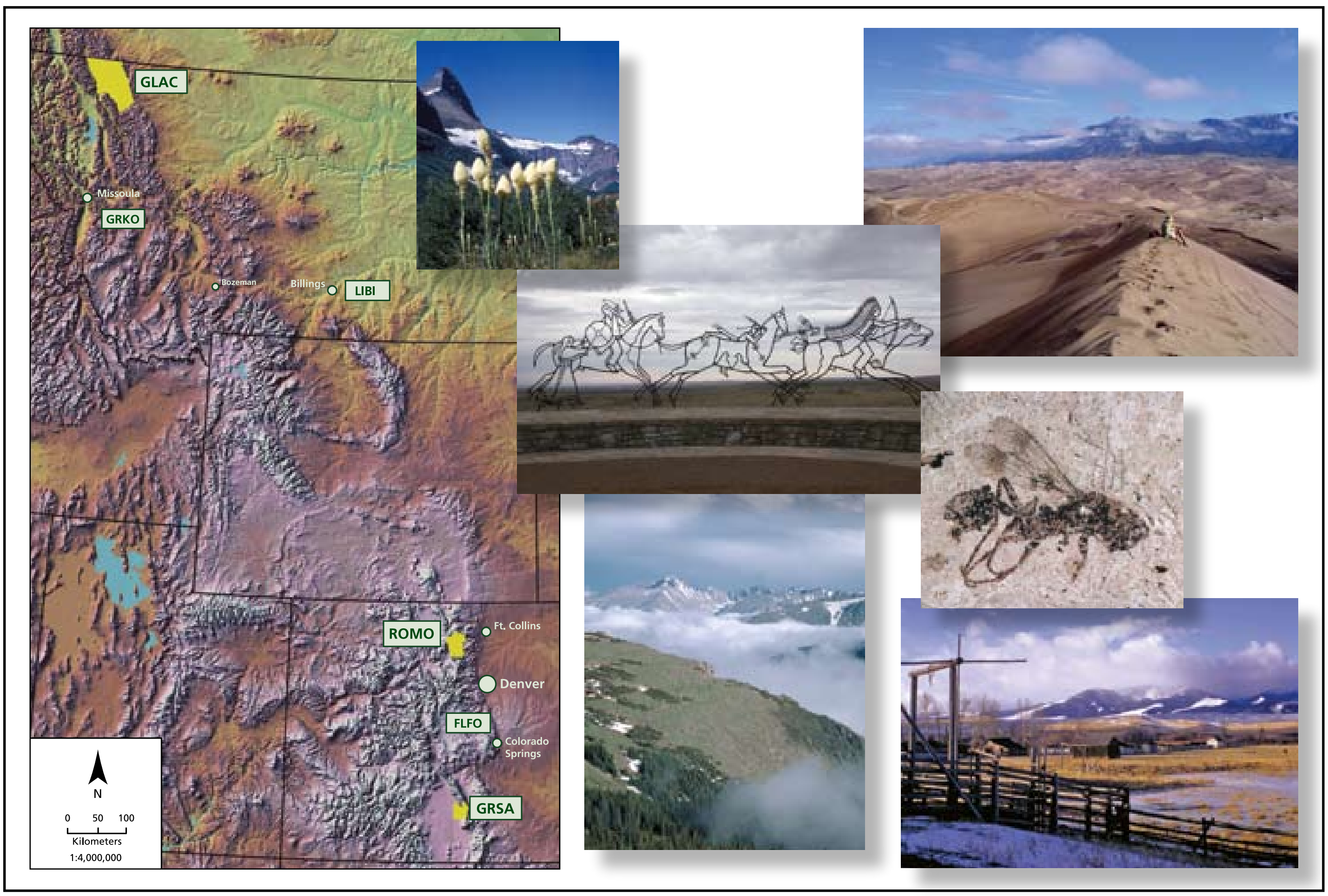
National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Rocky Mountain Network Vital Signs Monitoring Plan

Appendices

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 (NPS/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).

Rocky Mountain Network Vital Signs Monitoring Plan

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

Authors
Mike Britten, Program Manager
E. William Schweiger, Ecologist
Brent Frakes, Data Manager
Dan Manier, Ecologist
David Pillmore, Data Technician

Rocky Mountain Network
Natural Resources Program Center
1201 Oakridge Drive, Suite 200
Fort Collins, Colorado 80525

Editing and Design
Alice Wondrak Biel
Inventory & Monitoring Program
National Park Service–Intermountain Region
12795 West Alameda Parkway
Denver, Colorado 80225

August 2007

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly-published newsletters.

Printed copies of reports in this series may be produced in limited quantity, and are only available as long as the supply lasts. You may send a request to:

Rocky Mountain Network
Natural Resources Program Center
1201 Oakridge Drive, Suite 200
Fort Collins, Colorado 80525

This report is also available electronically from the Rocky Mountain Network website (http://www1.nature.nps.gov/im/units/romn/index.htm).

When original printed copies are exhausted, copies can be obtained from:

Technical Information Center (TIC)
Denver Service Center
National Park Service
P.O. Box 25287
Denver, CO 80225-0287

Please cite this publication as:

Britten, M., E. W. Schweiger, B. Frakes, D. Manier, and D. Pillmore. 2007. Rocky Mountain Network Vital Signs Monitoring Plan: Appendices. Natural Resource Report NPS/ROMN/NRR-2007/010. National Park Service, Fort Collins, Colorado.

