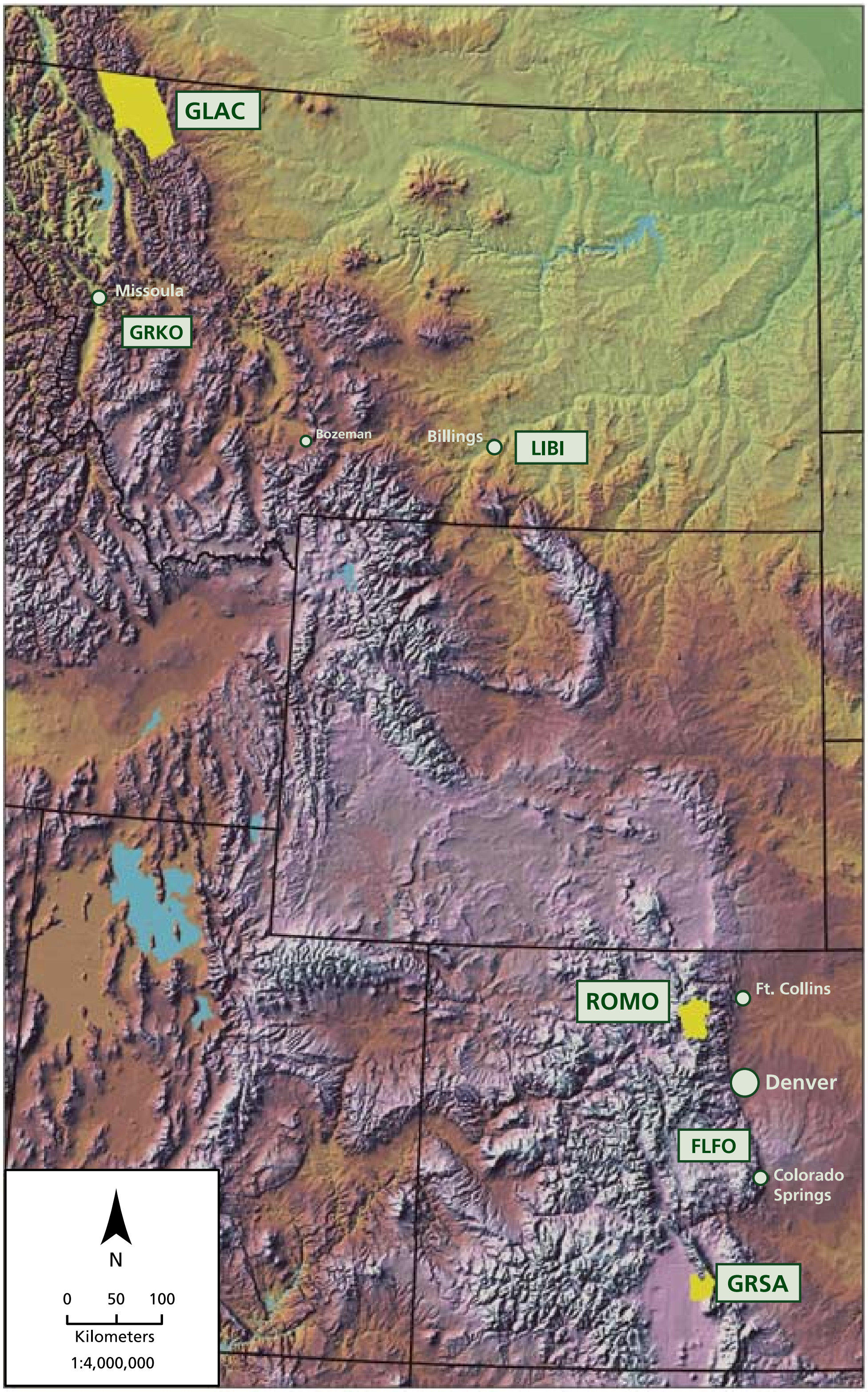


Figure 1.3.1.
The Rocky Mountain Inventory and Monitoring Network.

From north to south, Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), and Little Bighorn Battlefield National Monument (LIBI), Montana; and Rocky Mountain National Park (ROMO), Florissant Fossil Beds National Monument (FLFO), and Great Sand Dunes National Park and Preserve (GRSA), Colorado.

Canadian Rockies and GLAC continue to receive moist Pacific air. To the south, however, much of the interior western United States is under the influence of either dry continental air or monsoonal flows from the gulfs of Mexico and California.

1.3.1.4 Hydrology

River flow in the Rocky Mountain region is influenced heavily by snowmelt, which exhibits considerable spatial and temporal variations. More than half of the water supply is derived from mountain snowmelt (Lindquist and Dettinger 2003). Snowmelt varies spatially because of the influence of topography, storm tracks, and non-uniformity of depth and density during deposition. Annual streamflow in the mountainous areas is dominated by a single snowmelt peak of moderate duration during late spring or early summer, with low variability in daily mean discharge throughout the year (Zelt et al. 1999). At longer timescales, river flow depends in variations on annual snow deposition.

1.3.1.5 Paleoenvironment

Extant geologic, geographic, and ecological patterns are in part products of their paleoenvironmental context. The majority of the current Rocky Mountains uplifted during the late Cretaceous period (140 million–65 million years ago). Millennia of severe erosion in the Wyoming Basin transformed intermountain basins into relatively flat terrain. Periods of glaciation occurred from the Pleistocene (1.8 million–70,000 years ago) to the Holocene (fewer than 11,000 years ago). Recent episodes included the Bull Lake Glaciation (150,000 years ago) and the Pinedale Glaciation, which probably reached full glaciation 15,000–20,000 years ago. At the end of the Little Ice Age (1550–1860), the Agassiz and Jackson glaciers in GLAC reached their most forward positions. These periods of uplift and glaciation had profound effects on hydrologic and erosional processes, and thus on the sculpting of landscapes and distribution of communities.

1.3.1.6 Land cover

The Rocky Mountain region is characterized by high land-cover diversity. The most common land-cover type in the Rocky Mountain region is evergreen forest, at 50%, followed by grassland, at 27%. Shrubland is also fairly common, at 11%. The remainder of the region is split roughly equally among several fairly uncommon land-cover types.

1.3.1.7 Natural disturbance

Natural disturbances are important drivers of change. White and Pickett (1985) defined a natural disturbance as any relatively discrete event in space and time that disrupts ecosystem, community, or population structure and changes resources, substrate, or the physical environment. Within ROMN parks, fire is the primary natural disturbance agent, whether as a single, discrete event or as multiple events comprising a fire regime. Fire both controls and responds to the vegetation in large portions of each ROMN park. Hydrologic events, such as flooding and its impacts on groundwater and channel dynamics, are probably the second-most prevalent natural disturbance. These can shape important aquatic and transitional habitats and have disproportionate impacts on the biodiversity within each park.

Of course, anthropogenic factors have dramatically changed and influenced both of these natural disturbance processes, both within and external to each ROMN park. Contemporary fires may be unlike those with which many native species evolved, due to the current distribution of fuels across landscapes. A century of fire suppression, coupled with the introduction of non-native species, has changed the mix of species and increased fuels in many of these systems (Brooks et al. 2004). Single or multiple large-scale, catastrophic fires play an increasingly important role in ecosystem functioning. Similarly, changes in hydrologic regimes, typically acting in a cumulative fashion across watersheds, have led to dramatic changes in natural systems (Allan 2004).

1.3.1.8 Human use

Today, Rocky Mountain landscapes and biota may appear to be relatively unaltered when compared to other parts of North America, and to other mountainous areas such as the European Alps. However, human-induced changes have forever altered the Rocky Mountain region. The list of modifications based on human activities includes hunting and trapping wildlife to extinction or very low population levels (e.g., bison, beaver, wolves, grizzly bears); wholesale alteration of aquatic ecosystems through introduction of non-native fish and other organisms; development of a vast network of roads, railroads, and other rights-of-way providing easy access to the entire region; broad-scale timber, mineral, and oil development and extraction; diversion and impoundment of streams and rivers; and urban, suburban, exurban, and resort development. Two Rocky Mountain-region counties (Douglas in Colorado, and Summit in Utah) were the fastest-growing counties in the U.S. in the 1990s. Even Wyoming, the state with the lowest human population in the U.S., and Montana grew at 2–3 times the national average in the 1990s. Current improvements in transportation systems and communication technology are allowing continued exurbanization farther from cities and towns. Water needs and development to support population growth will continue to be a very important driver/stressor on Rocky Mountain ecosystems.

1.3.2 Park profiles: Key resources, threats, and monitoring

Important resources, threats, and monitoring programs for ROMN parks were identified through a variety of methods, including initial scoping meetings, a survey of park planning documents and other literature, issue/stressor/vital sign surveys, and multiple follow-up meetings at each park.

The sections below provide brief descriptions of the ROMN parks. The founding purpose(s) of each ROMN park and key resources of significance (e.g., important habitats, species and ecological processes), are shown in Table 1.3.2-1.

Table 1.3.2-2 identifies the most important threats and issues within each system. The six ROMN parks are subject to many of the same threats, several of which are exacerbated by climate change: loss of native species and degradation of natural habitats; altered hydrological and disturbance regimes; exotic species invasion; increasing pollution; growing urban and boundary development; harmful wildlife diseases; and inadequate scientific data with which to make informed management decisions. The many ecosystem components and threats common to ROMN parks, as well as the need for scientifically credible information to protect and manage their resources, link all parks within the network.

We summarize key monitoring activities within each ROMN park in Table 1.3.2-3. Tables 1.3.2-2 and 1.3.2-3 use a hierarchical classification of ecosystem components developed by the NPS (2005a) as an organizing framework at a general scale.

Florissant Fossil Beds National Monument.

1.3.2.1 Florissant Fossil Beds National Monument

Florissant Fossil Beds National Monument, situated near rapidly growing Colorado Springs, Colorado, protects the setting for a remarkably diverse paleoecological community preserved in the paper shales of the Florissant Formation. The site, primarily populated with insect and plant fossils from the Eocene Epoch, 34 million years ago, is among the richest fossil beds in the world. FLFO provides a landscape context to the science of paleontology. Visitors can see fossil excavations by pioneers in the field, such as that of Samuel Scudder in 1877.

1.3.2.2 Glacier National Park

Glacier National Park is at the center of the largest wilderness complex in the lower 48 states, and one of few ecosystems where all native carnivores live unassisted. Its wide elevation range (~2,000 m), complex topography, and location along the Continental Divide result in great biological diversity. Glacial features include active glaciers, large and small glacial lakes, cirques, and moraines. GLAC is the world's first International Peace Park, with Waterton Lakes National Park in Canada, and is also an International Biosphere Reserve.

Glacier National Park.

1.3.2.3 Grant-Kohrs Ranch National Historic Site

Established by Canadian fur trader John Grant and expanded by cattle baron Conrad Kohrs, Grant-Kohrs Ranch National Historic Site commemorates the Western cattle industry from its 1850s inception through recent times. The original ranch controlled more than 10 million acres of grazing lands in five western states and two Canadian provinces. The park was created in 1972, and today includes 1,618 acres and 90 structures. The site is still a working ranch, maintaining approximately 80 cow–calf pairs annually. It is important to note that the Clark Fork River is a Superfund site due to contamination (primarily heavy metals) from mining operations at Butte and Anaconda, Montana, upstream and upwind. The U.S. Environmental Protection Agency has completed a record of decision for the entire site (EPA 2004); restoration and mitigation are beginning.

Longhorn cattle, Grant-Kohrs Ranch National Historic Site.

1.3.2.4 Great Sand Dunes National Park and Preserve

Great Sand Dunes National Monument (designated in 1932) became Great Sand Dunes National Park and Preserve on September 13, 2004. GRSA protects the largest dunes in North America, as well as the hydrological system and landscape that maintain them. Seven insect species are endemic to the dunes. Park lands include spring-fed Big Spring and Little Spring creeks, as well as sandsheet wetlands and abundant archeological artifacts and sites. Preserve lands extend to the top of the Sangre de Cristo Range, and feature alpine lakes and tundra, giving GRSA rich biodiversity. The dunes and most of the preserve lands are designated as wilderness.

Wetland, Great Sand Dunes National Park and Preserve.

Little Bighorn Battlefield National Monument.

1.3.2.5 Little Bighorn National Monument

Little Bighorn National Monument commemorates a watershed battle in American history: the Battle of the Little Bighorn, in 1876. The park interprets this battle, as well as westward expansion and settlement of the U.S., and its effects on the Great Plains tribes. Protected since the battle in 1876, and central to its mission, LIBI's mixed-grass, native prairie has not been domestically grazed since 1891.

1.3.2.6 Rocky Mountain National Park

At 14,259 feet, Longs Peak dominates the surrounding landscape as part of Rocky Mountain National Park. Trail Ridge Road, the highest continuous paved road in the nation, provides easy access to alpine tundra for many American and international visitors. Wildlife viewing, especially for elk during the fall rut, can be spectacular. Most of ROMO, just miles from the largest urban area in the Rocky Mountain region, is designated and/or managed as wilderness, giving many Coloradans and other visitors an opportunity for solitude and wilderness recreation. Like GLAC, ROMO's complex topography and wide range of elevation result in remarkable biological diversity.

Rocky Mountain National Park.

1.4 Program Framework

1.4.1 Vital signs identification, prioritization, and selection

The ROMN approached the difficult tasks of identifying and prioritizing vital signs through an open and transparent three-phase process (see Chapter 3). Phase I involved defining general goals; starting to identify, acquire, evaluate, and synthesize existing data; and developing draft conceptual models for ROMN park ecosystems and ecological processes.

In Phase II, we identified candidate vital signs and general objectives, and prioritized and selected vital signs to be included in the network's initial integrated monitoring program. Early in the vital signs selection process, substantial efforts were made to summarize existing information about park resources and ongoing monitoring. Information acquired from the natural resource inventories contributed to the identification of vital signs. Scoping meetings at the park level, conceptual modeling workshops at the network level, and surveys conducted with NPS managers, scientific and technical staff and partners, the ROMN Science Panel, and ROMN staff generated a list of approximately 600 preliminary vital signs.

That list was revised through a series of ROMN vital signs objectives workshops in which participants (park professional staff and managers and outside scientists) evaluated each preliminary vital sign according to a set of five criteria: (1) ecological significance (e.g., as identified in conceptual models), (2) long-term management significance, (3) feasibility and cost of monitoring, (4) response variability, and (5) existing data and programs. Further analysis and scoring reduced the lists generated by the workgroups

Table 1.3.2-1. Purpose, significance, and key resources of ROMN parks.

Park	Purpose/significance/key resources	Important habitats	Important species	Important ecological processes
FLFO	Known and yet-to-be-discovered paleontological resources of the Florissant Formation Petrified tree stumps dating from the Eocene Cultural and natural landscape setting	Ponderosa pine woodlands Shrublands Mixed conifer forest	Elk Abert's squirrel Exotic invasive plants	Fire Exotic plant invasion Erosion
GLAC	Conservation and protection of game and fish Opportunities for visitors to experience, understand, appreciate, and enjoy the park in a "state of nature" Rare and primitive wilderness experience Scenery as an illustration of exceptionally long geologic history	Alpine tundra Rivers and riparian areas Glaciers Lakes Grasslands	Full complement of native carnivores: grizzly bears, gray wolves, lynx, wolverines, fishers, pine martens, mountain lions Ungulates: elk, bighorn sheep, mule deer, mountain goats, moose Fish: bull trout, non-native fish (and other exotic invasive aquatic organisms) Birds: common loons, raptors, songbirds Plants: rare and exotic invasive	Surface and groundwater flows Mountain building and glaciation Fire Herbivory Exotic plant and animal invasion
GRKO	Commemorates the Western cattle industry from its 1850s inception through recent times Cultural landscape Surrounding viewshed	Grassland, managed as pasture and hayfield Clark Fork River and associated riparian and wetland areas Native prairie Irrigated hay meadows	Domestic cattle Beaver Plants: native willows, other riparian plants, grasses (native and introduced)	Herbivory Hydrology of the Clark Fork River Erosion Exotic plant invasion
GRSA	Wind and hydrological processes and features of the San Luis Valley that maintain the Great Sand Dunes Sangre de Cristo watershed that contributes to San Luis Valley aquifers Wilderness recreation and hunting opportunities (in the preserve)	Dune field Sand sheet Sabkha Sandbed streams Medano and Sand creeks Riparian and wetland habitats Alpine tundra and lakes Pinyon pine/juniper and ponderosa pine woodlands	Endemic dune insects Mammals: elk, bison, bighorn sheep, black bears Fish: Rio Grande cutthroat trout, non-native fish Plants: exotic invasive and rare slender spiderflower (*Cleome multicaulis*)	Dune formation and maintenance (wind, surface water, groundwater) Fire Herbivory Exotic plant invasion Erosion
LIBI	Commemorates the Battle of the Little Bighorn	Native prairie Little Bighorn River and associated riparian and wetland areas Heavily managed national cemetery	Black-tailed prairie dogs Native bunchgrasses Big sagebrush Rocky Mountain juniper Cottonwood and associated floodplain shrubs Exotic invasive plants	Fire Herbivory (or lack thereof) effects on the native prairie Little Bighorn River hydrology Exotic plant invasion Erosion
ROMO	Wild landscape and scenery Opportunities for solitude and tranquility Wilderness recreational and wildlife-viewing opportunities Scenic and scientific values of alpine tundra Biodiversity	Tundra Montane habitats (especially ponderosa pine and upland shrub communities) Lodgepole pine Riparian and wetland habitats Aspen woodlands.	Ungulates: elk, bighorn sheep, mule deer, mountain goats (exotic), moose Beaver Carnivores: black bears, wolves (they may recolonize ROMO eventually), mountain lions, pine martens, river otters Fish and amphibians: greenback cutthroat trout, Colorado River cutthroat trout, non-native fish (and other non-native aquatic species), boreal toads Birds: raptors, white-tailed ptarmigans, songbirds Insects: butterflies, capshell snails Plants: rare, exotic invasive plants	Fire Herbivory and its effects on aspen and willow communities Predation (or lack thereof) Wildlife diseases Stream hydrology Exotic invasive plants and animals Erosion Water diversions Altered hydrological regimes

Table 1.3.2-2. Resources/issues of concern and active monitoring programs for each ROMN park.

Resources and/or issues of importance		FLFO	GLAC	GRKO	GRSA	LIBI	ROMO
Air and climate	Air contaminants		**X** (M)		x		X
	Ozone		(M)				x (M)
	Visibility and particulate matter		x (M)	x	x (M)		x (M)
	Wet and dry deposition	x	x (M)	x	x	x (M)	**X** (M)
	Weather and climate	x (M)	**X** (M)	x	x (M)	x (M)	x (M)
Biological integrity	T&E species and communities		**X** (M)	x (M)			X
	Amphibians and reptiles		x (M)	x	x (M)		x (M)
	Alpine tundra		x		x		X
	Birds		x (M)	**X**			x (M)
	Fishes		x	x	x		x
	Forest vegetation	x	x (M)		x		x (M)
	Freshwater communities		**X**	x	x		x
	Freshwater invertebrates		x	x			x
	Grassland vegetation	x	x	x	x	**X**	
	Vegetation communities	x (M)	**X**	**X**	x	**X**	x
	Mammals	x	**X** (M)	x (M)	**X**	x	**X** (M)
	Riparian communities	x	x	x	x	x	x (M)
	Shrubland vegetation	x			x		x (M)
	Terrestrial invertebrates		x		X		x
	Wetland communities		x	x	x		x
	Animal diseases		X		x		X
	Insect pests		x		x		x
	Plant diseases		x		x		x
	Invasive/exotic animals		x	x	x	x	x
	Invasive/exotic plants	X	X	X	X	X	X
Ecosystem pattern and process	Extreme disturbance events		x		x		x
	Fire and fuel dynamics	**X**	**X** (M)	x	**X**	**X**	**X** (M)
	Land cover/land use	**X**	**X**	**X**	x	**X**	x
	Nutrient cycling			X			x (M)
	Productivity		x	x	x	x	x
	Soundscapes	x	**X**	x	x	x	x
Geology and soils	Glacial features and processes		**X** (M)		x		x
	Hillslope features and processes	x	x		x	**X**	x
	Lake features and processes		x				x
	Stream/river channel characteristics	x	x	x	x	x	x
	Windblown features and processes				X		
	Soil function and dynamics	x	x	x	x	x	x
	Fossils	X					
Human use	Cultural landscapes	**X**	x	**X**	x	**X**	x
	Visitor usage	x	x		x	x	x
Water	Groundwater dynamics	x	x (M)	x (M)	**X** (M)		x (M)
	Surface water dynamics	x (M)	x (M)	**X** (M)	**X** (M)	x (M)	x (M)
	Aquatic macroinvertebrates and algae		x	x	x		x
	Toxics		x	**X** (M)			
	Water chemistry	**X**	**X** (M)	**X** (M)	x	x	**X** (M)

X = a high-priority issue; this designation required specific identification by park resource staff (during scoping) or GPRA.
x = an issue recognized as relevant in one or more sources, but nowhere noted as high-priority.
(M) designates presence of an active monitoring program with a measurement site(s) in the park unit.

Inventories, research projects, and extrapolated data (e.g., from national or regional surveys) may provide useful information for ROMN, but these are not included here as they are not active monitoring programs. This information was derived from park scoping meetings (Phase I), park GPRA goals, and vital signs scoping meetings (Phase II).

Table 1.3.2-3. Existing monitoring programs for each ROMN park.

Resource	Monitoring program	Lead agency	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO
Air and climate	Clean Air Status and Trends Network (CASTNet)	EPA	m	M	m	m	m	M
	Interagency Monitoring of Protected Visual Environments (IMPROVE)	Interagency; participation from federal and regional/ state organizations. CSU hosts website.	m	M	m	M	m	M
	National Atmospheric Deposition Program (NADP)	NPS/USGS	m	M	m	m	M	M
	U.S. Climate Reference Network (USCRN)	NOAA		M				
	Remote Automated Weather Station (RAWS)	USFS	m	M	m	M	M	M
	Western Airborne Contaminants Assessment Project (WACAP)	NPS		M				M
	Loch Vale Watershed	CSU/USGS						M
	Niwot Ridge Long-term Ecological Research (LTER)	LTER (CU)						m
	SNOTEL Network	NRCS	m	M		m		M
	Cooperative Network Weather Stations	NWS–NOAA						
	Gaseous Pollutant Monitoring Network (GPMN)	NPS	m	M	m	m	m	M
	Ozone Passive Sampler Monitoring Program	NPS	m	m	m	m	m	m
	Ambient Air Monitoring	Montana DEQ		m	m		m	
	USGS Snow Monitoring; Rocky Mountain Snow Chemistry Network	USGS/Fagre		M				M
	Columbia Falls Aluminum Company (CFAC) Fluoride Monitoring Program	CFAC/NPS		M				
	Ecological Monitoring and Assessment Network (EMAN)	Environment Canada		m				
Biological integrity	Environmental Monitoring and Assessment Program (EMAP)	EPA	m	M	m	m	m	M
	Regional Environmental Monitoring and Assessment Program (REMAP)	EPA	M			M	m	M
	National Wetlands Inventory Status and Trends	USFWS		M		M		M
	Forest Health Monitoring, Inventory, and Analysis	USFS	M	M		M		M
	Breeding Bird Survey	USGS	m	M	m	m	m	m
	Coram Experimental Forest, MT	USFS		m				
	Lake McDonald Fishery Investigations	FLBS/Stanford University		m				
	ROMO Elk Monitoring	NPS						M
	USFS Northern Region Landbird Monitoring Program	USFS/UMT/Hutto		m			m	
	Amphibian Research and Monitoring Initiative (ARMI)	USGS		M				M
	Burn Severity Mapping Project	USGS/NPS	M	M		M		
Ecosystem pattern and process	GAP Analysis Program	USGS	M	M	M	M	M	M
	Colorado Vegetation Classification Project	BLM/State of Colorado	M			M		M
	Section 305(b) Water Quality Assessments	EPA		M	M			M
Water	National Water Quality Assessment Program (NAWQA)	USGS	M					M
	State of Colorado Water Quality Monitoring	Colorado DPHE	M			M		M
	Montana Surface Water Monitoring Program	Montana DEQ		M	M		M	
	BOR Water Programs	BOR				M		
	NPS Water Rights Monitoring	NPS-Water Rights Branch		m		M	M	M
Geology and soils	Glacier Monitoring	USGS/Fagre						

“M” indicates monitoring occurring within the park. “m” indicates monitoring that is occurring outside the park but is still representative of the park.

BLM = U.S. Bureau of Land Management; BOR = U.S. Bureau of Reclamation; CSU = Colorado State University; CU = University of Colorado–Boulder; DEQ = Department of Environmental Quality; DPHE = Department of Public Health and Environment; EPA = Environmental Protection Agency; FLBS = Flathead Lake Biological Station; NOAA = National Oceanic and Atmospheric Administration; NPS = National Park Service; NRCS = Natural Resources Conservation Service; NWS = National Weather Service; UMT = University of Montana; USFS = U.S. Forest Service; USFWS = U.S. Fish and Wildlife Service; USGS = U.S. Geological Survey

Note: Each network park has some degree of ongoing natural resource monitoring, ranging from relatively well-developed programs in GLAC and ROMO to smaller efforts in the other parks. ROMN park projects were only considered past or existing monitoring here if measurements were taken at the same locations on several occasions (Elzinga et al. 1998).

ROMN High-Priority Vital Signs

- Wet and Dry Deposition
- Weather and Climate
- Water Chemistry
- Surface Water Dynamics
- Freshwater Communities
- Invasive/Exotic Aquatic Biota
- Groundwater Dynamics
- Wetland Communities
- Invasive/Exotic Plants
- Vegetation Composition, Structure, and Soils
- Focal Species (Beaver, Elk, Grizzly Bear, and GRSA Endemic Insects)
- Landscape Dynamics

and surveys to a more integrated and defined set of 62 candidate vital signs. The current list of 12 high-priority vital signs (see Chapter 3) was identified by the Technical Committee and endorsed by the ROMN Board of Directors.

The goal of Phase III was to present, for peer and programmatic review, a detailed draft vital signs monitoring plan designed to include background and foundational procedures needed to implement monitoring—such as developing specific monitoring objectives for each vital sign, developing sampling protocols and sample designs, developing a plan for data management and analysis, determining the type and content of various products of the monitoring effort (such as reports and websites), and establishing network administrative procedures including budget, staffing, and scheduling. In all steps, explicit feedback mechanisms allow adjustment and improvement of the ROMN program.

This vital signs monitoring plan has been reviewed and approved for adherence to I&M program guidance as well as scientific and technical quality. Implementation of this plan and each monitoring protocol will include initial pilot efforts of collection, analysis, and reporting of monitoring data. Because it would be impossible to monitor all attributes and vital signs of our systems at once (cost is one important reason), the ROMN program will evolve over time as we document change and patterns of variation in our parks' ecosystems. This evolution will be relatively slow and adaptive; we will evaluate the results of our monitoring annually and at five-year intervals. The initial focus will be on baseline information and pilot work that will build the foundation of our understanding and allow for confirmation that our sample designs and protocols are efficient and appropriate. Such an approach will allow the ROMN to build a robust knowledge of ecosystem change and the patterns of variation in system resources.

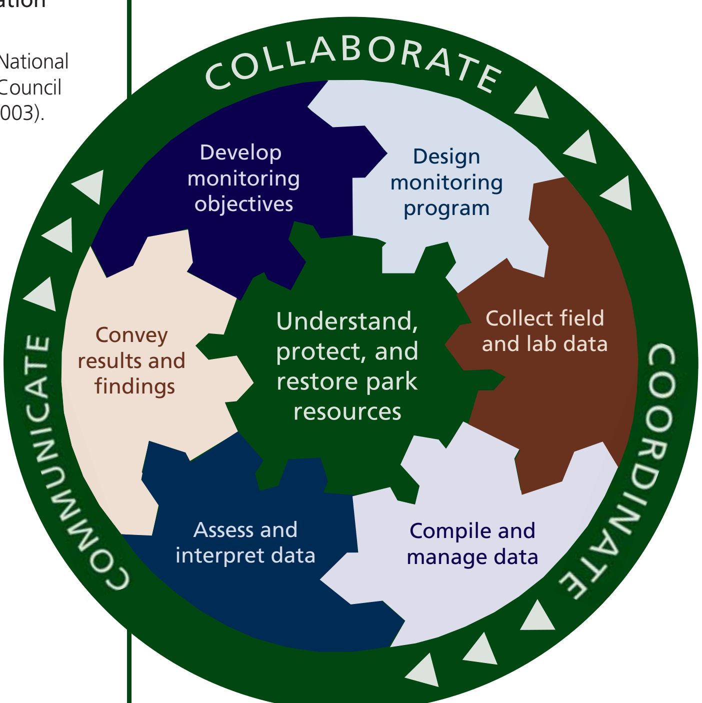


Figure 1.4.2. Model of ROMN monitoring as an information system.

Adapted from the National Water Monitoring Council (Peters and Ward 2003).

1.4.2 Data and information management system

All ROMN activity is organized around an "information management system" (Figure 1.4.2)—a conceptual model of a series of activities that, together, produce and convey information for better understanding, protection, and restoration of park resources. Its use helps ensure that individual ROMN activities maintain their connection with the network's original goals and makes clear that all the key elements of the ROMN program, from inventorying, to long-term ecological monitoring, to data analysis, management, and reporting, are part of an integrated process that works through collaboration, coordination, and communication amongst the ROMN and its partners. More details on the NPS and the ROMN approach to data and information management can be found in Chapter 6 and in the ROMN Data and Information Management Plan (Appendix D).

1.4.3 Monitoring goals and objectives

The monitoring goals and objectives of the ROMN program follow from the servicewide goals presented in Section 1.2.3. Specific objectives were created during the protocol development process following a series of steps (Figure 1.4.3) adopted from Caughlan and Oakley (2001) and Jean et al. (2005). The procedures in Figure 1.4.3 focus on the details of developing and prioritizing objectives; however, many of the steps nest within the information management system model in Figure 1.4.2, and have a similar capacity for feedback and support of adaptive change.

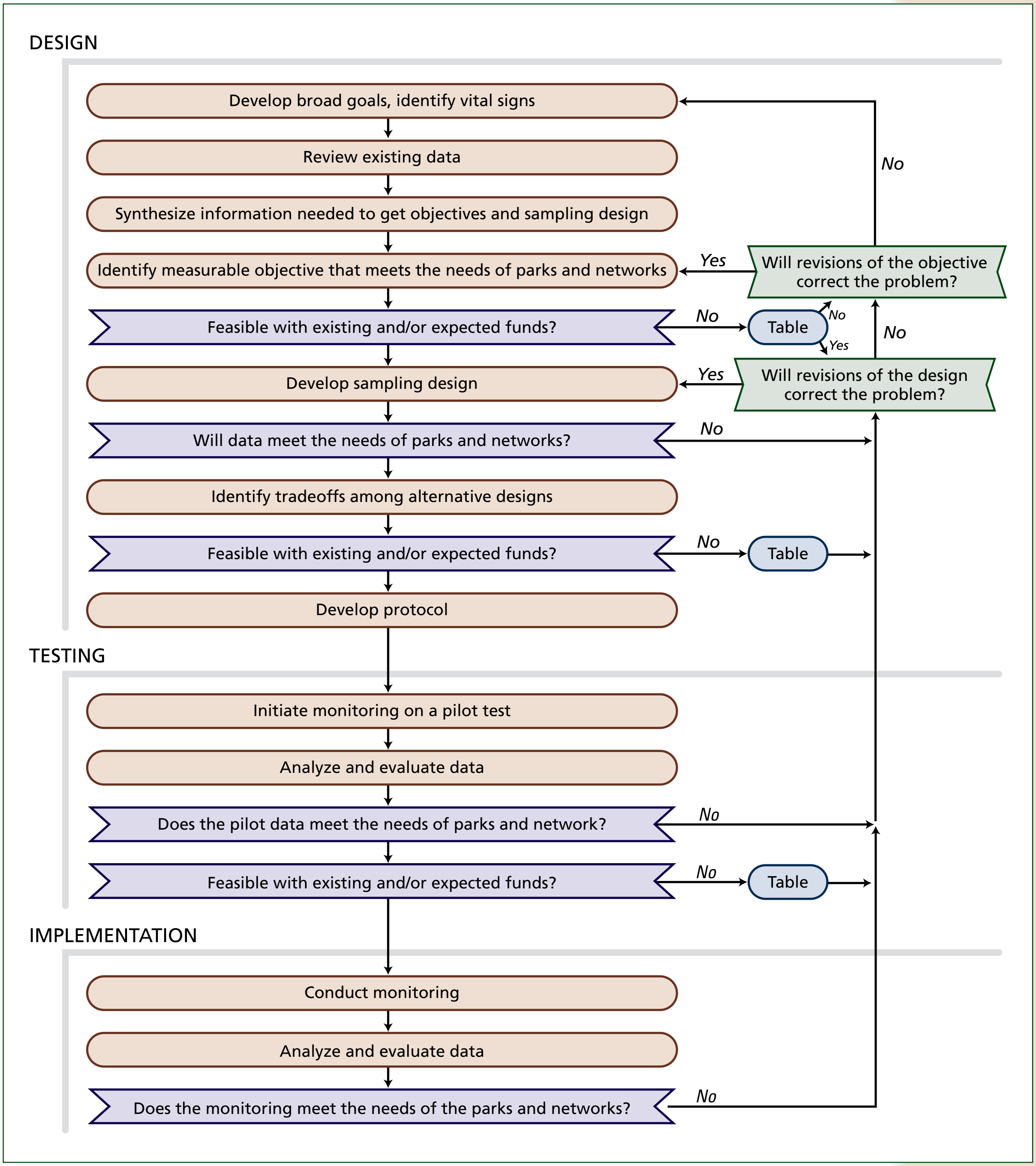


Figure 1.4.3. Diagram depicting the process used to develop and evaluate monitoring objectives in the ROMN.
Adapted from Caughlan and Oakley (2001) and C. Jean (2005).

ROMN monitoring objectives, identified through the vital signs objectives workshop process (see Section 1.4.1), are summarized for high-priority ROMN vital signs in Table 1.4.3. Detailed monitoring objectives and specific sampling objectives will be included in each monitoring protocol as the protocols are completed.

1.4.4 Monitoring approach

A key decision in the development of the ROMN program was the adoption of a monitoring paradigm that could effectively structure and guide the selection of vital signs and fulfill both the mandate of the NPS I&M program and the ROMN's responsibility to support the long-term management of network parks. We propose an integrated, multifaceted perspective, in which we emphasize the long-term monitoring of vital signs for drivers, stressors, focal resources, and especially key properties and processes of ecosystem integrity as measured through the bioassessment approach (Barbour et al. 1999; Bailey et al. 2004). This is similar to the approach taken by other long-term, large-scale monitoring programs (e.g., the response, exposure, and stress perspective of Hunsaker and Carpenter (1990)) and several other NPS I&M networks (e.g., NCPN, SCPN, SODN, and GRYN).

1.4.4.3 Spatial scale

Rocky Mountain Network monitoring will use a multi-scale perspective in objective formulation, vital sign selection, and sample designs. This approach will provide tools to address issues that occur at multiple sites in a park or multiple parks within a network, rather than addressing site-specific problems individually. Furthermore, managers will be able to develop general principles and guidelines that can be applied broadly to a particular type of issue or problem.

1.4.4.4 Temporal scale

Accordingly, ROMN monitoring will emphasize a long-term perspective to provide data that quantify signals with long periodicity or that have a gradual, slow-acting impact on ecological integrity (Magnuson 1990). Also, with a long-term perspective, ROMN park managers will be able to develop long-term management guidelines that can be applied broadly to a particular type of issue or problem.

1.4.4.1 Ecosystem integrity

Ecological integrity is an expression of 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. Data from a single indicator or vital sign is usually insufficient for evaluating ecosystem integrity.[†] Critical measures of integrity often vary with ecosystem type and the key drivers that influence system functioning and stability. In many systems, measures of structure or species composition (i.e., "biodiversity") are used as indicators of integrity (De Leo and Levin 1997). Similarly, focus is often placed on the dynamics of specific keystone species or functional groups. Alternatively, holistic measures of macro-level functional aspects (in particular, energy flows, nutrient recycling, and productivity) are also often used as efficient measures of integrity. Because the structure and function of biological systems are not mutually exclusive, the most useful suite of indicators of ecosystem integrity will likely include both.

1.4.4.2 Bioassessment

Bioassessment compares observed habitat, stressor, and biological measures with empirically defined reference conditions via actual reference sites, historical data, and/or modeling or extrapolation (Gibson et al. 1996; Stoddard et al. 2006). The incorporation of reference conditions facilitates assessment or interpretation of monitoring data, while the use of multiple forms of vital signs allows examination of interactions at multiple temporal and spatial scales (Wiens 1995).

The bioassessment model develops an empirical relationship between habitat quality and biological condition that is refined for a given

[†] The indicators the ROMN will monitor are much more specific than our vital signs, and the terms should not be used interchangeably. In most cases, the ROMN will monitor multiple indicators to provide information relative to a particular vital sign.

Table 1.4.3. Preliminary Rocky Mountain Network monitoring objectives.

NPS Ecological Monitoring Framework			ROMN vital sign(s)	ROMN protocol(s)	Monitoring objectives
Level 1	Level 2	Level 3			
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	Snow Chemistry	Determine status and trends in snowpack chemical deposition and snow–water equivalent at high elevations. Interpret (model) snowpack chemical deposition and snow–water equivalent within ROMN parks; contribute ROMN park data to regional models.
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	NADP/NTN	Determine status and trends in atmospheric deposition of chemicals (nutrients and pollutants) within ROMN parks. Interpret (model) chemical deposition within ROMN parks; contribute ROMN park data to regional models.
Air and Climate	Weather and Climate	Weather and Climate	Weather and Climate	Weather and Climate	Determine status and trends of common climate variables (e.g., temperature, precipitation, relative humidity) for individual stations within ROMN parks. Interpret (model) status and trends in climate variables and derived indices (e.g., drought, growing degree-days) within ROMN parks.
Water	Hydrology	Surface Water Dynamics	Surface Water Dynamics	Stream Ecological Integrity	Determine status and trends in select water-quality parameters at sentinel sites (e.g., 303(d) reaches). Determine status and trends in selected water-quality parameters at the park scale. Determine status and trends in benthic and periphyton stream assemblages and stream habitat using multimetric and multivariate indices at the park scale. Determine status and trends in the presence/absence of selected invasive plants in streams at the park scale. Determine status and trends in presence/absence of beaver in streams at the park scale.
	Water Quality	Water Chemistry	Water Chemistry		
Biological Integrity	Invasive Species	Invasive/Exotic Animals	Invasive/Exotic Aquatic Biota		
		Invasive Exotic Plants			
	Focal Species or Communities	Freshwater Communities	Freshwater Communities		
	Focal Species or Communities	Mammals	Focal Species–Beaver		
Water	Hydrology	Surface Water Dynamics	Surface Water Dynamics	Alpine Lake Ecological Integrity	Determine status and trends in selected water-quality parameters at specific alpine lakes (e.g., 303(d) water bodies.) Determine status and trends in algal (zoo- and phytoplankton) assemblages at sentinel alpine lakes. Monitor for trends in phenological events (e.g., ice-out/melt-out, insect emergence, and lake-turnover dynamics) at sentinel alpine lake sites. Determine status and trends in selected aquatic invasive plants at sentinel alpine lakes.
	Water Quality	Water Chemistry	Water Chemistry		
Biological Integrity	Invasive Species	Invasive/Exotic Animals	Invasive/Exotic Aquatic Biota		
		Invasive/Exotic Plants			
	Focal Species or Communities	Freshwater Communities	Freshwater Communities		
	Focal Species or Communities	Mammals	Focal Species–Beaver		

Table 1.4.3. Preliminary Rocky Mountain Network monitoring objectives, cont.

NPS Ecological Monitoring Framework: Level 1	Level 2	Level 3	ROMN vital sign(s)	ROMN protocol(s)	Monitoring objectives
Water	Hydrology	Groundwater Dynamics	Groundwater Dynamics	Wetland Ecological Integrity	Quantify extent of wetlands by key type within a park and monitor trends in extent over time. Monitor wetland condition at selected sites as required by federal and state regulatory programs in each ROMN park. Determine status and trends in wetland vegetation assemblages using multimetric indices. Determine status and trends in groundwater hydrologic regimes and any relationships with wetland vegetation assemblages (park-scale, with finer temporal resolution at sentinel sites). Determine status and trends in the presence/absence of selected invasive plants in wetlands at the park scale. Determine status and trends in presence/absence of beaver in wetlands at the park scale.
Biological Integrity	Invasive Species	Invasive/Exotic plants Invasive/Exotic Animals	Invasive/Exotic Aquatic Biota		
	Focal Species or Communities	Wetland Communities	Wetland Communities		
	Focal Species or Communities	Mammals	Focal Species–Beaver		
Biological Integrity	Invasive Species	Invasive/Exotic Plants	Invasive/Exotic Plants	Invasive/Exotic Plants–Early Detection	Detect incipient populations and new introductions of invasive plant species quickly after their arrival in a park. Estimate status and trends of invasive plant occurrences parkwide using spatially explicit models.
Biological Integrity	Focal Species or Communities	Grassland/ Herbaceous Communities	Vegetation Composition, Structure, and Soils	Alpine Vegetation Composition, Structure, and Soils	Determine the status and trend in alpine vegetation structure (relative cover of woody and herbaceous species and bare ground) and composition (species diversity). Detect and report arrival of weedy invaders in alpine environments. Establish relationships between alpine vegetation pattern and drivers and stressors (e.g., climate, chemical deposition, human use, herbivory).
	Invasive Species	Invasive/Exotic Plants	Invasive/Exotic Plants		
Biological Integrity	Focal Species or Communities	Grassland/ Herbaceous Communities	Vegetation Composition, Structure, and Soils	Grassland/Shrubland Vegetation Composition, Structure, and Soils	Determine the status and trend in grassland vegetation structure (relative cover of woody and herbaceous species and bare ground) and composition (species diversity) across a park (smaller parks), or in a representative sub-sample (large parks). Detect and report presence and parkwide distribution of invasive/exotic plants; provide data for "invasibility" model to evaluate trends in invasive species. Determine the status and trend in soil structure based on surface conditions (texture, stability, infiltration) and erosion potential. Determine the status and trend in soil nutrient function based on decay rates, nitrogen cycling, ion availability, or similar index.
	Invasive Species	Invasive/Exotic Plants	Invasive/Exotic Plants		
Biological Integrity	Focal Species or Communities	Terrestrial Invertebrates	Focal Species–GRSA Endemic Insects	Focal Species–GRSA Endemic Insects	Determine status and trends in endemic insect populations, especially Great Sand Dunes Tiger Beetle. Determine and monitor trends in habitat quality and distribution for selected (management-priority) endemic species.

Table 1.4.3. Preliminary Rocky Mountain Network monitoring objectives, cont.

NPS Ecological Monitoring Framework			ROMN vital sign(s)	ROMN protocol(s)	Monitoring objectives
Level 1	Level 2	Level 3			
Biological Integrity	Focal Species or Communities	Mammals	Focal Species–Elk*	[data harvested from non-ROMN monitoring] Landscape Dynamics Alpine and Grassland/ Shrubland Vegetation Composition, Structure, and Soils	Determine status and trends in elk habitat suitability. Determine status and trends in herbivory impacts across parks and in focal use areas.
Biological Integrity	Focal Species or Communities	Mammals	Focal Species–Beaver*	Stream Ecological Integrity Wetland Ecological Integrity Landscape Dynamics	Determine status and trends in beaver-engineered structures (lodges, dams, canals). Determine status and trends in beaver presence/absence (Stream and Wetland Ecological Integrity protocols)
Biological Integrity	Focal Species or Communities	Mammals	Focal Species–Grizzly Bear*	[data harvested from non-ROMN monitoring] Landscape Dynamics	Determine status and trends in grizzly habitat suitability based on regional-scale (landscape) distribution of indicator parameters (e.g., total area, core area, connectivity).
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use	Landscape Dynamics	Landscape Dynamics	Determine status and trends in selected metrics (e.g., connectivity and fragmentation, core habitat dimensions, road density) in and around each ROMN park. Determine status and trends in regional land cover using shifts in multi-spectral signatures and model assisted integrated analysis of reflectance signatures and auxiliary data. Determine status and trends in the distribution and connectivity of particular land-cover types based on the objectives and resource issues associated with other vital signs.

region (e.g., a specific ROMN park). As additional information is obtained from systematic monitoring, the predictive power of the empirical relationship is enhanced. Once the relationship between habitat and biological potential is understood, stressor impacts can be objectively discriminated from habitat effects, and management efforts can be focused on the most important source of stress.