NPS D-71, August 2007

Contents

Figures..v

Tables..vii

Appendix A
Supplemental Information on Conceptual Models 1

A.1 Landscape characterization model 1
A.1.1 Climate and physical processes... 1
A.1.2 Human activities......................... 1
A.1.3 Biotic processes.......................... 2
A.2 Grassland characterization model 3
A.2.1 Climate and physical processes... 3
A.2.2 Human activities......................... 3
A.2.3 Biotic processes.......................... 4
A.3 Alpine characterization model 5
A.3.1 Climate and physical processes... 5
A.3.2 Human activities......................... 6
A.3.3 Biotic processes.......................... 6
A.4. Stream Characterization Model 7
A.4.1 Climate and physical processes... 7
A.4.2 Human activities......................... 8
A.4.3 Biotic processes.......................... 9
A.5 Wetland Characterization Model 9
A.5.1 Climate and physical processes... 9
A.5.2 Human activities....................... 10
A.5.3 Biotic processes........................ 11
A.6 Literature Cited 11

Appendix B
Vital Signs Development........................ 15

B.1 Preliminary Vital Signs.......................... 15
B.1.1 Literature search....................... 15
B.1.2 Survey...................................... 15
B.1.3 Vital Sign Meetings................... 22
B.1.4 Vital Signs Database 24
B.1.5 Candidate Vital Signs from Workshops............................... 31

Appendix C
Supplemental Information on Sample Design 37

C.1 Design Types 37
C.1.1 Judgment designs 37
C.1.2 Model-based designs................ 37
C.1.3 Probability designs.................... 38
C.1.4 Hybrid designs.......................... 38
C.2 Target populations, sample frames, and sample populations...................... 39
C.3 Key design evaluation concepts 39
C.3.1 Status....................................... 39
C.3.2 Trend and effect size 41
C.3.3 Evaluating designs for status and trend 43
C.4 Literature Cited 46

Appendix D
Data and Information Management Plan 49

D.1 Introduction 49
D.1.1 Purpose.................................... 49
D.1.2 Scope....................................... 49
D.1.3 Goals and objectives 49
D.1.4 Organization 51
D.2 Conceptual Framework for Managing Data and Information......... 53
D.2.1 Data management conceptual model 53
D.2.2 Project life-cycle model............. 54
D.2.3 Operation life-cycle model........ 55
D.2.4 Integration of network, park, and national systems 56
D.3 Network Data Operations................... 58
D.4 Rocky Mountain Network Data Management Model.......................... 59
D.4.1 Acquire and/or Generate.......... 59
D.4.2 Quality Assurance and Quality Control.................................... 60
D.4.3 Document............................... 61
D.4.4 Determine sensitivity and ownership 62
D.4.5 Archive and Store..................... 64
D.4.6 Catalog.................................... 65
D.4.7 Analyze and Report.................. 65
D.5 Rocky Mountain Network Project Life-Cycle Model................................ 66
D.5.1 Initiate 66
D.5.2 Plan 67
D.5.3 Implement 67
D.5.4 Close....................................... 67
D.5.5 Organization 67
D.6 Roles and Responsibilities 67
D.7 Conclusion 69
D.7.1 Implementation........................ 69
D.7.2 Review and revision.................. 69
D.7.3 Relationship with the monitoring plan 70
D.8 Definitions.. 71
D.9 Change History 71
D.10 Literature Cited 72

Appendix E
Supplemental Information on Analysis and Reporting.................... 75

E.1 Analytical Constraints of Single-site Monitoring.. 75
E.2 Ecological Process Objectives (Sentinel Designs) 75
E.3 Constraints and Benefits of Model-based Analysis.................................... 75
E.4 Change Detection............................... 76
E.5 Park-scale Status and Trend Objectives (Probability Designs)........... 76
E.6 Constraints and Benefits of Design-based Analysis.................................... 76
E.7 ROMN Thresholds 77
E.8 Multimetric and Multivariate Biological Indices 78
E.9 ROMN Communication and Reporting Strategy.............................. 79
E.9.1 Form of ROMN reports 79
E.9.2 Summary of ROMN reports....... 80
E.10 Literature Cited................................ 82

Appendix F
Rocky Mountain Network Charter........ 85

Introduction.. 85
Organization and Responsibilities............... 85
Board of Directors..................................... 85
Major Responsibilities......................... 85
Membership...................................... 86
Meetings... 86
Alternates, Quorums and Decision Making 86
Technical Committee 86
Major Responsibilities......................... 87
Membership...................................... 87
Meetings and Communication............ 87
Alternates, Quorums and Decision Making 87
Scientific and Technical Partners................. 87
Rocky Mountain Network Staff 88
Guidance and Network Operations............ 88
Funding... 89
Amendments.. 89

Figures

Figure B.1.2. ROMN vital sign survey form. 20
Figure B.1.4.1. ROMN Vital Signs Database table structure. 24
Figure B.1.4.2.1. ROMN Vital Signs Database Initial Form. 24
Figure B.1.4.2.2. ROMN Vital Signs Database table structure. 25
Figure B.1.4.2.5. ROMN Vital Signs Database reporting options. 31
Figure C.3.3.Example output of variance components model. 44
Figure D.1.2. Location of Rocky Mountain Network office relative to each of the network parks. 50
Figure D.1.4.Hierarchy of information management plan, network operations, and standard operating procedures. 51
Figure D.2.1.Data management conceptual model. 53
Figure D.2.2. General project life-cycle model. 54
Figure D.2.3. Operation life-cycle model. 56
Figure D.2.4.Integration of network, park, and WASO data systems. 57
Figure D.7.2. Continuum of possible outcomes to the implementation of the Data and Information Management Plan, operations, and SOPs. 70
Figure E.9.1.1. Example ROMN website interface used for reporting monitoring results. 79