1.4.5 Water quality monitoring

The NPS I&M program places a special emphasis on water-quality monitoring, which involves separate funding and a subtly different administrative context. Water-quality vital signs, sample designs, analyses, and interpretation will be fully integrated with both the current water resources programs in ROMN parks and all aspects of ROMN vital signs monitoring that deal with aquatic or wetland systems. Planning for water-quality monitoring has followed the same steps and proceeded in parallel with other ROMN vital signs planning. The required water-quality measures and all Quality Assurance guidance provided by the NPS Water Resources Division will be fully encompassed within the integrated ROMN aquatic protocols.

The NPS GPRA goal for water resources requires that parks report on "impaired waters" as defined by section 303(d) of the Clean Water Act. The states of Colorado and Montana classify waters differently; however, in general, the ROMN will report on water bodies that are on each state's 303(d) list as part of any relevant vital sign or protocol.

1.4.6 Air quality monitoring

Under the Clean Air Act, park managers have a responsibility to protect air quality and related values from the adverse effects of air pollution. Protection of air quality in national parks requires knowledge about the origin, transport, and fate of air pollution, as well as its impacts on resources. To be effective advocates for the protection of park air resources, NPS managers need to know the air pollutants of concern, existing levels of air pollutants in parks, park resources at risk, and the potential or actual impact on these resources. Through the efforts of park personnel, support office staff, and the NPS Air Resources Division, the NPS meets its clean air affirmative responsibilities by obtaining critical data and using the results in regulatory-related activities. The Air Resources Division provides air quality information and data for ROMN parks and the network at: http://www2.nature.nps.gov/air.

Although current air quality in some ROMN parks is considered good by national standards, the ROMN recognizes air pollution from global and regional industrialization and other human development (e.g., nitrogen deposition from agricultural sources) as a potential driver of ecosystem change in network parks and the Rocky Mountain region (Baron 2006). Within the NPS, air-quality monitoring is managed nationally through participation in several established programs, each targeting a specific aspect of air quality. ROMO, GLAC, and GRSA are designated as Class I parks (where the most stringent standards apply) under the Clean Air Act (and Amendments of 1988), and have been sites of air-quality monitoring for decades. The ROMN will use data from these sites to track and report on air quality. Wet and dry deposition was specifically identified as a high-priority ROMN vital sign.

1.5 Limitations on Rocky Mountain Network Monitoring

Managers and scientists need to acknowledge the limitations of monitoring programs that result from the inherent complexity and variability of park ecosystems. Ecosystems are loosely defined assemblages that exhibit characteristic patterns on a range of scales of time, space, and organizational complexity (De Leo and Levin 1997). Definitions of ecological integrity can be problematic, partly because key terms such as "natural" remain somewhat vague (Noon 2003). Natural systems, as well as human activities, change over time, making it challenging to separate natural variability and desirable changes from undesirable anthropogenic sources of change to park resources. These complexities demand that we neither be overly prescriptive in our definitions of systems, nor ignore the differences that occur along a continuum of change.

Monitoring programs are limited by their inability to address all resource management interests because of funding, staffing, and logistical constraints. The intent of the ROMN is to monitor a select set of ecosystem components and processes (vital signs) that best reflect the condition and trends in park ecosystem integrity and are most relevant to management issues. Cause-and-effect relationships usually cannot be demonstrated with monitoring data, but monitoring data might suggest a cause-and-effect relationship that can then be investigated with a research study or a well-developed model. As monitoring proceeds, datasets are interpreted, and our understanding of ecological processes is enhanced, trends will likely be detected and future issues will emerge (Roman and Barrett 1999). A monitoring plan should therefore be viewed as a working document, subject to periodic review and adjustments over time as our understanding improves and new issues and technological advances arise.

Chapter 2
Conceptual Models

2.1 Conceptual Models within the ROMN Monitoring Program

Conceptual models are working hypotheses about system form and function (Manley et al. 2000). They are visual or narrative summaries of the central components of an ecological system, the forces of change impacting that system, and the key interactions that affect important natural resource processes; conceptual models also articulate assumptions about these components and processes. Conceptual models do not attempt to explain all possible relationships or factors that influence a system. Rather, they are intended to simplify and highlight the most relevant, influential, and important components of use in a long-term monitoring context. Using conceptual models helps us to identify the role of change in important biotic and environmental features and processes, provides insight into potential cause-and-effect relationships, and establishes standard formats and concepts for communication of complex ideas (Roman and Barrett 1999).

Following NPS I&M program guidance, the ROMN developed conceptual models as an aid for identifying and prioritizing vital signs and indicators. The network held two conceptual model workshops among park and network staffs and scientific and technical partners knowledgeable of ROMN resources and ecosystems. The models developed in the workshops informed the development of the more general conceptual models presented here. Most workshop participants also provided input into vital signs prioritization. Two criteria used to prioritize vital signs related directly back to the conceptual modeling: ecological significance and long-term management significance (see Chapter 3 and Appendix B for details on vital signs identification and prioritization).

This chapter presents general conceptual models for Rocky Mountain Network vital signs and briefly summarizes the content of each model.

2.1.1 Aggregated system characterization model

The ROMN has adopted a general system characterization model from Jenny (1941; 1980) and Chapin et al. (1996) to serve as a foundation for all ROMN models. This model (Figure 2.1.1) describes ecosystem processes as a function of hierarchical state factors and interactive controls. State factors, which operate at the largest scales, include global climate, continental- and regional-scale topography, parent material (e.g., soil and geologic substrate), time (e.g., system age) and the distributions of organisms within a landscape. To these, we added one obvious, but historically overlooked, primary determinant state factor: human land use. This factor recognizes the local- and regional-scale influences of human activities, including pollution sources, habitat conversion, geologic manipulation, perpetual disturbance (e.g., grazing, harvest, recreation) and direct impacts on wildlife populations. Interactive controls, such as local climate patterns, soil function and development, water availability, disturbance regimes, and the type and distribution of organisms, are constrained by these state factors (Dale et al. 2000).

Using the modified Jenny-Chapin model as our most coarse conceptual theme, we developed conceptual models for major ecosystems in the ROMN. The models were developed by park resource management staff, academic and other cooperators, and ROMN staff. The model types discussed here are ecosystem characterization (or driver) models. These models depict relationships among functional components of a system and the environmental conditions that control them by identifying pathways and connections between agents of change and ecological attributes of the systems (see Young and Sanzone 2002; Route and Elias 2003). Events or processes that impact ROMN ecosystem attributes range from major forces of change with large-scale influence to more local-scale stressors (Barrett et al. 1976).

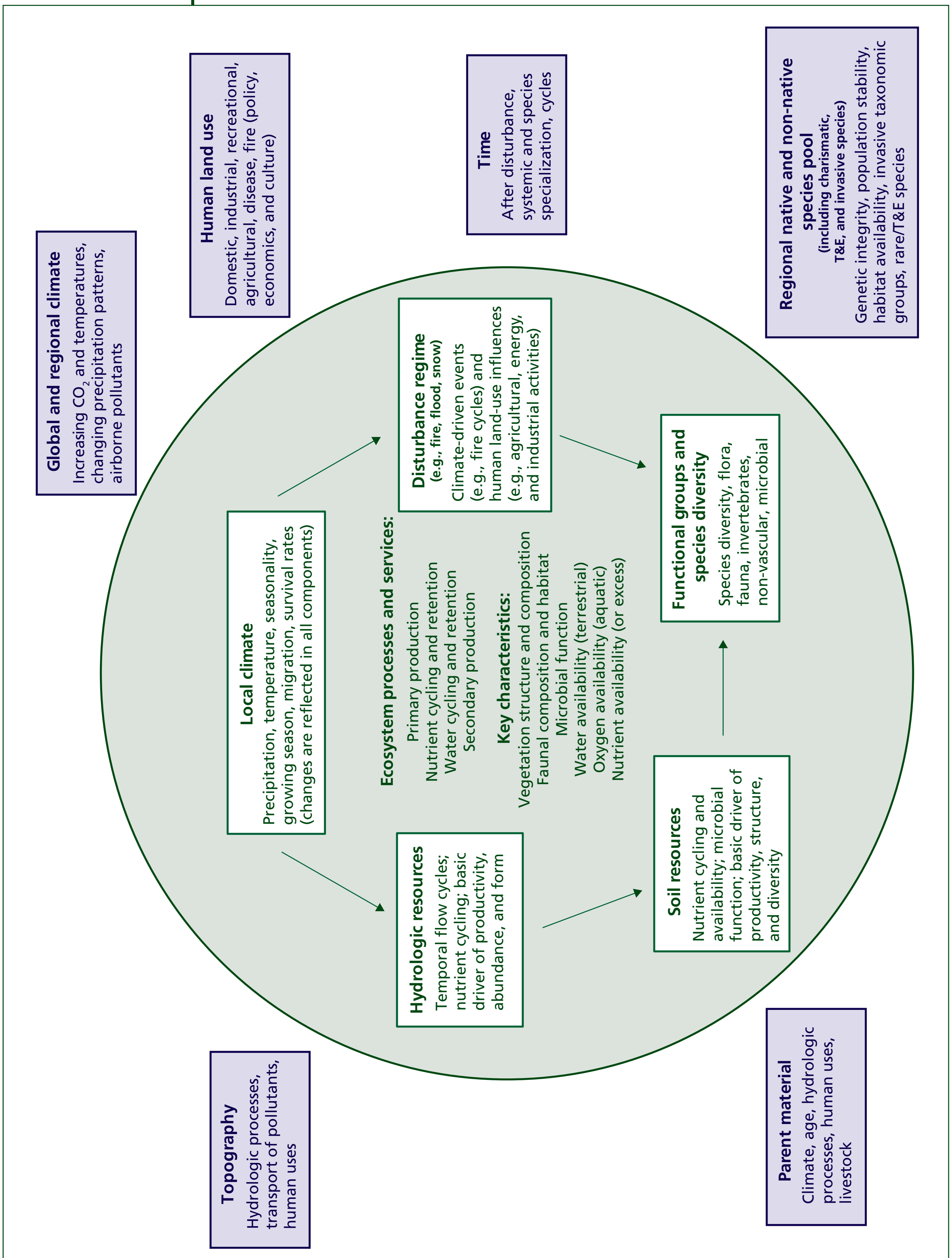


Figure 2.1.1. Aggregated system characterization model.

This model describes ecosystem processes as a function of hierarchical state factors (purple boxes), which operate at the largest scales, and interactive controls (white boxes) that are constrained by these state factors (Dale et al. 2000).

In this chapter we present general ecosystem characterization models for the five systems in which ROMN monitoring will be concentrated.

2.2 Ecosystem Characterization Models

The ecosystem characterization models presented here use a simple, standardized format:

- Key drivers of spatial and temporal patterns and process are shown as ovals at the top of each figure.
- Major system components are shown as rectangles in the center of the figures.
- Dotted-line boxes at the bottom of each figure contain known or anticipated stressors that drive changes in the processes and patterns that define a community or ecosystem.
- Letters in the balloons above the stressor boxes indicate the various drivers and/or components that are affected by each stressor.
- The combinations of letters and arrows in the balloons represent connections between stressors, drivers, and system components.

These models connect changes to the environment (stressors) with systemic effects by relating controlling elements (listed before the arrow(s) in the balloons) with system effects (listed after the arrow(s)). Stressors identified in these models are physical, chemical, and biological perturbations that are generally (1) imposed from outside the system, resulting in a new set of determining conditions, or (2) a natural part of the system but currently realized at an excessive (or deficient) level (Barrett et al. 1976). They represent aspects of the system that drive status and trends in the distribution and function of landscape components (e.g., communities associated with the functional components).

The following sections provide a generalized overview of the five ROMN ecosystem characterization models. Information on the ways in which the core drivers, systemic components, and stressors in each model interact, in terms of climate and physical processes, human use, and biotic processes in ROMN parks, can be found in Appendix A.

2.2.1 Landscape characterization model

The landscape characterization model (Figure 2.2.1) represents the fundamental relationships between abiotic processes and drivers and the structures and function of biotic components of ROMN landscapes. The parks of the ROMN range from relatively functionally complete landscapes composed of interacting yet heterogeneous ecosystems (GLAC, ROMO, GRSA), to smaller systems (FLFO, GRKO, LIBI), often characterized by fewer distinct ecosystem types nested within a landscape mosaic. Although changes are occurring in different ways, scales, and intensities in each park, the concerns about the potential ecological consequences are similar, and the dynamics and functionality of landscape-scale mechanisms are well-recognized as important drivers impacting all six parks. Therefore, the ROMN monitoring framework incorporates a multi-scale perspective, but emphasizes landscape-scale processes, structure, and composition; almost every model that we are developing incorporates landscape-scale components. However, the goal here is to focus on processes that work across large areas and patterns that only emerge with a regional perspective.

The major components of the landscape recognized here include upland (terrestrial) communities, wetlands, aquatic systems (lakes and streams), and abiotic resources (soils, hydrology, geology); these follow directly from the key components of the Jenny-based system model (Figure 2.1.1). The spatial patterns and processes that create ROMN landscapes result from the interactions of climate, geology and soils, geographic position, local disturbance events and cycles, and the distribution of human activities. Landscape patterns are closely tied to stressors (e.g., conversion of remnant habitat, water pollution, air pollution, disruption of hydrologic flow regimes, and direct effects of increased human population density around parks) that affect large areas and all components of the landscape. Human land-use patterns (including residential, agricultural, industrial, recreational, and resource-extraction activities)

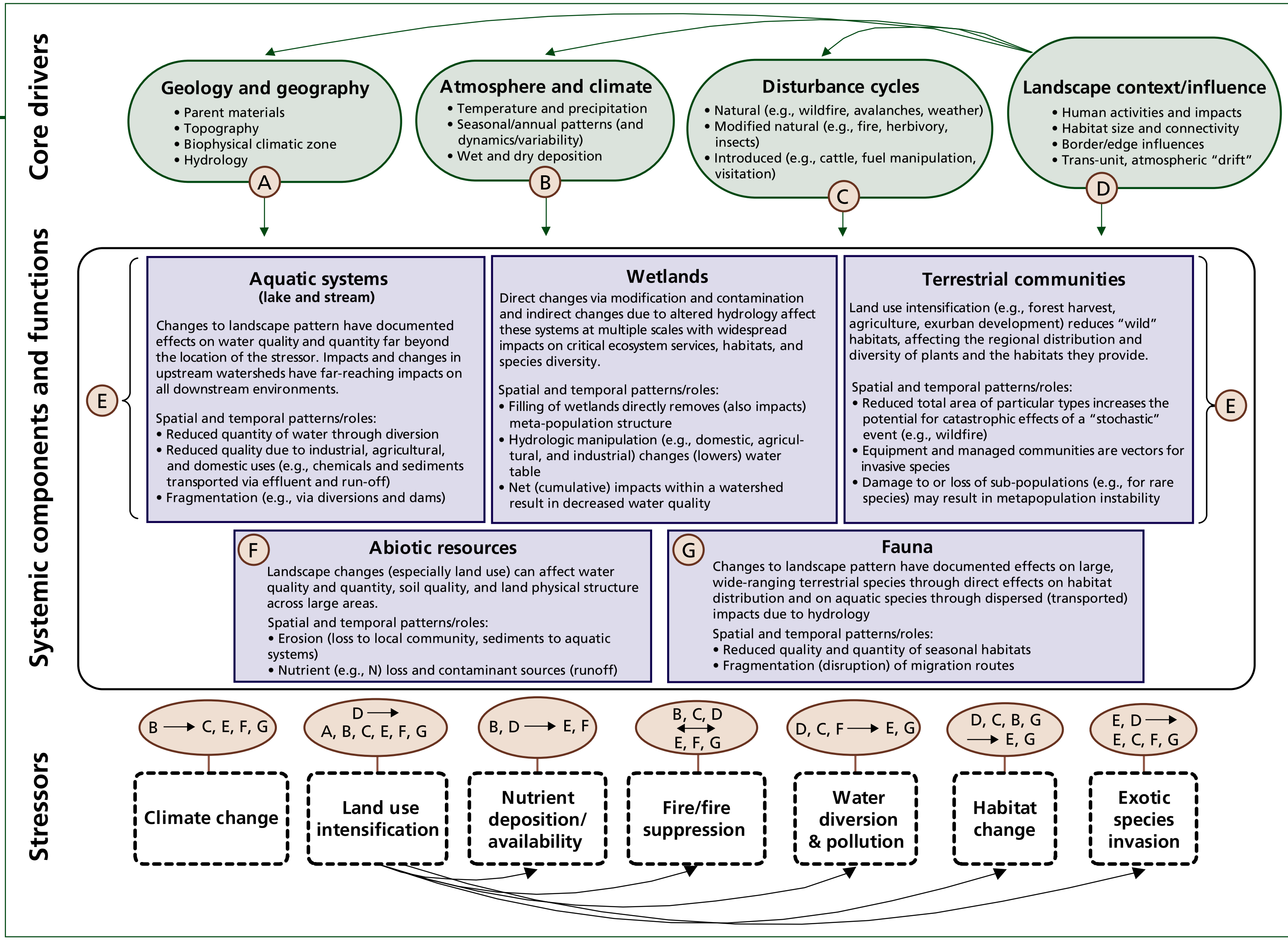


Figure 2.2.1. Landscape characterization model.

Information on how this model functions can be found in Section 2.2. More detailed information on this model can be found in Section 2.2.1 and Appendix A.

have a cascade of effects on landscape-scale drivers. Many of these changes occur because changes in landscape-scale patterns disrupt processes at the community level (e.g., species movement, nutrient dynamics, and surface hydrology) (Ims 1995; Hansen and Gryskiewicz 2003).

2.2.2 Grassland characterization model

The ROMN grassland model is applied to a heterogeneous set of grass- and shrublands ranging from semi-arid dune communities at GRSA, to semi-arid shortgrass steppe at LIBI, and wetter montane grasslands at ROMO and GLAC. This model also may apply to other terrestrial systems (including forests) and disturbance-driven grasslands of higher-elevation (e.g., subalpine) communities. Because drivers and stressors are similar across upland systems at this scale, local differences in the magnitude of a driver's (or drivers') importance are not reflected in models and monitoring methods. Therefore, although the ROMN model focuses on grasslands (because these are the focus of our monitoring), the logic can be applied across upland vegetation types.

The ROMN grassland model (Figure 2.2.2) recognizes the fundamental driving forces of climate and geography in determining the distribution of terrestrial vegetation and ecosystems. We also recognize as secondary, but critical driving factors, disturbance cycles, landscape patterns, and land uses. As previously indicated, this model lumps many critical ecosystem patterns and processes together. The dynamics and driver–response relationships between flora and fauna in upland systems (indicated by arrows connecting system components) are fundamental components of upland structure and function.

Vegetation structure and composition form the core of ROMN upland systems monitoring. The composition, structure, and distribution of grasslands and meadows are affected by stressors working across the landscape, including climate change (which affects water availability, phenology, species, and potential range), human uses (e.g., harvest and exotic species introductions), fire and natural disturbances (including altered fire regimes), and animal activities (e.g., herbivory). Vegetation structure and composition have important implications for wildlife habitat (i.e., is a driver/stressor for focal species).

2.2.3 Alpine characterization model

The alpine system model represents the fundamental relationship between abiotic processes and drivers and the structures and function of biotic occupants of the alpine zone. The model (Figure 2.2.3) portrays geography, geology, and climate as key drivers of the alpine system. Disturbance cycles and landscape effects contribute significantly to some alpine areas, so they are recognized as drivers in the model, but are understood to be secondary to climate and geography in determining the spatial pattern and function of alpine systems. Altered supplies of nutrients and contaminants from the atmosphere are generally attributed to human use, and are tracked across the landscape. These chemicals are often deposited in high-elevation systems.

Key components of the system include flora and fauna (the expected biotic characteristics of the community) and abiotic conditions (e.g., snowpack distribution, glacial processes, wind). The abiotic conditions are so closely intertwined with community character that they are included as a component (and additionally recognized as drivers as part of climate).

Because climate is a primary driver of alpine environmental conditions, changes in weather and climate that modify the balance of resource availability and environmental stress are expected to result in fundamental alterations to the composition and structure of these landscapes (e.g., new species arrivals, treeline/timberline movement, loss of rare/specialist species).

Nutrient deposition is a function of climate (atmospheric circulation) and landscape context (with human activities as the source) directly affecting abiotic conditions (soil chemistry) and flora. For example, shifts in nitrogen lead to changes in composition and primary production. Nutrient deposition is a known stressor at ROMO, and a potential stressor

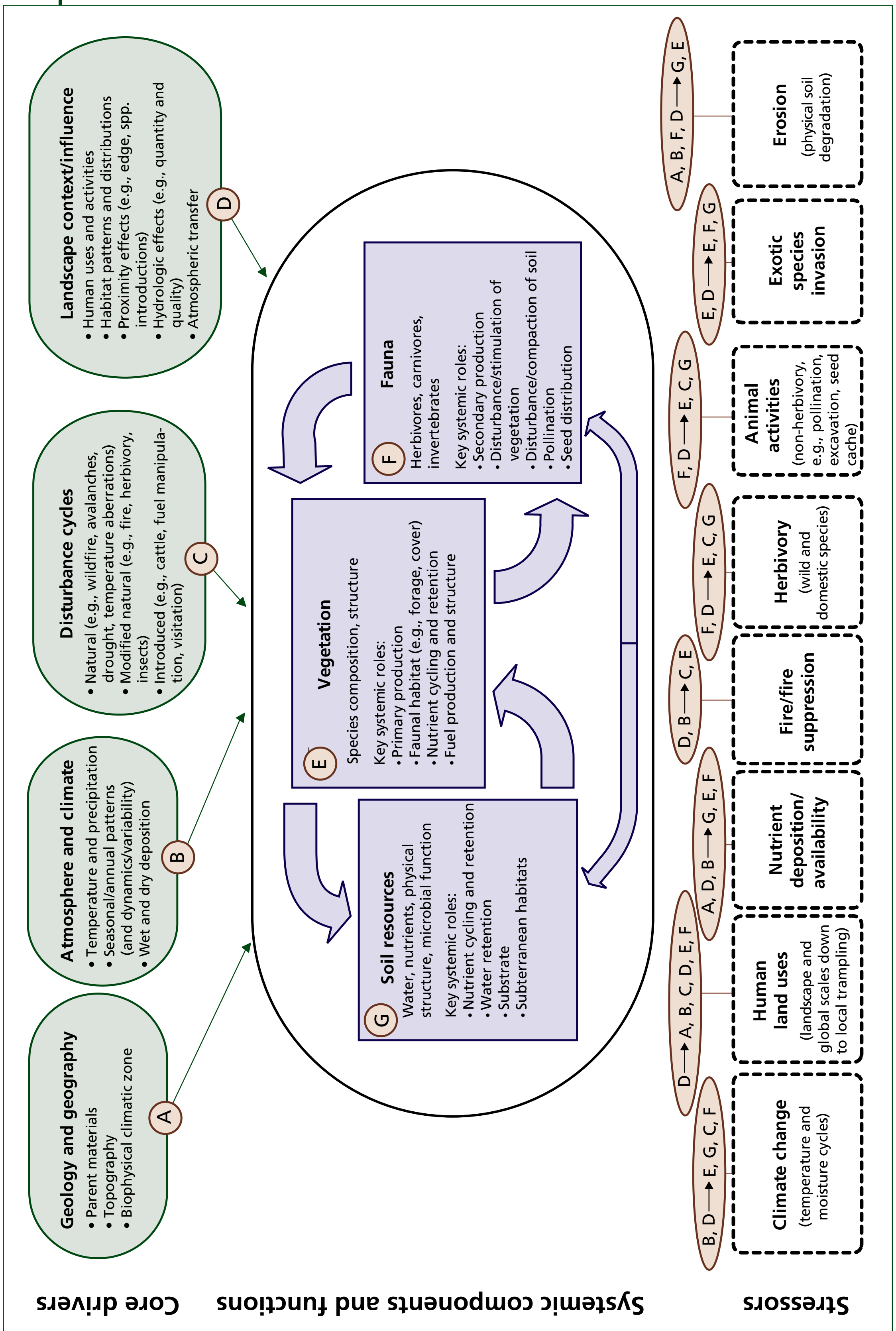


Figure 2.2.2. Grassland characterization model.

Information on how this model functions can be found in Section 2.2.2. More detailed information on this model can be found in Section 2.2.2 and Appendix A.

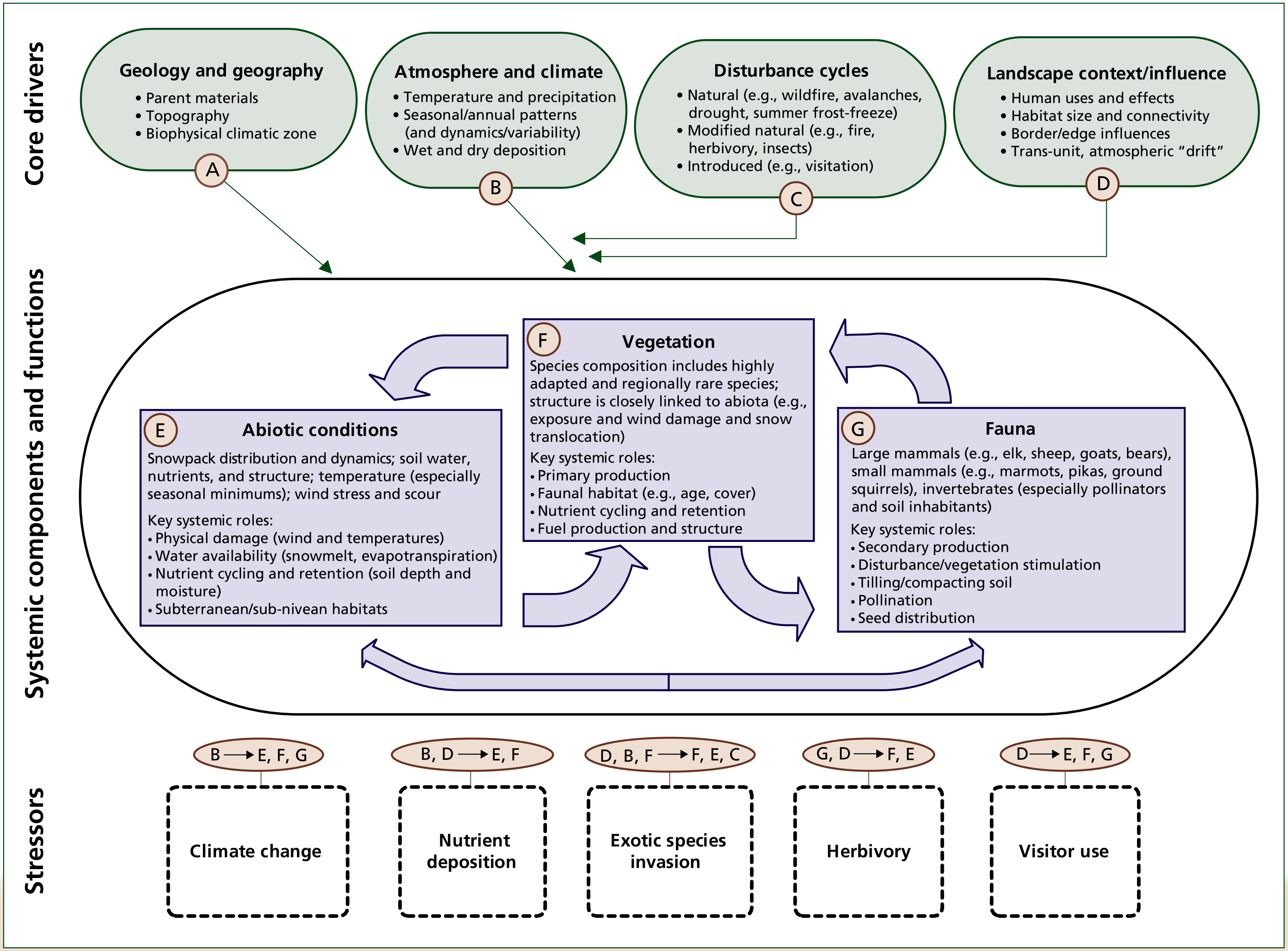


Figure 2.2.3. Alpine characterization model.

Information on how this model functions can be found in Section 2.2. More detailed information on this model can be found in Section 2.2.3 and Appendix A.

at other parks. Research at the Niwot Ridge Long-Term Ecological Research Site (adjacent to ROMO) clearly indicates the responsiveness of alpine vegetation to climatic and nutrient fluxes (Bowman et al. 1995). Changes in the concentration of atmospheric CO_2 are also expected to affect alpine plant composition, because adaptations to limited supply (caused by the rarefied atmosphere at high elevations) will not provide the same competitive advantage as levels increase.

Other potentially important stressors include exotic species invasions (facilitated by human activities and climate conditions) and herbivory by ungulates (altering the structure of vegetation), which in alpine systems also alters the accumulation and retention of water (snow) and nutrients. Visitor use is limited in the alpine systems, but because of increasing visitor numbers and abilities, impacts are likely to accumulate, to the detriment of the natural systems.

2.2.4 Stream characterization model

The stream characterization model represents the fundamental relationships between abiotic processes and drivers and the structures and function of biotic occupants of streams and rivers in the ROMN (Figure 2.2.4). Streams, rivers, and their associated transitional, riparian ecosystems are important components of all ROMN parks. Streams and rivers flow through nearly all park landscapes; riparian corridors and the aquatic systems within them are often foci of biodiversity, and embody multiple ecosystem functions (Sparks 1995). Freshwater systems are arguably the most imperiled ecosystems in the U.S., and are similarly at risk in ROMN parks. They are often altered by impoundments, diversions, channelizing, rip-rap, culverts, de-watering, pollution, and introduction of non-native species. In Montana, for example, biologists estimate that 95% of the state's waters are degraded, have lost native species, and/or have been invaded by exotics (Noss et al. 1995).

Perhaps the defining feature of streams and rivers is their dependence on the landscape in which they reside for inputs of energy and nutrients and the linear flow of these components through the system. ROMN streams are characterized by a high degree of variability, both in terms of hydrogeomorphology (e.g., hydrograph, channel form) and constituent biota. Streams in arid areas (GRSA, LIBI, and, to a lesser degree, FLFO) are inherently dynamic, with often-dramatic variation in streamflow within and between years. Flow variability also tends to increase with decreasing upstream catchment size; thus, high-altitude streams are also very flashy (Burkham 1972; Friedman et al. 1996). However, because this variability is often well-understood (e.g., Clements et al. 2000; Hughes et al. 2000), streams may be excellent indicators of overall park condition from a monitoring perspective. Our model was developed for perennial streams, and may not work in non-perennial streams given their unique ecology.

2.2.5 Wetland characterization model

The wetland characterization model represents the fundamental relationships between abiotic processes and drivers and the structures and function of biotic occupants of wetlands in the ROMN (Figure 2.2.5). Wetlands are important components of nearly all watersheds and support many valuable ecological and socioeconomic functions in and around ROMN parks. Examples of wetland ecosystem functions include the transfer and storage of water, biochemical transformation and storage, decomposition of organic material, and habitat for diverse and highly productive biota. Wetlands support a disproportionate amount of each ROMN park's biodiversity, relative to their area (Niering 1988; D. Cooper, pers. comm.). Wetlands are characterized by three features: hydrology, hydric soils, and wetland biotic communities (particularly hydrophytic vegetation). Hydrology is a defining characteristic of wetland ecosystems, creating wetland soils and leading to the development of biotic communities. ROMN wetland types vary markedly, from the alpine fens of ROMO and GLAC to the sandsheet playa lakes and emergent marshes of GRSA. Complicated regional geology generates important variability in groundwater patterns and flows, depth to groundwater, water chemistry, and surface hydrology, including

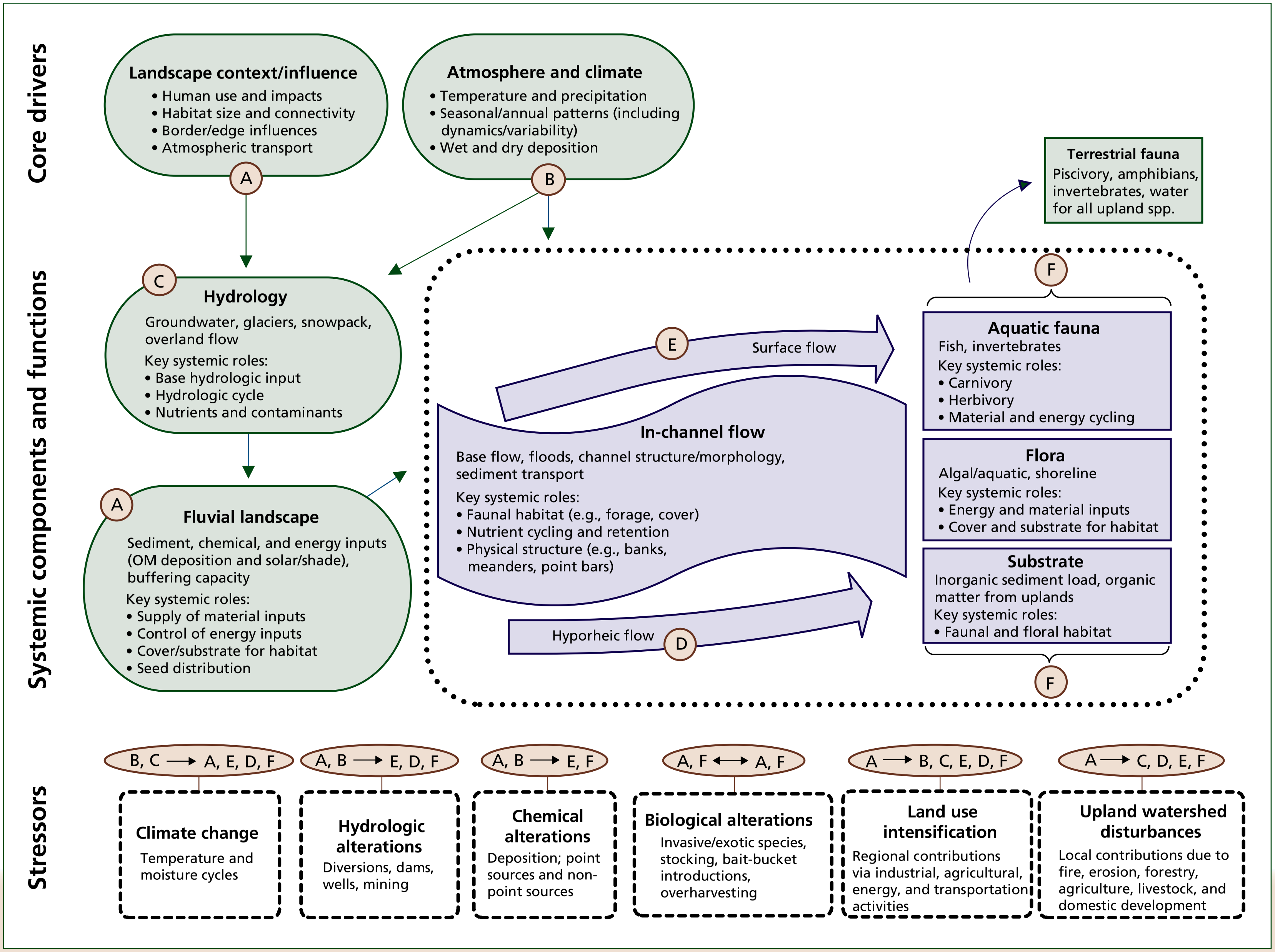


Figure 2.2.4. Stream characterization model.

Information on how this model functions can be found in Section 2.2. More detailed information on this model can be found in Section 2.2.4 and Appendix A.

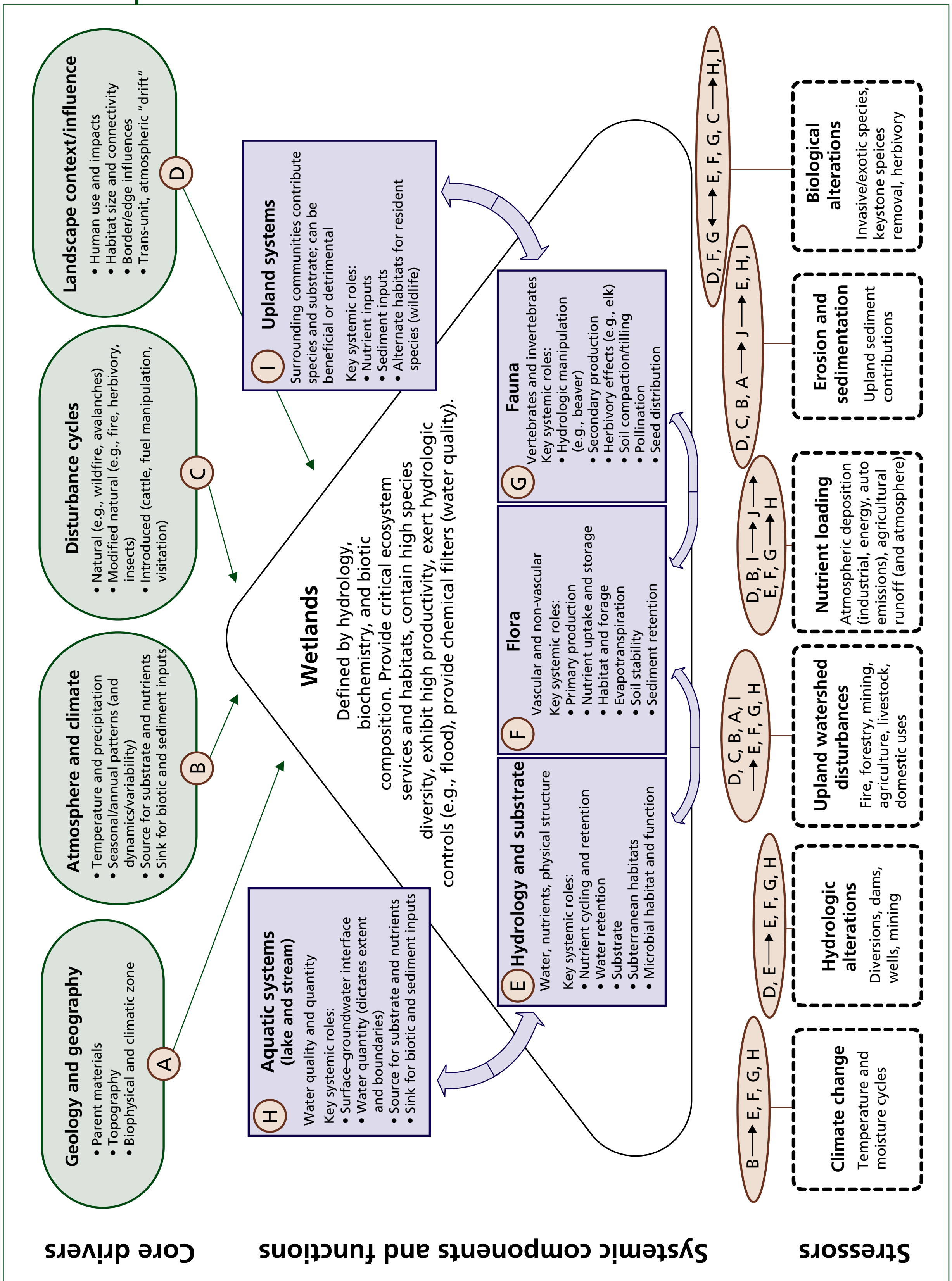


Figure 2.2.5. Wetland characterization model.
Information on how this model functions can be found in Section 2.2. More detailed information on this model can be found in Section 2.2.5 and Appendix A.

transportation of sediments, nutrients, and pollutants.

The ROMN wetland model balances the importance of biological and physical components of a wetland system, recognizing the multi-scale integration of chemical and physical stress that components of a community must accomplish to persist in a specific wetland or a complex of wetlands within a landscape. In addition, we must consider the chemical and physical context of a wetland (especially hydrology; Cooper et al. 1998) across multiple spatial and temporal scales to achieve a full understanding of wetland biota patterns and dynamics. Distinction of wetlands based on hydrologic and biogeochemical conditions (drivers) is a primary determinant of the patterns and dynamics of these systems. Our model depicts the mutual importance of hydrology and biota in defining wetland type and structure (system components) and identifies the key formative roles of geology, geography, climate, and upland condition. Landscape context is also important, because it affects both the quantity and quality of inputs to wetlands from uplands. Water diversion and backfilling of wetlands alters the size, quality, and distribution of wetlands at a landscape scale. In addition, the structure, composition, and function of wetlands are closely connected to aquatic systems and upland systems through hydrologic gradients, wildlife use and movement, and overlapping cover and distribution of some plant species.

2.2.6 Model applications

The process and products of model development formed an important step in the identification and development of ROMN vital signs and monitoring protocols. The ROMN will continue to develop and refine conceptual models as monitoring data improve our understanding of connections between system drivers and responses. In the future, these models, and other, more sophisticated system models and modelling approaches will become part of the analysis of each vital sign. This may simply include use as communication tool in a report, or may inform development of more detailed statistical or predictive models.

Chapter 3
Vital Signs

3.1 Overview

The NPS Inventory & Monitoring Program defines the term "vital sign" 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" (http://science.nature.nps.gov/im/monitor/). This chapter identifies Rocky Mountain Network vital signs, describes the process used to develop and prioritize them, and summarizes the set of products generated by that process. Additional detail and background information is provided in Appendix B.

The ROMN has identified 12 high-priority vital signs for monitoring. In the context of the NPS Ecological Monitoring Framework (NPS 2005a), two high-priority ROMN vital signs relate to Air and Climate, three relate to Water, six relate to Biological Integrity, and one relates to Ecosystem Pattern and Processes (see Table 3.2.6). These vital signs will be developed in detail as we complete and implement monitoring protocols (see Chapter 5) over the next three to five years.

The vital signs selection process was a collaborative effort among park managers, park professional staff, ROMN and other NPS staff, and scientific and technical partners outside the NPS through a series of workshops, meetings, and ranking exercises. Vital signs development began during Phase I (see Chapter 1), and included conducting park scoping meetings, developing descriptions of the natural setting and management issues in each park, and formulating conceptual models of key ecological processes within possible vital signs. Phase II efforts (see Chapter 1) continued the process of identifying, describing, and selecting vital signs, and were natural extensions of activities conducted during Phase I. Key efforts in Phase II included two workshops for developing vital signs objectives, a ROMN Technical Committee meeting devoted to identifying vital signs priorities, and a meeting dedicated to selecting vital signs. Meeting and workshop dates and locations are listed in Table 3.1.

The ROMN used the NPS Ecological Monitoring Framework as one source for identifying candidate vital signs (http://science.nature.

Table 3.1. Key ROMN vital signs planning meetings and workshops, 2004–2005.

Year	Date	Event	Location
2004	January 13–14	Vital signs scoping meeting (FLFO)	Florissant Fossil Beds NM, CO
	February 3–5	Vital signs scoping meeting (GRSA)	Great Sand Dunes NPP, CO
	February 24–26	Vital signs scoping meeting (GLAC)	West Glacier, MT
	March 9–10	Vital signs scoping meeting (LIBI)	Little Bighorn Battlefield NM, MT
	March 23–25	Vital signs scoping meeting (ROMO)	Estes Park, CO
	April 27–29	Vital signs scoping meeting (GRKO)	Deer Lodge, MT
	July 19–20	Conceptual model workshop (GRKO–LIBI)	Deer Lodge, MT
	August 10–11	Conceptual model workshop (GLAC)	West Glacier, MT
	August 17–18	Conceptual model workshop (FLFO, GRSA, ROMO)	Fort Collins, CO
2005	January 25–27	Vital signs objectives workshop (GLAC, GRKO, LIBI)	Flathead Lake BioStation, MT
	March 1–3	Vital signs objectives workshop (FLFO, GRSA, ROMO)	Estes Park, CO
	April 21	Technical Committee vital signs priorities meeting	Colorado Springs, CO, and Missoula, MT
	May 10–11	Vital signs selection meeting	Lakewood, CO

nps.gov/im/monitor/docs/vs_framework.doc). This national framework is hierarchical, with up to five levels, and is intended to provide consistent organization of vital signs among I&M networks. Throughout this document, only the first three levels of the framework are used when listing ROMN vital signs.