Tables

Table B.1.2. Candidate vital signs: surveys. 21
Table B.1.3-1. Participants in the Montana Park Vital Signs Objectives Workshop, January 25, 26, and 27, 2005, Flathead Lake Biological Station, MT. 22
Table B.1.3-2. Participants in the Colorado Park Vital Signs Objectives Workshop, March 1, 2, and 3, 2005, Estes Park, CO. 23
Table B.1.5. Candidate vital signs from the workgroups. 32
Table C.3.1.3. Precision and sample size in estimates of selected proportions.* 40
Table D.1.4.3. List of standard operating procedures (core SOPs). 52
Table D.6. Common data management responsibilities by position. 68
Table D.9. Change history for the ROMN Data and Information Management Plan. 72

Appendix A Supplemental Information on Conceptual Models

This appendix provides information about the ways in which the core drivers, systemic components, and stressors in each conceptual model presented in Chapter 2 model interact—in terms of climate and physical processes, human use, and biotic processes—in Rocky Mountain Network parks.

A.1 Landscape characterization model

A.1.1 Climate and physical processes

Climate dynamics affect a multitude of vital landscape functions because of the important role of water and temperature as controls. The amount and timing of water delivery across a landscape, and of water availability to organisms and processes, is a fundamental driver of aquatic, wetland, and terrestrial ecosystem function. The coupling of precipitation and temperature dictates the timing and quality of the growing season, snowpack accumulation and melt, amount and timing of surface water, quantity of groundwater, and the spatial/temporal distributions of many plants and animals (e.g., treeline and migration).

The cycling of the atmosphere also affects stressors such as the delivery and distribution of contaminants (e.g., nitrogen and sulfur) and fire history and behavior. Atmospherically driven changes are expected to be manifest as shifts in the spatial distribution of species and communities across a landscape, for example, increases in treeline elevation and latitude as the length of a growing season increases with warming trends.

Nutrient deposition and associated changes in nutrient availability are closely associated with human land uses (which are often their source) and atmospheric patterns (the distribution system). Air-pollution levels in the landscape surrounding a park can have a strong impact on various landscape mechanisms (Peterson et al. 1998), and because deposition is not bound to a linear, one-way, hydrologic network (rather, it is conveyed through a set of complex airsheds structured by topography, climate, and season) the ecological integrity of headwater parks (e.g., GLAC, GRSA, and ROMO) can be directly influenced by air pollution. Moreover, depending on the structure of a specific airshed and prevailing climatic patterns, air pollution may occur far removed from a park, yet have an important local impact.

Soils across the Rocky Mountain region are often nutrient-limited due to slow decomposition rates linked to climate regimes, steep slopes, erosion, and shallow surface layers (for a detailed discussion, see Schlesinger 1997, Chapter 4). Nutrient limitations (especially of nitrogen and phosphorus) have important determinant effects on system function and species diversity (Baron et al. 2000; Bedford et al. 1999). Increasing land use around NPS units results in increased sources of nutrient contaminants (e.g., industrial and automotive emissions). This, in turn, is expected (and has been demonstrated through experimental manipulation) to alter species composition of terrestrial and aquatic systems by changing the competitive environment and resource base.

A.1.2 Human activities

Land use is becoming more intense outside and along the borders of all ROMN units, and is the focus of most studies of landscape change. Widespread implications associated with human land-use patterns are just starting to be recognized; park-level concerns range from degraded visitor experience (e.g., viewshed impacts) to local extinctions (e.g., of rare species) and species introductions (e.g., via resource extraction, livestock use, or domestic landscaping activities).

Habitat change—for both plants and animals—is a critical repercussion of landscape disturbance. Particularly critical effects are occurring in wildlife habitats crucial to migratory species, because at the landscape scale, the distribution and configuration of habitat has important impacts on large, wide-ranging species (e.g., ungulates and bears). Many lands important to mobile and/or migratory species (e.g., seasonal habitat, population source/sink areas, migrational ranges) lie outside NPS boundaries. As anthropogenic land uses replace natural ecosystems, areas available for foraging, cover, reproduction, and safe travel are restricted and/or eliminated, thereby reducing the health and abundance of the wildlife that use them. Moreover, isolated populations may be dependent on particular habitat types (e.g., fireweed occurs in frequently disturbed, post-disturbance communities; sage grouse require sagebrush). Changes in the size, number, and distribution of rare and isolated populations are critical to the preservation of communities and species across the landscape, and the distribution of and connectivity between seasonally important habitats is critical to the survival of large, mobile species. Therefore, key patterns associated with these broad-scale ecosystem assessments are best recognized via monitoring change at the landscape level.

Another direct, widespread implication of intensified land use is alteration of the fire regime (i.e., fire suppression). The frequency and distribution of fire is understood as a landscape-scale, climate-driven phenomenon. Fire behavior and its regional distribution are a combination of the attributes of individual land areas (e.g., the amount and arrangement of fuels) and the surrounding landscape (e.g., the extent and distribution of closed-canopy forest). Thus, fire suppression aimed at protecting human values outside parks affects the condition and distribution of communities within park units.

The cumulative effects of residential, agricultural, commercial, and industrial development occurring across a landscape also change the characteristics of material and energy flowing through parks and can disrupt ecological functioning within their aquatic systems. Water quality, the hydrograph, and aquatic ecological integrity can all be impacted (Nelson and Booth 2002; Paul and Meyer 2001). The impacts of this pathway are more complex in headwater parks, given water's inclination to flow downhill (and thus carry many sources of stress away from a park). However, aquatic integrity in headwater parks still can be impacted via drivers and mechanisms such as air pollution and nitrogen deposition, or more indirectly via changes in species dispersal patterns (e.g., fish movement).