The list of vital signs monitored throughout the National Park System is expected to follow the "wedding cake" design (Figure 3.1), in which the majority of vital signs are selected to provide site-specific data needed by park managers for park protection and management. A smaller set of vital signs is monitored at the network or ecosystem level. The smallest set of vital signs is monitored in a standardized way to allow comparisons and synthesis of data across all NPS networks. The ROMN will monitor a subset of important vital signs for network parks. These will complement existing monitoring programs and efforts by utilizing multiple partners at multiple spatial scales. For example, network parks already monitor some resources and ecological processes (e.g., fire and fire effects) at the park level. At a broader scale, the states of Colorado and Montana monitor breeding landbirds, including sampling in some network parks. At the national scale, the NPS Air Resources Division monitors air quality using a combination of park site-level data and modeled data to provide servicewide information. The ROMN program seeks to utilize and complement existing information from established monitoring efforts in order to develop a comprehensive ecological-health monitoring program that is sustainable for the long-term.

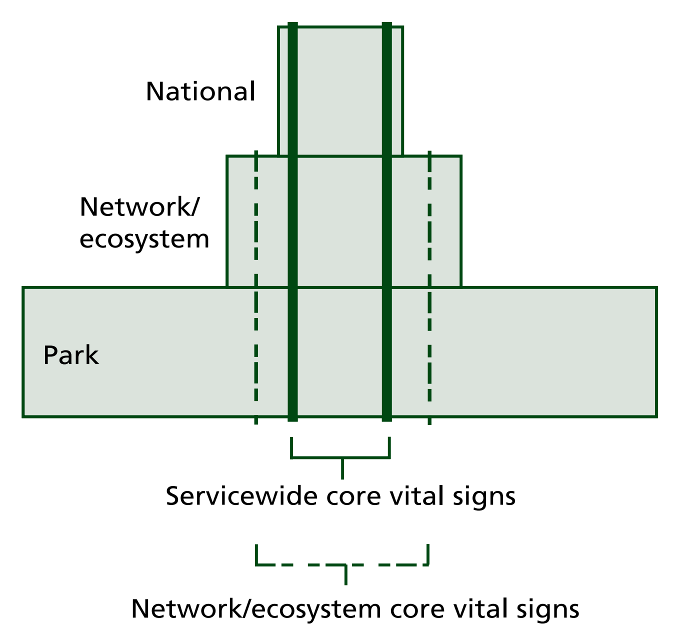


Figure 3.1. Expected distribution of vital signs at park, network/ ecosystem, and national scales.

3.2 Developing ROMN Vital Signs

3.2.1 Initial meetings, 2004

In the winter and spring of 2004, the ROMN held park-specific vital signs scoping meetings to become acquainted and develop good working relationships with park staff and partners, gather important natural resources information and data for each park, and learn about each park's management goals and issues. The ROMN also began discussing candidate vital signs during these meetings.

In the summer of 2004, the ROMN held three conceptual model workshops among ROMN park staff, Science Panel members, other scientific and technical partners, and ROMN staff to develop a common understanding of important ROMN natural resources and ecosystems and their functioning. We continued to develop candidate vital signs at the conceptual model workshops. A key outcome of the workshops was the identification of ecologically significant resources, ecosystem components, and processes.

3.2.2 Preliminary ROMN vital signs identification

To begin creating a set of possible ROMN vital signs, we provided our collaborators with the ROMN Phase I report and solicited their opinion of the five most important vital signs for the ROMN via an e-mailed survey. Using the survey responses and lists of vital signs from other networks and monitoring programs, we created a list of preliminary ROMN vital signs. This list contained approximately 600 vital signs (available upon request from ROMN staff). Appendix B provides additional detail on the survey and general process used to create this set of preliminary vital signs.

All preliminary vital signs were housed in an MS

Access Vital Signs Objectives database developed by ROMN staff. We adapted the database from similar tools developed by other networks (e.g., databases used by the Mojave and Cumberland/Piedmont networks). The database was also used to capture information developed in the workshops and to evaluate preliminary vital signs during and after the workshops. Appendix B provides additional detail on the ROMN Vital Signs Objectives database.

Vital signs evaluation criteria

1. Ecological significance (e.g., as identified in conceptual models)
2. Long-term management significance
3. Feasibility and cost
4. Response variability
5. Existing data and programs

3.2.3 Vital signs objectives workshops, 2005

The ROMN held two vital signs objectives workshops to develop and evaluate the preliminary vital signs generated by ROMN staff and the survey. Twenty-nine NPS managers and scientific/technical staff, ROMN Science Panel members, other scientific and technical partners, and ROMN staff met on January, 25–27, 2005, at the Flathead Lake Biological Station, Montana, for the first workshop, focused on the Montana parks. Forty-two people participated in the second workshop, for the Colorado parks, on March 1–3, in Estes Park, Colorado. Participant lists are provided in Appendix B. The goals of the vital signs objectives workshops were to identify candidate ROMN vital signs, identify opportunities to integrate or link candidate vital signs, estimate costs to monitor candidate vital signs (the first rough estimate), evaluate candidate vital signs with objective criteria, and suggest ROMN vital signs priorities.

We divided workshop participants into four workgroups: Air, Climate, and Ecosystem Processes; Aquatic; Terrestrial; and Wildlife, and provided explicit instructions about how workgroups should function. The Vital Signs Objectives database provided a consistent structure within and across workgroups. Each workgroup was instructed to review the list of preliminary vital signs and add any others that should have been included. As this list was refined to a set of more relevant, higher-priority vital signs, the workgroups developed a series of attributes for each vital sign, including the ROMN parks in which it applied, specific monitoring questions, important drivers and associated vital signs, appropriate scales for monitoring, amounts of spatial and temporal variability in the vital sign, appropriate sample design(s), existing protocols (field methods), and estimated costs (very rough, in most cases).

Workgroups also identified important references, related monitoring programs, and potential cooperators, and produced general notes on each vital sign. They then evaluated each vital sign using five criteria derived from the monitoring literature (Kurtz et al. 2001; Tegler and Johnson 1999; Dale and Beyeler 2001; Noss 1990; Whitford 1998) and other networks: (1) ecological significance, (2) long-term management significance, (3) feasibility and cost, (4) response variability, and (5) existing data and programs. The workgroups assigned each vital sign a score (range from 1–10) for each criterion and then generated an integrated score for each vital sign. These criteria and the scoring process are described in detail in Appendix B.

The workgroup process transformed the voluminous list of preliminary vital signs into a set of "candidate" vital signs and their associated descriptive attributes. These candidate vital signs were then organized according to the NPS Ecological Monitoring framework. At the end of each workshop, workgroup facilitators presented their candidate vital signs and evaluation scores, and provided a brief summary of the key attributes of each candidate vital sign. The Vital Signs Objectives database was used to generate a ranked set of vital signs across all workgroups. The final task for all participants was to submit another survey and "vote" for the five most important vital signs for ROMN monitoring. This allowed participants to privately re-evaluate the candidate vital signs after they had been briefed on each one and seen the evaluation scores.

Table 3.2.3. Rocky Mountain Network vital signs development products.

Product	Description	Ranked/Not ranked	Location in this report
Preliminary vital signs list	Approximately 600 vital signs from other networks, other appropriate monitoring programs, and ROMN collaborator surveys; used as seed material for vital sign workshops.	Not evaluated or ranked.	Available upon request (contained in ROMN vital signs objectives database)
Candidate vital signs survey results	Derived from pre- and post-workshop survey.	Ranked based on relative importance as assigned by collaborators and frequency of occurrence across survey responses, normalized to 0–1, with 1 assigned to "more important" vital signs.	Appendix B
Candidate vital signs list (workgroups)	Derived from workgroup process in the two vital signs workshops.	Ranked based on weighted sum of five criteria described above; normalized to 0–1, with 1 assigned to "more important" vital signs.	Appendix B
Candidate vital signs list (refined)	Combined list of candidate vital signs from surveys and workgroups with some processing and interpretation by ROMN staff.	Ranked based on average of survey score, workgroup evaluation score, and linkage score (see text); normalized to 0–1, with 1 assigned to "more important" vital signs.	Table 3.2.4 in Chapter 3
Selected, high-priority ROMN vital signs list	Final 12 high-priority vital signs as selected by ROMN Board of Directors.	Loosely ranked based on park-specific importance and realities of implementation.	Table 3.2.6 in Chapter 3
Protocol development summaries abstracts	Working documents that summarize the development, status, research needs, and status of each of the 12 high-priority ROMN vital signs (or their derivatives).	Loosely ranked based on park-specific importance and realities of implementation.	Chapter 5

All products from our vital sign development process are summarized in Table 3.2.3.[†]

3.2.4 Candidate ROMN vital signs selection

The workshops and associated surveys generated comprehensive lists of candidate vital signs, replete with attributes and evaluation scores. A central challenge to the network was to take these long, complex lists and apply a robust yet simple and transparent process for interpreting, integrating, scoring, and presenting the candidate vital signs, such that an effective, informed final selection could be made by the ROMN.

In summary, we created a single list of candidate vital signs by carefully examining the attributes of each vital sign (as described in the Vital Signs Objectives database and in the forms returned with each survey) and looked for overlap—for instance, in terms of the endpoint that a vital sign sought to describe, its spatial and temporal scales, field procedures, and parks to which it was applicable. Having all preliminary vital signs organized according to the national framework was helpful in defining candidate vital signs with possible overlap. Our analysis allowed us to combine some vital signs and refine others. In some cases, we averaged scores across two or more vital signs that were merged. The results of our analysis reduced the lists generated by the workgroups and the surveys to a more integrated, defined set of 62 candidate ROMN vital

[†]Two lists of candidate vital signs derived from this process can be found in Appendix B. The first list (Table B.1.2) was derived from the pre- and post-workshop surveys. This list contains 38 vital signs and represents 71 sets of responses from 63 people. The second list (Table B.1.5) was generated from the set of vital signs generated from both workshops (eliminating duplicate or very similar vital signs). This list contains 117 candidate vital signs and (for most) a score for each criterion plus a weighted mean summary score. Note that there is much overlap between the two lists; we attempted to deal with this in subsequent processing and interpretation (described below). While these are not the final set of vital signs selected for ROMN (see Section 3.2.5, below), they have value in that they document the process and development of ROMN vital signs and contain vital signs that may be more important for ROMN efforts in the future or are being measured and assessed by our partners and are therefore possible "shared" vital signs for the ROMN.

signs (Table 3.2.4). The ROMN maintains an archive of all original vital signs, including their evaluation scores prior to any combination or refinement.

After we had a combined list of candidate vital signs, we used three scores for each candidate vital sign to create a ranked list based on mean scores: (1) a score derived from a weighted combination of the rank order and frequency of occurrence of a vital sign from all survey responses (ISS in Table 3.2.4), (2) the evaluation score (IES in Table 3.2.4) from the workshops (based on the five criteria described above), and (3) a "linkage score" (ILS in Table 3.2.4), derived from workshop data and a metric that scored the degree to which each vital sign was connected to others (based on numbers of associated vital signs and the strength of these relationships), for instance, as a covariate in or key driver of an ecological process. These three scores were separately normalized to a scale of 0–1 (with 1 being a more "important," or higher-value vital sign) and then combined via a simple arithmetic average (IMS in Table 3.2.4). These scores were then ranked from most important to least important.

The scores are useful guides to how each vital sign compares to others based on a variety of criteria and methodologies. We feel that using this diverse set of metrics to generate scores ameliorated some of the inherent shortcomings of the process used to evaluate ROMN vital signs. For example, by relying on scores derived both from personal (surveys) and group (workshops) processes, we were able to consider opinions of more reserved individuals as well as consensus. In addition, many of the potential linkages and relationships among vital signs were likely not immediately obvious to participants; the linkage score illuminates this important aspect.

3.2.5 High-priority ROMN vital signs selection

Selection of high-priority ROMN vital signs, based on the list presented in Table 3.2.4, was accomplished in two meetings. The ROMN Technical Committee and ROMN staff met in April 2005 to review the results and products from the vital signs objectives workshops and to agree on set of high-priority vital signs to recommend for the ROMN. ROMN staff briefed Technical Committee members on the development of vital signs since the workshops, and participants agreed upon a list of 12 high-priority vital signs. From these meetings emerged a list of 12 high-priority vital signs for recommendation to the Board of Directors: a mix of those from the original candidate list and those that were a derived combination of vital signs.

Notes on Table 3.2.4 (next page)

Rank mean: scores were ranked from most important to least important, based on the mean score for each vital sign. The mean score was sorted in order with the workshop-derived IES (see below) as the secondary sort field, with any other ties not removed or modified in any way.

ROMN candidate vital sign: vital sign as designated by the ROMN.

ISS: Individual Survey Score, derived from a weighted combination of the rank order and frequency of occurrence of a vital sign from all survey responses.

IES: Individual Evaluation Score, the evaluation score from the vital signs workshops (based on the five criteria described above and in Appendix B).

ILS: Individual Linkage Score, derived from workshop data and a metric that scored the degree to which each vital sign was connected to others (e.g., as a covariate in or key driver of an ecological process), based on numbers of associated vital signs and the strength of those relationships.

IMS: Individual Mean Score, derived from the result when scores from three sources were separately normalized to a scale of 0–1 (with 1 being a more "important" or higher value) and then combined via a simple arithmetic average.

Park applicability: "x" = applies to the park; "-" does not apply to the park; "?" = may apply to park.

National Levels 1, 2, and 3: describes the placement of each ROMN Candidate Vital Signs within the national hierarchical framework.

Some scores with non-zero digits appear as 0.00 due to rounding precision.

Candidate vital signs later included under a broader vital sign category, or later identified as high-priority for monitoring, are shown in khaki.

Table 3.2.4. Rocky Mountain Network candidate vital signs.

Rank mean	ROMN candidate vital sign	ISS	IES	ILS	IMS	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	National Level 1	National Level 2	National Level 3
1	Land Use/Management Patterns	1.00	0.80	0.90	**0.90**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use
2	Landscape Composition	1.00	0.80	0.90	**0.90**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use
3	Landscape Structure	1.00	0.80	0.90	**0.90**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use
4	Core Weather	0.46	0.81	0.81	**0.69**	x	x	x	x	x	x	Air and Climate	Weather and Climate	Weather and Climate
5	Drought	0.46	0.81	0.81	**0.69**	x	x	x	x	x	x	Air and Climate	Weather and Climate	Weather and Climate
6	Snow	0.46	0.81	0.81	**0.69**	-	x	-	x	-	x	Air and Climate	Weather and Climate	Weather and Climate
7	Beaver Habitat, Wetlands	0.58	0.73	0.56	**0.62**	x	x	-	x	-	x	Biological Integrity	Focal Species or Communities	Mammals
8	Beaver Habitat, Aquatic	0.58	0.73	0.56	**0.62**	x	x	-	x	-	x	Biological Integrity	Focal Species or Communities	Mammals
9	Water Chemistry and Physical Attributes, Wetlands	0.48	0.90	0.17	**0.52**	?	x	x	x	-	x	Water	Water Quality	Water Chemistry
10	Water Chemistry and Physical Attributes, Aquatic	0.48	0.90	0.17	**0.52**	x	x	x	x	?	x	Water	Water Quality	Water Chemistry
11	Invasive Terrestrial Plants (Populations)	0.46	0.83	0.22	**0.50**	x	x	x	x	x	x	Biological Integrity	Invasive Species	Invasive/Exotic Plants
12	Invasive Aquatic Taxa (Physical Attributes or Habitat)	0.27	0.89	0.18	**0.45**	x	x	x	x	?	x	Biological Integrity	Invasive Species	Invasive/Exotic Animals and Invasive/Exotic Plants
13	Invasive Aquatic Taxa (Populations)	0.27	0.89	0.18	**0.45**	x	x	x	x	?	x	Biological Integrity	Invasive Species	Invasive/Exotic Animals and Invasive/Exotic Plants
14	Invasive Wetland Taxa (Physical Attributes or Habitat)	0.27	0.89	0.18	**0.45**	?	x	x	x	-	x	Biological Integrity	Invasive Species	Invasive/Exotic Animals and Invasive/Exotic Plants
15	Snow Chemistry	0.34	0.82	0.18	**0.45**	-	x	-	x	-	x	Air and Climate	Weather and Climate	Weather and Climate
16	Wet and Dry Deposition	0.34	0.82	0.18	**0.45**	-	x	-	x	-	x	Air and Climate	Air Quality	Wet and Dry Deposition
17	Beaver (Populations)	0.16	0.95	0.22	**0.44**	x	x	-	x	-	x	Biological Integrity	Focal Species or Communities	Mammals
18	Fuel	0.10	0.75	0.31	**0.39**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and Fuel Dynamics

Table 3.2.4. Rocky Mountain Network candidate vital signs, cont.

Rank mean	ROMN candidate vital sign	ISS	IES	ILS	IMS	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	National Level 1	National Level 2	National Level 3
19	Groundwater Hydrology, Wetlands	0.12	0.89	0.14	**0.38**	x	x	x	x	?	x	Water	Hydrology	Groundwater Dynamics
20	Groundwater Hydrology, Aquatic	0.12	0.89	0.14	**0.38**	x	x	x	x	?	x	Water	Hydrology	Groundwater Dynamics
21	Grizzly Bear (Populations)	0.14	0.83	0.16	**0.38**	-	x	-	-	-	-	Biological Integrity	Focal Species or Communities	Mammals
22	Elk (Populations)	0.16	0.77	0.22	**0.38**	-	?	-	x	-	x	Biological Integrity	Focal Species or Communities	Mammals
23	Vegetation Composition and Structure	0.09	0.84	0.14	**0.36**	x	x	x	x	x	x	Biological Integrity	Focal Species or Communities	Vegetation Communities
24	Invasive Terrestrial Animal Species (Populations)	0.07	0.84	0.14	**0.35**	x	x	x	x	x	x	Biological Integrity	Invasive Species	Invasive/Exotic Animals
25	Aquatic Habitat (includes surficial hydrology)	0.07	0.80	0.19	**0.35**	x	x	x	x	?	x	Geology and Soils	Geomorphology	Stream/River Channel Characteristics and Processes
26	Wetland Habitat (includes surficial hydrology)	0.07	0.80	0.19	**0.35**	x	x	x	x	?	x	Water	Hydrology	Groundwater Dynamics and Surface Water Dynamics
27	Gray Wolf (Populations)	0.14	0.75	0.16	**0.35**	-	x	-	-	-	x	Biological Integrity	Focal Species or Communities	Mammals
28	Soil Quality	0.15	0.71	0.18	**0.35**	x	x	x	x	x	x	Geology and Soils	Soil Quality	Soil Function and Dynamics
29	Medium-sized Mammals	0.16	0.68	0.21	**0.35**	x	x	x	x	x	x	Biological Integrity	Focal Species or Communities	Mammals
30	Small-mammal Assemblages	0.16	0.68	0.21	**0.35**	x	x	x	x	x	x	Biological Integrity	Focal Species or Communities	Mammals
31	Moose (Populations)	0.16	0.67	0.22	**0.35**	-	x	-	?	-	x	Biological Integrity	Focal Species or Communities	Mammals
32	Air Contaminants	0.19	0.73	0.11	**0.34**	x	x	x	x	x	x	Air and Climate	Air Quality	Air Contaminants
33	Rare Plant Taxa	0.14	0.72	0.15	**0.34**	x	x	x	x	x	x	Biological Integrity	At-risk Biota	T&E Species and Communities
34	Benthic Macroinvertebrate Assemblages, Wetlands	0.10	0.78	0.11	**0.33**	x	x	x	x	?	x	Biological Integrity	Focal Species or Communities	Freshwater Communities
35	Seston and Periphyton Assemblages, Wetlands	0.10	0.78	0.11	**0.33**	x	x	x	x	?	x	Biological Integrity	Focal Species or Communities	Freshwater Communities

Table 3.2.4. Rocky Mountain Network candidate vital signs, cont.

Rank mean	ROMN candidate vital sign	ISS	IES	ILS	IMS	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	National Level 1	National Level 2	National Level 3
36	Benthic Macroinvertebrate Assemblages, Aquatic	0.10	0.78	0.11	**0.33**	x	x	x	x	?	x	Biological Integrity	Focal Species or Communities	Freshwater Communities
37	Seston and Periphyton Assemblages, Aquatic	0.10	0.78	0.11	**0.33**	x	x	x	x	?	x	Biological Integrity	Focal Species or Communities	Freshwater Communities
38	Landscape-scale Wildlife Habitat, by Species	0.00	0.92	0.00	**0.31**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use
39	Pathogens	0.00	0.80	0.12	**0.31**	x	x	x	x	x	x	Biological Integrity	Infestations and Disease	Animal Diseases, Insect Pests, and Plant Diseases
40	T&E/Keystone Aquatic Taxa (P/A or Habitat)	0.11	0.69	0.12	**0.31**	x	x	x	x	?	x	Biological Integrity	At-risk Biota	T&E Species and Communities
41	T&E/Keystone Wetland Taxa (P/A or Habitat)	0.11	0.69	0.12	**0.31**	x	x	x	x	?	x	Biological Integrity	At-risk Biota	T&E Species and Communities
42	Native Trout spp. (Populations)	0.06	0.76	0.07	**0.30**	?	x	?	x	?	x	Biological Integrity	At-risk Biota	T&E Species and Communities
43	Fish Assemblages, Wetlands	0.06	0.75	0.09	**0.30**	x	x	x	x	?	x	Biological Integrity	Focal Species or Communities	Fishes
44	Fish Assemblages, Aquatic	0.06	0.75	0.09	**0.30**	x	x	x	x	?	x	Biological Integrity	Focal Species or Communities	Fishes
45	Ozone	0.30	0.60	0.00	**0.30**	x	x	x	x	x	x	Air and Climate	Air Quality	Ozone
46	Dune Insects (Populations)	0.02	0.85	0.00	**0.29**	-	-	-	x	-	-	Biological Integrity	Focal Species or Communities	Insect Communities
47	Dark Night Sky	0.10	0.74	0.04	**0.29**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Viewscape	Viewscape/Dark Night Sky
48	Bighorn Sheep (Populations)	0.16	0.48	0.22	**0.29**	-	x	-	x	-	x	Biological Integrity	Focal Species or Communities	Mammals
49	Visibility and Particulates	0.10	0.71	0.04	**0.28**	x	x	x	x	x	x	Air and Climate	Air Quality	Visibility and Particulate Matter
50	Primary production	0.08	0.66	0.09	**0.28**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Energy Flow	Primary Production
51	Boreal Toads (Populations)	0.10	0.61	0.07	**0.26**	-	x	?	-	-	x	Biological Integrity	Focal Species or Communities	Amphibians and Reptiles
52	Mule Deer (Populations)	0.16	0.41	0.22	**0.26**	-	x	-	-	-	x	Biological Integrity	Focal Species or Communities	Mammals

Table 3.2.4. Rocky Mountain Network candidate vital signs, cont.

Rank mean	ROMN candidate vital sign	ISS	IES	ILS	IMS	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	National Level 1	National Level 2	National Level 3
53	Bald Eagle (Populations)	0.06	0.58	0.08	**0.24**	-	x	x	-	-	x	Biological Integrity	Focal Species or Communities	Birds
54	Soundscapes	0.00	0.67	0.02	**0.23**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Soundscapes	Soundscapes
55	Amphibians (Assemblages)	0.09	0.51	0.02	**0.21**	-	x	-	-	-	x	Biological Integrity	Focal Species or Communities	Amphibians and Reptiles
56	Reptiles (Assemblages)	0.09	0.51	0.02	**0.21**	-	-	-	x	x	-	Biological Integrity	Focal Species or Communities	Amphibians and Reptiles
57	Birds of Prey (Assemblages)	0.02	0.53	0.03	**0.19**	-	x	-	x	-	x	Biological Integrity	Focal Species or Communities	Birds
58	Breeding Landbirds (Assemblages)	0.02	0.53	0.03	**0.19**	-	x	X	-	X	-	Biological Integrity	Focal Species or Communities	Birds
59	Common Loon (Populations)	0.02	0.42	0.03	**0.16**	-	x	-	-	-	-	Biological Integrity	Focal Species or Communities	Birds
60	Harlequin Duck (Populations)	0.02	0.36	0.03	**0.14**	-	x	-	-	-	-	Biological Integrity	Focal Species or Communities	Birds
61	Pollution Sources	0.03	0.00	0.19	**0.07**	x	x	x	x	x	x	Human use	Point-Source Human Effects	Point-source human effects
62	Viewscape	0.00	0.00	0.00	**0.00**	x	x	x	x	x	x	Landscapes (Ecosystem Pattern and Processes)	Viewscape	Viewscape/Dark Night Sky

In May 2005, the Technical Committee, Science Panel, and ROMN staff met in Lakewood, Colorado, to review the workshop results and products. The Technical Committee and ROMN staff subsequently met with the Board of Directors and ROMN park superintendents not on the board, as network staff summarized the vital signs planning process and presented the draft list of vital signs within the NPS framework. The board asked questions and discussed proposed vital signs before endorsing them as presented.

3.2.6 High-priority ROMN vital signs

Table 3.2.6 presents the 12 high-priority ROMN vital signs and their relationship to ROMN protocols in the context of the national vital signs framework. Those vital signs, not ordered or ranked in any way, are:

1. Wet and Dry Deposition;
2. Weather and Climate;
3. Water Chemistry;
4. Surface Water Dynamics;
5. Freshwater Communities;
6. Invasive/Exotic Aquatic Biota;
7. Groundwater Dynamics;
8. Wetland Communities;
9. Invasive/Exotic Plants;
10. Vegetation Composition, Structure, and Soils;
11. Focal Species: Beaver, Elk, Grizzly Bear, and GRSA Endemic Insects; and
12. Landscape Dynamics.

These high-priority vital signs (and indicators the ROMN is developing relative to each) were all identified as ecologically significant in the network conceptual-modeling process (with the possible exception of GRSA endemic insects, whose ecological significance is not well-known, but which rank high in management significance because they are endemic to the park). Key drivers, stressors, and response variables highlighted in the modeling exercise helped to inform the prioritization process.

It must be stressed that there are many important vital signs not on this high-priority list. Significant information on supporting attributes for all candidate vital signs is stored in the ROMN Vital Signs Objectives database. Some of these vital signs may be implemented in the future through a variety of mechanisms, such as collaboration with partners, acquisition of new funds by the ROMN, or reassessment of ROMN park and ROMN monitoring priorities. Any modifications will be proposed to and approved by the Board of Directors before being implemented.

Table 3.2.6. Rocky Mountain Network high-priority vital signs.

Note: The other candidate ROMN vital signs are important, but are not feasible for the network to implement at current funding levels. If funding becomes available, the network will consider adding additional vital signs monitoring.

National Level 1	National Level 2	National Level 3	ROMN final vital sign	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	Measures/Notes
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	-	x	-	x	x	x	Includes deposition of nutrients and select other parameters; integrated with Weather and Climate, Wetland Communities, and aquatic vital signs.
Air and Climate	Weather and Climate	Weather and Climate	Weather and Climate	x	x	x	x	x	x	Includes core weather, snow distribution, and climate dynamics; integrated with nearly all other ROMN vital signs.
Water	Water Quality	Water Chemistry	Water Chemistry	x	x	x	x	-	x	Integrated into a holistic protocol with physical, chemical, and biological measures; emphasis on physical habitat, surficial hydrology, and benthos/periphyton assemblages; will be developed for both streams and select lakes.
Geology and Soils	Geomorphology	Stream/River Channel Characteristics	Surface Water Dynamics	x	x	x	x	?	x	
Water	Hydrology	Surface Water Dynamics		x	x	x	x	?	x	
Biological Integrity	Focal Species or Communities	Freshwater Communities	Freshwater Communities	x	x	x	x	-	x	
		Riparian communities		x	x	x	x	-	x	
Water	Water Quality	Aquatic Macroinvertebrates and Algae		x	x	x	x	-	x	
Biological Integrity	Invasive Species	Invasive/Exotic Animals	Invasive/Exotic Aquatic Biota	x	x	x	x	-	x	Integrated with Aquatic and Wetland Communities vital signs; detection modeling.
		Invasive/Exotic Plants		x	x	x	x	-	x	
Water	Hydrology	Groundwater Dynamics	Groundwater Dynamics	x	x	x	x	-	x	Integrated with Wetland Communities vital sign; select application to other systems.
Biological Integrity	Focal Species or Communities	Wetland Communities	Wetland Communities	x	x	x	x	-	x	Integrated into a holistic protocol with physical, chemical, and biological measures; emphasis on groundwater hydrology and vegetation.

Table 3.2.6. Rocky Mountain Network high-priority vital signs, cont.

National Level 1	National Level 2	National Level 3	ROMN final vital sign	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	Notes
Biological Integrity	Invasive Species	Invasive/Exotic Plants	Invasive/Exotic Plants	x	x	x	x	x	x	Integrated with Vegetation Composition, Structure, and Soils vital sign; detection modeling.
Biological Integrity	Focal Species or Communities	Sparsely Vegetated Communities (Alpine)	Vegetation Composition, Structure, and Soils	-	x	-	x	-	x	Integrated into a holistic protocol with emphasis on vegetation assemblage dynamics and soil quality in alpine and grasslan/shrublands.
Geology and Soils	Soil Quality	Soil Function and Dynamics (Alpine)		-	x	-	x	-	x	
Biological Integrity	Focal Species or Communities	Grassland Vegetation		x	?	x	?	x	?	
Geology and Soils	Soil Quality	Soil Function and Dynamics (Grasslands)		x	?	x	?	x	?	
Biological Integrity	Focal Species or Communities	Mammals Beaver	Focal Species–Beaver	x	x	-	x	-	x	Beaver vital sign will include landscape-scale assessment of habitat and presence/absence within the Stream and Wetland Ecological Integrity protocols.
		Mammals Elk	Focal Species–Elk	-	x	-	x	-	x	Elk and grizzly vital signs will include some landscape-scale habitat assessment and some elk herbivory measures in the Wetland Ecological Integrity and Grassland/Shrubland and Alpine Vegetation Composition, Structure, and Soils protocols. Elk and grizzly data from ongoing monitoring by the NPS, state agencies, and academics will also be used.
		Mammals Grizzly Bear	Focal Species–Grizzly Bear	-	x	-	-	-	-	
		Insect Communities	Focal Species–GRSA Endemic Insects	-	-	-	x	-	-	GRSA Endemic Insect vital sign may include select population and habitat assessment.
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use	Landscape Dynamics	x	x	x	x	x	x	Includes measures of land cover and use, spatial structure, and change detection; integrated with nearly all other ROMN vital signs.

Dotted lines between records suggest areas where integration may lead to more efficient and meaningful assessment.

Rows highlighted in blue represent high-priority vital signs already being monitored by a combination of ROMN parks and outside agencies. The ROMN will harvest and interpret data relative to ROMN parks and important resources and issues and other vital signs.

Rows highlighted in green: ROMN parks and cooperating wildlife agencies are currently monitoring elk and grizzly populations; the ROMN will harvest and report their data. The network will also gather new data on elk and grizzly habitat as components of other protocols, such as Landscape Dynamics.

Chapter 4
Sample Design

4.1 Purpose and Definition

Providing valid, unbiased, and relevant information on the status and trend of selected vital signs is one of the overarching goals of Rocky Mountain Network long-term monitoring (see Chapter 1). Ensuring that monitoring data are representative of the resources of interest across space and time requires careful attention to sample design; a proper design is one of the major means by which the ROMN ensures scientific reliability and defensibility of the monitoring program.

In a general sense, a sample design defines locations for collection of monitoring data. Sample designs include sample size and specific strategies for arraying sites across space and time. Sample designs must be explicitly connected to (1) monitoring goals and objectives (e.g., Knopman and Voss 1989; Gilbert 1987; see Chapter 1) and (2) analyses of monitoring data (see Chapter 7). This chapter identifies the major themes and concepts behind Rocky Mountain Network sample designs and discusses how sample design facilitates integration among ROMN protocols and with other monitoring efforts. Details of specific sampling designs will be documented in their associated monitoring protocols.

4.2 Monitoring Across Space

To varying degrees, the ROMN will employ the following types of sample designs: judgment, model-based, probability (in particular, the Generalized Random Tessellation Stratified [GRTS] design), adaptive, and census, as well as hybrid combinations of various designs. Table 4.2 briefly describes these design types, shows the major advantages and disadvantages of each type, and identifies the degree to which each type will be used. Because GRTS designs will be the ROMN's default design type, they are also described in the text below. More details on some of these design types can be found in Appendix C.

Table 4.2. Major sample-design types to be used by the Rocky Mountain Network.

Design type	Description	Advantages	Disadvantages	ROMN use
Judgment	Employs expert knowledge to varying degrees in the selection of sampling locations (Gilbert 1987).	Convenient. Efficient.	Unknown selection bias is common (Stehman and Overton 1994; Stoddard et al. 1998; Olsen et al. 1999). Often mismatched to monitoring goals. Population-scale inference is only possible with a (usually complex) model (Burke and Lauenroth 1993; Gilliom et al. 1995).	Limited; elements will be incorporated into more robust design types as appropriate.
Model-based	Uses an explicit model to place sample locations in space and time.	May be well-suited to predict ecological patterns or processes in space and time.	Inference from sites selected with a model-based design may require an additional model.	Will be used when the match to objectives is clear, the model's underpinnings are explicit, historic use of the design is peer-reviewed, and the design has led to well-supported monitoring data. Many ROMN protocol development designs will have a modeling basis.

Table 4.2. Major sample-design types to be used by the Rocky Mountain Network, cont.

Design type	Description	Advantages	Disadvantages	ROMN use
Probability	Each unit or element in the resource of interest has a known, non-zero probability of being included in the sample; some form of randomization is always included in the selection of sample locations (Stevens 1994, 1997).	Is representative of the population of interest (Lohr 1999). Allows unbiased inference from sampled sites to unsampled elements of the resource of interest (Hansen et al. 1983). A measure of the precision of estimates can be calculated. Includes fewer assumptions and provides more reliable and defensible parameter estimates than judgment or model-based approaches (Stevens and Olsen 2003). Generally intended for estimation of response measures across entire resources (i.e., population-scale monitoring; Olsen et al. 1999).		Most ROMN monitoring protocols rely heavily on this design type.
Generalized Random Tessellation Stratified Design (GRTS; a form of probability design)	Uses a hierarchical randomization process to achieve spatial balance across regions and resources (Jean et al. 2005).	Produces a spatially balanced sample. Has a robust, unbiased variance estimator. Allows sites to be replaced in a logical way that maintains the validity of any sample (Stevens 1997; Stevens and Olsen 2003, 2004; Theobald et al. in press). Samples are more representative than those produced by other probability designs. Can be used in virtually any monitoring design scenario. Applicable to aquatic or terrestrial resources. Can incorporate subsets of indicator suites by nesting sub-samples within a larger design. Can be fully specified to occur across time and to contain a complex array of site revisits. Can include primary and alternate (or oversample) sites. Can integrate resource classification or spatial structure in the resource of interest into the design. Can account for variability in response across boundaries. Subpopulations can be defined a priori or created after sampling based on observed patterns of variability on the responses.	The underlying sampling process is less intuitive to understand than alternative sampling schemes (Jean et al. 2005).	ROMN default survey design.
Adaptive	Entails the selection of units that may be influenced by the value or type of unit selected (Thompson and Seber 1996); a decision rule is established a priori that triggers a change in the sampling as it occurs.	Can be an effective design for rare resources, particularly if prior information about the distribution of that resource is poorly known. Can modify sample intensity (similarly to GRTS). Can be incorporated into a wide variety of traditional designs.	Increases sampling intensity locally (GRTS intensity change is global). Can introduce bias (Thompson 2002).	If used, this design type will be discussed in relevant protocols.
Census	Examines every unit in the population of interest.	No sampling error to affect estimates.	Expensive. Rarely possible.	Will be used only where relatively inexpensive techniques allow efficient collection of monitoring data across entire parks and it is clear that the census is valid (applies to most monitoring that is remotely sensed).

Table 4.2. Major sample-design types to be used by the Rocky Mountain Network, cont.

Design type	Description	Advantages	Disadvantages	ROMN use
Hybrid	Combines elements of the design types discussed above.	When the final analysis must integrate two datasets of different designs, the design process is more efficient if the designs are treated together rather than separately. Allows elements of model-based design to be employed within a probability structure (i.e., model-assisted designs).		Will be carefully employed in GRTS models that incorporate complex spatial structure in the resource of interest as strata or subpopulations.

4.2.1 Target populations, sample frames, and sample populations

In any sample design, it is important to distinguish between target populations, sample frames, and sample populations (Figure 4.2.1). A target population is the conceptual resource of interest as specified in monitoring objectives, e.g., all the perennial streams of GLAC. It consists of sample units that may be either points in space (a location on a stream) or discrete patches (a well-bounded wetland).

Sample frames are used within a design as representations of the target population (e.g., a GIS data layer of all known or mapped streams in GLAC) within which potential sample locations are selected by a design algorithm.

A sample population is the realization of a monitoring effort, and is the actual resource that was sampled by the sites selected from the sample frame. For example, after reconnaissance and sampling is conducted (and information has been gained on the actual status of sites), a target population of all perennial streams in GLAC might be more explicitly described as the sampled population of accessible perennial streams in Glacier National Park during daytime base flow conditions of 2006. More detail on target populations, sample frames, and sample populations can be found in Appendix C.

4.2.2 Generalized Random Tessellation Stratified Design

The ROMN considers probability designs to be the most defensible way to conduct population-scale monitoring (i.e., where a population is a statistical entity, such as all streams within Glacier National Park; Olsen et al. 1999), and most of the monitoring protocols for the ROMN rely heavily on this technique. Moreover, the NPS I&M program has mandated their usage for all applicable monitoring objectives (NPS 2006a). Examples of ROMN goals and objectives that require a probability design are given in Table 4.5.

Probability designs can range from simple, random designs, to sophisticated, spatially balanced designs. The most common spatially balanced probability design currently in use is the Generalized Random Tessellation Stratified design (Stevens and Olsen 2003, 2004), which produces spatially balanced samples; has a robust, unbiased variance estimator; and allows sites to be replaced in a logical way that maintains the validity of any sample (Stevens 1997; Stevens and Olsen 2003, 2004; Theobald et al. in press). The spatially balanced samples produced by GRTS are more representative than those produced by other probability designs.

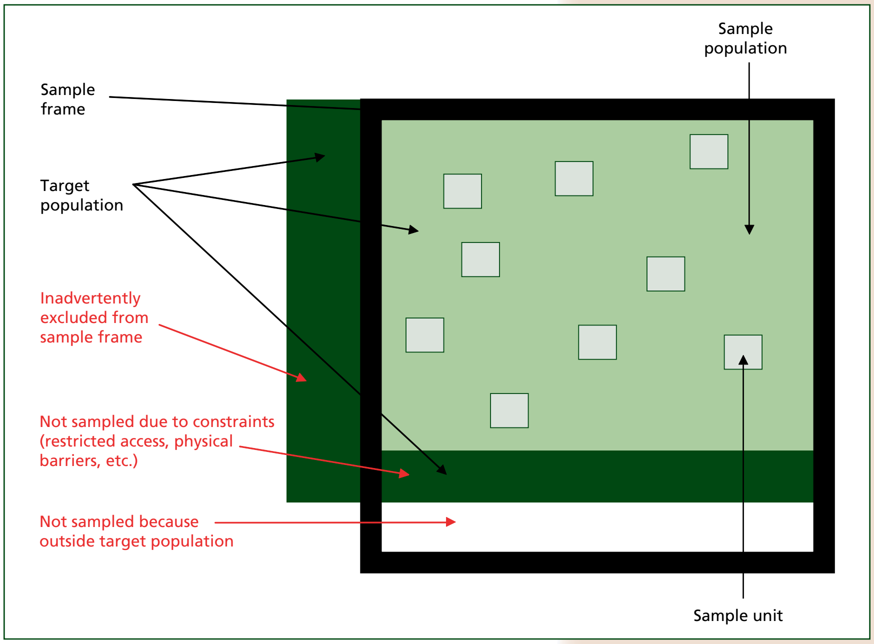


Figure 4.2.1. Conceptual illustration of target population, sample frame, and sampled population.

In some situations, units within a sample frame and/or a target population are not included in the sampled population.

Figure modified from R. Bennetts; original source: T. Olsen, unpublished presentations.

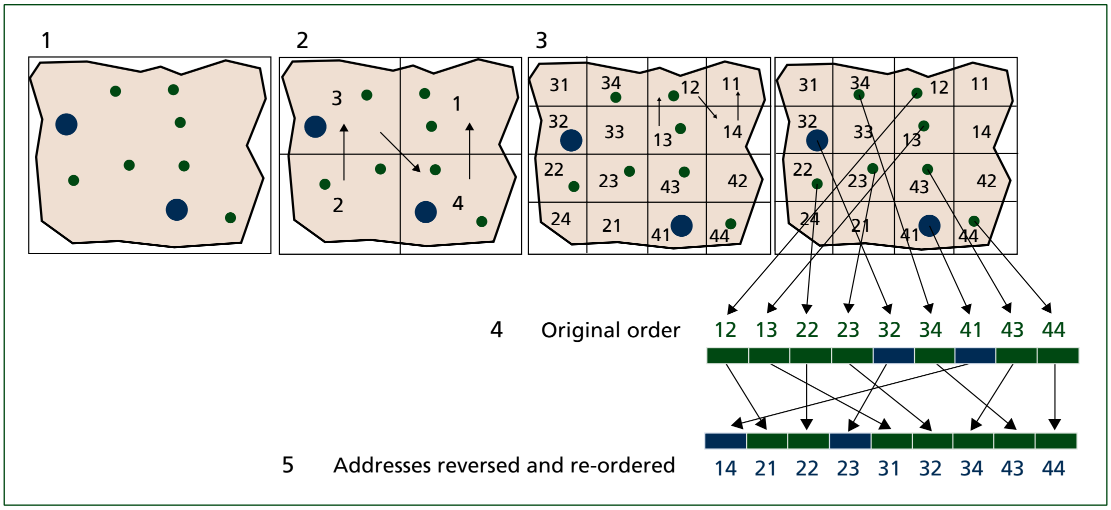


Figure 4.2.2. Graphical representation of the steps leading up to selection of sample units using GRTS design.

See text for explanation.

Figure modified from R. Bennetts; original source: T. Olsen, unpublished presentations.

The process of creating a GRTS design (Figure 4.2.2) may be summarized as follows:

Beginning with a well-developed sample frame (the circles in the figure) and target population (including any relevant subpopulations or strata, represented by different-sized circles in the figure; #1), a grid is placed over the region that bounds the frame (#2).

Next, the grid is sequentially subdivided and each cell randomly assigned a hierarchical address (#2) until only one sample unit exists per cell (#3).

At this point, each population unit is identified with a unique cell address, and the sample units are conceptually ordered based on their address numbers (#4).

The addresses are reversed (e.g., unit 12 becomes unit 21), and the units are resorted in this new order (#5).

A systematic sample of any size is then drawn using a random start point in this sequence. Reversing and re-sorting the address digits causes any contiguous set of sample sites to be spatially balanced and valid (i.e., sampling can start with the site at the beginning of the list and continue using sites until the required number of sites are sampled).

GRTS designs are highly malleable and can be used in virtually any monitoring design scenario. They can accommodate complex objectives requiring cluster designs or multi-stage samples (see Table 4.5), and can incorporate subsets of indicator suites by nesting sub-samples within a larger design. This allows different sets of indicators to be measured at different sites, yet maintains the integrity of the overall design. GRTS designs also can integrate resource classification or spatial structure into the design through stratification, which involves distinguishing artificially constructed regions (strata) within a resource of interest and creating separate sample designs for each of these strata (see Appendix C).

GRTS designs can be fully specified to occur across time and to contain a complex array of site revisits (see Section 4.3.2). GRTS samples can include primary and alternate (or oversample) sites. When circumstances prevent sampling at a primary site (e.g., because the site is not actually a member of the target population, access is denied, or hazardous site conditions exist), an alternate site is used in replacement. When site replacement rules are strictly followed, the representativeness of the final sample is still guaranteed (Stevens and Olsen 2004).

4.2.3 Cost and accessibility

Some environmental researchers avoid using probability designs, believing that the costs associated with randomly selected sites are prohibitive (Olsen et al. 1999). Indeed, because sampling sites in the remote, wilderness settings of some ROMN parks can be difficult to access, sampling front- and backcountry loca-

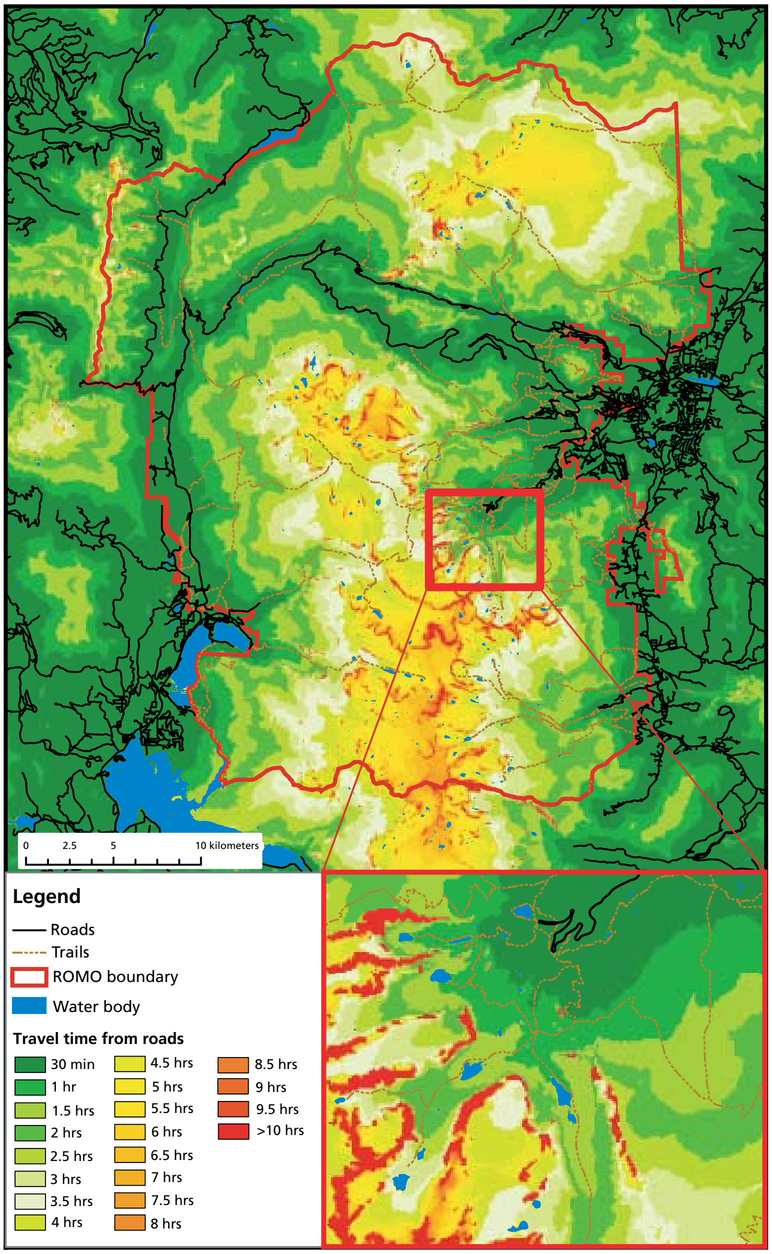


Figure 4.2.3. Example ROMN travel-cost surface estimating the time it would take to walk to a point starting from anywhere on the road network, Rocky Mountain National Park.

tions equally can be cost-prohibitive. However, GRTS designs can deal with the costs of accessing remote sites by adjusting the probability of selecting sites in high-cost areas to be low, limiting the number of sites in these kinds of areas.†

Travel-cost surface models that generate a map estimating the time it would take to walk to a point starting from anywhere on the road network in a park have been generated for all ROMN parks (see Figure 4.2.3 for an example). The central algorithm of this model predicts walking speed from the slope of the terrain being crossed (Tobler 1993; Imhof 1950), modified by a series of auxiliary variables (e.g., land-cover type). These surfaces are combined with the sample frames used in ROMN sample designs to integrate cost into the selection of sample locations.

†Restraint must be exercised, however, because creating large variances in the probability of selections (i.e., greatly reducing the chances of selecting high-cost areas) will inflate the variance of status and trend estimates. Selection probabilities should differ by a factor of less than 100, with less than 20 being ideal (T. Olsen, pers. comm.). For these reasons, most ROMN GRTS designs will not exclude high-cost sites completely. Rather, we will reduce the chance of selecting high-cost areas to balance the trade-offs between selection probability, sample variance, travel costs, and the available budget.

4.3 Monitoring Across Time

Because detecting change across time is a key goal of ROMN monitoring, sample designs always include a temporal dimension, or a distribution of samples across time. How sites are sampled through time has a strong impact on the temporal structure of all designs.

4.3.1 Temporal dynamics in monitoring objectives, capacity, and monitored resources

Monitoring objectives, the capacity to conduct monitoring, and target populations can all change through time. ROMN monitoring objectives have been carefully formulated to focus on key processes and identify variables of interest to park resource managers over the long term. Programmatic changes are sometimes unpredictable (we do not deal with their implications here, but see Chapters 9 and 10). Changes in the resource being monitored may occur due to natural processes (e.g., succession) and/or anthropogenic disturbance (e.g., climate change), and may also be difficult to predict or model. The dynamics of a target resource are both an important response to quantify and a source of difficulty for sample designs, which may become outdated (Overton and Stehman 1996). In general, long-term, longitudinal surveys are more difficult to conduct than a survey performed only once (Fuller 1999).

To deal with temporal dynamics in the resources being monitored, the ROMN will use vital signs that can account for these dynamics and sample designs that are amenable to modification. Such flexibility is one of the strengths of the GRTS design. With a GRTS design, a large oversample may be selected, and sites decommissioned or added, to enhance status and trend assessments or to expand the number and types of areas sampled as target populations change (Overton and Stehman 1996). The structure of the design allows this to occur in valid ways, maintaining representative and spatially balanced samples through time. Other solutions available within GRTS designs involve analytic techniques such as post-stratification or conditioning (see Overton and Stehman 1995; Kish and Scott 1971). However, because heavily structured designs complicate all of these fixes (Overton and Stehman 1995), simple design specifications are preferred. For example, the ROMN will attempt to use equal probabilities whenever achievable and limit use of stratification.

Most sample designs can be structured into panels that are implemented through time (discussed in detail in the next section and Appendix C). As a mechanism within longitudinal surveys, a properly specified panel structure can strike a balance between maintaining consistency in a design and accommodating resource dynamics (Urquhart et al 1993). For example, panel designs can overcome traditional limitations by replacing a subset of the sampling stations at specified intervals to continually survey new locations that would otherwise go unsampled. Sampling with partial replacement has the additional advantage of minimizing the bias in estimates of status while continually updating prior estimates through timeseries calculations (Skalski 1990). Most ROMN protocols also include sample sites that can be mobile through time based on models that estimate future error given current information, predicting the optimal spatial locations for sample sites in the future (Wikle and Royle 1999). When these mobile sites are connected analytically (e.g., two-phase regression estimation; Sarndal, Swensson, and Wretman (1992)) to fixed sites, they may allow an adaptive response to temporal dynamics in a monitored resource.

4.3.2 Panels

Most ROMN protocols rotate field-sampling efforts through various sets of sample units over time. A group of sample units that are always sampled together is called a panel, and the pattern of visits to panels across time is a panel design. During any given sampling occasion, either all of the sample units comprising a panel are sampled or none are sampled. In most designs, sites in a panel occur across an entire target population (i.e., panels are not spatially segregated). Panels retain all of the aspects of the design form used to array sites across space (e.g., with a GRTS design, spatial balance and site replacement rules exist within each panel). Paneled sampling designs are used to allocate sampling both spatially and temporally in order to manage the trade-off between status information and trend information effectively.

Ecological timescales and statistical issues interact with monitoring budgets to determine the panel design (i.e., the pattern of visits within and across years to sites in panels, number of sampling occasions when a panel is sampled, and the interval between samples of panels). Panel designs can take a variety of forms in response to these constraints (Urquhart et al. 1993; McDonald 2003; Table 4.3.2). Complete-revisit designs specify that each site in a design is revisited each year (Table 4.3.2, frame 1). Never-revisit panel designs specify that each site is visited only once (Table 4.3.2, frame 2). In repeating panel designs, each panel is measured repeatedly over time (Table 4.3.2, frame 3). Finally, split-panel designs partition panels into two or more forms (Table 4.3.2, frame 4).

A common split-panel design combines two panel types: one with smaller sample sizes that are resampled in consecutive years as a way to account for annual variability (see below) and one with larger sample sizes sampled infrequently to establish status (Table 4.3.2, frame 4). These forms of split panels are also known as partially augmented, serially alternating designs. Split-panel designs have the desirable feature of being linked, because some plots are measured in consecutive years. This connectivity allows the user to estimate year effects, if present, and is important if it is necessary to estimate annual means and the contrasts among them. Split-panel designs can also be specified to deal with longitudinal change in the target resource, by allowing "refreshment" of the design through time (Skalski 1990). Many ROMN panel structures will use a split-panel form.

Table 4.3.2. Hypothetical panel design forms.

	Sample occasion (year)									
	1	2	3	4	5	6	7	8	9	10
Frame 1. Always revisit $(1\text{-}0^{1}_{35})$*										
Panel 1	35	35	35	35	35	35	35	35	35	35
Frame 2. Never revisit $(1\text{-}n^{10}_{35})$*										
Panel 1	35									
Panel 2		35								
Panel 3			35							
Panel 4				35						
Panel 5					35					
Panel 6						35				
Panel 7							35			
Panel 8								35		
Panel 9									35	
Panel 10										35
Frame 3. Split panel $[(1\text{-}0^{1}_{35}), (1\text{-}4^{9}_{5})]$*										
Panel 1	35	35	35	35	35	35	35	35	35	35
Panel 2	5				5					
Panel 3		5				5				
Panel 4			5				5			
Panel 5				5				5		
Panel 6					5				5	
Panel 7						5				5
Panel 8							5			
Panel 9								5		
Panel 10									5	
Frame 4. Split panel, partially augmented serially alternating $[(1\text{-}4^{1}_{30}), (2\text{-}4^{5}_{5})]$*										
Panel 1	30					30				
Panel 2	5	5				5	5			
Panel 3		5	5				5	5		
Panel 4			5	5				5	5	
Panel 5				5	5				5	5
Panel 6					5	5				5

Notes on Table 4.3.2.

Values in the cells are expected sample sizes within each panel.

*The notation commonly used to describe panel designs is a pair of digits. The first digit is the number of consecutive occasions on which a panel is sampled; the second is the number of consecutive occasions on which a panel is not sampled (McDonald 2003). For example, if a single panel is visited on every sampling occasion, its panel design can be expressed as [1-0]. If a panel is to be sampled once, then never revisited, the notation is [1-n]. If a panel is revisited for two consecutive years then rested for 7, it is [2-7]. The notation [1-0, 1-4] signifies that units in one set of panels are visited on every occasion, and units in a second set of panels are visited once every five years. The number of panels within a revisit form may be noted with a superscript and the sample size within each panel with a subscript. For example, $[1\text{-}0^{5}_{10}, 1\text{-}4^{10}_{3}]$ has five panels of sample size 10 visited every year and another 10 of sample size 3, visited every fifth year.

All sample-design types with multiple sites can be structured into panels; however, GRTS designs lend themselves to this approach, and many of the analyses the ROMN will use to assess the adequacy of a sample design for quantifying temporal dynamics assume that a representative probability sample, like that derived from GRTS, has been used (Urquhart et al. 1993; Larsen et al. 1995).

4.3.3 Timing of sampling

The selection of when to sample within a sample interval (e.g., a given month, week, or day during a year, or a particular hour during a 24-hour period) is presented in each protocol. The timing of sampling must be carefully chosen and justified. Often, a method known as index-period sampling is used. Index-period sampling focuses the time of sampling on the most ecologically relevant or seasonally consistent period(s) for a given response measure so the data collected will function as the most useful barometer of a vital sign or of the condition of target populations within a given sampling interval (Larsen et al. 1995; Kaufmann et al. 1988; Landers et al. 1988; Messer et al. 1986). Index-period sampling also reduces inter-annual variability. Examples of index periods might be the late-summer period of maximum standing crop for a given plant community (if total growth is most critical), or the early-fall, base-streamflow period, when aquatic communities might be most stressed. Index-period sampling might also be used to deal with phenological changes in a resource (if these can be identified a priori). While an index-period approach is not appropriate for some response measures, it is a useful and efficient way to conduct most population-scale, long-term monitoring, and ROMN protocols will employ the technique when appropriate.

4.4 Specifying and Evaluating ROMN Sample Designs

A critical part of the sample-design process involves determining the specifications of a design needed in order to meet monitoring objectives (or alternatively, evaluating the capability of an affordable design). This includes design characteristics such as sample size and panel-design structure, given their influence on the power to reveal trend or provide precise status estimates. Below, we provide a brief overview of some key concepts in design evaluation.

4.4.1 Key design evaluation concepts

Time and space considerations are inseparable when developing a design, and the capacities of a design to meet both status and trend objectives are ideally considered together. However, for clarity, we treat these separately before presenting an integrated approach.

4.4.1.1 Status and its precision

Status is defined as some statistic (e.g., a mean or a proportion) of a vital sign over all monitoring sites within a single or well-bounded temporal window. Status will always have some measure of statistical precision (e.g., a confidence interval, standard error, variance). The precision of a status estimate determines the "quality" of the measure and (in a general sense) how it might perform in statistical analysis (e.g., in a comparison of two status estimates). Status may be expressed in a cumulative frequency distribution (generated by accumulating sorted indicator estimates across spatially distinct samples), which has the advantage of capturing subtle variability across an entire distribution versus a single number like a mean.

The criteria we use to evaluate a design's capacity to estimate status include (1) how well the design matches monitoring goals, (2) how representative the design is of the target population, and (3) how precise status estimates are. Two tools are used to evaluate the precision of status estimates: a linear model and variance components tool, and a simple approximation tool. Detailed information on these criteria and tools can be found in Appendix C.

4.4.1.2 Trend and effect size

Ecological resources are dynamic, and change over time is to be expected. Thus, a successful monitoring program must identify not only whether changes have occurred, but also whether or not those changes are part of a true trend, whether there has been a meaningful change (ecologically and/or to park managers or the public), what may have caused that change, and whether the resource is expected to change further.

The ROMN defines trend as a non-cyclic, directional change in a response measure that can be with or without pattern (Urquhart et al. 1998). Some response measures may have a temporal pattern that is not a trend, and vice versa. Trend may be site-specific (often called individual) or apply to an entire target population as an average (or net) trend. Furthermore, if trend is present, linear trend will be present (Urquhart and Kincaid 1999). Trend is the primary way in which the effect size, or amount of a long-term change in a vital sign or target population, is quantified across time. Moreover, in this context, trend of a given magnitude is synonymous with a minimum detectable change in a vital sign.

Change or trend in a response measure can occur both at the site and the population scale. To ensure that sample sizes and allocation of sampling across panels (time) is sufficient, all ROMN panel designs will use a model recently developed to explore attributes of panel designs as well as characteristics of the indicators and resource populations of interest that influence population-scale status description and trend detection (Urquhart et al. 1993, 1998; Larsen et al. 1995; Urquhart and Kincaid 1999). The model is an expansion of the usual linear regression equation (e.g., Draper and Smith 1967; Urquhart et al. 1998; Larsen et al. 2001) that explicitly includes the effects of multiple sources of variance (Figure 4.4.1.2). These variance components include site-to-site differences, year-to-year differences, the interaction of site and year, and a residual term that represents "unexplained" variance in the data (Table 4.4.1.2). Single-site monitoring actually becomes a special case of the model (Larsen et al. 2001), and the ROMN will apply the technique to single-site designs as appropriate.

$$\mathrm{var}(slope)=\frac{\dfrac{\sigma^2_{Site}}{l}+\sigma^2_{Year}+\dfrac{\sigma^2_{Interaction}+\dfrac{\sigma^2_{Residual}}{r}}{l}}{\sum\left(Y_i-\bar{Y}\right)^2}$$

Figure 4.4.1.2. General model used in power-for-trend and standard error of status analyses.

σ^2_{xxxx} are the relevant variance components (see Table 4.4.2), l is the total number of unique sample sites, r is the number of samples within a year, and Y is year.

Table 4.4.1.2. Variance components involved in estimating power for trend and standard error of status.

Component of variation	Description
Site	Variation among values of an indicator (response) across all sites in a park or group of related parks or across a population or subpopulation of sites. Persistent differences among sites across a target population are expressed through site-to-site variation. For example, stream size or gradient differs across the landscape. Some stream channels are constrained by V-shaped valleys and are regularly scoured to bedrock; other channels are contained in broad alluvial valleys and have high alluvial loads. These differences among stream reaches in a region are captured by site-to-site variation.
Year	Coherent or synchronous variation among values of an indicator (response) across years for *all* sites in a target population or subpopulation. This is *not* variation in an indicator across years at a single site. It is the de-trended remainder, if a trend is present (effectively the deviation away from the trend line or other curve). The synchronous or coherent yearly variation among all sites in a network that might be influenced by regional-scale forces such as climate, broad-scale disturbances, or ocean conditions. An example is the synchronous variation in stream flows that are higher than normal at all sites during a wet year but lower than normal at all sites during a dry year.
Interaction	The independent, de-synchronized yearly variation among all sites in a network, subject to local-scale influences (what most ecologists would call year-to-year variation). An example is the yearly variation in the amount of wood or fine sediments in stream channels. The supply of wood or sediments might be quite patchy spatially and variable temporally such that some reaches receive high amounts in particular years but lower amounts in other years, whereas the reverse might be true for other reaches. The interaction component can be combined with the residual component into a variance component called the index term.
Residual	Residual variance captures the remaining variation. It consists primarily of (1) short-term variation during the temporal window when measurements are made, (2) measurement error, and (3) team-to-team differences in applying the same field protocol. The residual term includes within-sample interval (e.g., year) variation, important in single-site trend estimation. The interaction component can be combined with the residual component into a variance component called the index term.

Adapted from Larsen et al. (2004).

Population-scale trend. Two methods using the model in Figure 4.4.1.2 were used to develop and evaluate ROMN sample designs for population-scale monitoring. The first method uses the linear modeling and analysis of components of variation approach as presented in Urquhart et al. (1993, 1998) and Larsen et al. (1995), with all input parameters derived externally from the tool. The second method, the Complex Survey Design Simulator (CSDsim; Garman et al., in prep.) tool, differs from the first method primarily by simulating the values of a response measure at each site in a hypothetical network of monitoring sites (and therefore the input to the linear model analysis of power for trend). More detail on both of these models can be found in Appendix C.

Site trend. Trend-detection capability can be evaluated at a single site as a special case within the linear-modeling approach (Larsen et al. 2001). The formal statistical and analytical basis for the site-scale trend detection model and power estimation, along with justification for assumptions regarding the distribution of slope values, are given in Urquhart et al. (1993) and Larsen et al. (2001). The tool we used to develop power-for-trend curves at a site was the same as for multi-site scenarios, albeit with fewer input parameters. Relevant results and interpretation are presented in ROMN protocols.

Select ROMN protocols will use "sentinel sites"—the term adopted by the network for the limited set of judgment- or model-based designs, and the sites created by them, that the ROMN will employ—to monitor trend at specific locations. Data from sentinel sites typically are not intended to be used in combination with other sites to make direct inference to some target population. Rather, monitoring results from sentinel sites apply either to the site alone or must be incorporated into a model to extrapolate results to unsampled locations in a ROMN park (see Chapter 7).

4.4.1.3 Evaluating designs for status and trend

We use the linear modeling and analysis of components of variation approach as presented in Urquhart et al. (1993, 1998) and Larsen et al. (1995) to evaluate designs for both status and trend monitoring. The model quantifies trade-offs between estimating status and trend and how sample designs influence these trade-offs (Urquhart et al. 1993, 1998). By varying key inputs and holding others constant, we can investigate the impact of specific attributes of a design on power-for-trend detection and/or SE (standard error) of status estimates. Hypothetical results that illustrate key patterns in power for trend and SE of status with different design specifications can be found in Appendix C; real results of this form are presented in ROMN protocols.

4.4.1.4 Ecological and statistical significance

To understand what constitutes a meaningful trend, it is essential to realize the difference between statistical significance and ecological significance. Statistical significance relies on probability and is influenced by sample size. Thus, even changes that are minor or of small magnitude from an ecological perspective will be statistically significant if the sample size is large enough. Ecological significance is the product of experience, ecological theory, and interpretation. Identifying ecologically meaningful change requires context provided by informed reference condition or threshold identification (see Chapter 7), connections between vital signs and key system covariates, models that help to explain and predict ecological patterns, intelligently applied ecological knowledge, and professional intuition. Regardless of statistical significance, the ROMN would consider a change to be ecologically significant if it facilitated a major shift in ecosystem structure or function. Some examples might be the loss of one or more dominant or keystone species, the addition of non-native species, or changes in ecosystem production or decomposition rates.

The ROMN is concerned with both ecological and statistical significance—specifically, with knowing whether monitoring is likely to detect trends statistically that would be considered biologically meaningful. To answer this, the network first needs to know what level of statistical significance to strive for (i.e., the Type-I error rate or alpha), what level of ecologically meaningful change it hopes to detect, and how variable the resource to be estimated is. This information will enable the network better to determine the likelihood of detecting a change (statistically) that it would consider biologically meaningful. Statistical significance may be more relevant to the details of a sample design, and is our focus here.

4.4.1.5 Statistical power

Statistical power is the ability of a test to detect an effect—given that the effect actually exists—and is an important concept in sample-design evaluation. Statistical power refers to the probability of not making a Type-II error (i.e., failing to detect a real trend). It is important to note that statistical power depends on the level of acceptable Type-I error (i.e., detecting a trend that is not real), the effect size (i.e., departure from zero-trend), and the relationship between variation in the resource being measured and in the sample size used to detect the trend. Power analysis, executed when a sample design is being planned, provides the likelihood that a design will be able to detect trend of a particular size (or effect size). Power analysis can also be used to compare various panel designs and determine the sample size needed to detect trend of a given magnitude with reasonable confidence.

4.4.2 Summary

In summary, all ROMN sample designs for goals and objectives with an inferential component (e.g., estimating status and trend at the park scale) have the following attributes:

- They are derived using a GRTS approach;
- They assume that site-level (response) protocols generate valid estimates at the scale of the site and the index period (accounting for much of the residual variance);
- They use a split-panel structure (partially augmented, serially alternating), including main panels separated in time by multiple years and linkage or connection panels with a smaller sample size revisited in consecutive years until the main panel is sampled again;
- The effect sizes to which the design must respond are either empirical or modeled real trends within the resource or thresholds set by management needs;
- Sample size within panels is set by the optimization of the impacts of the expected trend for the primary response measures of each vital sign, the year and interaction effects, and the need for useful status estimates (by the main panels, but also across multiple years); and
- Sample sizes will be refined by optimizing the amount and quality of vital signs data/information obtained relative to costs within and across all ROMN monitoring protocols.

Single-site designs have many of the same attributes, with emphasis placed on understanding the relative contribution of within- and across-year variability and efficient site-level protocols to optimize allocation of effort across time.

4.5 Sample Designs for ROMN Protocols

Each ROMN vital sign or protocol has a research and development plan (see Chapter 9) that specifies how information is generated to enable estimation of these sample-design specifications. In some cases, this information comes from a period of 1–3 protocol-development years during which year, site, and other variance components are estimated using a simple approximation of the likely long-term monitoring design. In other cases, existing monitoring provides sufficient data for parameter estimation, allowing the monitoring design process to begin sooner. Alternatively, some protocols may use predictive or simulation models to estimate variance components that are then analyzed by the linear models mentioned above, with monitoring designs based on the results. In all cases, a degree of flexibility is built into the designs so that adjustments (e.g., to sample sizes or revisit allocation) can be made as the network staff learns more about variance structures. This will ensure use of the most efficient sample designs to meet ROMN goals and objectives.

Each ROMN protocol will include specific sample designs with all of the details of sample size, panel designs, and power-for-trend capabilities as discussed above. Table 4.5 presents a summary of the likely designs for each ROMN protocol.

4.6 Integration

In a successful, comprehensive monitoring program, individual components must be integrated so that the interpretation of the whole program yields information more useful than that of its individual parts (see Figure 1.4.2). Integration among vital signs is needed for the ROMN to (1) understand the dynamic responses to changes in drivers or stressors within parks, (2) understand the interaction effects among vital signs, and (3) reduce the confounding effects of other vital signs in the interpretation of a given vital sign. Much of this depends upon compatible sample designs and analytical strategies (see Chapter 7). The remainder of this chapter deals with how ROMN monitoring is integrated both within and outside of the NPS I&M program, and how sample designs factor into this.

4.6.1 Across I&M networks

One goal of the NPS I&M program is to provide the information needed by park managers for understanding and managing network parks. However, it also is intended that some subset of the selected vital signs will provide information at scales broader than network parks. Thus, an additional sample design consideration is whether or not there is a need, value, or expectation for implementing designs that can be scaled up to levels beyond the ROMN. Several ROMN protocols share elements with fellow networks (especially the GRYN, NCPN, SCPN, SODN, SIEN, HTLN, NCCN and NGPN). Because many of these vital signs are using GRTS or similar model-based designs, integration at the design level with ROMN protocols will be more efficient. Measurements and field methods also are standardized as much as possible with other NPS networks (see protocols) to facilitate future, comparative analyses.

4.6.2 Across agencies

Although the I&M program is an NPS endeavor, many vital signs cross jurisdictional boundaries, and concerns about these vital signs are often shared by other agencies. Cooperative efforts among agencies also can increase efficiency and broaden application. Thus, the ROMN coordinates and collaborates with other agencies and organizations that share a common interest in certain vital signs. Several ROMN protocols are modeled after monitoring occurring at the state or regional scale (e.g., the EPA EMAP and USGS NAWQA programs). Because many state and regional programs are using GRTS or model-based designs and analyses similar to those of the ROMN, integration at the design level with ROMN protocols will be facilitated. Measurements and field methods are also standardized as much as possible with state and federal programs (see protocols).

4.6.3 Within and across ROMN protocols

Vital signs are not environmentally and ecologically independent entities. Rather, they are often the products of complex interactions among other vital signs and/or other ecosystem components or attributes. Without some consideration of how vital signs interact, the ROMN monitoring program would have no added value apart from the sum of its parts. As such, many ROMN sample designs use a common form (GRTS) and similar sample frames (e.g., both the Alpine Lake and Stream Ecological Integrity protocols use the National Hydrography Database). This will allow for analytical as well as operational integration of the vital signs within these protocols.

4.6.3.1 Co-location and co-visitation

The ROMN's sample designs emphasize both co-location (monitoring multiple vital signs at the same physical locations) and co-visitation (recording observations on multiple vital signs during a sampling occasion), both of which are greatly facilitated by common or similar sample designs. One obvious benefit to co-location and co-visitation is operational efficiency; time and costs for plot establishment and sampling are reduced when multiple vital signs are measured at the same place and time. Co-location of samples also can facilitate assessment of the response of the system to drivers or stressors

Table 4.5. Summary of ROMN sample design specification by protocol.

Protocol	Vital signs	Sample design type	Generalized target population[1]	Sample frame	Strata Sub-populations	Panel design Total unique N after all cycles
Snow Chemistry	Wet and Dry Deposition	Sentinel (judgment)	Sentinel sites and/or entire park through models; variable buffering	NA	NA	TBD
NADP/NTN	Wet and Dry Deposition	Sentinel (judgment)	Sentinel sites and/or entire park through models; variable buffering	NA	NA	TBD
Weather and Climate	Weather and Climate	Sentinel (model-based)	Sentinel sites and/or entire park through models; variable buffering	NA	NA	TBD
Stream Ecological Integrity	Water Chemistry Surface Water Dynamics Freshwater Communities Invasive/Exotic Aquatic Biota Invasive/Exotic Plants Focal Species–Beaver	GRTS (linear)	All accessible, perennial[2], base flow streams or rivers within each ROMN park; variable buffering	Modified National Hydrography Database (NHD)	None Accessibility and Strahler Order	(Likely) panel design: [1-9130, 2-995] (Likely) total unique N: 90
		Sentinel (model-based)	Sampled site(s) and/or contributing basin of each site via SPARROW models	NA (but NHD used for placement of sites and some models)	NA	1–3 per park, sampled 4–5 times per year
Alpine Lake Ecological Integrity	Water Chemistry Surface Water Dynamics Freshwater Communities Invasive/Exotic Aquatic Biota Invasive/Exotic Plants Focal Species–Beaver	Sentinel (judgment and/or model-based)	Sampled site(s) and/or contributing basin of each lake via TBD/proprietary models	Modified NHD	NA	TBD

Table 4.5. Summary of ROMN sample design specification by protocol, cont.

Protocol	Vital signs	Sample design type	Generalized target population[1]	Sample frame	Strata Sub-populations	Panel design Total unique N after all cycles
Wetland Ecological Integrity	Surface Water Dynamics Groundwater Dynamics Wetland Communities Invasive/Exotic Aquatic Biota Invasive/Exotic Plants Focal Species	Three-stage GRTS (discrete and areal)	All[4] accessible, late summer fens/riparian/wet meadow wetlands[5] within an ROMN park; variable buffering	Reach level catchments classified by type[6] and derived Vegetation Map	1st stage stratified by basin type.[7] 2nd stage: none. 3rd stage: stratified by individual wetland complexes. 1st stage: none. 2nd stage: Accessibility and Wetland Type. 3rd stage: none.	TBD
		Sentinel (judgment and/or model-based)	Sampled site(s) and/or contributing basin of each wetland via TBD/proprietary models	Derived Vegetation Map used to place some sites	NA	TBD
Invasive/Exotic Plants–Early Detection	Invasive/Exotic Plants	Model-based	Complete holdings of each ROMN park; variable buffering	NA	NA	TBD
Alpine Vegetation Composition, Structure, and Soils	Vegetation Composition, Structure, and Soils Invasive/Exotic Plants	Sentinel (judgment and/or model-based)	Sampled site(s) and/or peak tops around each site via TBD/proprietary models	Derived Vegetation Maps used to place some sites	NA	TBD
Grasslands/Shrubland Vegetation Composition, Structure, and Soils	Vegetation Composition, Structure, and Soil Invasive/Exotic Plants	GRTS	All accessible, early summer upland alpine areas within three large ROMN parks; variable buffering	Soils and/or Ecological Sites Maps	None Accessibility and Vegetation type?	TBD

Table 4.5. Summary of ROMN sample design specification by protocol, cont.

Protocol	Vital signs	Sample design type	Generalized target population[1]	Sample frame	Strata Sub-populations	Panel design Total unique N after all cycles
Focal Species–Beaver	Focal Species–Beaver	GRTS (see Stream and Wetland protocols)	See Stream and Wetland protocols	See Stream and Wetland protocols	See Stream and Wetland protocols	See Stream and Wetland protocols
Focal Species–GRSA Endemic Insects	Focal Species–GRSA Endemic Insects	TBD (adaptive?)	TBD	TBD	TBD	TBD
Focal Species–Elk	Focal Species–Elk	TBD	TBD	TBD	TBD	TBD
Focal Species–Grizzly Bear	Focal Species–Grizzly Bear	TBD	TBD	TBD	TBD	TBD
Landscape Dynamics	Landscape Dynamics	Census and sentinel (model-based)	Complete holdings of each ROMN park; variable buffering	NA	NA	TBD

[1]In combination with any strata (usually), the target population also may be considered the reporting unit(s).
[2]"Perennial" may be defined as flowing at time of visit (for at least GRSA); see Stream Ecological Integrity protocol.
[3]Treeline elevation varies with park.
[4]Because of the two-stage design, "all" is actually only wetland in the selected basins within a park; however, inference may be extended to all wetlands via the two-stage design.
[5]Wetland type definitions are complex and are given in the Wetland protocol.
[6]Lake basin classification model needed (see GRYN).
[7]Basins classified by multivariate analysis of geology, precipitation, landform, etc. (see protocol).

(e.g., vegetation responses to climate) as well as interactions among vital signs (e.g., effects of upland erosion on water turbidity). Under some circumstances, co-location can aid in the interpretation of confounding effects and increase sampling efficiency.

However, co-location of samples within and across protocols is not a panacea for ecological insights, and the costs and benefits need to be considered. To decide whether samples warrant co-location, the ROMN considers (1) the specific objectives of the vital sign(s) being sampled, (2) the feasibility of co-locating samples, (3) the probability of expected increased insights, and (4) the compatibility and overlap in the target populations and the vital signs spatiotemporal scale.

4.6.3.2 Analytical, spatial, and temporal integration

ROMN protocols and their sampled designs are intended to monitor scale-dependent processes and to accommodate integration within and among scales (Figure 4.6.3.2). For example, 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. Status and trends in fine-scale attributes are monitored with ground-based field plots (with the capacity for park-scale inference when GRTS designs are used). 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, for instance, the effects of regional climatic conditions on patterns and trends in landscape condition, or 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 and interpretation of land condition), and potentially as the basis for interpolating fine-scale measures to the landscape (Ohmann and Gregory 2002).

Ecological integration involves considering the ecological linkages among system drivers and the components, structures, and functions of ecosystems when selecting vital signs. An effective ecosystem monitoring strategy will employ a suite of individual measurements that collectively monitor the integrity of the entire ecosystem. By defining the analysis at a scale that encompasses multiple vital signs, data from different protocols can be analyzed as covariates, drivers, or responses to changes in each other. Defining the relevant scale of analysis and integrating data across vital signs is a critical component of analysis and interpretation (also see Chapter 7). One approach for effective ecological integration is to develop measures at various hierarchical levels of ecological organization (e.g., landscape, community, population, genus).

Spatial integration involves establishing linkages of measurements made at different spatial scales within a park or network of parks, or between individual park programs and broader regional programs. It requires an understanding of scalar ecological processes, the co-location of measurements of comparably scaled monitoring indicators, and the design of statistical sampling frameworks that permit the extrapolation and interpolation of scalar data.

Temporal integration involves establishing linkages between measurements made at various temporal scales. It requires determining a meaningful timeline for sampling different indicators while considering characteristics of temporal variation in those indicators. For example, sampling changes in the structure of a stream channel (e.g., channel sinuosity) may require much less frequent sampling than is required to detect changes in the composition or density of aquatic invertebrates. Temporal integration requires nesting the more frequent and, often, more intensive sampling within the context of less frequent sampling.

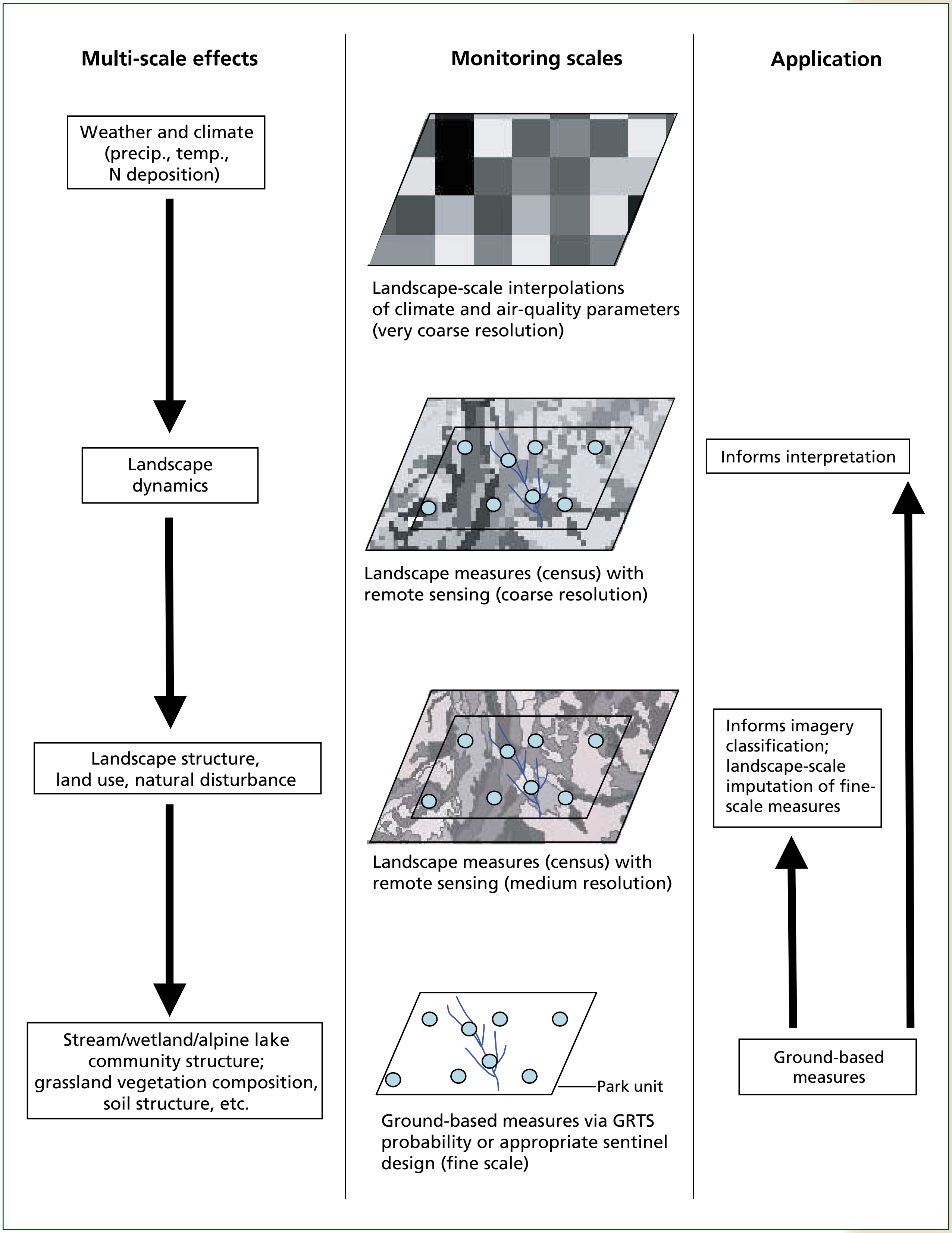


Figure 4.6.3.2. Example of integration across ROMN protocols and spatial scales.

Figure modified from O'Dell et al. 2005.

Chapter 5
Sampling Protocols

5.1 Overview

This chapter presents overviews of the protocols that the Rocky Mountain Network will use to implement monitoring of our 12 high-priority vital signs (see Chapter 3). We include brief summaries of key monitoring objectives for each protocol and provide links to more complete protocol development summaries housed on the ROMN website. Fully reviewed and documented protocols are stand-alone documents, and are not included with this report.

After vital signs are selected, methods must be specified for their monitoring. These methods are documented in monitoring protocols that describe the background, approach, and detailed methods for conducting the monitoring, and establish how information will be analyzed and reported. Protocols are detailed study plans designed to ensure that changes detected by monitoring actually are occurring—that is, that they do not stem from measurement variability introduced when different people or methods are used. Protocols must be thoroughly documented, periodically reviewed, updated as necessary, and archived.

Each monitoring protocol also includes a narrative providing the rationale for vital sign selection and a history of the protocol's development; a framework for making and documenting necessary decisions or revisions relative to that protocol and its development; and standard operating procedures (SOPs) that explain, in a step-by-step manner, how each procedure identified in the protocol narrative will be accomplished.

At a minimum, SOPs address personnel and training requirements, safety, sample and response designs, equipment operations, data collection techniques, data management, data analysis, reporting, and any activities required at the end of a field season (e.g., equipment maintenance and storage).

Finally, monitoring protocols identify supporting materials critical to their development and implementation. Supporting materials are any materials developed or acquired during the protocol's development phase; examples may include databases, reports, maps, geospatial information, species lists, species guilds, analysis tools tested, and any decisions resulting from these exploratory analyses.

For efficiency and to enhance interpretation, some ROMN vital signs will be monitored at the same time and place as others, and thus are included in the same protocol(s). Other vital signs appear in more than one protocol. Therefore, there are 14 protocols for the 12 high-priority vital signs (Figure 5.1).

5.1.1 Protocol development

Prior to formal implementation, many ROMN protocols require methods development and documentation, index calibration, delineation of reference conditions, generation of data needed to understand variability in measures (e.g., within and across years, across sites), and evaluation of potential sample design capability (see Chapters 4 and 9, especially Table 9.1). These protocol development phases are critical to meeting the requirements established by the NPS I&M program. Using protocols and design methods adapted from existing programs will expedite this process, but a significant investment of time and resources still may be required for each protocol.

Development efforts also include investigating and possibly acquiring "non-field" protocols from other programs, such as for climate (e.g., National Oceanic and Atmospheric Association–National Weather Service), air quality monitoring (e.g., the National Atmospheric Deposition Program–Nationl Trends Network, NPS–Air Resources Division), and landscape dynamics (e.g., U.S. Census, National Land Cover Dataset, NPS Fire, U.S. Bureau of Land

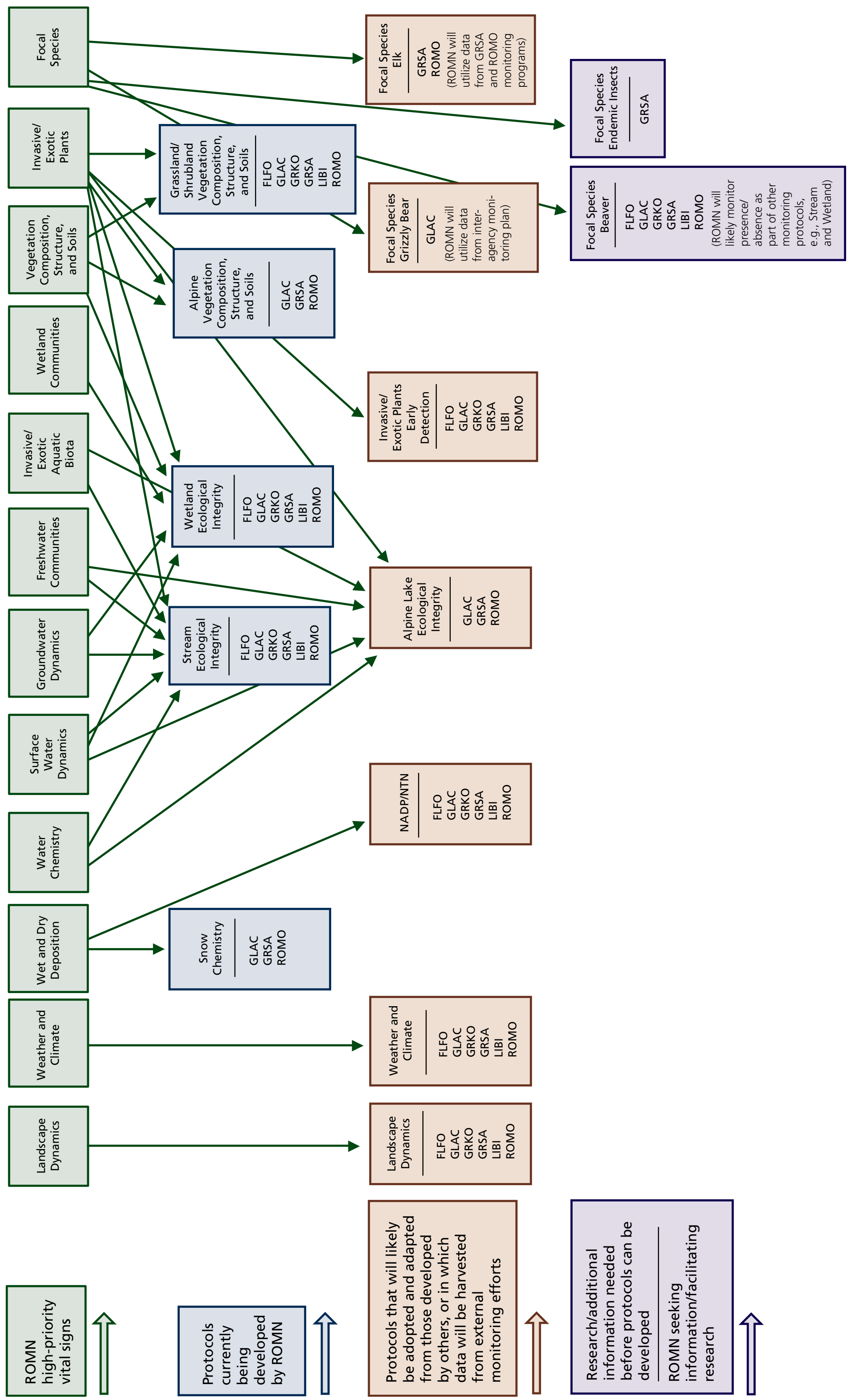


Figure 5.1. Rocky Mountain Network vital signs and associated protocols.