A.1.3 Biotic processes

Exotic species are perhaps the most distressing problem facing land conservation managers in the twenty-first century. The proliferation of introduced species, due to intentional introduction of non-native species, abundant and widespread modern movement vectors, lack of natural population controls, and land-use patterns that provide suitable habitats, threatens even the most isolated parks in the continental United States. Land uses that disrupt the cover and vigor of native species often result in niche availability for invading species. Similarly, disturbances in highly productive environments (e.g., wetlands) create high-quality niche availability for invaders.

Wildfire and fire suppression are a landscape-scale disruption to the processes and patterns associated with natural disturbance, regeneration, and patch dynamics. There are numerous implications for vegetation structure and species composition associated with the frequency and distribution of wildfires and the results of their suppression. Wildfire, as a process, is the product of biotic, climatic, and topographic drivers. Some species have strong adaptations for surviving particular fire behaviors (e.g., ponderosa pine, *Pinus ponderosa*), while other species have "post-fire reproductive triggers" in which seed output (e.g., lodgepole pine, *Pinus contorta*) or sprouting frequency (e.g., quaking aspen, *Populus tremuloides*) is triggered or increased by fire. Other species are dependent on seed dispersal from survivors or germination from the seed bank (e.g., Douglas-fir, *Pseudotsuga menziesii*; fireweed, *Chamerion angustifolium*).

At a community and landscape scale, the mosaic of different ages and structures (e.g., the spatial realization of the "time" factor in the Jenny model) is created by periodic disturbances to different parts of the landscape in different years. Management activities, natural disturbances, and disturbance history across the landscape together determine current fire behavior and landscape patterns. Thus, changes in the disturbance regime (i.e., to type, size, intensity, frequency) are correlated with changes in the spatial-temporal distribution of community structure (i.e., distribution and attributes of landscape elements), and vice-versa.

A.2 Grassland characterization model

A.2.1 Climate and physical processes

As primary drivers of terrestrial system function, climate and atmospheric processes, geographic position, and geology exert multi-scale influences on the structure and productivity of terrestrial vegetation (see Kuchler 1975; Bailey 1976). While geologic resources are relatively stable, the soils layer that is critical to biota is more sensitive to atmospheric contributions and activities on the surface. Weather is clearly a variable process, and while regional patterns of climate do exist (e.g., continental versus maritime), current trends and variability in long-term climate records and research indicate that climate is a powerful, dynamic driver of community distribution, ecosystem function, and biogeography. The atmosphere is also responsible for transport of nutrients and pollutants from source areas to remote deposition areas, such as ROMN parks.

Vegetative biomass production is driven by temperature and soil moisture availability, which are generally controlled temporally by the onset of the growing season (with a cascade of impacts if this is modified via global climate change). Climatic variation interacts with essentially every other driver in grasslands, making its effects complex and often indirect. As precipitation patterns change and temperatures increase, we expect shifts in the distribution of vegetation across North American grasslands, resulting in marked changes in species composition within several ROMN units.

Soil type, development, and function have important deterministic and interactive effects on upland community function. Differences in parent materials, aging and erosion, deposition, and processing and development by organisms result in a complex spatial mosaic of substrate quality that dictates plant community patterns at broad and local scales. Surface litter, soil porosity, and high soil organic matter content help produce low surface run-off (Seastedt 1995). Soil losses due to sheet or rill erosion are typically low in most grasslands with sufficient grass height. Even in burned prairies, surface roughness is often adequate to maintain low overland flow velocities. However, in steeper areas, erosion occurs with precipitation in the absence of protection from vegetation. Surface stability and soil function—critical aspects of upland system health—are subject to direct impacts from people, livestock, and wildlife, as well as climate-driven changes to vegetation structure.

Fire is an important part of most temperate ecosystems, and it has evolved as a natural component of disturbance and nutrient cycling in most North American grasslands. As a driver of plant community structure and function, climate (growing season and fire weather) interacts with vegetation (structure and composition), which is further affected by herbivory (fuel volume), exotic species invasions (fuel profile), and human activities (e.g., altered fire regimes, harvesting, land-use conversions). For instance, periodic droughts are typical; this permits vegetation to dry and become more flammable, thereby working with climate to drive the wildfire regime. Without fire, many grassland types succeed to forests or shrublands (Sauer 1950), with significant shifts in productivity and trophic structure.

A.2.2 Human activities

Key anthropogenic drivers in lowland grasslands include the indirect effects of land use intensification (largely external to parks), direct human use of the grassland within and around a park, and fire management (e.g., suppression). Agricultural conversion, with its often-significant removal of biomass (harvest), is a dominant human land use within and around grassland ecosystems. With the exception of GRKO, where the purpose of the park is tied to agricultural use of the landscape, these impacts are mostly indirect.

The sources for atmospheric pollutants are anthropogenic, and atmospheric circulation moves these chemicals from industrial and agricultural sources to deposition sites near and far from their origin (e.g., high elevations within ROMN units). The effects of these chemicals on the environment are partially dependent on the ability of soil and geologic substrates (e.g., limestone versus granite parent materials) to buffer the effects of new inputs.

Nitrogen deposition is a particular concern in ROMN units, because western soils are often nitrogen-limited. Increased nitrogen availability is expected to drive a change in species composition (and potentially structure and function) as inter-species competitive relationships change and new niches become available. Many non-native invasive plants are known to thrive in nitrogen-rich environments.

Human effects on disturbance regimes are a potentially critical stressor across ecosystems. The abrupt alteration of fire regimes, beginning in the early 1900s, has had a dramatic effect across many ecosystems, from montane forests to coastal dunes. Fire suppression policies in grasslands (as in forested areas) are actively implemented in all ROMN parks; however, wildfires still occur, and several units have active prescribed fire and fuel manipulation programs. It is also important to recognize that these activities have not affected all systems in the same ways; some systems are largely unaffected by fire-suppression activities. Further, the effects of humans on disturbance regimes extend beyond active fire suppression. Changes in landscape configuration that affect the spread of fires, and land uses (e.g., livestock removal of fine fuels, timber harvest, and regeneration) also have had widespread impacts on the frequency and distribution of natural disturbances.

The role of wildlife and introduced livestock is also very important across grassland landscapes; current and historic human activities have affected the role of fauna in these systems. For example, tens of millions of bison on the western plains were replaced by an estimated 45 million cows and an equal number of domestic sheep by 1890 (Fedkiw 1989). Cattle and fences have created vast, homogeneous landscapes by removing the differential intensities of grazing among sites that historically created a mosaic of habitats supporting many species (Knopf and Samson 1996). Grassland systems converted to pastureland (i.e., as at GRKO) provide surrogate habitat for some vertebrate and plant species, but in general have reduced ecological function (Herkert 1993; 1994).

Visitors have the potential to directly affect grassland ecosystems, especially in small parks with intense, concentrated use (i.e., LIBI). Visitors can facilitate exotic species dispersal, alter soil properties and vegetation through trampling and increased erosion, and impact wildlife behavior and habitat utilization by causing aversion or habituation behaviors.

A.2.3 Biotic processes

In addition to temperature and water, the availability and cycling of nutrients, especially nitrogen, strongly influences grassland community structure and function; it is closely tied to variation in ecosystem processes including vegetation production and decomposition (Blair et al. 1998). Variation in nitrogen availability is closely associated with soil biotic function, as soil organisms utilize organic materials deposited on the soil and process them into forms useful for vegetation. Additional drivers and stressors such as fire, grazing, elevation, topography, and precipitation regimes can determine and limit soil productivity, soil composition, litter inputs, and rates of litter decomposition. Grassland herbivores, both native and introduced (i.e., cattle in GRKO), are important components of nitrogen-cycle processes and outcomes. Nitrogen also may be lost through volatilization as a result of fire (Seastedt 1988; Ojima et al. 1990; Hobbs et al. 1991).

One of the most important biological processes impacting grassland systems in and around ROMN parks is herbivory. Herbivory interacts with climate, fire regime, and annual net primary production (ANPP) in complex ways. For example, Frank and McNaughton (1992) examined patterns in the Yellowstone system and concluded that in the absence of drought, herbivory can result in a compensatory growth response and, hence, stimulate grassland productivity. The composition and structure of shrub- and grass-dominated communities is directly affected by ungulate use (Manier and Hobbs 2006). Prairie dogs also have controlling effects on composition and structure of vegetation, and the activities of microtine small mammals (e.g., voles) have widespread, important effects on both vegetation and soil structure (Detling 1998). Under pressure from climate stressors (e.g., drought), intense herbivory, and human land uses, vegetation dynamics can result in exposed soils, opening the way for erosion, exotic species invasions, and loss of systemic function. However, grassland systems are also resilient because the species that create grass and shrub communities are adapted to climate variability, disturbance, and herbivory. Further, intense herbivory is not typical throughout ROMN parks. The impacts of native grazers extend throughout the nutrient cycle. Herbivory by native ungulates can affect spatial patterning in plant species composition, in particular where large grazing species interact with small herbivores (Detling 1998).

The balance between herbaceous and woody species over time is often controlled by disturbance. In these areas, a shift in the disturbance regime will result in changes to vegetation composition and structure, changed wildlife habitats, and alteration of cultural landscapes. Fire suppression and livestock production are critical biotic stressors imposed on grasslands, woodlands, and forests by human activities. A final, key stressor in grassland systems is the presence of invasive species. The increasing presence of exotic species (although still patchy within most parks) has already greatly altered some ROMN grassland communities. Invasions are often facilitated by disturbances and human activities that transport and introduce species to new areas. Outside park boundaries, entire systems have been changed through the invasion of exotic flora.

A.3 Alpine characterization model

A.3.1 Climate and physical processes

Climatic and physical processes are likely the most important set of drivers in alpine and subalpine systems. Extreme topography, high elevations and rarefied atmosphere, and young, shallow, disturbed soil profiles combine with weather and climate to create highly sensitive, adapted biotic communities (Seastedt et al. 2004). While other factors can have significant effects, especially locally, climate is the key limit on the physiology and growth of nearly all organisms in alpine systems (Tranquillini 1979). Changes in climate are linked to watershed hydrochemistry (Williams et al. 1996), which points generally to the close connection between alpine climate and biochemistry.

Temperature and precipitation extremes, coupled with high radiation levels, cause the alpine ground surface to heat up during the day and cool rapidly at night. Temperature functions synergistically with other drivers to create even more extreme conditions. For example, wind combined with low temperatures may limit high-elevation forest growth. Wind also drives the ice and snow that scour and abrade surfaces and plant tissues, and causes snow to accumulate, providing water and insulation. Snowdrifts often do not melt until well into the alpine growing season, limiting early-growth stages of alpine plants. These fluctuations dictate physiological processes such that only plants with metabolic systems capable of functioning at very cold temperatures during the short alpine growing season can persist. This set of drivers also operates in subalpine areas, but is mediated there by the less-exposed substrate and higher density of tree stands, which influence microclimate. Short-term temperature cycles, sometimes only 24 hours long, also disrupt wet alpine soils, resulting in churning of soil particles and an unstable substrate. Substrate thaw–freeze actions serve to maintain the instability of these slopes.