Table 5.1.2. Timeframe for implementing Rocky Mountain Network vital signs monitoring protocols.

Protocol	FY2006	FY2007	FY2008	FY2009	FY2010
Snow Chemistry		Work with USGS to analyze existing data and to adapt USGS protocol to the ROMN	Submit draft protocol for peer review	Implement monitoring	Continue monitoring
NADP/NTN		Work with parks and partners to upgrade current equipment	Submit draft protocol for peer review	Implement monitoring	Continue monitoring
Weather and Climate			Evaluate available data and information and research its application to ROMN needs	Submit draft protocol for peer review	Implement monitoring
Stream Ecological Integrity		Conduct pilot monitoring using well-established methods and design techniques	Continue pilot monitoring using well-established methods and design techniques	Submit draft protocol for peer review	Implement monitoring
Wetland Ecological Integrity	Conduct pilot monitoring using well-established methods and design techniques	Continue pilot monitoring using well-established methods and design techniques	Continue pilot monitoring using well-established methods and design techniques	Submit draft protocol for peer review	Implement monitoring
Alpine Lake Ecological Integrity				Evaluate protocols and research of other networks and organizations	Submit draft protocol for peer review
Alpine Vegetation Composition, Structure, and Soils			Evaluate protocols and research of other networks and organizations	Submit draft protocol for peer review	Implement monitoring
Grassland/Shrubland Vegetation Composition, Structure, and Soils	Conduct pilot monitoring using well-established methods and design techniques	Continue pilot monitoring using well-established methods and design techniques	Submit draft protocol for peer review; implement monitoring.	Continue monitoring	Continue monitoring
Invasive Exotic Plants–Early Detection				Evaluate protocols and research of other networks and organizations	Submit draft protocol for peer review
Landscape Dynamics			Evaluate protocols and research of other networks and organizations	Work with parks to develop specific objectives, draft protocol	Submit draft protocol for peer review
Focal Species–GRSA Endemic Insects	Initiate protocol development research	Continue protocol development research	Continue protocol development research	Draft protocol	Submit draft protocol for peer review

Table 5.1.2. Timeframe for implementing Rocky Mountain Network vital signs monitoring protocols, cont.

Protocol	FY2006	FY2007	FY2008	FY2009	FY2010
Focal Species–Elk*		Conduct pilot monitoring using well-established methods and design techniques	Continue pilot monitoring using well-established methods and design techniques	Submit draft protocol for peer review	Implement monitoring
Focal Species–Beaver*		Conduct pilot monitoring using well-established methods and design techniques	Continue pilot monitoring using well-established methods and design techniques	Submit draft protocol for peer review	Implement monitoring
Focal Species–Grizzly Bear				Draft protocol for peer review	Implement monitoring

Khaki shading = protocol development period.

Blue shading = protocol approved, monitoring implemented or continuing.

*Elk, Beaver, and Grizzly Bear protocols may be included as components of other protocols (e.g., Wetland Ecological Integrity or Landscape Dynamics).

Management, U.S. Forest Service, and individual counties and states).

5.1.2 Schedule overview

Monitoring development and implementation are staggered through time and parks (see Table 5.1.2 and Chapter 9). The ROMN initiated protocol development for Grassland/Shrubland Vegetation and Soil, and Wetland Ecological Integrity in FY2006. Development of the Stream Ecological Integrity protocol will begin in FY2007. Snow Chemistry (as a key part of our Wet and Dry Deposition vital sign) monitoring is being integrated with the USGS Snow Monitoring Network. Through this partnership, the ROMN will begin receiving and analyzing data on snowpack (snow–water equivalent; SWE) and snow chemistry (concentrations of chemical ions) in FY2007.

Weather and Climate data are collected by other agencies, especially NOAA–NWS. Methodology and analyses may vary as dynamics and other vital signs dictate, but core data on weather and climate (e.g., daily temperature and precipitation derivatives) will be collected, analyzed, and reported with all vital signs. The ROMN investigated development of the Alpine Lake Ecological Integrity protocol (e.g., at the Alpine Monitoring Workshop), and an approved protocol exists (i.e., the NCCN's), but ROMN implementation of alpine lake monitoring will occur only as financial resources permit or natural resources demand it.

Immediate implementation of one component of Invasive/Exotic Plants monitoring will begin in FY2007, when data collection for target species is added to the Vegetation Composition, Structure, and Soils methods. A second phase of invasive plant monitoring, using models and field data for rapid detection of new arrivals, is targeted for future development, based on the methods and recommendations of several ongoing research programs funded by the NPS. The GRSA Endemic Insects protocol is being developed through cooperative agreements, and will take several years to develop. The Focal Species–Beaver protocol is integrated with the Stream, Wetland, and Alpine Lake Ecological Integrity protocols. Elk and grizzly focal-species protocols are currently not targeted for priority implementation due to costs associated with wildlife monitoring and the ongoing efforts by GLAC, GRSA, and ROMO relative to these species.

5.2 Protocol Summaries

The following sections provide summaries of monitoring protocols for ROMN vital signs. Each summary includes a list of the vital signs to be monitored within the protocol, a list of parks in which the protocol will be implemented, a general justification, a synopsis of key methods, and a list of key monitoring objectives. Current, referenced, and more complete protocol summaries can be found on the NPS Intranet at <http://www1.nrintra.nps.gov/im/units/romn/>.

Each protocol contains a set of similar steps; Figure 5.2 depicts an operational workflow for a generalized protocol. Operations displayed at the top of the diagram represent aspects of the selection and scoping process. Results, analyses, and reports leave each protocol and are subsequently managed through other network operations (e.g., Data Management; see Chapter 6).

5.2.1 Snow Chemistry

The Snow Chemistry protocol addresses atmospheric deposition as an ecosystem stressor and addresses a single ROMN vital sign: Wet and Dry Deposition. The ROMN is cooperating with the USGS–Water Resources Discipline (USGS–WRD) to develop a citable "standard protocol" for annual collection of snowpack samples (snow–water equivalent and major-ion chemistry) within the three ROMN mountain parks (GLAC, GRSA, ROMO).

Although this protocol addresses atmospheric deposition like NADP/NTN methods, it should be noted that NADP/NTN data often lack accuracy in high-elevation sites due to methodological difficulties. This shortcoming is being addressed by the NADP Program Office through a series of high-elevation retrofits to the NADP sampler. Chemical deposition profiled in seasonal snowpack can be used as a surrogate for continuous monitoring of wet deposition across the Rocky Mountains during November through March, at elevations that do not experience mid-winter melt.

The ROMN snowpack-monitoring design uses sentinel sites selected based on the ability of a topographic position to preserve seasonal snowpack (based on the techniques and recommendations of the USGS–WRD monitoring program). This protocol will follow USGS snowpack-monitoring protocols relative to field collection of samples and sample processing (chemical analyses) in a central laboratory.

Objectives for snow chemistry monitoring include:

1. Analyze winter snowpack at selected locations in ROMO, GLAC, and GRSA for water content (snow–water equivalent) and deposition and concentration of chemical species (sulfur and nitrogen ions, free acidity [pH], conductance, calcium, sodium, potassium, magnesium, chloride, and mercury).
2. Combined with other spatial data (e.g., snow-covered area), provide spatial estimates of snow chemistry for parameterization of a regional interpolation model.

5.2.2 NADP/NTN

The NADP/NTN protocol addresses a single ROMN vital sign: Wet and Dry Deposition. The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) was established to monitor the chemistry of wet deposition (major anions and cations, especially dissolved species of nitrogen and sulfur). Data from this network will be used to track changes in deposition chemistry in ROMN parks that have existing collectors (GLAC, LIBI, ROMO), and will be extrapolated to the other ROMN parks (FLFO, GRKO, GRSA).

Atmospheric deposition is the process by which airborne particles and gases are deposited on the earth's surface either through precipitation (rain, snow, clouds, and fog) or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Deposition can include a wide variety of chemical species and anthropogenic pollutants, including inorganic elements and compounds (e.g., nitrogen, sulfur, basic cations, mercury, and other metals) and organic compounds (e.g., pesticides and herbicides).

Once deposited, pollutants can have a variety of effects on ecosystems. Chemicals in the atmosphere, both naturally occurring and human contributions, are dispersed and transported through atmospheric cycling and eventually deposited "downwind" of the source. Global

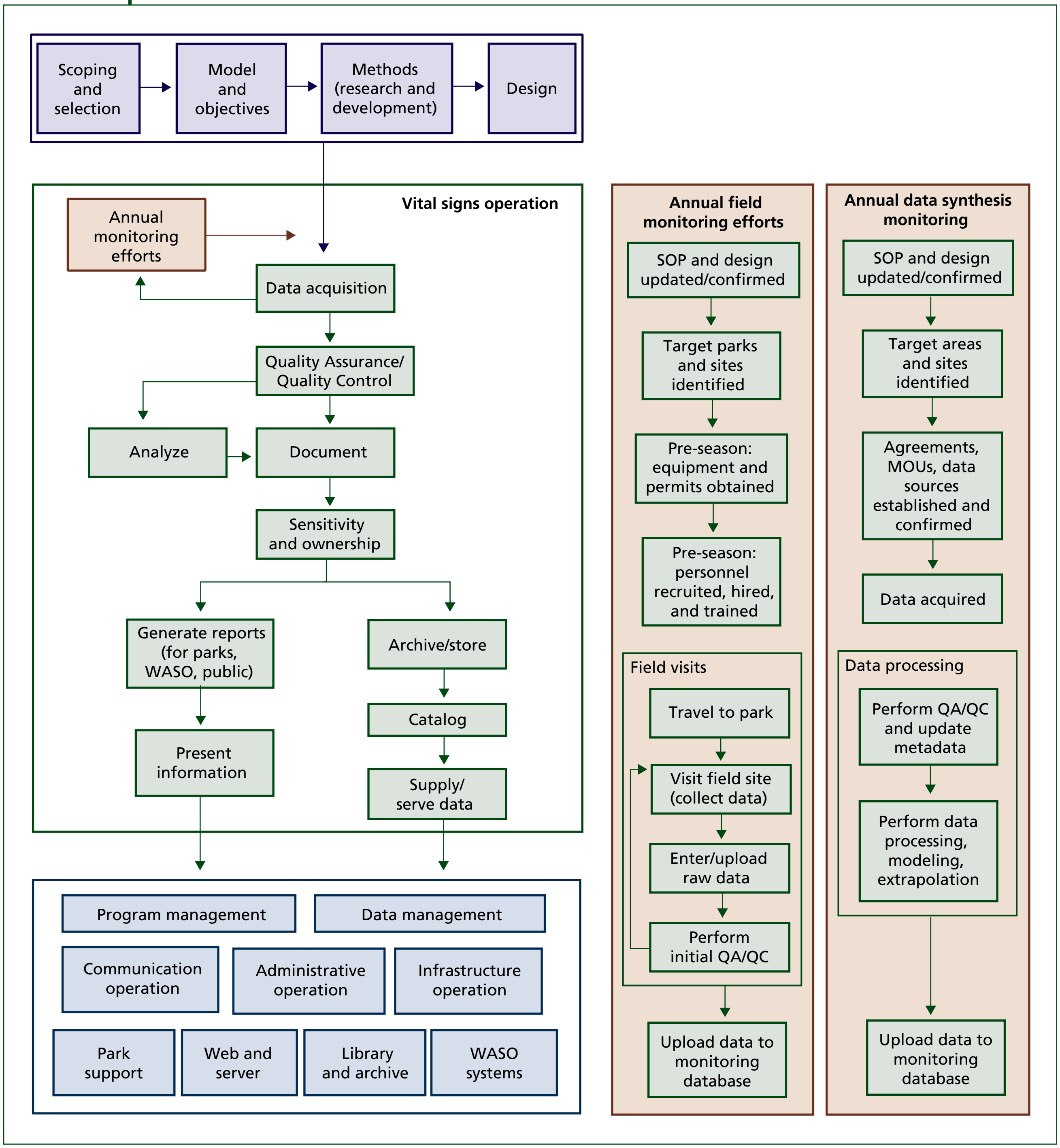


Figure 5.2. Conceptual diagram of the cycle of Rocky Mountain Network protocol operations.

transport of pollutants is becoming an increasingly important issue in parks and protected areas. Deposition is a known stressor at ROMO, and a potential concern at GLAC and GRSA. Climate dynamics (i.e., controlling atmospheric vectors) and surrounding land uses (which provide new sources) create the potential for deposition to emerge as an issue at other ROMN parks, as well.

The ROMN will not create a sample design for this protocol, because established methods direct the acquisition, processing, analysis, and reporting of data from the existing program and the established design.

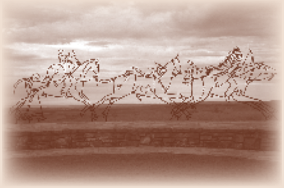
Objectives for NADP/NTN monitoring include:

1. Determine the annual status and trend in chemical-ion deposition and concentrations in selected ROMN parks (LIBI, GLAC, ROMO). Conduct chemical analysis of samples including major ions, with emphasis on nitrate, sulfate, and ammonium (chemical analysis also provides information on free acidity [pH], conductance, calcium, sodium, potassium, magnesium, and chloride).
2. Based on NADP/NTN models, extrapolate the annual status and trend in chemical-ion deposition and concentrations to ROMN parks not directly monitored by NADP/NTN (FLFO, GRKO, GRSA).

5.2.3 Weather and Climate

The Weather and Climate protocol addresses a single ROMN vital sign: Weather and Climate. The protocol will be implemented in all six ROMN parks (with buffers based on watersheds and/or ecoregion boundaries), but is currently on hold as regional and national examples are developed.

Weather and climate are primary drivers of almost all physical and ecological processes in the ROMN. Climate controls ecosystem fluxes of energy and matter as well as the geomorphic and biogeochemical processes that underlie the distribution and structure of ROMN ecosystems. Climatic effects are particularly notable in the strong zonation and steep elevation gradients displayed by vegetation types in the larger parks that extend from montane up to alpine zones (GLAC, GRSA, ROMO). Archival proxy records on glacial ice, lake sediments, tree rings, and fossil corals show that the earth's climate has varied significantly over timescales from months to millennia. Studies using combinations of instrumental records and paleoproxies confirm, however, that global climate changed rapidly during the twentieth century, and that the speed of those changes exceeded that of most previous fluctuations.



These global-scale drivers and stressors, both natural and anthropogenic, will inevitably affect each ROMN park's ecological systems in the short and long term. It is important that ROMN park managers are able to understand climate variations at multiple spatial and temporal scales that allow for both the characterization of climate and an understanding of how other ecological systems vary. Removing the climate signal clarifies the underlying changes in other network vital signs. Our primary approach to the Weather and Climate vital sign will be to use data from current, ongoing monitoring programs (e.g., NPS and NOAA–NWS) to achieve an understanding of the connections between climate and park resource conditions and other ROMN vital signs.

Objectives for weather and climate monitoring include:

1. Describe daily status and temporal pattern in minimum, average, and maximum temperature and accumulated precipitation from established weather stations in and near each ROMN park.
2. Describe daily status and temporal pattern in daily, park-level indices of minimum, average, and maximum temperature and accumulated precipitation (by averaging data across all appropriate weather stations in and near each ROMN park).
3. Describe monthly status and temporal pattern in precipitation, minimum and

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Benthos sampling in Akokola Creek, Glacier National Park.

maximum temperatures, and dewpoint using the Parameter-elevation Regressions on Independent Slopes Model from the PRISM Group at Oregon State University) for each ROMN park.

4. Describe bi-weekly status and trends in snow cover (including snow depth and snow–water equivalent) using the Snow Data Assimilation System (SNOWDAS) dataset of the National Operational Hydrologic Remote Sensing Center for each ROMN park.
5. Describe monthly status and trends in appropriate drought indices from NOAA for each ROMN park.
6. Determine monthly status and trends in atmospheric and oceanic division indices relevant to important climatological and ecological processes for each ROMN park.

5.2.4 Stream Ecological Integrity

The Stream Ecological Integrity protocol addresses multiple ROMN vital signs: Surface Water Dynamics, Groundwater Dynamics, Freshwater Communities, Invasive/Exotic Aquatic Biota, Invasive/Exotic Plants, Water Chemistry, and Focal Species–Beaver. The protocol will be implemented in all six parks, with initial effort focusing on GLAC.

Streams and rivers are fundamental components of nearly every ROMN park, and their ecology is both intimately linked with and reflective of the watersheds they drain. A defining feature of streams and rivers is their dependence on the landscape for inputs of energy and nutrients; streams integrate all systems within a landscape. Streams also support a broad spectrum of ecological services, including wildlife habitat, nutrient processing, hydrologic cycling, and multiple socioeconomic functions for humans (e.g., water sources, fisheries, recreation). Because streams are typically sensitive to stressors at both local and landscape scales, they are one of the most useful types of ecosystems for long-term ecological monitoring in the ROMN.

The long-term monitoring and assessment of ROMN streams and rivers requires a multidisciplinary, comprehensive approach that both incorporates the significant body of existing research on how best to monitor stream ecosystems and meets the long-term management needs of the parks. Site-level stream assessment field methods are well established for Colorado and Montana systems, and we draw upon this wealth of knowledge for this ROMN protocol. Sources of methods include the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EPA EMAP), extensive research and procedure development from the Flathead Lake Biological Station, multiple USGS approaches, and well-established methods from other organizations and individuals (e.g., state agencies, academics).

The sample design for this protocol will be a hybrid approach between fixed sentinel sites and survey locations selected using a GRTS design within each park (see Chapter 4). Survey sites will be sampled using a panel structure across time, with sentinel sites sampled more frequently within a year. Data collection at survey sites will focus on measures of biological assemblages (benthos and periphyton), coupled with explanatory chemical and quantitative physical measures (primarily water chemistry, surface water hydrology, sediment composition, channel morphology, and landscape-scale structure and composition in the catchment above each site).

Survey-site data will be used for making statistically valid inferences about stream condition across each ROMN park, as well as population-scale, long-term trend assessments. Sentinel sites will be used for more intensive (both in terms of sampling frequency and instrumentation) protocols to quantify loadings, site-scale trend, and possible mechanisms. Sentinel sites will occur on reaches as required by regulatory programs, in existing long-term stream sampling locations, at key confluences, and/or at watershed pour points.

Objectives for stream ecological integrity monitoring include:

1. Determine the seasonal, annual, and/or decadal status and trend, at the park scale, of benthos and periphyton assemblages (using multimetric and multivariate indices), physical habitat, and select physiochemical measures (e.g., NPS–Water Resources Division (WRD) core parameters, anions, cations, nutrients, and sediment).
2. Quantify the seasonal, annual, and/or decadal patterns in benthos and periphyton assemblages, hydrologic dynamics, and physiochemical loadings of key water quality analytes (e.g., NPS–WRD core measures, any 303(d)-listed analyte, critical anions and cations, nutrients, and sediment) at sentinel stream sites.
3. Determine the long-term status and trend of stream length and proportion in each park where select invasive plant and aquatic taxa are present.
4. Determine the long-term status and trend of stream length and proportion in each park where beaver are present.

5.2.5 Alpine Lake Ecological Integrity

The Alpine Lake Ecological Integrity protocol addresses multiple ROMN vital signs: Surface Water Dynamics, Freshwater Communities, Invasive/Exotic Aquatic Biota, Invasive/Exotic Plants, and Water Chemistry, Focal Species–Beaver. This protocol will be implemented in GLAC, GRSA, and ROMO, but is currently on hold due to funding considerations.

Alpine lake systems are an important component of alpine landscapes. The ecology of alpine lakes is closely linked to conditions in the watershed; therefore, the condition of alpine vegetation may be a covariate in analyses of alpine lake monitoring data. In addition, alpine lake systems provide critical habitat for facultative and obligate aquatic taxa, support many terrestrial taxa, and contribute to nutrient and hydrologic cycling. Alpine lakes are also very sensitive to perturbation, both at local and landscape scales. Accordingly, they were selected as ideal aquatic systems for long-term monitoring in the alpine zones of ROMN parks.

Upper Sand Creek Lake, Great Sand Dunes National Park and Preserve.

Alpine lakes will be assessed using sentinel sites in all three large ROMN parks. Models will be used to understand sentinel lake monitoring results in the context of other, non-sampled lakes in ROMN parks.

Objectives for alpine lake monitoring include:

1. Monitor status and trend in the timing of seasonal, annual, and/or decadal patterns in plankton/periphyton assemblages, hydrologic dynamics, and phys-

iochemical loadings of key water quality analytes (e.g., NPS–WRD core measures, any 303(d)-listed analyte, critical anions and cations, nutrients, and sediment) at sentinel alpine lake sites.

2. Monitor for trends in phenological events (e.g., ice-out, melt-out, green-up, insect emergence, flowering dates, and lake-turnover dynamics at sentinel alpine lake sites).
3. Determine status and trends in selected aquatic invasive plants at sentinel alpine lakes.

5.2.6 Wetland Ecological Integrity

The Wetland Ecological Integrity protocol addresses multiple ROMN vital signs: Surface Water Dynamics, Groundwater Dynamics, Wetland Communities, Water Chemistry, Invasive/Exotic Aquatic Biota, Invasive/Exotic Plants, and Focal Species–Beaver. The protocol will be implemented in FLFO, GLAC, GRSA, and ROMO, with initial emphasis in ROMO.

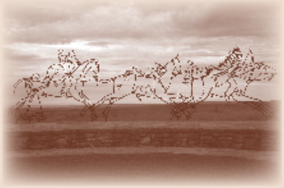
Wetlands are important components of nearly all ROMN watersheds and provide many valuable ecological and socioeconomic functions. For example, relative to their area, wetlands support a disproportionate amount of the biodiversity in each ROMN park. Wetland vegetation is also an excellent indicator of changes in groundwater levels and sediment dynamics. However, wetlands are vulnerable to stressors functioning at the site and landscape scales, and many ROMN wetlands are likely in a degraded condition (e.g., species assemblages and dynamics may not be within a normal range of variability due to hydrologic modifications such as changes in groundwater levels or stream diversions, fill, overgrazing by native ungulates, historical grazing by domestic livestock, atmospheric deposition, and invasion by exotic taxa).

Wet meadow, Florissant Fossil Beds National Monument.

This protocol emphasizes the measurement of groundwater hydrology and wetland vegetation assemblages. Vegetation data will be analyzed and interpreted with multimetric indices. We also will attempt to monitor the functions of ROMN wetlands, both directly (e.g., sediment processing) and indirectly through select habitat characteristics (e.g., physiochemistry, groundwater hydrology, and landscape-scale attributes). Wetland condition has a complex regulatory context, with multiple federal and state laws requiring attention by ROMN park management. Landowners surrounding ROMN parks are subject to similar requirements. Therefore, there are many existing efforts to monitor wetlands in the landscapes of ROMN parks, with well-developed protocols already in place. Site-level wetland assessment protocols are typically well established for Colorado and Montana systems, and we draw upon this wealth of knowledge for this ROMN protocol.

We will utilize two complementary, integrated sample designs to locate sample sites: (1) a spatially balanced probability survey within key wetland types in GLAC, GRSA, and ROMO, using a three-stage GRTS design and a complex panel structure (see Chapter 4), and (2) temporally intensive measurement of a subset of indicators at sentinel wetlands (FLFO will have only sentinel sites). The first approach will allow valid statements of condition and long-term trend at the park scale. The second will track short-term dynamics, link to existing long-term monitoring, and potentially allow more explicit development of associations and possible causal mechanisms.

Survey-site protocols will largely follow established methods for assessing vegetation composition and structure and collecting supporting



information on habitat (especially groundwater dynamics and select soil and water physiochemistry). For example, quantitative vegetation samples will be collected with a nested set of quadrats located systematically within a site. Sentinel-site protocols will include all survey-site methods, plus additional continuous monitoring of groundwater dynamics and water physiochemistry, again using established methodology.

Objectives for wetland ecological integrity monitoring include:

1. Determine long-term status and trend in spatial extent of wetland by key type within each park.
2. Monitor the status and trend in vegetation assemblages at the park scale using multimetric indices.
3. Quantify the seasonal, annual, and/or decadal water-table depth and dynamics and its statistical relationship with a multimetric vegetation index of biotic integrity at a subset of wetland sites.
4. Determine the proportion and long-term trend in wetland areas that meet regulatory criteria for water and sediment chemistry (nitrogen, phosphorus, sulfur) and/or derived reference levels.
5. Determine the extent, temporal dynamics, and relative importance of impacts from ungulate herbivory, beaver presence/absence, and invasive species at a subset of wetland sites and/or at the park scale.
6. Determine the status and trend in select measures (e.g., area, fragmentation, connectivity) of the meso- (the buffer zone around a given wetland or its immediate drainage catchment) and landscape-scale context, composition, and structure of wetland systems.

5.2.7 Invasive/Exotic Plants–Early Detection

The Invasive/Exotic Plants–Early Detection protocol addresses a single ROMN vital sign: Invasive/Exotic Plants. The protocol will be implemented in all ROMN parks, with initial emphasis in GRKO or LIBI.

All parks within the ROMN recognize invasive species as a primary management concern, both currently and for the future. Because many invasive taxa establish rapidly and are difficult to manage once established, it is necessary to develop an early-detection monitoring system for new arrivals. By predicting the areas most likely to host new invasions, and monitoring these areas intensively, we hope to provide managers with timely information for implementation. Further, by monitoring the effectiveness and accuracy of our predicted invasion surface—and comparing those data to information provided by vegetation-community sampling across parks and observations made by other crews, park visitors, and park staff—we can refine our understanding of what makes communities good targets for invaders. This will promote long-term protection of our most vulnerable protected areas.

The NPS, USGS, and other cooperators are developing methods for creating landscape models of invasibility and early detection of invasive species. Invasion biologists have defined a number of biotic and abiotic attributes linked to successful invasions that can be used as predictors of invasiveness. Species attributes include fitness across a range of environments, plasticity, and high reproductive rate. Community attributes include available niche/resources, disturbance, proximity to sources, and lack of natural predators. These predictors complement the modeling process, which is an integral part of early detection. Species distribution modeling is a statistical approach relating the likelihood of a species's occurrence (based on field observations) to a set of predictor variables (e.g., topographic position, community type, geographic context). The Pacific Island Network is currently developing protocols for early detection of invasive plants that will detail methodology for surveys of targeted species along road and trail corridors (within and near parks), surveys of selected plant distribution centers (e.g., nurseries and garden stores), incidental reporting (e.g., from park and network staff observations), and, potentially, a system for public reporting of target species.

Objectives for invasive species monitoring include:

1. Create and maintain a list of "watch species" that are either known to exist in the region or have the potential to become problematic in the area. The list will require regular updating to properly inform methods and other objectives.
2. Detect occurrence and trends in the distribution of new, invasive species spreading to and establishing in ROMN parks.

5.2.8 Alpine Vegetation Composition, Structure, and Soils

The Alpine Vegetation Composition, Structure, and Soils protocol addresses one ROMN vital sign: Vegetation Composition, Structure, and Soils. This protocol will be implemented in GLAC, GRSA, and ROMO, with initial emphasis on GRSA and ROMO.

The alpine environment is one of the most sensitive terrestrial ecosystems because of the extreme environmental conditions (e.g., wind, temperature, snow and ice, solar radiation, thin atmosphere) that help define this ecological type, and the adaptation of species to those conditions (e.g., low stature, determinant growth, leaf morphology). Alpine communities are threatened by changes to known systemic drivers, including climate change, atmospheric deposition, and human use. The ROMN has selected alpine communities as a key resource for monitoring because they are important to visitor experiences and are threatened by changes to systemic drivers.

NPS/C. FLANAGAN

Dr. Bill Bowman and a field assistant identify tundra plants, Rocky Mountain National Park.

An international effort to monitor changes in alpine communities (GLORIA, the Global Observation Research Initiative in Alpine Environments) was initiated in 2001. The goals of the GLORIA program include providing a global baseline for vegetation monitoring in alpine environments and assessing the risks of biodiversity loss and ecosystem instability from climate change. This methodology is being extended by cooperators to create a long-term monitoring network at the global scale. Locally, GLORIA aims to collect baseline and monitoring data by using an array of plots to measure vegetation across a set of four neighboring peaks.

A GLORIA site was established in GLAC by the USGS Northern Rocky Mountain Science Center in 2003. Additional sites are planned for Niwot Ridge (outside ROMO), North Cascades National Park (NCCN), and Yellowstone National Park (GRYN). The ROMN may incorporate this design at ROMO and GRSA, using a sentinel-site approach based on the GLORIA methods.

Objectives for alpine vegetation composition, structure, and soils monitoring include:

1. Determine status and trends in species richness, species composition, and vegetation and ground cover (including snow) in appropriate ROMN parks (GLAC, GRSA, ROMO).

5.2.9 Grassland/Shrubland Vegetation Composition, Structure, and Soils

The Grassland/Shrubland Vegetation Composition, Structure, and Soils protocol addresses two ROMN vital signs: Vegetation Composition, Structure, and Soils and Invasive/Exotic Plants. The protocol will be implemented in all six ROMN parks.

The structure and composition of grassland vegetation are among the primary characteristics used to define these ecosystems. Vegetation structure and composition are fundamental determinants of wildlife habitat characteristics and quality, visitor experiences, historic preservation (in the cases of LIBI and GRKO), and the basic functioning of the ecosystem (e.g., via primary production; cycling of carbon, nitrogen, and other nutrients; and micro-climate controls). In addition to providing information about the condition of vegetation, data from grassland/shrubland vegetation and soil monitoring will help characterize parkwide ecosystem responses to other vital signs (drivers), including Weather and Climate, Wet and Dry Deposition, Landscape Dynamics, Invasive/Exotic Plants, and habitat conditions for Focal Species (i.e., elk, grizzly bear, and GRSA insects).

The ROMN response design is derived from the protocols and recommendations of the U.S. Department of Agriculture–Agricultural Research Service and the U.S. Forest Service's Forest Inventory and Assessment program. This design includes both transect- and plot-based sampling, organized in a "spoked-wheel" pattern covering a 0.5-ha (1.2-acre) footprint at each site. We are using a set of relatively simple, repeatable measures of vegetation and soil conditions to be implemented across the sample design, with detailed evaluation of spatial/temporal dynamics left to research projects. The sample design for the three small parks (FLFO, GRKO, LIBI) is a probability-based GRTS design constructed using the entire park (minus facilities and sensitive resource areas) as the target area. The sample design for GLAC, ROMO, and GRSA is a GRTS design that uses a subset of all grasslands/shrublands in each park.

Objectives for vegetation composition, structure, and soils monitoring include:

1. Determine the status and trend in vegetation structure (relative cover of shrubs, grasses, herbs, trees, and bare ground) and composition (within classes and at the species level) across the community/management types found within the park (FLFO, GRKO, LIBI), or in a representative sample of meadows and grassland communities (GLAC, GRSA, ROMO).

NPS/M. STICHMAN

Grassland monitoring, Little Bighorn Battlefield National Monument, Montana.

2. Determine the status and trend in soil structure based on texture and stability, water infiltration rates, evidence of erosion, and extent of bare (non-vegetated) soils.
3. Determine status and trends in the presence or absence of invasive/introduced species based on park-specific lists of likely and ecologically significant invaders (these lists will be periodically updated based on national, state, and NPS "invasive species of concern" lists).
4. Determine the status and trend in soil biochemical function using trends in nitrogen availability from *in situ* resin bags, carbon and nitrogen content as derived from laboratory analysis, or a decomposition index (based on decay of introduced biomass). *(This objective is recognized as important for ecosystem condition and function, but because of funding limitations, relevant methods will not be implemented as part of the standard monitoring protocols. They may be implemented as part of further research [e.g., implementation triggered by monitoring results or implications].)*

5.2.10 Focal Species

5.2.10.1 Elk

The Focal Species–Elk protocol addresses one ROMN vital sign: focal species. This protocol will be implemented in ROMO and GRSA. Population dynamics and behavior of large ungulates can have critical effects on the vegetation structure and hydrologic function of their habitats. Heavy browsing incurred by large populations and/or intensive use of particular locations or species (e.g., willow and aspen) reduces the vigor of mature plants and the reproductive success of plant populations. Therefore, the number of animals in a population, in addition to patterns of seasonal migration and habitat use, are important for conservation of wild ungulates as well as of plant species and communities.

Currently, we do not anticipate network funding for population-level monitoring of elk (*Cervus elaphus*) in any ROMN park. We will incorporate data from park-level monitoring (especially in ROMO) in our reports. Select measures of elk herbivory (qualitative classes for browse off-take) are included in the Wetland, Grassland, and Alpine protocols; we can report on elk habitat usage trends with these methods.

Objectives for elk monitoring include:

1. Monitor trends in the parkwide distribution of removal of woody vegetation (e.g., shrubs and young trees) by herbivores. (Data will be collected through Wetlands, Vegetation and Soils, and Stream protocols.)

5.2.10.2 Beaver

The Focal Species–Beaver protocol addresses one ROMN vital sign: focal species. This protocol will be implemented in all six ROMN parks. Beaver (*Castor canadensis*) are a keystone species in many ROMN ecosystems. The dam and canal-building and foraging activities of beaver have profound effects on ecosystem structure and function. Beaver dams slow current velocity; increase deposition and retention of sediment and organic matter; reduce downstream turbidity; increase the area of soil–water interface; elevate the water table; change the annual stream discharge rate by retaining run-off during high flows and slowly releasing it during low flows; alter stream gradients by creating a stairstep profile; and increase resistance to disturbance. Beaver ameliorate the establishment and survival processes of willow and other phreatophytic species and have a cascade of effects throughout park ecosystems, with direct benefits to avian and plant diversity.

NPS/J. SCHMIDT

American beaver (*Castor canadensis*).

Although beaver reintroduction has helped populations to recover throughout much of their former range, beaver populations remain far below historic levels in some ROMN parks. Given their keystone role, reduced numbers, and threats to continued viability, beaver are a focal-species vital sign in at least ROMO. Currently, we plan to monitor beaver (likely using simple presence/absence measures) as part of the Stream, Wetland, and Alpine Lake Ecological Integrity protocols, with an emphasis in ROMO. We also may include specific remote-sensing methods for beaver in the Landscape Dynamics protocol.

Objectives for beaver monitoring include:

1. Determine the status and long-term trend of stream length and proportion and wetland area within select ROMN parks where beaver are present. Presence will be documented using both remotely sensed (e.g., dams, canals, and lodge density) and field measures (e.g., lodges and dams observed or beaver-cut woody vegetation).

5.2.10.3 Grizzly Bear

The Focal Species–Grizzly Bear protocol addresses one ROMN vital sign: focal species.

This protocol will be implemented in GLAC. The Crown of the Continent ecosystem, with GLAC at its center, is the largest ecosystem in the lower 48 states that includes intact native carnivore populations. A critical component (ecologically and politically) of this system is the grizzly bear (*Ursus arctos*). Preservation of this species in the continental U.S. depends on sound management both of animal numbers and of important habitats distributed across a large landscape.

Currently, we do not anticipate network funding for population-level monitoring of grizzly bears in GLAC. We will incorporate data from GLAC, the State of Montana, the USFWS, and other monitoring and research in the Crown of the Continent ecosystem in our reports. We may develop remote-sensing methods specific to grizzly habitat (e.g., landscape-level habitat and use patterns) as part of the Landscape Dynamics protocol.

Objectives for grizzly bear monitoring include:

1. Monitor trends in the size, quality, and distribution of critical habitat types for grizzly bears. (This requires a specialized habitat model that potentially incorporates satellite data, land-use data, and calculated indices—e.g., drought, avalanches, topography—to describe and predict changes affecting grizzly bears.)

5.2.10.4 GRSA Endemic Insects

The Focal Species–GRSA Endemic Insects protocol addresses one ROMN vital sign: focal species. This protocol will be implemented in GRSA. Seven taxa of rare, special-interest, and/or endemic insects occur in and around Great Sand Dunes National Park and Preserve. These include the Great Sand Dunes tiger beetle (*Cicindela theatina*), a darkling or circus beetle (*Eleodes hirtipennis*), Werner's ant-like flower beetle (*Amblyderus werneri*), a hister beetle (*Hypocaccus sp.*), a noctuid moth (*Copablepharon sp.*), a robber fly (*Proctacanthus sp.*), and the giant sand treader camel cricket (*Daihinibaenetes giganteus*). These insects have strong habitat associations and many only occur on active dunes, sandy blowouts, or shifting sands with sparse vegetation. For example, *C. theatina* is one of only two tiger beetles to be a true endemic in North America, due to its presence in a restricted geographical region and ecosystem, and absence of other sand dune fields in the area.

The protection and preservation of these species is an important management objective for GRSA, making their population dynamics, habitat associations, and community interactions a high-priority vital sign. The population dynamics and seasonal activity of similar taxa are known to be affected by a variety of factors such as climate, temperature, moisture, wind, available light, and available food. GRSA staff is leading efforts to develop this monitoring protocol, with academic partners and the assistance and support of ROMN staff.

Objectives for insect monitoring include:

1. Determine long-term trends in the distribution and abundance of *C. theatina* within selected areas of GRSA.
2. Determine long-term trends in the distribution and abundance of the six other insect taxa within selected areas of GRSA.
3. Determine status and trends in the age-class distribution and phenological patterns of selected GRSA insect taxa in selected areas to help predict population trends.
4. Determine status and trends in optimal foraging and breeding habitat for GRSA endemic insects. Optimal habitat will be determined from initial results of Objective 2.

5.2.11 Landscape Dynamics

The Landscape Dynamics protocol addresses a single ROMN vital sign: Landscape Dynamics. The protocol will be implemented in all six ROMN parks (with buffers based on watersheds and/or ecoregion boundaries), but is currently on hold as regional and national examples are developed.

Viewshed preservation is an important management issue at Grant-Kohrs Ranch National Historic Site.

Landscapes within and surrounding protected areas, including ROMN parks, are undergoing varying degrees of anthropogenic and natural modification that can have cascading effects on park resources. ROMN parks include both relatively large landscapes composed of interacting yet heterogeneous ecosystems (GLAC, GRSA, ROMO) and smaller areas that are often critically influenced by the surrounding landscape structure and use (FLFO, GRKO, LIBI). Although the effects of landscape dynamics differ in scale and intensity, concerns about potential ecological consequences are similar; landscape-scale mechanisms are well-recognized as important drivers impacting all six parks.

Critical management issues and ecological processes extending across parks and beyond their boundaries include wildfire and fire management (all parks), large mammal populations (e.g., elk at ROMO, grizzly bears at GLAC, bison at GRSA), abiotic conditions and processes (e.g., ground- and surface water dynamics at GRSA), viewshed preservation (especially at FLFO, GRKO, and LIBI, but also along the borders of GLAC, GRSA, and ROMO), and the spread and control of invasive exotic plants (all parks).

The importance of landscape context is underscored by its recognition as a systemic driver in nearly all ROMN vital signs. Aspects of vital signs influenced by landscape context include wetland classification, condition, and spatial arrangement (Wetland Communities), beaver status via remotely sensed measurement of lodges, dams, ponds, and canals (Focal Species–Beaver), streams, which may extend across and beyond park boundaries (Water Chemistry, Surface Water Dynamics, Groundwater Dynamics and Freshwater Communities), the composition, structure, and distribution of plant communities (Vegetation Composition, Structure, and Soils), invasive species (Invasive/Exotic Plants), and atmospheric deposition (Wet and Dry Deposition). At a minimum, understanding landscape change will enhance our power to explain changes in the other vital signs.

Objectives for landscape monitoring include:

1. Determine annual status and trends in selected metrics of landscape composition, configuration, and connectivity within a Greater Park Ecosystem (GPE) designation for each ROMN park. Composition refers to amount of land cover (vegetation formation, rock, aquatic), and land use (anthropogenic developments such as roads, buildings, agriculture). Configuration refers to spatial arrangement of land-cover and land-use types. Connectivity refers to the contiguous nature of a specific type. GPE is the park area plus an area around the park that is assumed to influence the flow of energy and materials within a park. Landscape metrics will be generated for GPE components (park, area around the park) and for the GPE in total.
2. Determine status and trends in regional land cover using shifts in multi-spectral signatures and spatial models that integrate remotely sensed imagery with auxiliary data.
3. Determine status and trends in the distribution and connectivity of particular land-cover types important to other high-priority ROMN vital signs or resources of concern.

Chapter 6
Data and Information Management

6.1 Data Management Goals

The goal of Rocky Mountain Network data management is to provide scientifically and statistically sound data to support management decisions for the protection of park resources. To accomplish this goal, we will ensure the quality, interpretability, security, longevity, and availability of the information resulting from network resource inventory and monitoring efforts. The network's data management is based on a suite of fundamental principles:

Quality. The ROMN will take measures during all phases (project development, data acquisition, data handling, summary and analysis, reporting, and archiving) to guarantee the quality of the data. These measures will reflect current best practices and meet rigorous scientific standards.

Interpretability. A dataset is only useful if it can be readily understood and appropriately interpreted in the context of its original scope and intent. Data taken out of context can lead to misinterpretation, misunderstanding, and poor management decisions. Similarly, datasets that are obscure, complex, or poorly documented can be easily misused. Sufficient documentation (metadata) will accompany each dataset (and all reports and summaries derived from it) to ensure that users will have an informed appreciation of the dataset's applicability and limitations.

Security. The ROMN will maintain and archive datasets in an environment that provides appropriate levels of access. The network's data management system will take advantage of existing systems for network security and systems backup, and augment these with specific measures aimed at ensuring the long-term security and integrity of the data.

Longevity. The longevity of a dataset is reliant on thorough documentation (metadata). Longevity is also realized through continued use, which requires that the data be maintained in an accessible and interpretable format.

Availability. Natural resource information can inform decisions only if it is available to managers at the right times and in appropriate forms. We will ensure that the products of inventory and monitoring efforts are created, documented, and maintained in a manner that is transparent to the potential users of these products.

6.2 Data Management Activities

In most cases, data generated by the ROMN will come from projects that are temporary endeavors undertaken to create specific products (PMI 2004). Short-term projects may include network assistance to parks (e.g., clean-up of existing, or "legacy" data), research projects, inventories, or pilot work done in preparation for long-term monitoring. Monitoring protocols central to the ROMN program will be implemented as long-term projects. Although protocols are continuous, we will treat each field season as a separate project through the Annual Administrative Report and Work Plan process (see Chapter 8), with project planning occurring prior to each field season and closure occurring at season's end. Other long-term projects might include research programs and monitoring performed by other agencies and cooperators.

Although the ROMN is part of the NPS I&M program, monitoring (and the direct management of monitoring data) is only one important network activity. ROMN activities are divided into five quasi-independent "operations" (defined here as primary and continuous functions that routinely support the fundamental needs of the network) that all require management of data and information. All of these operations are essential to the success of the network:

The Data Management Operation (NPS-ROMN 2007e) is charged with the development, implementation, enforcement, and maintenance of the Data and Information Management Plan (Appendix D) and its associated documents and standard operating procedures. It is also responsible for the management of the network's official and/or certified datasets. Official data includes general geospatial layers such as roads, trails, and park boundaries (which may come from other governmental or non-governmental agencies), as well as information and data derived from the other network operations. By providing an official and definitive data repository, it ensures that there is a single point for data requests and that consistency, quality, and accuracy are maintained among all network activities.