Snowpack depth, duration, and distribution are important determinants of alpine system pattern and function (Walsh et al. 1994) because of their influence on moisture content, growing-season length, and physical damage to vegetation, as well as the role of snowpack as a carrier of atmospheric (nutrient) deposition. Melt-out patterns influence water availability and loadings of many toxic compounds. Snowbanks and melt zones have a unique phenology and diversity linked to the seasonal thaw and melting process (Billings and Bliss 1959). Excess snow cover can lead to tree infection and tissue damage (Marr 1977). Further, snowpack is critically linked to glacial formation and deterioration, and melt-off from glaciers has important determinant effects on stream, lake, and wetland hydrology and water chemistry far downstream from the toes of glaciers.

While topography is relatively stable in alpine environments, changes do occur, creating an abiotic disturbance regime. Avalanches can have dramatic effects on vegetation and soils under the snow, and they perpetually restrict the growth of tall and slow-growing species. Solifluction (frost action) results in surface soil movement, textural sorting, and localized stress on plants. At high elevations, even small changes in slope and aspect alter the extremes of the environment.

A.3.2 Human activities

Given the severity of the alpine climate, direct human use and impacts are relatively less common and less intense in the upper elevations of this zone than in lower-elevation systems. However, alpine systems are highly sensitive to even remote or subtle anthropogenic disturbance; for example, the presence of roads in GLAC and ROMO that cross the Continental Divide can lead to localized impacts. Roads into alpine areas also generate a local source for nitrogen and sulfur deposition. Trampling of sensitive alpine flora by visitors loosens substrate and plants, especially cushions or mats, making them susceptible to wind scour (Hartley 1976; Jackson 1998), and the short growing season means plants take longer to recover from trampling. With little or no protection provided by vegetation, trails are subject to greater erosion potential. Seeds of exotic species travel on feet, clothing, and vehicles. Animal behavior is altered by presence of roads, trails, vehicles, and hikers. Glacier and Rocky Mountain national parks have hardened some trails and excluded travel in other places, with the hope of protecting alpine plant communities in areas of heavy human use.

The current and historical land use of a region is an important driver of the structure, composition, and function of the region's ecosystems. Human activities often have wide-ranging impacts such as the lasting impacts of historic sheep grazing, or the widespread effects of industrial, resource-extraction, and agricultural activities (e.g., air- and water-borne pollutants and nutrients). Airborne pollutants may play the most important role in high-altitude systems because of the increased concentration of pollutants at high elevations (Stottlemyer et al. 1997) and the influential role of atmospheric quality and climate patterns in alpine zones. Loss of ozone (5–10% over the U.S., depending on the season) increases ultra-violet radiation, with several impacts on physiological and ecological processes—primarily, increases in damage to DNA and inhibited development of vegetation (WMO 2003). Increases of atmospheric CO_2 may result in a reduced need for photosynthetically efficient plants, possibly resulting in changes in vegetation (e.g., treeline, species composition). Nitrogen deposition has been shown to drive species-dominance changes in alpine communities (Bowman et al. 1995).

A.3.3 Biotic processes

Introduction of exotic plants into the alpine/subalpine zone does not play as important a role in vegetation community modification as it does in lower-elevation zones. However, exotic species can occur in high-altitude areas, especially where trails and roads have been established. As climate and atmospheric conditions change, alpine environments are likely to become more suitable for species previously restricted to lower elevations; therefore, we should expect to see increasing numbers of invasive species in alpine areas.

Herbivory (wild and domestic grazing and browsing) alters composition of alpine systems through plant consumption and trampling. Historically, sheep were grazed across many alpine areas in the west, but the lasting effects of these activities are largely unknown. Wild-ungulate herbivory can be substantial when use is concentrated; for example, modification of shrub structure affects patterns of snowpack accumulation and, subsequently, hydrology and herbaceous species composition. Elk herbivory is a primary consideration, because intensive browsing of shrubs by elk can have drastic effects on the stature of mature individuals and survival of immature individuals (e.g., at ROMO). Although herbivory is not as significant a stressor as some of the climatic factors, it works synergistically with other drivers to alter alpine vegetation community composition.

The composition and altitudinal limits (timberline and treeline) of subalpine forests vary according to the combined influence of several key drivers (Hessl and Baker 1997; Klasner and Fagre 2002). Ongoing warming, nutrient deposition, diseases, and changes in snowpack are expected to cause an observable rise in the elevation of treeline. Although this change is slow, evidence of past treeline locations can be found in presence of tree remnants well up in the alpine zone (Graumlich 1991; Lloyd and Graumlich 1997). Consequently, the composition and upper limits of subalpine forest may be good indicators of changes occurring within ROMN parks. For example, whitebark pine, an important subalpine treeline species, has become infected with blister rust over the past several decades (Keane et al. 1994) in GLAC. This disease has the potential to eliminate or greatly reduce the whitebark pine community, thus eliminating whitebark pine seeds, a primary food source for threatened grizzly bears. Blister rust is also affecting five-needle pines in ROMO and GRSA, but is currently having less impact in those parks than in GLAC.