The Library Operation (NPS-ROMN 2007j) is responsible for maintaining the digital and analog collection of documents used and/or generated by the network. Documents are in final form and may include administrative records, reports, and scientific manuscripts or papers.

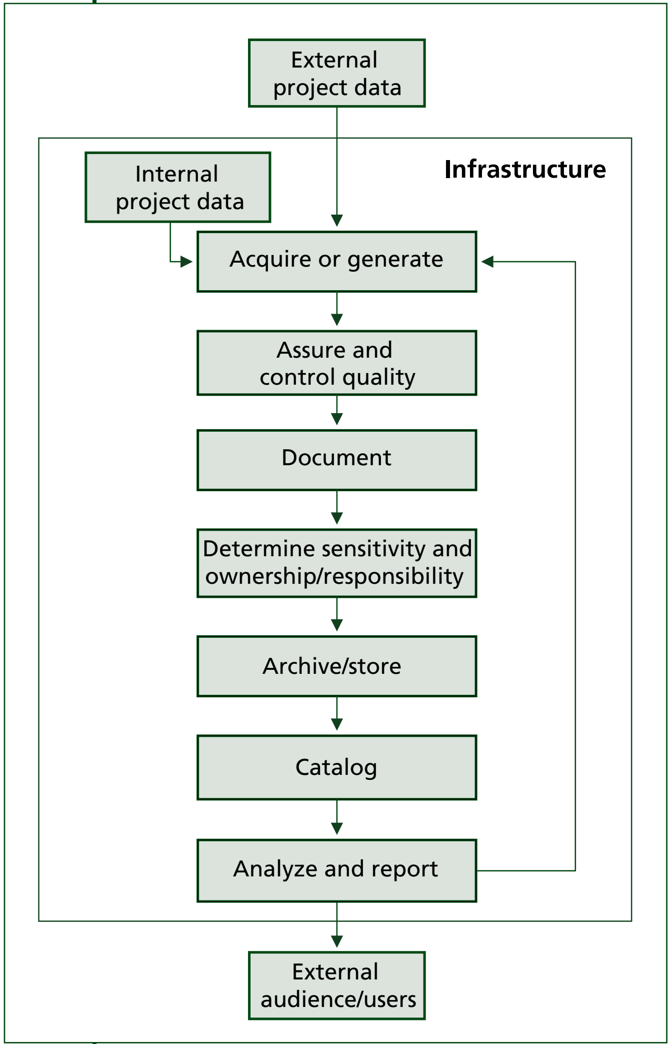


Figure 6.3.1. Data management conceptual model.

The Park Support Operation (NPS-ROMN 2007q) includes network support of park activities through development and oversight of discrete projects. Many park-support projects relate to mining legacy information, resurrecting and documenting non-functional databases, and supporting continuing natural resource inventories.

The Infrastructure Operation (IFO) (NPS-ROMN 2007i) oversees the hardware, software, and local area network that support ROMN activities. This operation is also concerned with backing up the digital files found on the network's server. Finally, this operation is charged with maintenance of the network's Internet and Intranet web pages.

The Administrative Operation (NPS-ROMN 2007a) includes program management related to planning, budget and accountability, compliance, travel, personnel, agreements, and communication.

6.3 Data Management Framework

6.3.1 Data management conceptual model

The data management conceptual model (Figure 6.3.1) is a framework that all ROMN staff regularly follow to manage data. This model is scalable; it applies at a micro-level (i.e., reflects the day-to-day stewardship of data by staff) and at a macro-level (i.e., shows the systematic framework for managing all network data through time). This model also emphasizes the importance of infrastructure, which is the medium through which all information is managed and includes the hardware, software, local-area network (LAN), and wide-area network (WAN).

Each step in the data management conceptual model is essential to ensuring effective data management; failure to account for any step will ultimately compromise data integrity. While these steps are presented as a series, it should be recognized that many of the steps are concurrent.

6.3.1.1 Step One: Acquire and/or generate

This step defines the scope of data to be acquired and/or generated and maintained. Without a clear vision of scope, the network may be overloaded with unnecessary and/or irrelevant information, or fail to collect critical information. Data may be acquired internally or externally. Internally, we will generate data annually through the implementation of each monitoring protocol (see Chapter 5). Certified datasets will be shared, or integrated, among protocols through the use of standardized database tables and structures. As an example of data to be acquired externally, we will track the NPS Research Permitting and Reporting System (RPRS) (NPS 2006b) regularly to determine whether research projects complement the vital signs. Other agencies also may be distributing relevant information (e.g., weather and climate data) that informs the network vitals signs.

6.3.1.2 Step Two: Assure and control quality

Quality assurance (QA) involves planning, monitoring, and evaluating the aspects of a project to ensure that standards of accuracy and consistency are being met. Quality control (QC) involves checking collected data for accuracy and completeness in order to minimize the risk of producing poor-quality data. To ensure that all data generated by each of the protocols is of the highest quality, each protocol will:

- Use standard file-naming conventions that guide the naming of any digital file, accommodate data versions, and differentiate between draft and final versions of data and documents;
- Adhere to a standard directory structure that provides consistent rules for how data will be organized for each vital sign; and
- Follow specific QA/QC procedures that detail how to perform effective QA and QC on network data.

6.3.1.3 Step Three: Document

The careful documentation of datasets, data source(s), and the methodology by which data were collected or acquired is essential for preserving information over the long term. Documentation also establishes the basis for appropriate use of the data in resulting analyses and products. We will adequately document all vital signs data and information, and describe all datasets, including traditional geospatial layers and tabular datasets, using Federal Geographic Data Committee standards (FGDC 2006) and the NPS Metadata Profile (NPS 2006c). The network will use the NPS Metadata Tools and Editor (NPS 2006d) to develop and maintain all metadata.

6.3.1.4 Step Four: Determine sensitivity and ownership/responsibility

Sensitive information is defined as information whose use by unauthorized individuals would threaten a park's natural and/or cultural resources and/or legal obligations. Ownership can take on different meanings, depending on context. In some cases, ownership refers to proprietary or copyrighted information. In other cases, it indicates whether the network or a park has the ultimate authority and responsibility for the information.

The network will ensure that all sensitive information collected from any project or protocol is diligently managed. Sensitive information will be treated accordingly in consultation with ROMN park staffs. We will verify the sensitivity of all other information with the respective parks. Information not flagged as sensitive is assumed to be non-sensitive, and will be fully accessible to the public (NPS 2006e). Determining whether data falls under the purview (ownership/responsibility) of the network or of one of the member parks is critical, because it specifies which organization is responsible for making this information available and who will respond to questions concerning its source, meaning, accuracy, and implications. The network will work with the parks and Technical Committee to develop a clear ownership policy.

6.3.1.5 Step Five: Archive and store

Archiving and storage refers to how information is physically organized. Protection from disaster, malice, and degradation is paramount. All data will be securely stored on-site. We will maintain duplicate datasets and documentation to ensure that datasets are not lost to disaster or other accident. Certified datasets and information will be archived on the NPS Natural Resources GIS Data Store (NPS 2006h). All data will be stored in a format that adheres to the NPS natural resource database template standards (NPS 2006f), which follow best practices for database design.

6.3.1.6 Step Six: Catalog

Cataloging refers to how information (datasets, reports, maps, projects, ideas) is logically organized. Data may be stored and protected, but if users are not able to discover and retrieve that information in a logical manner, it may never be utilized. In addition to formally storing protocol data and information, it is important to maintain a working inventory of all network data and information. The network will track all vital signs information using systems that are coherent, organized, and follow accepted NPS cataloging standards. Locally, we will track all projects using project management software, and catalog all publications and datasets. At the national level, the RPRS (NPS 2006b), NatureBib (NPS 2006g), and the Natural Resources Data Store (NPS 2006h) function as cataloguing systems for projects, publications, and datasets, respectively.

6.3.1.7 Step Seven: Analyze and report

Analysis involves the examination of information elements and their relations. Reporting involves the export of information, whether as an analyzed product or in original form. The network's analysis and reporting strategy is presented in Chapter 7 and Table 7.3.3. In summary, there will be a simple annual report for each protocol, likely consisting of summary statistics and a text summary of the accomplishments and highlights of each field season, and an annual report summarizing and integrating the results of all monitoring activities. At five-year intervals, the ROMN will report on a formal review of the network program. After one full monitoring cycle for a protocol, the ROMN will prepare a comprehensive synthesis and analysis report. The ROMN will specify a more rigorous evaluation after a full cycle of sampling of all sites in all parks has occurred. In all cases, reports will follow publication management guidelines (NPS 2006i) and the technical report series format. Whenever appropriate and possible, the network will also publish results in peer-reviewed periodicals. The ROMN will also report annual highlights and accomplishments and account for network funds and resources through its Annual Administrative Report and Work Plan process.

6.3.2 Reporting and distribution

This section provides a summary of how the ROMN intends to integrate vital signs data with park, network, and national systems. For each field season, we will collect and track data in a working database. At the end of the field season, we will certify, or "quality-control" the data, and create reports based on data analysis. All certified data will be integrated and accrued into the network's master vital signs datasets, where it will be available for integrative analysis with the other network protocols (see Chapter 7).

External sharing of data from the network depends on both ownership/responsibility and sensitivity. Non-sensitive data and reports owned by the network will be provided annually to NPS national systems (see below) as a snapshot of the data and associated analyses that will be delivered as a final product for each field season. Park-owned and/or sensitive data will be provided to the parks, which will be responsible for deciding what action to take regarding its distribution.

This data will be available to the public and the parks through a number of avenues. Non-sensitive reports and datasets for each field season will be available through the NPS systems. These systems, in certain instances, will link to other federal database systems, including EPA's water-quality database, STORET (EPA 2006b). Parks also have the option of distributing their own data through their web pages. Access to all of this information also will be facilitated by a number of data brokers, including the NPS Research Learning Centers, which can provide context and meaningful links to the multiple systems that house data.

To provide for comprehensive reporting, we will send (or upload) all of the certified monitoring datasets and reports to the following, as appropriate:

- The Technical Committee, Board of Directors, and park staff will be first to receive all data and information.
- The NPS Natural Resources GIS Data Store (NPS 2006h) will be the primary repository for all certified network datasets and information for each field season. For each protocol, all data, metadata, and supporting documents will be bundled together and uploaded.
- NPSTORET (NPS 2006j), the NPS Water Resource Division's equivalent to EPA's STORET (short for STOrage and RETrieval), accepts all water quantity and quality data. All water-quality data from each protocol also will be submitted here, and will cross-reference to the archive on the Data Store (NPS 2006h). Annually, the NPS will upload all of the data to the EPA's STORET.
- NatureBib (NPS 2006g) is the NPS database for cataloging park and network natural resource-related documents, publications, and references. Citations and documents for all finalized reports and publications will be uploaded (in portable document format, *.pdf) to NatureBib and cross-reference to the archive maintained in the Data Store (NPS 2006h).
- NPSpecies (NPS 2006k) is the NPS database for storing, managing, and disseminating information on all organisms in NPS units. All appropriate species-related information will be submitted to NPSpecies and will cross-reference to NatureBib or the archive in the Data Store as the original source.
- The network will provide simple investigator annual summary reports to the NPS Research Permit and Reporting System (NPS 2006b). Each report will contain a link to complete report and dataset archives in the Data Store.
- On request, the network will distribute any of its master databases via compact disc.

As much as possible, we will work to minimize replication of information, make all data available through one interface, and serve multiple audiences who require data in different formats and at various levels of synthesis. Figure 6.3.2 summarizes the process from vital signs data generation to its ultimate destination on WASO, network, and park systems.

6.4 Roles and Responsibilities

Although primary responsibility for data resides with data managers, good data stewardship is a collaborative endeavor that involves many people (Table 6.4). As such, a valid data management system must be developed and continually modified to meet the needs of everyone who has a role in coordinating, generating, maintaining, and using natural resource information in its many forms.

Although numerous positions share responsibility for data management, the chief personnel involved with data management include the data manager, project leader, and network coordinator. Implementation of data management policies and procedures will occur in an ongoing, evolutionary cycle as a product of learning, testing, refining, and technology changes. The Data and Information Management Plan (NPS 2006l; Appendix D) is seen as a living, changing tool to aid in preserving and protecting the information required for successful long-term monitoring and management of the network's constituent parks.

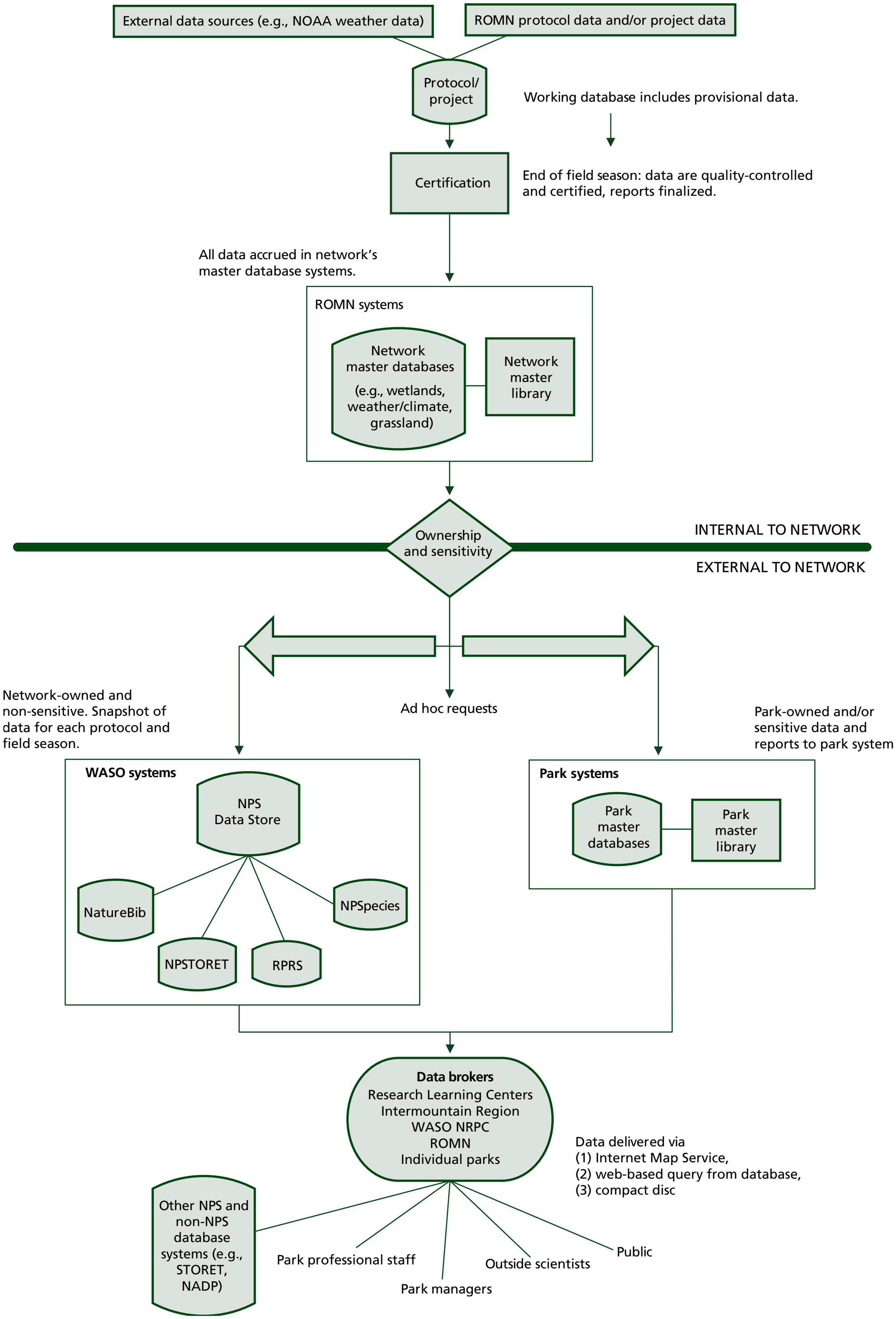


Figure 6.3.2. Integration of network, park, and WASO data systems.

Table 6.4. Common data management responsibilities by position.

Organization	Position	Data stewardship responsibilities
ROMN	Data manager	Ensure that I&M data are organized, useful, compliant, safe, and available. Develop data management policies and procedures.
ROMN	Ecologist	Oversee and direct certain protocols. Analyze data and report results.
ROMN	Program manager	Coordinate and oversee all network activities. Ensure that adequate data management resources are available for network activities. Enforce data management policies and report monitoring results.
ROMN cooperator or temporary staff	Field crew member	Collect, record, and verify data.
ROMN cooperator or temporary staff	Ecologist/crew leader	Train and supervise crews in field data collection. Organize and perform quality assurance/quality control on field data. Prepare summary statistics and reports for each field season.
ROMN cooperator or temporary staff	Geospatial analyst	Process and manage data.
ROMN cooperator or temporary staff or ecologist	Protocol or project leader	Oversee and direct project, including data management.
ROMN or ROMN cooperator	Database application developer	Know and use database software and database applications.
Park	Natural resource managers and specialists/ ecologists/biologists/ hydrologists	Inform the scope and direction of science information needs and activities. Validate and make decisions about data. Integrate science in park and network activities.
Park	GIS coordinator	Support park management objectives with GIS and resource information management.
Park	Curator	Oversee all aspects of specimen acquisition, documentation, and preservation. Manage park collections.
Park	Park research coordinator	Facilitate data acquisition by external researchers. Communicate NPS requirements to permit holders.
Park	End users (superintendents, resource managers, interpreters, rangers, facility managers, et al.)	Inform the scope and direction of science information needs and activities. Interpret information and apply to decisions.
WASO	I&M data manager (national level)	Provide servicewide database availability and support.
WASO cooperator	NRPC information technology specialist	Provide IT support for hardware, software, and networking.
Other agencies and academia	Scientists	Inform the scope and direction of science information needs and activities. Interpret results.
ROMN Technical Committee	Natural resource managers and research coordinators	Inform the scope and direction of science information needs and activities. Interpret results.
ROMN Board of Directors	Park superintendents and managers	Inform the scope and direction of science information needs and activities.
ROMN Science Panel	Scientists	Inform the scope and direction of science information needs and activities during vital signs planning in the context of current scientific research and knowledge of park ecosystems.

Chapter 7
Data Analysis and Reporting

7.1 Definition and Guiding Principles

Analysis is the process by which monitoring data are turned into meaningful information. We define analysis broadly to include all steps after data are collected and entered into an electronic file. Thus, data analysis includes quality assurance and control (especially confirming logical consistency), exploratory data analysis, and all analytical procedures leading to conclusions and interpretations of the data. Reporting includes all forms of communication of monitoring results, including traditional hard-copy reports, scientific journal articles, oral presentations, and web-based reports.

The primary goal of all ROMN analysis and reporting is to support park resource management, the ROMN program, and the specific objectives of each protocol. The guiding principles underlying all ROMN analysis and reports ensure that all monitoring and associated data will:

- Be scientifically defensible;
- Be rigorously quality-assured;
- Match analytical methods to the objectives of a given vital sign;
- Match analytical methods to the sample design used;
- Accurately and precisely establish status and trend in vital signs;
- Aid in interpretation of results for various constituents, from park management to the I&M program, to Congress and the public;
- Identify possible warning signals of abnormal conditions and bring this information to the attention of managers and the public;
- Synthesize the strengths and weaknesses of the monitoring effort in meeting I&M program goals;
- Provide information that will help to assess the performance of the I&M program and the parks with respect to legal mandates (e.g., GPRA, Clean Water Act), and to report such information in a usable format for park staff; and
- Provide analyses and reports to ROMN parks in a timely manner.

7.2 Overview of Analyses

Rocky Mountain Network analyses fall into three general categories:

1. Analyses primarily concerned with measuring and describing the attributes of a statistical population in terms of its distribution and structural features, involving parameter estimation;
2. Models used to augment status and trend (parameter) estimation, helping us to better understand the dynamic nature and condition of park resources by revealing relationships among resources, ecosystem drivers, and stressors; and
3. Hypothesis testing, used when the status or trend of a vital sign or model prediction is tested against an ecological threshold or previous estimate (e.g., for trend). Developing these thresholds is a critical component of the ROMN program.

All of these analyses are connected to the five general goals of the I&M program (Figure 7.2). The ROMN analytical strategy also incorporates feedback with park management (i.e., adaptive management; Holling 1978) and protocol review for purposes of improving efficiency (e.g., modifying sample sizes to lower costs or enhance precision).

Several ROMN vital signs have similar monitoring goals and, therefore, share similar sample designs and analytical approaches. In kind, this section is organized around five general classes of analytical objectives: (1) site-specific trend, (2) ecological processes, (3) landscape status,

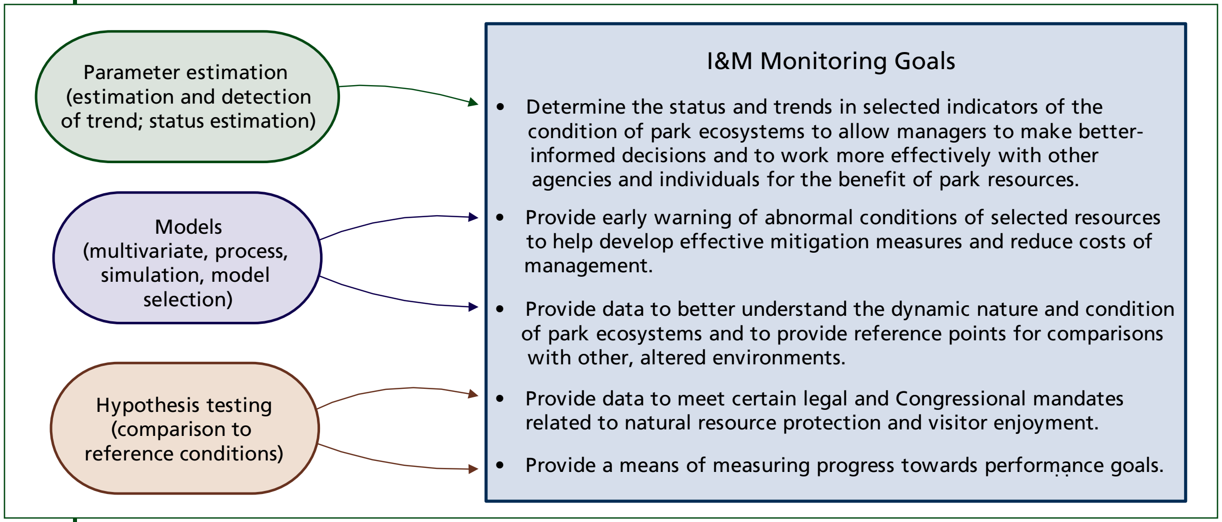


Figure 7.2. Conceptual replationships between major types of ROMN analysis and primary I&M goals.

trend, and change detection, (4) focal taxa population dynamics and habitat quality, and (5) park-scale status and trend.

The first step in all ROMN data management and analytical strategies is to quality-assure all data (detailed in ROMN protocols and Appendix D). In particular, it is critical that sample weights are properly adjusted and included with all survey design datasets. Data quality control includes identifying missing values, outliers, and any other problems related to data collection procedures and the data-entry process (Jeffers 1994; Reid 2001). Once a quality-assured dataset is available, a series of possible analyses follows, as discussed below. All analyses begin with some level of summary statistics (e.g., means and variances), with simple graphical displays to assess the data distribution, consider outliers, and observe trends. Another common step is to conduct various forms of trend analysis for variables collected over time. Trend detection is important because if it exists, it is a key monitoring result and must be accounted for in status estimates.

7.2.1 Site-specific objectives (sentinel designs)

Select ROMN monitoring objectives require monitoring data at a specific site, typically because of regulatory requirements or because of a known occurrence of a rare, high-value resource. The sample design for this type of monitoring is always a sentinel design (see Chapter 4). Site-specific objectives and sentinel designs occur in the Stream, Wetland, and Alpine Lake Ecological Integrity protocols, and possibly for Alpine Vegetation Composition, Structure, and Soils, due to accessibility limitations (see Table 7.2).

Once data are quality-assured and basic summary statistics and graphical displays of the data have been investigated, a series of possible analyses for site-specific objectives follows. A key step is to determine if a response measure has detectable site-level trend. We use linear models presented in Chapter 4 (Larsen et al. 2001; Kincaid et al. 2004) and/or non-parametric, site-level trend analyses (Mann-Kendall tests; Hirsch and Slack 1984, Helsel and Hirsch 2002) to quantify trend.†

After we know if trend is present or not, we can proceed with several analyses that account for trend as applicable. Status can be calculated for a single site. If site-level status is reported, it must be labeled clearly as pertaining to multiple sample periods.

When trends are recognized or expected, time-series analysis (Hamilton 1994; Brockwell and Davis 2002) can be used to (1) identify the nature of the phenomenon represented by the

†The Mann-Kendall test is a rank-based procedure especially suitable for non-normally distributed data, censored data, data containing outliers, and non-linear trends.

Table 7.2. Summaries of key analyses, frequency, and responsibility for each ROMN protocol or vital sign.

Protocol	Vital sign(s)	Summaries of key analyses	Frequency	Analyst(s)
Snow Chemistry	Wet and Dry Deposition	• Quality-assure data. • Basic summaries (snow-pit scale) of mean (SE) snowpack concentration and loading of major ions (nitrate, sulfate, and ammonium), pH, conductance, calcium, sodium, potassium, magnesium, chloride and mercury. • Basic summary (snow-pit scale) of snow water equivalent (SWE). • CUSUM (snow-pit scale) of SWE and snow-deposition parameters. • Geostatistical models (kriging) to distribute snow deposition parameters and SWE across park and regional landscapes, (e.g., PRISM model). • Multivariate models of SWE and snow-deposition parameters with other vital signs in order to understand associations (possible causal relationships). • Analysis of SWE and snow-deposition parameters in RHESSys and other process models. • Station-scale linear models and/or non-parametric trend analyses of snow-pit scale SWE and snow deposition parameters. • Qualitative and quantitative (linear-model based) comparisons of snow pit and modeled snow deposition parameter status and trends among ROMN parks (GRSA, GLAC, ROMO), with regional trends and with park- or ecoregion-specific ecological thresholds.	Annual	Principal investigator (PI)s and ROMN ecologist(s) with cooperators (e.g., from USGS)
NADP/NTN	Wet and Dry Deposition	• Quality-assure data. • Basic summaries (station scale) of monthly and annual mean (SE) deposition and loading of major ions (nitrate, sulfate, and ammonium) pH, conductance, calcium, sodium, potassium, magnesium, and chloride in LIBI, GLAC, and ROMO, and from nearby monitoring sites such as Alamosa, Colorado, near GRSA. • CUSUM (station scale) of deposition parameters. • Geostatistical models (kriging) to distribute deposition parameters across regional landscape, including FLFO, GRKO, and GRSA. • Multivariate models of deposition parameters with other vital signs in order to understand associations (possible causal relationships). • Analysis of wet and dry deposition parameters in RHESSys and other process models. • Station-scale linear models and/or non-parametric trend analyses of station-scale wet and dry deposition parameters. • Qualitative and quantitative (linear-model based) comparisons of station-scale and modeled wet/dry deposition parameter status and trends among ROMN park units, with regional trends and with park- or ecoregion-specific ecological thresholds and criteria (as available).	Monthly Annual	PIs and ROMN ecologist(s) with NPS–ARD cooperators
Weather and Climate	Weather and Climate	• Quality-assure data. • Basic summaries (weather-station scale) of mean (SE) climatic parameters (temperature and precipitation) for each climate station in a park (monthly and annual); number of days above 95th percentile and below 5th percentile of air temperature and precipitation, number of days below freezing. • CUSUM (at each weather station) of climatic parameters. • Derivation of multimetric indices (at station and park scales) such as Palmer Drought Severity Index, Standardized Precipitation Index, and growing degree-day indices. • Time series analysis (uni- and multivariate) to understand temporal nature of the climate parameters and forecast future values and climate scenarios. • Geostatistical models (kriging) to distribute weather and climate parameters and indices across park and regional landscape. • Multivariate models of weather and climate parameters with other vital signs in order to understand associations (possible causal relationships). • Process models of climatic parameters using (for example) PRISM model. • 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 (linear-model based) comparisons of station-scale and modeled weather parameter status, trends, and climatic extremes among ROMN park units, with regional trends and with park- or ecoregion-specific ecological thresholds.	Monthly Annual	ROMN data manager and ecologist(s)

Table 7.2. Summaries of key analyses, frequency, and responsibility for each ROMN protocol or vital sign, cont.

Protocol	Vital sign(s)	Summaries of key analyses	Frequency	Analyst(s)
Stream, Wetland, and Alpine Lake Ecological Integrity*	Water Chemistry Surface Water Dynamics Freshwater Communities Invasive/Exotic Aquatic Biota Invasive/Exotic Plants Focal Species–Beaver	• Quality assurance and control; identify anomalous values indicating need for re-analyzing samples; censor values below method detection limits, etc. • Basic summaries (site scale, adjusted for trend, if present) of water-quality parameters (anions/cations, total and dissolved nutrients, etc.; adjusted for season and flow as applicable) using summary tables, histograms, and box and whisker plots to show frequency distribution, median, and interquartile ranges (for non-normally distributed data), mean (SE) (for normally distributed data), and 95% confidence intervals for means and medians of parameters at each site. • CUSUM (station scale) of key water-quality parameters. • Tabulate water-quality values exceeding, and approaching exceedance of standards (20% or less below the applicable standard). • Site-level trend analysis (adjusted for season and flow as applicable for individual constituents); statistical tests include Seasonal Kendall tests for monotonic trends and Seasonal Rank Sum tests for step trends. • Site-scale multivariate models of alpine lake response measures with other vital signs in order to understand associations (possible causal relationships). • Derivation of macroinvertebrate and periphyton (stream) and vegetation (wetland) of multimetric and multivariate indices such as an Index of Biotic Integrity and O:E indices. • Linear-model and/or Mann-Kendall tests for trend using mean stream and wetland multimetric and multivariate biological assemblage metrics, physical habitat measures, and water-chemistry parameters (as applicable). • Design-based inference of park-scale status (using means and cumulative frequency distributions of proportions) of stream and wetland response measures (biological assemblage IBI and O:E, physical habitat measures, and water-chemistry parameters). • Local neighborhood variance estimates for all response measures analyzed with design-based methods. • Small area estimation to extrapolate survey design results to a spatially explicit context (each stream or wetland in a park). • Design-based inference of length of stream or area of wetland with focal and park-specific invasive plants/aquatic taxa presence/absence. • Park-scale status and trend from linear models (correct for trend). • Integration of sentinel site and survey design data via found data procedures. • Analysis of surface and groundwater hydrology in RHESSys, IHA, and other process models. • SPARROW and LoadEst models to establish flux and loadings at sentinel sites (and survey sites if data available). • Geostatistical models (kriging) to distribute stream/wetland/alpine lake response measures across park and regional landscape. • Multivariate models of stream/wetland/alpine lake response measures with other vital signs in order to understand associations (possible causal relationships). • Comparison of empirical probability survey CDFs to state and federal standards, management triggers, and reference-condition thresholds using Wald, Rao and Scott tests. • Small area models compared on a reach-specific basis to state and federal standards, management triggers, and reference-condition thresholds using non-parametric methods.	Monthly (water quality at sentinel sites) Annual (precision of annual status estimates and power for trend highest with main panel (every 10 years); in intervening years, these increase slowly with unique site visits (status) or revisits (trend))	ROMN ecologist(s)
Invasive/Exotic Plants–Early Detection	Invasive Exotic Plants	• Derivation of taxa and park-specific early detection models. • Spatial pattern analysis of early detections (correlative analyses with biophysical features, regression analysis using similar factors and interpreted using AIC criterion). • 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 ROMN park units and among other regional networks, where possible.	Annual	PIs and ROMN ecologist(s)

Table 7.2. Summaries of key analyses, frequency, and responsibility for each ROMN protocol or vital sign, cont.

Protocol	Vital sign(s)	Summaries of key analyses	Frequency	Analyst(s)
Grassland/ Shrubland and Alpine Vegetation Composition, Structure, and Soils*	Vegetation Composition, Structure and Soils; Invasive/ Exotic Plants	• Quality-assure data. • Basic summaries (site scale, adjusted for trend, if present) of vegetation response measures (relative cover by taxa and/or functional group, soil parameters) using summary tables, histograms, and box and whisker plots to show frequency distribution, median, and interquartile ranges (for non-normally distributed data), mean (SE) (for normally distributed data), and 95% confidence intervals for means and medians. • CUSUM (station scale) of vegetation and soil response measures. • Linear-model and/or Mann-Kendall tests for trend using vegetation and soil response measures. • Design-based inference of park-scale status (using means and cumulative frequency distributions of proportions) of vegetation and soil response measures. • Local neighborhood variance estimates for all response measures analyzed with design-based methods. • Small area estimation to extrapolate survey design results to a spatially explicit context (a specific grassland/shrubland or alpine point in a park). • Park-scale status and trend from linear models (correct for trend). • Design-based inference of area of grassland with park-specific invasive plants presence/absence. • Geostatistical models (kriging) to distribute vegetation and soil response measures across park and regional landscape. • Multivariate models of vegetation and soil response measures with other vital signs in order to understand associations (possible causal relationships). • Regional pattern and trend analysis using ROMN data combined with comparable data from other monitoring programs (including other NPS networks, GLORIA/ CIRMOUNT). • Comparison of empirical probability survey CDFs to reference condition thresholds using Wald, Rao and Scott tests.	Annual (precision of annual status estimates and power for trend highest with main panel (every 10 years); in intervening years, these increase slowly with unique site visits (status) or revisits (trend))	ROMN ecologist(s)
Focal Species–Beaver	Focal Species	• Design-based inference of length of stream or area of wetland with beaver presence/absence (includes local neighborhood variance). • Harvest data and results from demographic studies of beaver. • Derivation of beaver-specific landscape indices of habitat quality.	Annual 5-year cycle	Cooperating PIs and ROMN ecologist(s)
Focal Species–GRSA Endemic Insects	Focal Species	• Occupancy and distance-sampling based population abundance, adjusted for adaptive sample design. • Occupancy and distance-sampling based community-level indices (diversity, etc.), adjusted for adaptive sample design. • Habitat quality measures. • Multivariate models of demography, diversity, and habitat quality with other vital signs (e.g., Landscape Dynamics, Weather and Climate).	Annual 5-year cycle	Cooperating PIs and ROMN ecologist(s)
Focal Species–Elk	Focal Species	• Design-based inference of presence (or level) of ungulate herbivory effects in wetlands and grasslands/shrublands (includes local neighborhood variance). • Harvest data and results from demographic studies of elk. • Derivation of elk-specific landscape indices of habitat quality.	Annual 5-year cycle	Cooperating PIs and ROMN ecologist(s)
Focal Species–Grizzly Bear	Focal Species	• Harvest data and results from demographic studies of grizzly bears. • Derivation of grizzly-specific landscape indices of habitat quality.	Annual 5-year cycle	Cooperating PIs and ROMN ecologist(s)

*Protocols treated together due to similarity in vital signs, objectives, and analyses.

Table 7.2. Summaries of key analyses, frequency, and responsibility for each ROMN protocol or vital sign, cont.

Protocol	Vital sign(s)	Summaries of key analyses	Frequency	Analyst(s)
Landscape Dynamics	Landscape Dynamics	• Derivation of ecologically meaningful (especially focal taxa-specific) and management-relevant landscape indices; measures of landscape structure (composition, configuration, and connectivity) on the basis of land-cover types (from classified satellite imagery) and derived with FRAGSTATS. • Derive summary statistics for land use, e.g., the area affected by recent, human land-use activities, 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). • Change detection among years using spectral comparison methods (indices such as NDVI, and non-indexed methods such as PCA or tasseled-cap analyses); 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. • Park- and buffer-scale assessments using linear and geospatial models to assess trends and correlation between adjacent-land changes with proximate changes in park units; assessment of trends for individual land-use activities, where applicable; spatial-pattern assessment of land-use activities; patterns in land-use or land-cover change with indirect implications for park resource conditions (e.g., introduction of invasive species); targeted analyses to assess status and trends in sub-park areas or specific habitat types. • Regional assessments using qualitative and quantitative comparisons of landscape-structure status and trends among ROMN park units and among other regional networks; correlation analyses between land-use and vital-sign measures logically responsive to specific land-use activities; correlation of broad-scale climate parameters with changes in landscape structure.	Annual 5-year cycle	ROMN ecologist(s)

sequence of observations and (2) predict future values of the timeseries variable. In most cases (e.g., when more than one vital sign is measured at a site), multivariate timeseries analysis will be used for describing possible cross-relationships among individual series (in addition to the usual univariate timeseries results; Reinsel 2003).

Details on analytical constraints related to single-site monitoring can be found in Appendix E.

7.2.2 Ecological process objectives (sentinel designs)

Select ROMN objectives require quantification of ecological processes at specific sites and/or across entire landscapes (e.g., watersheds) within a ROMN park. In most cases, designing a monitoring program to quantify an ecological process requires a single or multiple-site sentinel design, because this allows monitoring location(s) to be targeted or located using model-based approaches in ecologically important points in parks. Explicit ecological process objectives using sentinel designs occur in the following protocols (see Table 7.2): Weather and Climate; Snow Chemistry; NADP/NTN; Invasive/Exotic Plants–Early Detection; Stream Ecological Integrity, and Wetland Ecological Integrity. While change or trend in an ecological process may be of interest (e.g., how nutrient loadings in a basin change through time), details of spatial and temporal variability are often not directly measured in all locations; rather, a small number of sites is used to inform a model that interpolates and extrapolates data based on correlation of the process with features of the landscape.

After quality assurance and basic data summarization, ecological processes of interest are analyzed using models including univariate and multivariate regression, ordination, select Bayesian approaches (Berger and Sellke 1987; Berger and Berry 1988; Dennis 1996), and geostatistical techniques like kriging that incorporate spatially explicit information (via a variogram) into a set of linear regression routines. All of these models quantify pattern and relationships amongst vital signs that must then be interpreted as revealing or describing an ecological process of interest.

We also will use more complex process or simulation models that integrate both statistical techniques and empirical relationships in an attempt to explicitly quantify ecological process. Candidate process models include the Spatially Referenced Regressions On Watershed attribute model (SPARROW; Schwarz et al. 2006) and LoadEst (Runkel et al. 2004), used to establish water quality flux and loading at a basin pour point (Alpine Lake and Stream Ecological Integrity protocols); the Indicators of Hydrologic Alteration model (Richter et al. (1996, 1997, 1998) used to quantify hydrologic dynamics (Wetland Ecological Integrity protocol); the Regional Hydrological Ecosystem Simulation System (RHESSys) hydroecological modeling framework (Tague and Band 2004) used to simulate carbon, water, and nutrient fluxes across a landscape (multiple protocols); the PRISM model used to infer the spatial variation of precipitation patterns as a function of orography (Weather and Climate protocol; Daly et al. 1994); the Palmer Drought Severity Index, used to synthetically summarize precipitation and temperature at a station (Weather and Climate protocol; NCDC 2006; Yarnal 1993); the Spatially Explicit Regional Growth Model (SERGoM; Theobald 2005) that spatially distributes human density (housing density) across landscapes; and invasibility models used to predict the invasion dynamics of plant taxa within a landscape (e.g., Rew et al. 2005).

Model-selection algorithms such as Akaike's Information Criteria (AIC) will be used to help us to understand ecological processes by helping select the best model quantifying pattern or process in ROMN vital signs (Akaike 1973; Burnham and Anderson 2002). The ROMN will use model averaging for estimating parameters of interest when the parameters are derived from a selected model where alternative models exist (see Appendix E).

The results from ecological process models will be integrated with or followed by comparisons (hypothesis tests) of results with management triggers, reference conditions, or other thresholds. This allows explicit incorporation of ROMN monitoring results into park management, and will augment decisions parks must make within regulatory programs.

Information on constraints and benefits of model-based analysis can be found in Appendix E.

7.2.3 Landscape status, trend, and change detection objectives (census and sentinel designs)

The ROMN Landscape Dynamics vital sign includes two forms of monitoring objectives: (1) those that quantify the status and trend of complete ROMN park landscapes and (2) those that focus on change in specific parts of the landscapes of ROMN parks. The first requires a census design (see Chapter 4 and Appendix C) and contiguous (usually remotely sensed) monitoring data across entire parks. The second also relies on remotely sensed data, but uses a targeted or model-based sentinel design.

Monitoring of landscape status and trend (see Table 7.2) often relies on unique indices to summarize data and connect landscape pattern to ecological process (O'Neill et al. 1988; Turner 1990). Once calculated, these indices (and their source spatial data) are analyzed much like data from sentinel sites—with basic summarization, linear models, and multivariate approaches—to reveal the status and trend of these landscape indicators. Because the design used to generate landscape data is an assumed census, there is no application available for the analytical methods used with survey designs (see below). Landscape indices may be used as inputs into process or simulation models to calculate higher-order measures of landscape response to external and internal stressors (e.g., climate change, hydrologic modification). An important aspect of the Landscape Dynamics vital sign is the role it plays in other ROMN protocols; landscape data are used in analyses within almost all other vital signs as possible explanatory covariates.

7.2.3.1 Landscape indices

Landscape indices quantify spectral properties of landscape data (e.g., measures of productivity) or specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (Gustafson 1998). The ROMN is identifying and supporting development of several landscape indices in collaboration with multiple I&M networks and other partners (e.g.,

NASA, EPA, Colorado State University, and the Flathead Lake Biological Station). Indices will be generated for a time series of available land-cover and land-use data for each ROMN park (plus a relevant buffer defined by watersheds or ecoregions). Likely indices include spectral signatures correlated with photosynthetic activity and canopy structural variations (e.g., Normalized Difference Vegetation Index (NDVI); Tucker 1979); compositional metrics, such as the proportion of a land-cover type in a study area; and structural metrics, such as weighted mean patch size.

All ROMN landscape metrics will be robust, independent (Baudry and Merriam 1988), and grounded within an ecological framework (Li and Wu 2004). They will explicitly connect to ecological processes of relevance within other ROMN vital signs and (most importantly) park management. For example, measures of landscape connectivity will be based on the autecology of focal species like grizzly bears (GLAC), elk (ROMO, GRSA) and beaver (ROMO).

7.2.3.2 Change detection

Change detection analyses detect and describe changes in the type and configuration of specified components or discrete areas within a park. Several methods for analysis of parkwide landscape data are well established, including using indices to summarize conditions with a numeric score, alternately paired comparisons, principal-component and spectral-mixture analysis, and spatial models and analyses that integrate geographic information and remote-sensing data (see Appendix E).

ROMN methods will include established and developing methods to provide a combination of classification and spectrally based change-detection techniques. Analyses will focus on sets of park-specific metrics and on spatial trends generated by processes differentiated at and beyond park boundaries (e.g., land use, climate, and disturbance). Change detection results may feed into another model, or the analysis of another vital sign, to support analysis of higher-order processes (e.g., drought effects on primary production and, therefore, forage availability in select basins of a park).

7.2.4 Focal species dynamics and habitat quality (special designs)

The objectives of the Focal Species–Beaver, GRSA Endemic Insects, Elk, and Grizzly Bear ROMN vital signs focus on the status and trend in habitat quality and/or population dynamics for single species or discrete communities of these key taxa within relevant ROMN parks. As such, these present very different monitoring objectives, sample designs, and analytical requirements relative to any other ROMN vital sign. Moreover, for at least the three mammal taxa, the cost of robust demographic monitoring exceeds funding available within the ROMN budget (see Chapter 10).

The ROMN will harvest demographic results for beaver, elk, and grizzly bears from parks, state and federal wildlife agencies, and academic collaborators, integrate these results with other ROMN monitoring, and report synthetic results (see Table 7.2). The analyses for these vital signs are, therefore, embedded within these external programs and beyond our scope here. In some cases, we may harvest actual raw data (e.g., abundances, occurrence) and apply our own analyses. When this occurs, we always will use current population and distribution estimators as discussed in our protocol documents.