A.4. Stream Characterization Model

A.4.1 Climate and physical processes

Climate plays a large role in many aspects of ROMN stream systems. Changes in climate, both short- and long-term, can directly and indirectly affect hydrology, temperature, channel morphology, and many other aspects of streams. Watershed-scale processes and structure typically interact with climatic variation (Ziemer and Lisle 1998). Extreme variability in stream discharge selects for organisms that have stress-resistant life stages, short generation times, rapid growth, rapid colonization potential, or combinations of these traits (Matthews 1988; Gray and Dodds 1998). Water temperature influences a number of biological processes. Increasing temperature can affect the biota of rivers directly—for example, by limiting distribution of coldwater species (Rahel et al. 1996) or by affecting fish growth rates, including those of invasive species like lake trout (Hill and Magnuson 1990). Glacial meltwater can ameliorate some of this variability by providing critical additions to base streamflow (Kohshima 1987). However, declining glacial mass balance suggests that this hydrologic pattern will not persist in the future. Climate variability also impacts seasonal timing of ice-out. While more important in lake systems (Likens 2000), ice-out also occurs on rivers and sets many important seasonal cycles in lotic and riparian systems (Magnuson et al. 2000).

The morphology of stream channels and off-channel areas (e.g., backwaters, border fill) is a function of hydrology that is, in turn, driven largely by climate (precipitation and snowmelt) and the geology of the drainage basin. Bedrock geology, topography, and climatic factors, along with valley form, determine, in large part, the morphology of rivers and streams, as they adjust to valley gradient and varying supplies of water and sediment inputs. Stream morphology impacts nearly every aspect of the physical structure of streams, from stream discharge and power, to water temperature and substrate composition, to habitat quality for amphibians and juvenile fish (Gozlan et al. 1998; Giannico and Hinch 2003). Hydrology also impacts the interaction between a stream and its floodplain. Especially in larger systems (Junk et al. 1989) and in areas with a prominent hyporheic zone, groundwater hydrology can structure the physical and biological nature of a system (Hynes 1983; Stanford and Ward 1993).

Sediment load, substrate type, and substrate composition are also key components in streams. Low-frequency, high-sediment load flows that exceed the banks lead to channel changes that may be irreversible or require decades to recover (Wolman and Gerson 1978). Sediment load and discharge generate alternating deep (pool) and shallow (riffle) areas as a result of particle sorting. Sedimentation affects some components of a stream more than others; it is important in the succession of riverine plant communities and, along with plankton, controls the turbidity of water. Increased sediment deposition can also decrease the availability of gravel spawning habitat for fish and invertebrate habitat (Osmundson et al. 2002; Chutter 1972; Brusven and Prather 1974; Berkman and Rabeni 1987) and smother eggs and larvae (Soulsby et al. 2001). Furthermore, sedimentation increases the amount of total suspended solids in the water, increasing turbidity and decreasing the photosynthetic potential of submerged aquatic plants (Blanch et al. 1998; Parkhill and Gulliver 2002) and algae (Weitzel 1979). This can lead to reduced plant vigor and the depletion of dissolved oxygen in water.

Water-quality attributes (physiochemistry) have a well-established role as important drivers in streams. For example, low dissolved oxygen concentrations can make certain areas of a system unsuitable for use by fish and may occasionally cause fish kills. Metals and toxic chemicals can concentrate in the tissues of fish and bioaccumulate in organisms (Cabana and Rasmussen 1994). Nutrient dynamics and nutrient cycles are another important aspect of water quality (Baron et al. 2000). The effects of nutrient deposition in streams can vary because of the buffering capacity of the watershed. When significant amounts of introduced nitrogen (or other nutrients such as phosphorus) become part of a stream, primary production and species composition shifts often drive extreme fluctuations in dissolved oxygen and nutrient availability, triggering a cascading system decline.

A.4.2 Human activities

Anthropogenic drivers in streams typically involve modification of the physical and biological agents of change that operate in these systems, for instance, modification of the hydrologic cycle through impoundment and drawdown, modification of land cover at the watershed and local scales, and point input of pollutants and sediment. Physical and chemical modifications on one part of the landscape generally have direct and indirect impacts on physical and chemical conditions and the community structure of streams and rivers far beyond their point of impact.

Visitors can directly affect lotic ecosystems, especially in parks with intense recreational fishing. Visitors may also facilitate the dispersal of exotic species, start fires that affect riparian cover and sediment input, and impact wildlife behavior and habitat utilization. Indirect effects include creating demand for expansion of visitor-use facilities; increasing human use can only exacerbate human impacts.

Disruption of the hydrologic cycle (which is often referred to as the most important driver in streams; (Richter et al. 1997a; Poff et al. 1997; Galat and Lipkin 2000), is a primary stressor of most stream systems; it changes the interaction of the channel with its floodplain and can dramatically alter the variability in a hydrograph. Dams and diversion structures can change the morphology of downstream reaches, causing downcutting and channel armoring. ROMN parks are not directly influenced by major dams, but most do suffer indirect effects from down- or upstream impoundments and several (e.g., FLFO) have smaller dams or remnants that impact streams. The most extreme hydrologic land-use change occurs with urban development: impervious surfaces reduce infiltration and increase run-off, and smooth surfaces speed movement of water to streams, making the run-off regime flashier, with shorter time lags and higher peaks. Established urban areas also have a characteristic signature, yielding a peak of (often noxious) sediment with the first rain of the season as accumulated toxins are flushed off streets and out of storm drains.

Land use (agricultural, residential, and industrial) also impacts streams. Run-off and sediment transport differ dramatically in catchments with similar lithology and climate but different land-use regimes (Jones et al. 2000). For example, the intensive forestry around GLAC, ROMO, and FLFO can produce several times the pre-modification run-off and sediment load in a stream. Agricultural land use usually involves fertilizers, pesticides, and herbicides, all of which travel with surface run-off into streams. In general, run-off through both agricultural and urban landscapes can contaminate streams with a variety of toxins (Pedersen et al. 2002).