To estimate population demography of GRSA insect taxa, we will use a suite of demographic and distribution analyses that account for adaptive sample designs (see Chapter 4 and Appendix C; Thompson 2002). These include occupancy estimates adjusted for detectability (MacKenzie and Kendall 2002) and methods that incorporate distance-sampling procedures (Buckland et al. 1993, 2001). Distance-sampling analyses will use a detection function (the probability of detecting an object, given that it is at a specified distance from a transect line or point) to derive estimates of species densities within habitats of interest at GRSA. The Focal Species–GRSA Endemic Insects vital sign also includes community-level objectives, such as species richness and change in species richness over time. Similar design-appropriate approaches to community-level objectives will be used (e.g., multi-species detection probabilities and relative species richness; Boulinier et al. 1998; Nichols et al. 1998). Relative species richness enables comparison among areas receiving different management or experiencing different disturbances.

Many habitat-quality objectives for focal taxa are included within other ROMN protocols and their analyses. For example, beaver occurrence is a key response measure of the Stream, Wetland, and Alpine Lake Ecological Integrity protocols. Using the analytical approaches discussed below, we will generate park-scale, unbiased estimates of beaver occurrence in stream and wetland habitats as well as modeled, spatially explicit occurrences. A similar approach will be used for invasive plant and aquatic taxa as part of these vital-sign analytical strategies. Finally, as discussed above, habitat quality for beaver, elk, and grizzly is a key part of the Landscape Dynamics vital sign. Many of the landscape indices we develop will focus on the distribution and availability of habitat for these taxa, as quantified within remotely sensed data.

7.2.5 Park-scale status and trend objectives (probability designs)

Several ROMN vital signs require quantification of the status and trend in a vital sign at the scale of a park (i.e., population-scale objectives in the Stream and Wetland Ecological Integrity and Grassland/Shrubland Vegetation Composition protocols; see Chapter 4 and Table 7.2). Probability surveys using multiple sites spread across time with a complex panel structure are the preferred sample-design form for these objectives. Many analyses of survey data are similar to those employed within single-site or ecological process objectives; therefore, our focus in this section is largely on analyses unique to population-scale objectives and their survey design.

Once a quality-assured dataset is available, several analytical steps can be taken. A key is to determine if a response measure has detectable population-scale trend (see Section 7.2.1).[†] After we know if trend is present or not, we can proceed with several analyses that account for trend as applicable. These include simple graphical techniques, cumulative summary techniques (Page 2006), multi-year or trend-corrected status estimates (both from linear models; Courbois and Urquhart 2004), multivariate and geostatistical analyses of relevant co-located response measures, select Bayesian approaches, and model selection. Spatially distributed, unbiased, survey design-based data may be particularly useful as empirical verification of the parameters and predictions of process models.

When linear models or Mann-Kendall tests suggest there is no trend in a vital sign, unbiased estimates of status may be derived using design-based inference (Hansen et al. 1983; Gregoire 1998)—a powerful analytical strategy specific to population-scale objectives and their survey design (see Appendix E). This approach may be used to generate any status statistic, such as a mean, total, or proportion of any response measure (e.g., bryophyte relative cover in wetlands) or derived metric (e.g., a macroinvertebrate Index of Biotic Integrity) for a ROMN vital sign.

In summary, design-based approaches resemble traditional formulae for a statistic, but incorporate sample weights for each site in a design with the value of a given response measure at the sample point to account for the selection probabilities in the sample design. When a GRTS design is used, we generate precise variance estimates around design-based estimates of status using a proprietary technique developed by Stevens and Olsen (2003). Known as local neighborhood variance, it is derived from smoothed or averaged contrasts among values in the local neighborhood of a sampled point. It provides estimates 20–60% percent smaller (i.e., more precise) than similar traditional survey-design variance estimators (Horvitz and Thompson 1952).

Information on constraints and benefits of design-based analysis can be found in Appendix E.

[†] Our panel designs distribute a subset of the full spatial distribution of sites among survey years when sites across the park are sampled, and a smaller set of sites are sampled in staggered, overlapping years to establish temporal connectivity. Thus, status and trend are intertwined in our designs. Accounting for temporal trends is necessary for proper assessment of status, and accounting for spatial variability is necessary for proper interpolation of trend assessment.

7.2.6 ROMN thresholds and hypothesis tests

The final type of analysis we introduce involves comparisons (hypothesis tests) of the status or trend in a ROMN vital sign with ecological thresholds. In scientific settings, hypothesis testing is a keystone approach used to compare results in an experimental context to determine effects of treatments. We will use this method to test whether or not conclusions can be drawn about the relationship between a parameter estimate or model prediction and a reference to which it is being compared. We first summarize key concepts behind ecological thresholds, then briefly present select analyses employed to test vital signs results against thresholds.

NPS/E. W. SCHWEIGER

A USGS staffer samples the North Fork Belly River near the Canadian border, Glacier National Park.

7.2.6.1 Thresholds in ROMN vital signs

Thresholds define transitional states in ecosystem structure, composition, and/or function where abrupt changes in quality or properties occur, or where small changes in driver(s) produce large responses in ecosystems (RASFI 2004; Groffman et al. 2006). Thresholds also define the boundary zone between degraded, impaired ecosystems and unimpaired systems. When a threshold along a controlling variable in a system is passed, the nature and extent of feedbacks change, such that there is a change in the direction in which the system moves. We use the term "reference condition(s)" to describe minimally disturbed biological conditions above thresholds (Stoddard et al. 2006). Reference conditions allow assessment of ROMN vital signs by evaluating response measures or index scores for sampled sites against reference-condition expectations.

Vegetation monitoring, Little Bighorn Battlefield National Monument.

While it is often fairly straightforward to define break points suggestive of thresholds in distributions of data, the meaningful delineation of ecological thresholds and their application to resource management can be complicated by several factors: (1) the non-linear behavior of ecosystem response to stressors, (2) the mismatch between the temporal scale of most ecosystem responses relative to the period and frequency over which we have data, (3) the multiple stable states typical of ecosystems, and (4) the need to separate human-induced change in ecosystems from other causes. Nevertheless, identifying thresholds (and their underlying cause) in ROMN vital signs and incorporating them into long-term monitoring remains a critical task. Thresholds can define a change in the state of a park resource such that, if exceeded, future management actions may become limited (Friedel 1991), policy choices may be forced, and, in some circumstances, changes in park resources may be irreversible (Holling 1973; Stringham et al. 2003). Moreover, a priori thresholds allow development of a more efficient monitoring program (e.g., they assist calculation of a minimum detectable change needed in power for trend analysis; see Chapter 4 and Appendix C).

Detailed information on thresholds and reference conditions can be found in Appendix E.

7.2.6.2 Hypothesis tests

Formal hypothesis testing is limited within ROMN protocols. This method of analysis will be used when the status of a given resource is tested against an ecological threshold (especially legal criteria), or specified condition comparison (e.g., mean quantity at A vs. B). In the context of I&M program goals, this would likely be for testing whether or not certain legal or Congressional mandates have been met, or whether or not performance targets have been achieved. Many of the analyses discussed above allow this, especially the linear models we commonly use to estimate status and trend. For population-scale, design-based results (in the form of CDFs), non-parametric tests that incorporate the complex GRTS design structures we use are available. Specifically, the Wald statistic and two chi-squared statistics suggested by Rao and Scott (1981) can be used for testing differences between CDFs (Kincaid et al. 2004).

The ROMN will use these approaches to test whether or not the uncertainty about parameter estimates warrants conclusions about the relationship between a given resource state and the reference to which it is being compared. This method is considered as a type of statistical hypothesis testing, primarily because it will be extended to include comparisons with a priori reference values. However, the focus of the network will be on estimating parameters to ensure that biological and statistical significance are appropriately distinguished, following Yoccoz (1991).

7.2.7 Multimetric and multivariate biological indices

Multimetric indices (e.g., Indices of Biotic Integrity; Karr 1991; Jones 2004) and multivariate indices (e.g., Observed:Expected or RIVPACS; Hawkins et al. 2000; Clarke et al. 2003) used in the ROMN Stream, Wetland, and Alpine Lake Ecological Integrity protocols (see Table 7.2) warrant brief mention here as de facto analytical forms.

Multimetric indices (MMIs) are derived measures of condition based on biological assemblage data (e.g., vegetation, macroinvertebrates, or periphyton). MMIs incorporate multiple biological community characteristics and measure the overall response of the community to environmental alteration and stress on the community. Such a measure is an appropriate indicator of ecological quality, reflecting biological responses to changes in physical habitat quality, the integrity of soil and water chemistry, geophysical process, and land-use changes. The Observed:Expected (O:E) multivariate index measures biological condition or quality by estimating the taxonomic completeness of a standard sample (Hawkins 2006; Van Sickle et al. 2005). Taxonomic completeness is a fundamental aspect of ecological integrity and is defined as the proportion of the taxa that should occur in a sample that was actually sampled.

These indices are analytical methods in and of themselves, and may also be used as input in many of the analyses introduced above. For example, they may be used in park-scale estimates of status using design-based inference, in multivariate models that associate them with other response measures, or in geostatistical models that develop a spatially explicit response surface of the index across a park. Once developed, they may also be applied to appropriate data collected at single sentinel sites and analyzed with various methods (see above) at these sites. For more information on these indices, see Appendix E.

7.3 ROMN Communication and Reporting Strategy

The ROMN views the communication of results and program effectiveness as a key link in the information management model presented in Figure 1.4.2. ROMN reports are a key step in the NPS's effort to "improve park management through greater reliance on scientific knowledge" (NPS 2006a); effective communication of scientific results serves as the final link in transforming data into information. Also, because adaptive management relies on the incorporation of timely feedback, it is crucial for the ROMN program to develop and institutionalize effective means of communication both within and outside of the network in order to link the results of vital signs monitoring to park resource-management decisions (Failing and Gregory 2003).

7.3.1 Audience for ROMN reports

The primary audience for many ROMN products is park staff, as the key role of the program is to provide resource managers with the information they need to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources. However, certain data are also needed at the regional or national levels for a variety of purposes and, as stated by the National Park Service Advisory Board, the findings "must be communicated to the public, for it is the broader public that will decide the fate of these resources."

Our specific internal audiences include (1) the ROMN Board of Directors (including park superintendents) and Technical Committee, (2) all ROMN park managers and employees, and (3) the national I&M program and the U.S. Congress. Our external audiences include (4) the academic community, (5) other government agencies, (6) non-profit/non-governmental organizations, and (7) the general public.

In order to reach this wide range of audiences, the ROMN will need to consider the information needs of each audience and develop messages and delivery methods that will reach the targeted group(s). In some cases, the audience

NPS/R. MENICKE

Stream monitoring on Paradise Creek, Rocky Mountain National Park.

NPS/L. NYGAARD

Volunteers set a hair snare as part of a bear population study, Rocky Mountain National Park.

NPS/L. NYGAARD

Citizen scientists monitor butterfly populations during a 10-year study, Rocky Mountain National Park.

For information on Citizen Science at ROMO, see (see http://www.nps.gov/archive/romo/downloads/CDRLC/citizenscience.pdf.

may desire complete, official reports, databases, and analyses. More often, however, a target level of detail and length will drive the format and content of the message.

7.3.2 Form of ROMN reports

7.3.2.1 Web-based

The ROMN will use several tools or media to present various programmatic documents, synthetic reports, results, and interpretations of monitoring data. We will use the Internet as a means to communicate monitoring conclusions and data as well as to distribute more traditional, static reports. Web-based communications will allow the ROMN to provide synthesis, analyses, and background data either to large (e.g., the public on an Internet site) or focused (e.g., the Technical Committee on an Intranet site) audiences with relative ease. They will also facilitate user control over the level of detail that is needed and provide for timely, up-to-date reporting that is essential for effective adaptive management. All ROMN monitoring reports will use a web-based interface as their primary communication mechanism. A hypothetical prototype ROMN web interface is shown and described in Appendix E.

7.3.2.2 Traditional publications and oral presentations

While the web is a useful way to present results, it does not entirely replace the need for more traditional methods of communicating our results. Many audiences may be unfamiliar with Internet access or unaware that monitoring information exists on the network website, it is sometimes more efficient to distribute complex datasets via CD, and the longevity of web information is not assured. Therefore, many ROMN products will also be developed in a traditional static report format. These include all administrative documents, peer-reviewed scientific journal publications, and popular articles for park brochures and newspapers.

Further, to facilitate effective communication of resource information to different members of park staffs (e.g., resource managers, interpreters, facilities managers, volunteers, and senior managers), the ROMN will develop a communication plan. The plan will investigate and describe the needs of the audiences, recognize management issues associated with vital signs, and connect these with appropriate audiences through directed approaches that provide a useful level of information to each targeted audience.

In short, printed and electronic documents will form the core of ROMN official reporting, but the ROMN will also adopt active methods that utilize interactive, web-based data access, include participation in meetings and trainings, and summarize and highlight the availability of detailed information and support from the network. We are actively collaborating with our Research Learning Centers to communicate inventory and monitoring results to parks, the academic community, and the public more effectively.

Network staff and cooperators also will present posters and give oral presentations at professional meetings. We will distribute these via the web and in their native data formats as CDs and hard copies as required by our audiences. We will use traditional communication methods to increase the awareness of the ROMN web site, including e-mails, public and scientific meetings, and other oral presentations. Finally, we will meet with park staff on a regular basis to discuss our results and highlight the web-based reports and tools.

7.3.3 Summary of ROMN reports

Table 7.3.3 presents a summary of all ROMN reports, including their purpose, primary audience(s), the media or method used, their frequency, who the author(s) are, and the process used to review each report. The table includes both those reports required by the national I&M program and additional reporting mechanisms developed by the ROMN to communicate its progress in an effective manner. These reports should also provide a source of accountability for mandates, such as GPRA. In addition, all reporting will carefully follow the sensitivity and ownership policies and procedures identified in the "Approving Information for Distribution" SOP (NPS-ROMN 2006). Appendix E provides additional detail about these products.

Table 7.3.3. Summary of proposed reports for the Rocky Mountain Network.

Report or product	Purpose	Primary audience(s)	Media	Frequency	Author(s)	Review
Administrative and programmatic reports						
Annual Administrative Report and Work Plan (AARWP)	Accounts for funds and FTE expended. Describes highlights, objectives, tasks, accomplishments, and products of the network program. Improves communication within park, network, region, and NPS. Provides an administrative history of the network.	Board of Directors/ superintendents, TC and park staffs, network staff, regional and national I&M coordinators/managers	Traditional hard-copy reports Distributed by ROMN Intranet	Annually (November)	Network program manager	Reviewed and approved by Board of Directors and TC, regional I&M coordinator and servicewide program manager
Protocol	Documents monitoring objectives, sample design, methods, analyses, etc.	Network staff, park professional staff, TC, scientific cooperators	Traditional hard-copy reports Distributed by ROMN Intranet Distributed by ROMN Internet Distributed by WASO website(s)	As completed from FY2007–2009	Network staff and protocol-specific cooperators	Peer-reviewed at Intermountain Region level
Protocol review report	Reviews procedures of individual protocols; determines where actual procedures fall short of stated expectations; suggests revisions to protocols. Not a stand-alone product; linked to annual and comprehensive reports (see below)	Board of Directors/ superintendents, TC, park natural resource staffs, network staff, servicewide program managers, outside scientists	Interactive ROMN Intranet Interactive ROMN Internet Traditional hard-copy summary reports	Annually (February) After each complete monitoring "cycle," which varies by protocol: 3, 5, or 10 years	Network staff and protocol-specific cooperators	Park professional staff and network staff review; IMR-coordinated scientific peer-review of results.
Program review report	Documents formal review of operation 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 decisionmaking, and 3. The ability to engage in data sharing or designing complementary resource-monitoring studies. Recommends needed changes, including changes to budgeting network monitoring funds.	Board of Directors/ superintendents, TC, park natural resource staffs, network staff, servicewide program managers, outside scientists	Traditional hard-copy reports Distributed by ROMN Intranet	5-year intervals beginning in FY2012	Network program manager	Board of Directors and TC review, followed by administrative and peer review at Intermountain Region and national levels

Table 7.3.3. Summary of proposed reports for the Rocky Mountain Network, cont.

Report or product	Purpose	Primary audience(s)	Media	Frequency	Author(s)	Review
Data reports: results, interpretations, and conclusions						
Project report	Documents objectives, methods, results, recommendations, etc., from ROMN-sponsored inventory and research projects.	Park and network staffs, external scientists	Traditional hard-copy reports Distributed by ROMN Intranet Distributed by ROMN Internet	At project's completion	Network and park staffs and cooperators	Peer-reviewed at the network level
Annual report	Provides hierarchical summary of key results, more detailed interpretations, and database for protocols (see text). Available by park and protocol. Includes general review of protocols (see above and text). Input for WASO State of the Park reports.	Park superintendents, TC, park professional staffs, external scientists, public	Interactive ROMN Intranet Interactive ROMN Internet Traditional hard-copy summary reports	Annually (February)	Network staff and protocol-specific cooperators Program manager	Peer-reviewed at the network level
Comprehensive synthesis and analysis report	Provides hierarchical summary of status and trends for protocols and/or vital signs; describes and interprets relationships among vital signs, including relationships among drivers/stressors, measured responses, and any relevant covariates. Also includes interpretation of trends in the context of the entire network and the region (benefits for data from other networks). Highlights key resources in need of management action and documents management alternatives and recommendations. Available at park and network level. Includes comprehensive review of protocols (see above and text).	Park superintendents and professional staff, TC, network staff, external scientists and resource managers, public	Interactive ROMN Intranet Interactive ROMN Internet Traditional hard-copy reports	Approximately 5-year intervals (bulk of information will be available only after each complete monitoring "cycle," which varies by protocol: 3, 5, or 10 years)	Network staff	Peer-reviewed at the network level
Symposia, workshops, and conference presentations	Review and summarize information on specific topics. Communicate latest findings to peers. Identify emerging issues and generate new ideas.	Park and network staffs, outside agency staffs, external scientists	Traditional electronic presentations Distributed by ROMN Intranet Distributed by ROMN Internet	Vary with annual park research meetings (GLAC and ROMO), George Wright Society conference, outside scientific or professional meetings, etc.	Network staff and cooperators	Reviewed by editor if papers published

Table 7.3.3. Summary of proposed reports for the Rocky Mountain Network, cont.

Report or product	Purpose	Primary audience(s)	Media	Frequency	Author(s)	Review
Scientific journal articles and book chapters	Document and communicate advances in knowledge.	External scientists, park professional staff, network staff	Traditional hard-copy reports Distributed by ROMN Intranet Distributed by ROMN Internet Distributed by WASO website(s)	Various	Network staff and cooperators	Peer-reviewed through journal or book editor
State of the Parks Report	Describes current conditions of park resources and ecosystems. Reports interesting trends and highlights of monitoring activities. Identifies situations of concern and explores future issues and directions.	Congress, Office of Management and Budget, NPS leadership, superintendents, public	Traditional hard-copy reports Distributed by WASO website(s)	Annual	Compiled by WASO from information provided by networks, parks, NRPC, etc.	Peer-edited at the national level

Chapter 8
Administration and Implementation

This chapter describes the organizational and administrative structure and processes of the Rocky Mountain Network, including how the network relates and integrates with ROMN parks, the Intermountain Region offices, the NPS Office of Inventory, Monitoring, and Evaluation, the Natural Resource Program Center, and outside partners.

8.1 Location and Organizational Context

The ROMN program is co-located with the Washington Area Service Office (WASO) Natural Resource Program Center (NRPC) in Fort Collins, Colorado. One half-time program assistant is based in the Intermountain Region office in Lakewood, Colorado, and a temporary computer technician is based at ROMO. In the future, some staff may be stationed in Montana, where three ROMN parks are located (including GLAC, the largest).

The ROMN is in the NPS Intermountain Region, which is headquartered in Lakewood, Colorado. Within the IMR, there are several other multi-park programs and networks, including Cooperative Ecosystem Studies Units (CESUs), Exotic Plant Management Teams, and Fire Program Clusters (Figure 8.1). The network is coordinating its work with these programs, especially the Rocky Mountains CESU (RM-CESU), which provides a network of researchers and research institutions to answer the research needs of the NPS, other agencies, and tribes. The RM-CESU representative serves on the ROMN Board of Directors and Technical Committee.

The ROMN shares boundaries with six other networks: Greater Yellowstone, Northern Great Plains, Northern Semi-Arid, Northern Colorado Plateau, Southern Colorado Plateau, and Southern Plains (Figure 8.1b). The ROMN also shares ecological affinities with the Northwest Coast and Cascades, Klamath, and Sierra Nevada networks, all based in the Pacific West Region.

Research Learning Centers are a science-based NPS program with a mandate to encourage park research, promote science partnerships, and develop science information transfer and outreach programs. There are two Research Learning Centers in ROMN parks, the Crown of the Continent Research Learning Center (CCRLC) in GLAC and the Continental Divide Research Learning Center (CDRLC) in ROMO. Their directors serve on the ROMN Technical Committee, thereby facilitating collaboration between these two programs. Like the I&M program, Research Learning Centers were initiated under the servicewide Natural Resource Challenge.

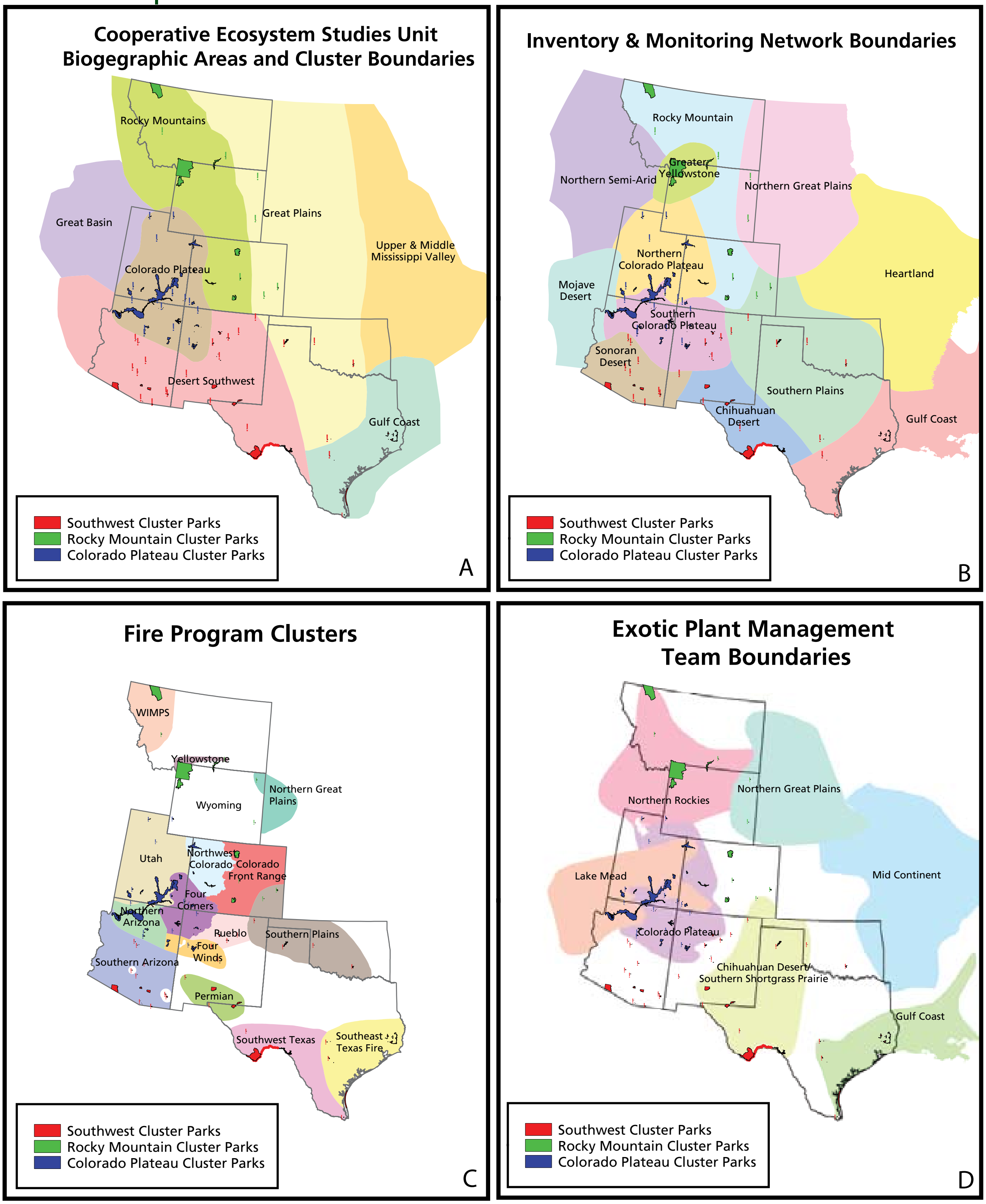
8.2 Program Functions

There are three key ROMN program functions: (1) data management and park resource management support, (2) ecological inventories, and (3) long-term ecological, or vital signs, monitoring. Integrating the inventory and monitoring processes will be crucial to program success.

8.2.1 Data management and park resource management support systems

The network's central mission is to provide ready access to current and useful scientific data, metadata, and information about the status and trends of park resources to help park managers and staff, the academic community, and the public to understand, preserve, and protect the parks. The data will come from existing NPS and external monitoring programs as well as ROMN inventory and monitoring efforts. The ROMN will summarize, analyze, and interpret the data with the goal of making it most useful to park management. These activities, coupled with the process of making the information accessible and understandable, will evolve into a resource management support system. When park managers rely on ROMN data and information for decisionmaking purposes, the program will be succeeding.

The network's central mission is to provide ready access to current and useful scientific data, metadata, and information about the status and trends of park resources to help park managers and staff, the academic community, and the public to understand, preserve, and protect the parks.



Produced by the Intermountain Region Geographic Resource Information Management Team

January 2005

Figure 8.1. Intermountain Region I&M Networks, Cooperative Ecosystem Studies Units, Exotic Plant Management Teams, and Fire Program Clusters.

8.2.2 Ecological inventories

By order of the NPS Office of Inventory, Monitoring, and Evaluation, all parks with "significant natural resources" must possess at least a minimal complement of resource inventory information in order to manage resources effectively. The minimal inventory information required by all parks has been defined in terms of 12 datasets (see Table 1.2.1.1) that include a variety of biotic and abiotic ecosystem components. The ROMN helps parks to acquire, access, manage, interpret, and use these basic datasets. The network and parks also may define additional inventory datasets to be acquired and managed.

8.2.3 Long-term ecological, or vital sign, monitoring

The ROMN and other networks are mandated to monitor vital signs of park ecological health. ROMN vital signs monitoring includes gathering data and information from existing park monitoring programs, external monitoring programs, and vital signs monitoring performed with ROMN funds.

Because many ROMN vital signs are interrelated, and are important components in multiple ecosystems, we have grouped common elements together into a series of protocols that will be central to ROMN monitoring (see Figure 5.1). This approach will allow the ROMN to report status and trends for specific vital signs, by ecosystem, and by protocol. While this Vital Signs Monitoring Plan describes the ROMN program generally, the heart and science of the program can be found in the protocols.

A protocol may have a 1:1 relationship to a vital sign (e.g., the Landscape Dynamics protocol addresses the Landscape Dynamics vital sign), a "1:many" relationship to vital signs (e.g., the Stream Ecological Integrity protocol includes the Water Chemistry, Surface Water Dynamics, Freshwater Communities, and Invasive Aquatic Biota vital signs), or a "many:1" relationship to a vital sign (e.g., both the Stream Ecological Integrity and Alpine Lake Ecological Integrity protocols will generate data and information on the Water Chemistry vital sign).

8.2.4 Integrating inventories and monitoring

Because natural resource inventories are essentially snapshots in time, the ROMN will strive to maintain current inventories in order to maximize their usefulness both to park managers and to the network. For example, the ROMN is presently updating the existing vegetation maps for FLFO and ROMO. The ROMN also will use inventory data, information, and updates to inform the development and revision of its own monitoring protocols.

8.3 Administration and Operations

Scientific and technical guidance as well as funding for the ROMN come from the WASO office via the Intermountain Region office as prescribed in the servicewide Natural Resource Challenge funding initiative. ROMN activities and operations are conducted according the ROMN charter signed by all network park superintendents in 2003, and amended by the Board of Directors in September 2007 (see Appendix F). Figure 8.3 depicts the ROMN organizational chart.

8.3.1 Board of Directors

The ROMN Board of Directors includes the superintendent (or his/her designee) for each ROMN park and the IMR I&M coordinator (Figure 8.3). Current (2007) park membership includes four superintendents, one deputy superintendent, and one chief ranger. The board elects a chairperson to serve a two-year term; the current chair is GRSA superintendent Art Hutchinson. All board members are voting members (except the IMR I&M coordinator, who is ex officio), but the group makes decisions by consensus. The Technical Committee chair and ROMN program manager are staff to the board, and attend all meetings and conference calls.

The board is ultimately responsible for decisions regarding ROMN work plans, budget, and staffing. To date, the board has relied heavily on the recommendations of the Technical Committee and ROMN program manager.

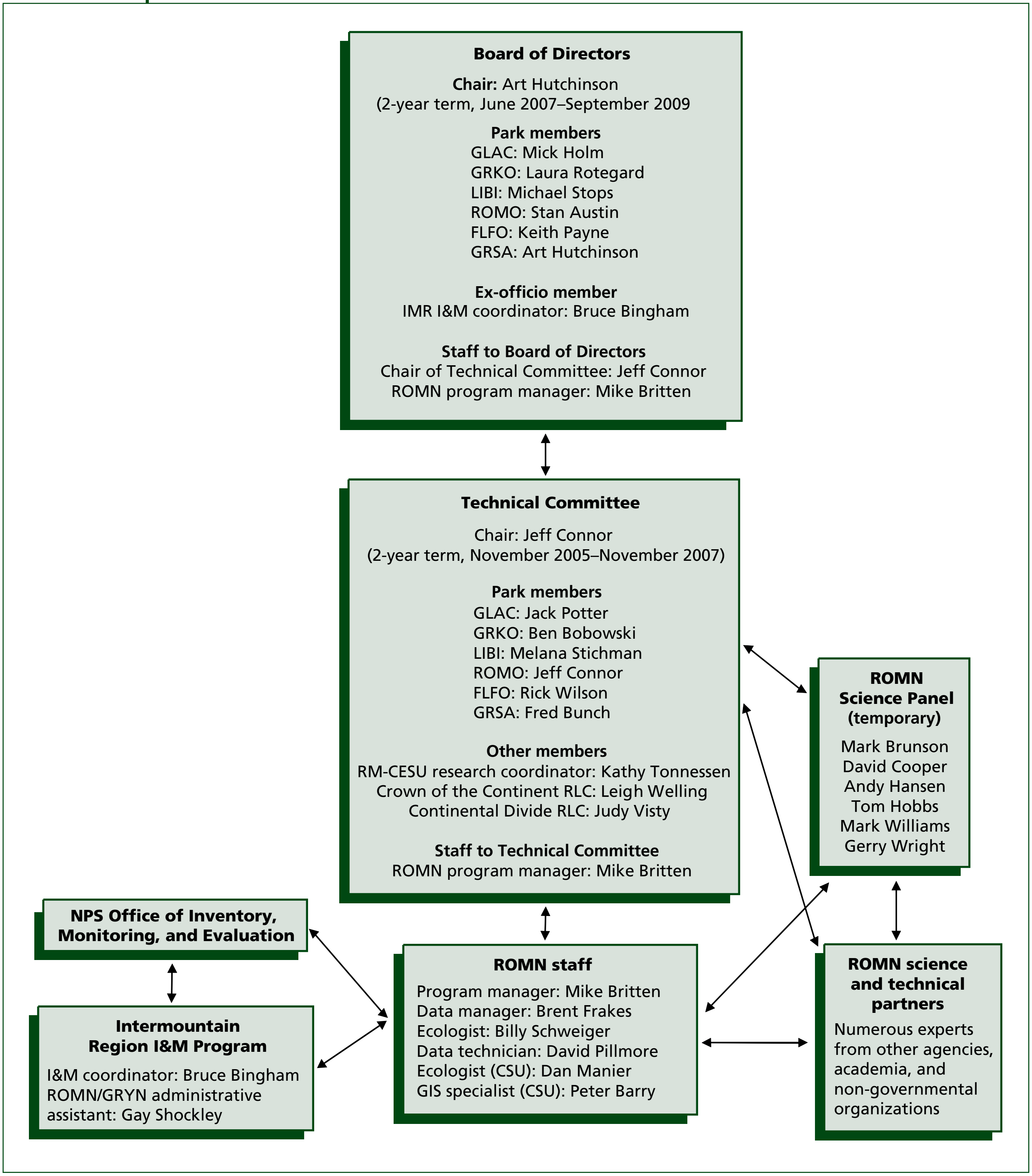


Figure 8.3. Rocky Mountain Network organizational chart, September 2007.

8.3.2 Technical Committee

The Technical Committee (TC) consists of the lead person responsible for natural resource management for each park, the directors of the CCRLC and CDRLC, and the NPS RM-CESU representative and science coordinator (see Figure 8.3). Park representatives currently on the TC include two chiefs of resource management and research, one resource manager, two natural resource specialists, and one chief ranger. The ROMN program manager serves as staff to the TC, and ROMN staff participate in TC meetings to provide technical and scientific information on ROMN activities.

The Technical Committee is the core planning group for the network. Members advise the ROMN program manager on projects and activities for the annual work plan and budget, work closely with ROMN staff, participate on hiring panels for ROMN staff, and communicate and collaborate with scientific and technical partners about ROMN activities. The TC, working with the program manager, seeks consensus to develop recommendations for the annual work plan and budget (submitted to the board for approval and then to IMR and WASO for funding), and reviews network reports and products, including the annual administrative report. The board has relied heavily on TC recommendations for all network activities and decisions.

In the future, the Technical Committee will have an important role in developing and communicating alternatives for park management, based on monitoring results and information.

8.3.3 Science Panel

An independent science review panel advised the ROMN during the development of its Vital Signs Monitoring Plan (see Table 8.3.3). Broad goals for the panel have included providing scientific review of ROMN inventory and monitoring plans, helping the ROMN coordinate its inventory and monitoring efforts with other groups (especially academic institutions), and identifying opportunities for the ROMN to partner with other inventory and monitoring efforts. The panel is temporary; its role will end upon final publication of this document in September 2007. However, it is likely that individual panel members will continue to work with the network on specific protocols or projects beyond 2007.

8.3.4 Rocky Mountain Network staff

A small group of employees performs the ROMN program's "core activities." Permanent network staff includes the program manager, data manager, and ecologist. Although the current administrative assistant is a term employee, the network has a permanent need for administrative assistance. As the network implements monitoring, it will likely identify further core activities, such as writing and communication, making it necessary to utilize additional temporary ROMN or ROMN-funded staff (e.g., university staff working through a cooperative agreement with the network) or NPS employees shared among multiple networks.

The ROMN program manager is responsible for planning and development of the ROMN program, overall program management, communi-

Table 8.3.3. Rocky Mountain Network Science Panel members.

Name	Position	Affiliation	Expertise
Tom Hobbs	Chairman	Department of Forest Range and Watershed Science, Colorado State University	Animal and landscape ecology
Mark Williams	Professor and Fellow at INSTAAR	Department of Geography and Institute of Arctic and Alpine Research, University of Colorado–Boulder	Alpine biogeochemistry, hydrology, and snow hydrology
Mark Brunson	Associate Professor	Deptartment of Environment and Society, Utah State University	Ecology and social science
David Cooper	Research Scientist	Department of Forest Range and Watershed Science, Colorado State University	Wetland/riparian hydrology, botany, and ecology
Gerry Wright	Professor Emeritus	Department of Fish and Wildlife Resources, University of Idaho	Wildlife biology and ecology
Andy Hansen	Director	Landscape Biodiversity Laboratory, Montana State University	Landscape ecology

cation and coordination with the many people and groups that make up the network, supervision of ROMN staff, and ensuring adequate program review. The program manager works closely with the TC and the board, and is the primary ROMN contact and liaison with other NPS programs and offices as well as outside agencies and institutions. The program manager facilitates regular monthly TC conference calls, two face-to-face TC meetings per year (alternating between Montana and Colorado), and two Board of Directors meetings/conference calls per year. S/he also coordinates ad hoc meetings among park managers, ROMN staff, and scientific and technical partners; manages the network budget; and provides an annual accounting of funds via the Annual Administrative Report and Work Plan process.

The data manager is responsible for planning and implementation of data and information management; assisting ROMN parks with data management planning and data management projects; and communicating network data and information to NPS and outside consumers. The data manager works closely with the TC, park staffs, and IMR- and WASO-level data and information managers. S/he also works closely with scientific and technical staff and partners responsible for data gathering, entry, and other functions.

The ecologist is responsible for the program's scientific design and integration; coordination with scientific and technical partners; and data analysis interpretation and reporting. The ecologist works closely with all ROMN and park staff who gather and use ROMN data and information, and with all other people gathering data for the ROMN program.

The administrative assistant (a half-time term position shared with the Greater Yellowstone Network) is responsible for tracking and management of budgets, personnel actions, procurement, payroll, and travel. The administrative assistant works closely with the program manager on all of these responsibilities.

8.3.5 Staffing plan

The activities provided by ROMN staff (program management, data management, scientific data gathering, interpretation, analysis and reporting, and administrative assistance) are core activities for the network and will continue as the program moves from planning to implementation; again, there is a need for administrative assistance on a permanent basis. Field monitoring and other data gathering, field crew management (e.g., hiring, training, and providing logistical support), and geospatial data analysis and management will become ROMN core activities once the monitoring plan is approved and protocols are implemented.

Table 8.3.5 provides a summary of ROMN core activities and staffing options, with estimates of the FTE needed to implement the network program. The details and alternatives of a complete staffing plan will be developed in conjunction with the Technical Committee and approval of the Board of Directors. The staffing plan will evolve as ROMN objectives as well as budgets and other resources, including partnership opportunities, evolve over time.

8.4 Implementation

8.4.1 Integration of ROMN program with park operations

Integrating ROMN activities with park operations is one key to program success. ROMN staff will rely on the Technical Committee and, to a lesser degree, the Board of Directors, to ensure that the ROMN program provides the data and information needed for park management, including interpretation, resource and visitor protection, facilities management, and planning. The network also is expected to serve as a catalyst for linking individual park resource management programs together such that they become more effective in achieving park inventory and monitoring, research, and resource management goals and objectives. In fact, this has already begun. Network parks have worked together for the past three years to develop competitive proposals for both I&M and resource management funds. In 2006, the network collaborated with the NRPC–Water Resources Division (NRPC–WRD) to obtain funds and start two Watershed Condition Assessment projects—one for GLAC, and one for FLFO and ROMO. A primary goal of the projects is to

Table 8.3.5. Rocky Mountain Network core activities and staffing proposal.

Position	Role/functions	Appointment type	FTE
Permanent ROMN staff			
Position	**Role/functions**	**Appointment type**	**FTE**
Program manager	Program management, staff supervision, liaison with parks and other offices	Permanent	1
Data manager	Network data management, integration with park and other data management operations	Permanent	1
Ecologist	Monitoring design, data analysis, and reporting	Permanent	1
Administrative assistant	Administrative functions, including budget tracking and management, travel, and personnel time, attendance, and actions	Permanent	0.5
ROMN temporary staff and cooperators working with ROMN funds			
Position	**Role/functions**	**Appointment type**	**FTE**
Ecologist/Crew leader 1	Field crew training and management and monitoring data analysis and reporting	Cooperative or NPS term employee	1
Ecologist/Crew leader 2	Field crew training and management	Cooperative or NPS term employee	0.5
Field crew member 1	Field monitoring	Cooperative or NPS seasonal employee	0.25
Field crew member 2	Field monitoring	Cooperative or NPS seasonal employee	0.25
Field crew member 3	Field monitoring	Cooperative or NPS seasonal employee	0.25
Field crew member 4	Field monitoring	Cooperative or NPS seasonal employee	0.25
Field crew member 5	Field monitoring	Cooperative or NPS seasonal employee	0.25
Field crew member 6	Field monitoring	Cooperative or NPS seasonal employee	0.25
Geospatial data analyst	Geospatial data analysis and reporting	Cooperative of NPS term employee	0.6
Writer-editor-web content developer	Writing, editing, layout, and design for ROMN reports and communication products, including web content	Temporary or permanent NPS employee or cooperative	0.25

provide park managers with data and tools to assess and report their progress toward meeting Department of the Interior (DOI) land health goals. The network also facilitated a USGS partnership (to be funded in FY07) to assess water quality on the North Fork of the Flathead River in and near GLAC.

8.4.2 Field efforts

Fieldwork in the ROMN will represent a continuum of efforts ranging from work conducted entirely in-house (by park and ROMN staff) to work performed by cooperators and partners (Table 8.4.2). In some cases, the ROMN will obtain data from external sources at no cost—for instance, data collected by the National Weather Service or the U.S. Forest Service Forest Inventory and Analysis Program. The completed protocols, including analysis of potential sources, alternatives, and costs of field monitoring, will identify which fieldwork will be done by the network and which by outside partners.

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

8.4.3 Partnerships

Many individuals and organizations played a role in developing this draft plan and the ROMN

Table 8.4.2. Potential models for fieldwork for Rocky Mountain Network protocols.

Protocol	Model 1 Fieldwork by park staff	Model 2 Fieldwork by ROMN staff/ technicians*	Model 3 Fieldwork by ROMN staff and cooperators**	Model 4 Fieldwork conducted by cooperators only
Snow Chemistry	X	X		X
Alpine Lake Ecological Integrity		X	X	X
Stream Ecological Integrity		X	X	X
Wetland Ecological Integrity		X	X	X
Alpine Vegetation Composition, Structure, and Soils		X	X	X
Grassland/Shrubland Vegetation Composition, Structure, and Soils		X	X	
NADP/NTN	X			X

*Technicians may be undergraduate or graduate students or interns hired by a cooperator through a cooperative agreement. They would be trained by and receive guidance from ROMN staff.

**ROMN staff would provide field monitoring for some parks as in model 2, but cooperators would provide fieldwork for other parks (e.g., larger ROMN parks).

monitoring protocols, and the ROMN will continue to cooperate with other agencies and organizations to develop and implement its program for two important reasons. First, ROMN funding will not allow the network to monitor even the highest-priority vital signs solely with ROMN resources and funds. Second, collaboration with other organizations and agencies that have long-term monitoring expertise and interest will improve the quality and comprehensiveness of monitoring. As such, the ROMN will actively and thoughtfully engage with both NPS and outside scientists to develop monitoring plans, protocols, and projects.

Under several protocols, the ROMN will harvest monitoring information from outside sources (e.g., NWS data will be used to report on the Weather and Climate protocol). In some cases, the ROMN will provide its own monitoring data and information to an existing monitoring program (e.g., the ROMN will provide snow chemistry samples for analysis and reporting by the USGS Rocky Mountain Snow Chemistry Monitoring Network). In other cases, the ROMN may utilize field or scientific staff from a university or agency for sampling (e.g., student interns from a local university may be used to monitor grassland/shrubland vegetation and soils).

8.4.3.1 External partnerships

The ROMN is, by definition, a set of partnerships within and outside the NPS (see Figure 8.3). Linking NPS professional management needs and perspectives with scientific and technical data, information, and input is the foundation of the ROMN program. ROMN project planning, and protocol development efforts have relied heavily on partnerships with academic institutions, other government agencies, and non-governmental organizations (Table 8.4.3.1). Vital signs planning and development efforts have involved hundreds of scientists and subject matter experts from the NPS, other agencies, NGOs, and academia (see Chapter 3 and Appendix B).

Most ROMN projects have included multiple external partners. For example, the GRSA vegetation mapping inventory, coordinated by ROMN staff, receives funding and resources from the NPS, USGS, U.S. Fish and Wildlife Service (USFWS), and U.S. Forest Service. Expertise is provided by the Colorado Natural Heritage Program (field plot data for classification and accuracy assessments), NatureServe (vegetation classification), and the USFWS, Bureau of Reclamation, and USGS (mapping). The product is a map, data, and report for GRSA,

Table 8.4.3.1. Important current external partnerships for the Rocky Mountain Network.

Partner	Purpose/work accomplished	Principal investigator
Colorado Natural Heritage Program	Fieldwork for vegetation mapping (GRSA)	Joe Stevens
CSU, Department of Forestry, Range, and Watershed Science	Wetland Ecological Integrity protocol development	David Cooper
CSU, Department of Forestry, Range, and Watershed Science	Watershed Condition Assessment (FLFO and ROMO)	Dave Theobald
CSU, Department of Forestry, Range, and Watershed Science	Alpine Vegetation, Composition, Structure, and Soils protocol development	Heidi Steltzer
MSU, Landscape Biodiversity Lab	Landscape Dynamics protocol development	Andy Hansen
Nature Serve	Vegetation classification for vegetation mapping (GRSA)	Keith Schultz
UMT, Division of Biological Sciences	Fieldwork for vegetation mapping (GRKO and LIBI)	Peter Rice
UMT, Division of Biological Sciences	Vegetation mapping/historical imagery acquisition (GRKO and LIBI)	Will Gustafson
UMT, Flathead Lake Biological Station	Stream Ecological Integrity protocol development	Ric Hauer
UMT, Flathead Lake Biological Station	Watershed Condition Assessment (GLAC)	Ric Hauer
U.S. Bureau of Recreation	Vegetation mapping (GRSA)	Mike Pucherelli
USGS, Rocky Mountain Geographic Data Center	Vegetation mapping (GRSA)	Bev Friesen
USGS, Water Resources Division, Colorado District Office	Snow Chemistry monitoring protocol development	George Ingersoll
USGS, Water Resources Division, Colorado District Office	Stream Ecological Integrity protocol development	Alisa Mast
Western Regional Climate Center	Weather and Climate inventory and monitoring protocol development	Kelly Redmond

CSU = Colorado State University; MSU = Montana State University; UMT = University of Montana; USGS = U.S. Geological Survey

the Baca National Wildlife Refuge, portions of the Rio Grande National Forest, the Zapata Ranch (managed by The Nature Conservancy), and small acreages of lands managed by the Bureau of Land Management and Colorado State Parks.

Almost all ROMN protocol development efforts are formal partnerships funded with ROMN vital signs funds. The network will continue to rely on outside partnerships to develop scientifically credible and effective inventory and monitoring data and products.

8.4.3.2 National Park Service partnerships

Other networks. The ROMN and other NPS vital signs program benefit as a whole when networks coordinate, cooperate, and collaborate on scientific and technical aspects of protocols, projects, and programmatic activities. The benefits include cost savings and improved scientific and technical quality and efficiency. The ROMN is cooperating and collaborating with other networks on specific activities; Table 8.4.3.2 shows some examples. The ROMN will explore other opportunities to collaborate on similar programmatic needs, such as reporting monitoring results.

Servicewide Inventory and Monitoring Program and NRPC. While each network's vital signs and monitoring objectives must contain elements unique to its parks and ecosystems, common elements also are included so that status and trends in natural resources may be compared and reported across all national parks in the program. To facilitate this process, the Office of Inventory, Monitoring, and Evaluation has provided guidance for all NPS networks to follow. In addition, the NRPC–WRD has identified "core" water quality parameters that all networks must include in their water

Table 8.4.3.2. Examples of ROMN inter-network partners.

Effort	Network partner
Wetland Ecological Integrity protocol development	SIEN
Grassland/shrubland Vegetation Composition, Structure, and Soils protocol development	NGPN, NCPN, SCPN, SOPN, and HTLN (through participation in a Grassland Monitoring workshop)
Stream Ecological Integrity protocol development	GRYN, NCPN, and SCPN
Alpine Lake Ecological Integrity protocol development	Other networks such as NCCN (future)
Alpine/high elevation ecosystem monitoring	SIEN, KLMN, NCCN, GRYN, and SWAN (through a ROMN-hosted alpine monitoring workshop to develop core or common indicators in alpine ecosystems)
Increasing inter-network communication and coordination	GRYN, SIEN, and Parks Canada's Montane Monitoring Network (through participation in ROMN TC meetings)
Publication writing/editing/layout	Other IMR networks
Administrative assistant funding	GRYN

GRYN = Greater Yellowstone Network, HTLN = Heartland Network, KLMN = Klamath Network, NCCN = Northern Coast and Cascades Network, NCPN = Northern Colorado Plateau Network, NGPN = Northern Great Plains Network, SCPN = Southern Colorado Plateau Network, SIEN = Sierra Nevada Network, SOPN = Southern Plains Network, SWAN = Southwest Alaska Network.

quality monitoring work, and has developed technical water quality monitoring guidance for networks to follow. There is also servicewide technical guidance for vital signs monitoring of the following: air quality and air-quality-related values; geology; water quality, contaminants, and aquatic biology; invasive species; and landscape-level vital signs monitoring using remote sensing. The result is that the ROMN program relates closely to other network programs. ROMN will take advantage of guidance, data, reports, and analysis relevant to ROMN parks in its program.

The National Park Service, and all other government agencies, must set strategic and annual goals and report results under GPRA. The Department of the Interior also requires all bureaus to report GPRA land health goals. These systems provide a mechanism and structure for all I&M networks to use when developing monitoring plans and reporting systems that are useful at the park, network, regional, and national scales.

Intermountain Region. The IMR I&M coordinator works closely with all seven IMR networks by serving on the Board of Directors for each network, through frequent communication with all network program managers (and other network staff), and through workshops among IMR networks. The IMR I&M coordinator supervises the ROMN program manager, promoting close communication and coordination between the ROMN program and the IMR I&M program (i.e., all seven IMR networks collectively).

8.4.4 Program review

Periodic administrative, scientific/technical, and programmatic reviews are critical processes in building the long-term ROMN I&M program. Chapter 7 discusses proposed scientific and technical reporting and feedback mechanisms. Scientific and technical reports will link closely with the program review mechanisms for administration and management, discussed here.

Annual administrative reports and reviews will be coupled with work planning via the established Annual Administrative Report and Work Plan (AARWP) process. Protocol-specific review reports will be completed after each full cycle. Full program reviews will occur at 5-year intervals, beginning in FY2012 (Table 8.4.4). Reports will review costs and benefits and make recommendations to improve the implementation, administration, and effectiveness of network activities.

The primary goal of the AARWP is to provide accountability for network activities and funds.

Table 8.4.4. Review process for the Rocky Mountain Network program.

Review	Timing	Author(s)	Reviewers	Intent of review
Annual administrative report and workplan	Annual	Program manager	Technical Committee, Board of Directors, IMR I&M coordinator, WASO I&M program	Provide program and funding accountability, report on accomplishments, and document goals and projects for next fiscal year.
Protocol review reports	After complete cycle for the protocol	ROMN lead and protocol collaborators	Technical Committee, select outside scientific/technical reviewers, IMR I&M coordinator	Evaluate implementation of protocols, evaluate scientific and technical merits of protocols, make recommendations for improving protocols.
Program review	5-year intervals, beginning in 2012	Program manager and staff	Technical Committee, Board of Directors, IMR I&M coordinator, WASO I&M program	Provide synthesis of data collected by program, evaluate utility to park management, evaluate administration and operations of program, make recommendations for improvement of all aspects of program.

Each AARWP reports on network accomplishments, accounts for all funds expended during the past fiscal year, and proposes specific network activities and projects linked to a budget for the upcoming fiscal year. The AARWP also provides an administrative history for the network and allows all ROMN activities to be tracked, evaluated, and improved, task-by-task. AARWPs are signed by the chairs of the network's Board of Directors and Technical Committee, the program manager, and the IMR I&M coordinator.

Protocol review reports document monitoring results and analyses, evaluate the performance of an individual protocol, and suggest revisions and improvements to the protocol. These reports, produced in cooperation with scientific partners after a complete monitoring cycle through all ROMN parks (1–10 years, depending on the protocol), are technical and scientific in nature, and are meant to be reviewed by outside experts as well as park professional and management staffs.

Chapter 9
Schedule

This chapter describes the plan and schedule for implementing Rocky Mountain Network vital signs monitoring, including protocol development projects, initiation of formal monitoring and a proposed schedule into the foreseeable future.

9.1 Protocol Development

Pilot, or developmental, phases are required for all ROMN protocols. These range from multi-year, intensive projects to simpler, single-year efforts. For some protocols, intensive efforts are conducted largely in a single park, with select testing and careful application of the results from these projects expanded to other parks during or shortly after the pilot phase. In all cases, protocol-development projects will be based on well-established, peer-reviewed methods, and will provide relevant monitoring data for the park(s) where the pilot is being conducted. Table 9.1 summarizes a schedule of key tasks for currently planned ROMN protocol development projects. Similar to formal monitoring (see below), the scheduling of pilot efforts requires some rotation of field data collection across protocol–park combinations within the ROMN. An overall timeframe for protocol implementation appears in Table 5.1.2.

The general goals of the intensive ROMN protocol-development projects are to develop sampling frames and classification systems; to gather data needed for understanding variability in measures (e.g., within and across years, across sites) and its effect on statistical power; to develop novel or adopt existing reference conditions or other thresholds; to develop novel or adopt existing indices and assessment metrics; to estimate monitoring costs; and to work with parks to comply with laws, regulations, and policies to minimize adverse impacts of ROMN monitoring activities. These projects are critical to meeting the requirements established by the NPS I&M Monitoring Program (NPS 2005b). The protocols that require this caliber of development include Stream Ecological Integrity, Wetland Ecological Integrity, Alpine Vegetation Composition, Structure, and Soils, and Grassland/Shrubland Vegetation Composition, Structure, and Soils.

Some projects (e.g., Alpine Lake Ecological Integrity and Focal Species–GRSA Endemic Insects) will require empirical, site-level data, but may not need to be as intensive as those listed above. Finally, other ROMN protocols only may need single-year development projects to work out the details of operation within a given park(s), develop costs, or parameterize the core models we will use to conduct monitoring or interpret results (e.g., Landscape Dynamics, Weather and Climate, NADP/NTN, Snow Chemistry, and Invasive/Exotic Plants–Early Detection).

Once we have completed a development project, we will evaluate the protocol and modify it as needed to maximize its usefulness and cost-effectiveness for the park(s) and the ROMN as a whole. We anticipate relatively minor changes to all protocols, but cannot rule out significant changes. Proposed changes will be thoroughly evaluated by the ROMN and subject matter experts, and documented before being adopted (see Appendix D).

The WASO I&M program and the IMR have established a strict protocol development and approval process that networks must follow. This guidance dictates the outline and content of protocols and establishes a scientific peer-review process and requirement that is achieved at the IMR level. The ROMN will follow this guidance in developing protocols and will submit them to the IMR for peer review and approval according to the schedule in Table 5.1.2. The ROMN will develop detailed protocols according to I&M program guidance (following Oakley et. al 2003), and submit them to the IMR I&M coordinator for peer review and approval according to the schedule in Table 9.1.

9.2 Protocol Implementation

For ROMN protocols that involve intensive field data collection, Table 9.2-1 depicts the anticipated timing, frequency, and nature of sampling across the network parks. To ensure linkage of monitoring results across time, we will conduct some degree of data collection at survey design sites for all field-intensive protocols every year in the parks where they are implemented (i.e., linkage panels with a sample size of around five; see Chapter 4). We will also typically collect data from sentinel sites on at least an annual basis for these protocols. Annual monitoring at sentinel and linkage sites will help the ROMN to understand annual variability and provide information useful in interpreting monitoring results, especially in regard to detailed ecological processes at each sentinel site.

The main panels of survey sites (likely on the order of 35–50 sites) will be sampled every five-to-ten years in order to allow implementation of other field-intensive efforts. As far as the network's budget allows it, we will design the sample size of a given main panel to adequately describe the status or condition of the vital sign within that sample interval. The linkage panels will contribute to quantifying trend in the intervening years; in some cases, a trend will be detectable in five years. Planned intervals and sample sizes are preliminary, pending results from the development projects. Sample size also must be evaluated in a detailed cost analysis across all ROMN protocols. For some protocols at some parks, we will monitor only one or a few sentinel sites annually, under the assumption that the results will be useful to park management even if they do not allow valid statistical inference across the entire park.

Table 9.2-2 depicts pilot protocol development efforts and likely annual or cyclic monitoring efforts, by park, for ROMN protocols that primarily involve analyzing and reporting existing data (e.g., from remotely-sensed data or broad-scale regional and national monitoring program data such as Western Regional Climate Center monitoring or NADP/NTN data). This table also includes protocols that are largely based on modeling efforts. All of these protocols require some field data, either to help parameterize a model or to confirm a pattern suggested in remotely-sensed data. Many of these data will come from other ROMN protocols (e.g., all of the field-intensive protocols will collect data on invasive taxa presence).

Monitoring results reportage will also be phased in over time. As we collect data, we will prepare annual reports of activities, summaries, and findings for each protocol. As data accumulate, reporting will be expanded to include comprehensive analysis and synthesis reports. When we have sufficient samples, reports will include trend assessments within the parks, as well as network-level summaries and comparisons. Reporting details are presented in Chapter 7.

As we implement ROMN protocols at each park over the next several years, the network will continually evaluate how well implementation of each protocol—and the ROMN vital signs plan as a whole—is succeeding. This evaluation will occur vital sign-by-vital sign. We also will evaluate how implementation on the whole is progressing, and use that information for adjusting future work plans and budgets.

Table 9.1. Proposed schedule and key tasks for ROMN protocol development projects, 2006–2010.

Protocol	Park(s)	Key ROMN protocol development tasks, 2006–2010
Weather and Climate	All	Evaluate national and other protocols as templates for ROMN protocols.
		Evaluate existing weather stations (e.g., Western Regional Climate Center stations) and select appropriate subset of stations for each park for reporting daily, station-level observations
		Review literature (regionalization and interpolation) and develop daily park index procedures.
		Define area of interest for each park for reporting monthly temperature and rainfall using the Precipitation-elevation Regressions on Independent Slopes Model (PRISM) dataset from Oregon State University
		Define area of interest for GLAC, ROMO, and GRSA for reporting bi-weekly snow cover using the Snow Data Assimilation System (SNODAS) dataset (NOAA).
		Review literature on appropriate drought and precipitation indices for ROMN parks and other vital signs.
		Depending on the results of the review, potentially create park-level drought indices.
		Review literature on appropriate atmospheric indices important to ROMN parks and other vital signs.
Snow Chemistry	GLAC ROMO	Develop and adopt protocol results from GRSA project.
	GRSA	With the USGS, select two sentinel sites (judgment design) (2006).
		Sample suite of physical and chemical measures using well-established USGS methods at GRSA sites.
		Develop models of snow-chemistry deposition, nutrient loadings, etc.
NADP/NTN	All	Evaluate national and other protocols as templates for ROMN protocols.
Stream Ecological Integrity	All	Develop and adopt protocol results from GLAC project (2007–2009).
	GLAC	Hold stream workshop to present protocol outline and discuss monitoring options with ROMN park staff and other stakeholders (February 2007).
		Confirm Strahler/Shreve stream classification system.
		Develop National Hydrography Dataset sampling frame.
		Develop GRTS survey design with North Fork basin as subpopulation within the whole park.
		Develop criteria for sentinel site selection.
		Select sentinel sites (likely co-located with USGS Partnership Project in the North Fork basin).
		Sample habitat, water chemistry, macroinvertebrate, and periphyton assemblage data at survey sites (late 2007 summer index period with sufficient intra-annual revisits and inter-annual in 2008).
		Work with USGS on sentinel-site sampling (hydrology and physiochemistry sampled seven times per water year at key points on the hydrograph).
		Analyze survey-site data to confirm response design in wade-able and non-wade-able sites (species–effort curves, crew effort optimization, subsample density, etc.).
		Analyze survey data to generate variance components for understanding variability in measures (within and across years, across sites, etc.).
		Analyze survey data for signal:noise and other response-measure evaluations.
		Generate power for trend and SE status curves.
		Compare GLAC results for response-design optimization, variance structure, power for trend, etc., with EMAP Western Pilot Montana mountain ecoregion data.
		Work with USGS to develop sentinel-site models (SPARROW, LOADEST, etc.) for loading and flux estimates.
		Integrate survey, sentinel, and USGS synoptic (targeted design) site data into design-based inferences for North Fork target population using found data procedures.
		Develop novel or adopt existing reference conditions or other thresholds by placing development data to existing reference condition delineations, classifying ambient distributions, etc.
		Develop novel or adopt existing multimetric (i.e., Indices of Biotic Integrity) and multivariate (i.e., Observed: Expected) assessment metrics.
		Complete monitoring cost estimates for each component of the protocol based on development data.
		May expand data collection to the entire park (main panel of formal monitoring), keeping the North Fork sites as a subpopulation (2008 or 2009).

Table 9.1. Proposed schedule and key tasks for ROMN protocol development projects, 2006–2010, cont.

Protocol	Park(s)	Key ROMN protocol development tasks, 2006–2010
Alpine Lake Ecological Integrity	GLAC ROMO GRSA	Evaluate national and other protocols as templates for ROMN protocols.
Wetland Ecological Integrity	FLFO GRSA GLAC	Develop and adopt protocol results from ROMO project (2006–2009).
	ROMO	Confirm Cooper/Colorado Natural Heritage Program/USGS VegMap wetland classification system.
		Continue to develop second stage sampling frame using USGS VegMap data.
		Continue to develop GRTS survey design.
		Develop criteria for sentinel site selection.
		Select sentinel sites.
		Sample vegetation assemblage, groundwater, other habitat, herbivory, beaver, and invasive taxa presence or absence at survey sites parkwide (2007 summer period with sufficient intra-annual revisits and inter-annual in 2008).
		Sample sentinel sites (same suite of responses measures, more intensive frequency).
		Analyze survey-site data to confirm response design in wetland types (species–effort curves, crew effort optimization, subsample density, etc.).
		Analyze survey data to generate variance components for understanding variability in measures (within and across years, across sites, etc.).
		Analyze survey data for signal:noise and other response-measure evaluations.
		Generate power for trend and SE status curves.
		Compare ROMO results for response-design optimization, variance structure, power for trend, etc., with CNHP Southern Rockies ecoregion/Colorado River Headwater data.
		Develop sentinel-site models (IHI, etc.) for groundwater hydrology.
		Integrate survey, sentinel, and CNHP site data into design-based inferences using found data procedures.
		Develop novel or adopt existing reference conditions or other thresholds by placing development data to existing reference condition delineations, classifying ambient distributions, etc.
		Develop novel or adopt existing multimetric (i.e., Indices of Biotic Integrity, Floristic Quality Indices) assessment metrics.
		Complete monitoring cost estimates for each component of the protocol based on development data.
		May expand data collection to FLFO and GRSA (2009).
Invasive/Exotic Plants–Early Detection	All	Evaluate national and other protocols as templates for ROMN protocols.
Alpine Vegetation Composition, Structure, and Soils	GLAC	Develop GIS tool as an aid in identifying potential sentinel sites, likely based on GLORIA criteria.
	GRSA	Select sentinel sites, likely based on GLORIA methods; site already established by USGS in GLAC (2003); coordination for ROMO and GRSA with CIRMOUNT and GLORIA.
	ROMO	Work with USGS and other partners (e.g., Niwot LTER, INSTAAR) on sentinel site sampling.
		Work with USGS–Northern Rocky Mountain Science Center, CIRMOUNT, and GLORIA to develop sentinel-site models and regional and global analysis approach.
		Develop novel or adopt existing multimetric (i.e., Indices of Biotic Integrity) and multivariate (i.e., Observed: Expected) assessment metrics.

Table 9.1. Proposed schedule and key tasks for ROMN protocol development projects, 2006–2010, cont.

Protocol	Park(s)	Key ROMN protocol development tasks, 2006–2010
Grassland/ Shrubland Vegetation Composition, Structure, and Soils	GRKO LIBI	Sample vegetation and soils using proposed techniques (beginning 2006). Analyze survey data for efficiency (cost vs. information) and precision of techniques (response design). Analyze survey data to generate variance components for understanding variability in measures (within and across years, across sites, etc.). Analyze survey data for signal:noise and other response-measure evaluations. Generate power for trend and SE status curves. Complete monitoring cost estimates for each component of the protocol based on development data.
	All	Develop and adopt protocol results from GRKO–LIBI project (2006–2009). (Because the majority of development work is occurring in small parks, we may need to test several aspects of the protocol more carefully in a large park(s)). Develop sampling frame (larger effort for large parks; mostly complete for small parks). Hold meeting, conference call, or workshop for each large park to define target population (e.g., montane zone, Alliance or Association, elevational limits). Develop GRTS survey design. Implement a pilot project in one large park (2008 or 2009).
Focal Species–Elk	ROMO GRSA	Develop connection to park and state agency monitoring efforts. Develop adaptation of landscape protocols to quantify elk habitat.
Focal Species–Beaver	ROMO	Develop adaptation of landscape protocols to quantify beaver habitat. Develop measures of presence or absence into stream, wetland, and alpine lake (if completed) protocols. Develop use of stream, wetland, and alpine lake (if completed) survey designs and design-based inference. Generate estimates of extent of streams, wetlands, and alpine lakes (if completed) with beaver presence.
Focal Species–Grizzly Bear	GLAC	Develop connection to park and state agency monitoring efforts. Develop adaptation of landscape protocols to quantify grizzly habitat.
Focal Species–GRSA Endemic Insects	GRSA	Evaluate existing data and protocols. Develop survey or adaptive sample design. Develop Proportion of Area Occupied population abundance estimators.
Landscape Dynamics	All	Evaluate national and other protocols as templates for ROMN protocols. Hold meeting, conference call, or workshop for each park to define important issues, spatial and temporal scales of interest, potential indicators and metrics, etc.

Table 9.2-1. Proposed schedule for ROMN field-intensive protocols.

Park	Protocol	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
LIBI	Stream Ecological Integrity				☼	S	S	S	S	S	S	S
	Grassland/Shrubland Vegetation Composition, Structure, and Soils	☼	☼	☼	**P AFE**	P	p	p	P	p	p	p
GLAC	Stream Ecological Integrity		☼	☼	☼	**S, P AFE**	S, p	S, p	S, p	S, p	S, p	S, p
	Alpine Lake Ecological Integrity					☼	S	S	S	S	S	S
	Wetland Ecological Integrity					☼	☼	☼	S, p	S, p	S, p	S, p
	Alpine Vegetation Composition, Structure, and Soils						☼	☼	S	S	S	S
	Grassland/Shrubland Vegetation Composition, Structure, and Soils			☼	☼	☼	p	p	p	**P AFE**	p	p
GRKO	Stream Ecological Integrity				☼	S	S	S	S	S	S	S
	Grassland/Shrubland Vegetation Composition, Structure, and Soils	☼	☼	☼	**P AFE**	p	p	p	p	p	p	p
GRSA	Stream Ecological Integrity						☼	**S, P AFE**	S, p	S, p	S, p	S, p
	Alpine Lake Ecological Integrity				☼	S	S	S	S	S	S	S
	Wetland Ecological Integrity				☼	S	S, p	S, p	S, p	S, p	S, p	**S, P AFE**
	Alpine Vegetation Composition, Structure, and Soils					☼	☼	S	S	S	S	S
	Grassland/Shrubland Vegetation Composition, Structure, and Soils				☼	**P AFE**	p	p	p	p	p	p
	Focal Species–GRSA Insects		☼	☼	☼	☼	A					A
FLFO	Stream Ecological Integrity				☼	S	S	S	S	S	S	S
	Wetland Ecological Integrity			☼	S	S	S	S	S	S	S	S
	Grassland/Shrubland Vegetation Composition, Structure, and Soils			☼	p	**P AFE**	p	p	p	p	p	p
ROMO	Stream Ecological Integrity					☼	☼	S, p	**S, P AFE**	S, p	S, p	S, p
	Alpine Lake Ecological Integrity								☼	S	S	S
	Wetland Ecological Integrity	☼	☼	☼	**S, P AFE**	S, p	S, p	S, p	S, p	S, p	S, p	S, p
	Alpine Vegetation Composition, Structure, and Soils	☼	☼	☼	S	S	S	S	S	S	S	S
	Grassland/Shrubland Vegetation Composition, Structure, and Soils							☼	p	p	**P AFE**	p

Codes
☼ = Pilot efforts (protocols, sample size, and design may not match the final protocol)
A = Adaptive or other special designs
AFE = Annual field emphasis
P = Probability survey main panels
p = Probability survey linkage panels
S = Sentinel sites

2017	2018	2019	2020	2021	2022	2023
S	S	S	S	S	S	S
p	**P AFE**	p	p	p	p	p
S, p	S, p	**S, P AFE**	S, p	S, p	S, p	S, p
S	S	S	S	S	S	S
S, P AFE	S, p	S, p	S, p	S, p	S, p	S, p
S	S	S	S	S	S	S
p	p	p	p	p	p	**P AFE**
S	S	S	S	S	S	S
p	**P AFE**	p	p	p	p	p
S, p	S, p	S, P	S, P	**S, P AFE**	S, p	S, p
S	S	S	S	S	S	S
S, p	S, p	S, p	S, p	S, p	S, p	S, p
S	S	S	S	S	S	S
p	p	**P AFE**	P	p	p	p
			A			
S	S	S	S	S	S	S
S	S	S	S	S	S	S
p	p	**P AFE**	p	p	p	p
S, p	S, p	S, P	S, p	S, p	**S, P AFE**	S, p
S	S	S	S	S	S	S
S, p	**S, P AFE**	S, p	S, p	S, p	S, p	S, p
S	S	S	S	S	S	S
p	P	p	p	p	p	p

Table 9.2-2. Proposed schedule for ROMN reporting and model-based protocols.

Park	Protocol	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
FLFO	Landscape Dynamics		☼*	☼*						R					R					R
	Weather and Climate					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	NADP/NTN				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Invasive/Exotic Plants–Early Detection						M	M	M	M	M	M	M	M	M	M	M	M	M	M
GLAC	Landscape Dynamics		☼*	☼*						R					R					R
	Weather and Climate					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	NADP/NTN				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Snow Chemistry				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Invasive/Exotic Plants–Early Detection						M	M	M	M	M	M	M	M	M	M	M	M	M	M
	Focal Species–Grizzly Bear				☼	☼	H	H	H	R, H	H	H	H	H	R, H	H	H	H	H	R, H
GRKO	Landscape Dynamics				☼	☼				R					R					R
	Weather and Climate					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	NADP/NTN				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Invasive/Exotic Plants–Early Detection						M	M	M	M	M	M	M	M	M	M	M	M	M	M
GRSA	Landscape Dynamics		☼**	☼**	R					R					R					R
	Weather and Climate					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	NADP/NTN				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Snow Chemistry	☼	☼	☼	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	Invasive/Exotic Plants–Early Detection						M	M	M	M	M	M	M	M	M	M	M	M	M	M
LIBI	Landscape Dynamics									R					R					R
	Weather and Climate					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	NADP/NTN				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Invasive/Exotic Plants–Early Detection						M	M	M	M	M	M	M	M	M	M	M	M	M	M

Table 9.2-2. Proposed schedule for ROMN reporting and model-based protocols, cont.

Park	Protocol	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
ROMO	Landscape Dynamics		☼*	☼*					R					R					R	
	Weather and Climate					H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	NADP/NTN				H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Snow Chemistry			☼	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Invasive/Exotic Plants–Early Detection						M	M	M	M	M	M	M	M	M	M	M	M	M	M
	Focal Species–Beaver			☼	☼				R					R					R	
	Focal Species–Elk				☼	H	H	H	R, H	H	H	H	H	R, H	H	H	H	H	R, H	H

Codes
* = Landscape pilots via Watershed Condition Assessment projects in FLFO, GLAC, and ROMO
** = Landscape pilots via EPA Sustainability project in GRSA

☼ = Pilot efforts (protocols, sample size, and design may not match the final protocol)
H = Data harvesting and reporting (data generated and funded by others)
M = Modeling conducted by ROMN (with some field QA and/or input of field data from other protocols)
R = Remotely sensed data (with some field QA and/or input of field data from other protocols)
S = Sentinel site sampling

Chapter 10
Budget

10.1 Funding and Accountability

Under the NPS Natural Resource Challenge (NRC) funding initiative (NPS 1999), the Rocky Mountain Network received full funding for vital signs and water quality monitoring starting in FY2004. NRC funds are base funds held at the NPS Office of Inventory, Monitoring, and Evaluation and transferred annually to the ROMN via the Intermountain Region. ROMN funds are managed by the program manager under the oversight of the Board of Directors. Annual ROMN accomplishments, budgets, and work plans are documented in the Annual Administrative Report and Work Plan (AARWP) prepared by the program manager and reviewed and approved by the Board of Directors and at the regional and national I&M program levels. All task or project expenditures (planned and actual) are documented in detail by major category (personnel, agreements, contracts, operations and equipment, travel, and "other"). Funds are not transferred to the network until the budget and program accountability and planning have been documented and approved by the Board of Directors and at the regional and national I&M program levels.

10.2 Budget Projections

Actual ROMN income and expenditures by major category for FY2004 and FY2005 were used to project the network budget over the next five years (Table 10.2). This includes an estimated increase in vital signs monitoring funding of $1,151 (the average increase in ROMN vital signs funding for FY2005 and FY2006). The network has not received an increase in water-quality funding; in fact, the WASO Water Resources Division began assessing administrative costs for water quality monitoring in FY2006. In fiscal years 2007, 2008, and thereafter, vital signs networks can expect to see funding increases (at the same rate as parks) to help offset annual salary and cost of living increases (S. Fancy, pers. comm.).

Income and expenditures for FY2006–FY2010 are projections based on specified staffing and rate levels and projected rate changes based on previous two-year trends. Personnel costs are based on current ROMN staff (including GS- and step-level increases and benefits costs). Although it is likely that current staff will turn over in the mid- to long-term and that actual costs will vary, Table 10.2 provides a reasonable estimate of personnel costs. Projected expenditures in Table 10.2 include personnel costs for permanent ROMN staff (program manager, data manager, ecologist, and administrative assistant—currently a term position but for which there is a permanent need); IT support; office leasing; travel; operations and equipment; and administrative assessments by the WASO Water Resources Division and NPS Intermountain Region, based on real assessments in FY2005 and FY2006). It is anticipated that these will be recurring, or "fixed costs." In FY2007, fixed costs will consume 61% of the total ROMN budget; by FY2010, 70% of the total budget will be spent on fixed costs.

It is important to note that the budgets for FY2004 and FY2005 reflect ROMN expenditures during the program development and vital signs planning phase. These budget figures are helpful in formulating the future ROMN discretionary monitoring budget (especially the costs for permanent ROMN staff and certain operational expenditures such as for office leasing), but they will change as the network moves from program development and planning to implementation of the monitoring program.

Because all protocols are still in the development stage, reliable monitoring cost estimates for most protocols are currently unavailable. These will be developed as complete, detailed monitoring protocols—including sample designs across space and time, field and lab protocols, and analysis and reporting plans—are completed. As part of that process, a range of models for implementing each protocol will be identified (e.g., by utilizing volunteers for fieldwork, hiring temporary NPS monitoring

Table 10.2. ROMN budget/projected budget, fiscal years 2005–2010.[a]

	Fiscal year					
	2005	2006	2007	2008	2009	2010
Income						
Vital signs monitoring	$633,500	$634,800	$635,951	$637,104	$638,259	$639,416
Water quality monitoring	$61,000	$61,000	$61,000	$61,000	$61,000	$61,000
Total income	**$694,500**	**$695,800**	**$696,951**	**$698,104**	**$699,259**	**$700,416**
Expenditures (fixed costs)						
Assessments						
WASO Water Resources Division assessment	$860	$860	$860	$860	$860	$860
Intermountain Regional Office assessments	$3,240	$3,240	$3,246	$3,252	$3,258	$3,264
Total assessments	**$4,100**	**$4,100**	**$4,106**	**$4,112**	**$4,118**	**$4,124**
Permanent ROMN staff[b]						
Program manager	$100,993	$108,063	$113,308	$121,191	$126,429	$134,134
Data manager	$78,241	$82,494	$88,122	$92,815	$98,630	$103,133
Ecologist	$98,253	$103,147	$110,680	$116,175	$120,691	$129,100
Administrative assistant (0.5 FTE; currently term)	$23,587	$25,819	$27,805	$29,485	$31,204	$32,833
Total permanent ROMN staff	**$301,074**	**$319,523**	**$339,915**	**$359,666**	**$376,954**	**$399,200**
Other fixed costs[c]						
IT support[d]	$9,504	$9,789	$10,083	$10,385	$10,697	$11,018
Office lease[d]	$0	$13,588	$13,996	$14,416	$14,848	$15,293
Travel[d]	$41,981	$33,666	$34,676	$35,716	$36,787	$37,891
Operations/equipment[d]	$28,556	$17,409	$23,672	$24,382	$25,113	$25,867
Total other fixed costs	**$80,041**	**$74,451**	**$82,426**	**$84,899**	**$87,446**	**$90,069**
Total fixed costs	**$385,215**	**$398,074**	**$426,447**	**$448,676**	**$468,517**	**$493,392**
Percentage of fixed costs relative to income	**55%**	**57%**	**61%**	**64%**	**67%**	**70%**
Discretionary monitoring budget (total income minus total fixed costs)[e]	**$309,285**	**$297,726**	**$270,504**	**$249,428**	**$230,742**	**$207,024**
Temporary monitoring personnel (expenditure starting FY2007)						
Ecologist crew leader #1 (GS-09, 1.0 FTE)	-	-	$61,932	$67,141	$71,860	$77,177
Ecologist crew leader #1 (GS-09, 0.5 FTE)	-	-	$30,966	$32,480	$34,815	$36,250
Biological technician crews (two crews of three GS-04 employees, total 1.5 FTE)	-	-	$33,778	$33,879	$33,981	$34,083
Geospatial data analyst cost (GS-09, 0.6 FTE)	-	-	$37,159	$39,918	$41,785	$43,507
Total temporary monitoring personnel	**-**	**-**	**$163,835**	**$173,418**	**$182,441**	**$191,017**
Discretionary monitoring budget minus temporary monitoring personnel	**$309,285**	**$297,726**	**$106,669**	**$76,009**	**$48,301**	**$16,007**

[a] Figures for fiscal years 2005–2006 are actual costs; figures for fiscal years 2007–2010 are projections.
[b] Assumes GS and step levels of 2006 ROMN staff.
[c] Fixed costs are costs for assessments, permanent staff, IT support, office lease, travel, and operations and equipment.
[d] Assumes 3% annual inflation.
[e] In fiscal years 2005 and 2006, the discretionary monitoring budget was spent on protocol development projects.

technicians, working with academic cooperators via cooperative agreements, or working with other agencies via interagency agreements).

A key step in developing and budgeting for the ROMN Vital Signs Monitoring Program will be identifying, engaging, and evaluating potential partners—both internal (e.g., park, IMR, or NRPC) and external (e.g., academic institutions, other agencies, or NGOs). The costs and benefits of each partnership will be evaluated and compared. Excellent long-term partnership opportunities exist that will increase the scientific merit and rigor of the monitoring program and decrease monitoring costs.

After all protocols are completed, a ROMN staffing plan will be developed for all activities to be conducted by NPS personnel. Until protocol development and staffing planning are completed, ROMN monitoring costs cannot be identified, except in a general way. It is anticipated that protocol and staffing planning and budget formulation will take several years.

Because monitoring costs are not known, the balance of the funding (ROMN income minus recurring fixed costs) is presented as the "discretionary monitoring budget" in Table 10.2. Note however, that all expenditures identified in the table contribute to vital signs monitoring, and that permanent ROMN staff also will have monitoring duties, including field monitoring, training and managing field monitoring staff or partners, data management, analysis, and reporting.

Table 10.2 also presents a preliminary budget estimate for NPS temporary personnel to conduct field monitoring and/or basic monitoring data gathering and analysis (e.g., a geospatial analyst obtaining and doing GIS-based analyses of land cover datasets for the Landscape Dynamic protocol). The costs are for salary and benefits for NPS temporary employees at the identified GS- and full-time-equivalency (FTE) levels, and include an annual cost-of-living adjustment. Although it is likely that the ROMN will not implement all (or even most) monitoring protocols by hiring NPS temporary employees, these estimates provide a helpful starting point for planning to allocate monitoring funds. They also will help the network to evaluate proposals and budgets from potential cooperators by establishing a baseline cost estimate for personnel.

The ROMN will continue to evaluate progress and formulate work plans annually through the AARWP process. As the program evolves, it is expected that the planning and budget formulation process will evolve through periodic, protocol-specific reviews and integrated program reviews (see Chapter 8) to ensure that the program is as effective and efficient as possible.

For the ROMN and all national parks, personnel costs have been increasing faster than funding (Figure 10.2). Inflation also will likely increase ROMN costs in all other categories. This means that the ROMN must adjust its long-term monitoring program (either on the income or the expenditure side) periodically.

10.3 Data Management, Reporting, and Communications Costs

National Park Service guidelines for developing a monitoring program suggest that approximately 30% of the budget should be allocated to information and data management so that information is not lost, results are communicated to various audiences (especially managers), and adequate reporting takes place (see Chapter 6). The ROMN has a permanent, full-time data manager whose salary and benefits comprised approximately 12% of the ROMN budget in FY2006. The data manager has an overarching role in the ROMN program to ensure that inventory and monitoring data are organized, useful, compliant, safe, and available, and to develop data management policies and procedures. However, because all ROMN staff and cooperators have data management "roles and functions" (see Table 6.4) and spend significant amounts of time on data management, ROMN expenditures for data management are much higher than 12%. For example, the ecologist plays a key role in data analysis and reporting; it is anticipated that 50% or more of the ecologist's time will be spent on this aspect of data management. Field crews and field crew leaders will also spend significant amounts of time on data management, especially on data entry and quality assurance/quality control and documentation. A geospatial data analyst, who will have a primary role in data acquisition, manipulation, analysis, documentation and archiving for spatially explicit ROMN data, will likely be needed. Ultimately, the portion of the ROMN budget devoted to data management is expected to be well above 30%.

Reporting and communicating monitoring results to park managers, academic communities, other agencies, and the public is another important component of a successful monitoring program. Reporting and communication are included as part of the ROMN data management function (Chapter 6), but these needs will be specifically identified as each protocol is developed, generally in the ROMN Data and Information Management Plan (Appendix D), and in network budget and staffing planning. The network is also exploring opportunities to collaborate and share the costs for reporting and communication with the CCRLC, CDRLC, and other IMR networks.

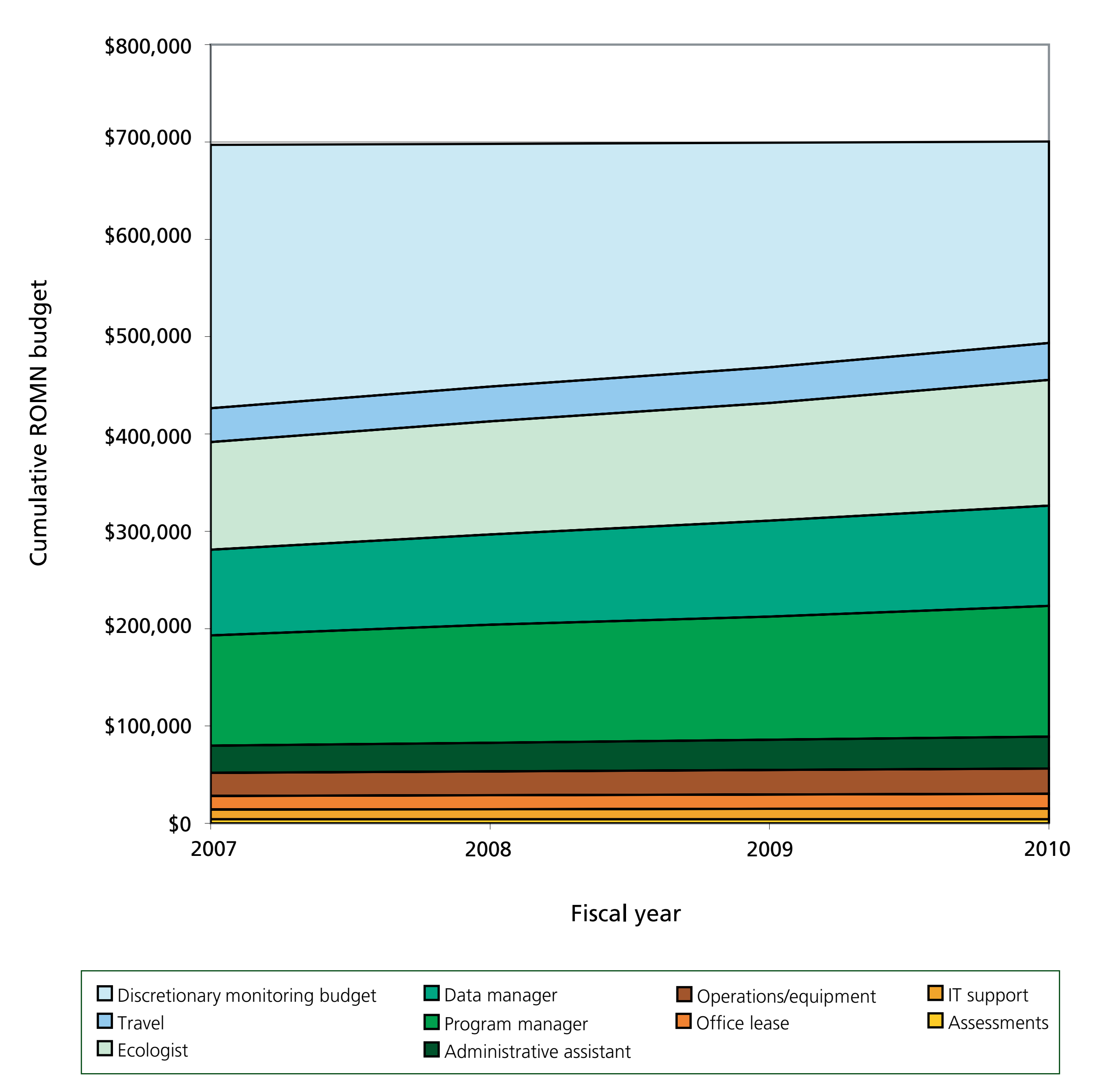


Figure 10.2. Projected cumulative ROMN budget by major cost category, fiscal years 2007–2010.

Chapter 11
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Key Terms and Concepts

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

Attribute: any living or non-living 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).

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. Drivers include major external forces like climate, fire cycles, biological invasions, and hydrologic cycles, as well as 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.

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 (http://science.nature.nps.gov/im/monitor/Glossary.htm). Key properties and processes of ecosystem integrity provide the long-term baseline needed to judge what constitutes unnatural variation in park resources. Ecological integrity also implies the capacity to support and maintain a balanced, integrated and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region. Ecological integrity includes biotic and abiotic processes, as both of these are responsible for maintaining ecosystems. The concept recognizes that the dynamics of ecological processes vary with the scale of description and is, by definition, explicitly linked to management objectives.

Ecological site: a kind of land with specific physical characteristics that 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).

Ecosystem: “a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries” (Likens 1992).

Ecosystem 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*.

Endpoints: Ecosystem attributes of ecological and/or societal importance. Endpoints may or may not be indicators of overall ecosystem condition.

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. 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.

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

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

Hydrologic function (lotic and lentic systems): capacity of an area to dissipate energies associated with (1) high stream flow (lotic) or (2) wind action, wave action, and overland flow (lentic), thereby reducing erosion and improving water quality; filtering sediment, capturing bedload, and aiding floodplain development; improving floodwater retention and groundwater recharge; developing root masses that stabilize streambanks against cutting action; developing diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and supporting greater biodiversity.

Indicator (general use of term): a term reserved for a subset of environmental 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).

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

Invasibility: the known or predicted susceptibility of part of the landscape to invasion by non-native species. This is generally a value attributed to a location based on the context of the surrounding lands, especially human uses and activities, correlated with the distribution characteristics of a set of likely invaders (e.g., derived from local, state, or national weed lists).

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: the specific variables used to quantify the condition or state of an *attribute* or *indicator* (or *vital sign*). These are specified in definitive sampling protocols. For example, stream acidity may be the indicator, while pH units are the measure.

Metadata: Data about data. Metadata describes the content, quality, condition, and other characteristics of data. Its purpose is 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.

Orography: 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.

Sedimentation: the process of settling.

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.

Soil 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).

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.

System resilience: the ability of an ecosystem to maintain its characteristic patterns and rates of process in response to the variability inherent in its climate regimes.

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 that 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*.)

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

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