An indirect anthropogenic impact on streams in the ROMN is high nitrogen loading from atmospheric deposition, particularly in areas downwind from power plants or intensive agriculture (Fenn et al. 2003). For example, deposition in Loch Vale (ROMO) has been implicated in changing lake phytoplankton assemblages (Baron et al. 2000; Wolfe et al. 2001). Eutrophication from excess nutrients is also a pervasive stress in many streams through increased primary production, changing biotic assemblages, and decreased water clarity (Smith 1998; Goldman 1988; Peterson et al. 1998).

Mineral and petrochemical extraction (historically at GRKO and a current concern outside GLAC) also has well-documented impacts on streams. Mining produces sediment and noxious chemicals that arise from oxidation of exposed subsoil or direct use in mineral extraction (e.g., the use of mercury to extract gold from crushed ore). Acidic mine drainage is one of the more pervasive impacts on streams in mountainous areas like the ROMN (Clements et al. 1988; Herlihy et al. 1990; Niyogi et al. 2002).

Finally, direct use of streams by humans can have a variety of impacts. National parks are often prime fisheries, and fishing can create multiple impacts to stream biota above and beyond the actual taking of fish. In particular, navigation to sites can facilitate dispersal of exotic species and disease (e.g., zebra mussels, tamarisk, whirling disease), generate pollution from exhaust gases (two-cycle boat motors produce more emissions than most autos, and their exhaust is partially injected into the water), and increase bank erosion and associated turbidity due to boat wakes.

A.4.3 Biotic processes

Exotic species are another biological stressor impacting streams in and around ROMN parks. During the past half-century, the indigenous fisheries of GLAC and ROMO have been radically altered from their pristine condition through introductions of non-native fishes (Taylor et al. 1984; Marnell 1986; Moyle et al. 1986). Impacts include establishment of non-native fish populations in historically fishless waters, genetic contamination (i.e., hybridization) of native taxa, and ecological interferences with various life-history stages. Other species, such as zebra mussels (*Dreissena polymorpha*), Eurasian watermilfoil (*Myriophyllum spicatum*), the spiny water flea (*Bythotrephes cederstroemi*), New Zealand mudsnails (*Potamopyrgus antipodarum*), multiple riparian and aquatic plants such as tamarisk (*Tamarix spp.*), and purple loosestrife (*Lythrum salicaria*), also threaten many aquatic systems in ROMN parks. These species have changed ecosystem structure and composition wherever they have successfully colonized.

Pathogens, diseases, and parasites also can be a problem in streams. The sources of most pathogens include fecal material from wildlife or livestock and malfunctioning septic systems. In urban areas, the major sources are pet wastes, wildlife that may be present in high numbers (such as birds), septic systems, and discharge from sewage treatment plants. Whirling disease (*Myxobolus cerebralis*) has invaded rivers in the ROMN region, impacting the native cutthroat trout populations (Ruzycki et al. 2003).

Overgrazing of uplands, especially in the riparian corridor, can be another biotic stressor in streams. Overgrazing increases both the water and sediment yield in drainage, and affects succession and plant structure in riparian systems (Johnson 1994; Scott et al. 1997). Trampling of uplands compacts the soil and increases the ratio of run-off to infiltration, thereby increasing peak flows while decreasing base flows.

A.5 Wetland Characterization Model

A.5.1 Climate and physical processes

Weather patterns are closely linked to wetland conditions because of atmospheric controls of the growing season and landscape-level water supply. Climate controls the hydrologic regime of streams, influencing riparian wetlands through the timing and magnitude of flows. Most precipitation in the higher-elevation mountains and valleys of the ROMN occurs in the form of snow; high-elevation areas generally receive much greater amounts of precipitation than lower-elevation areas. The input of water via precipitation supports an abundance of wetlands of varying types, because large, groundwater-driven wetland complexes are found primarily in association with aquifers recharged by snowmelt.

Hydrology plays a fundamental, determining role in the function and structure of wetlands. Surface-water supply is produced by climate (with some interactions with topography and vegetation). Groundwater is driven by precipitation, but because of spatial and temporal effects of the landscape and geology with annual supplies, dynamics associated with groundwater occur at a different temporal scale than precipitation-driven surface hydrology. Groundwater hydrology is critical to wetland delineation and definition; the relationship between groundwater and the surface distinguishes a riparian system from a fen, marsh, or bog system, and from upland communities relatively far from the water table. Prolonged drought or increasing evapotranspiration stress (moisture limitation driven by temperature stress) will have marked effects on the condition, composition, and structure of wetland vegetation. Some wetlands are connected to glacial-melt hydrology. As a glacier melts, debris within the ice is deposited, creating kettles and ground moraines that often form wetlands. Therefore, climate change and associated glacial declines will impact some ROMN wetlands.

Differences in mineral-ion and salt concentrations dissolved in groundwater (which supplies fens) influence plant species composition largely by forming mineral-rich to mineral-poor gradients (Cooper and Andrus 1994). The presence of calcium carbonate ($CaCO_3$) in rocks has particular functional importance for wetlands, because $CaCO_3$ is dissolved into surface- and groundwater, affecting pH and nutrient availability. Thus, depending on the geology, calcareous wetlands are expected to respond differently to atmospheric chemical deposition than non-calcareous ones.

Finally, landscape conditions are drivers (and stressors) of wetland condition. Excess sediment can accumulate from upland erosion (e.g., overland flows, gullying, mass wasting). Human and wildlife activities in wetlands may influence these rates by affecting the loading and deposition of waters that flow through a wetland. Further, human activities on the upland that introduce or expose chemicals (e.g., pollutants) are transported via surface flows and often deposited in wetlands with other sediments. Fire is a natural disturbance in uplands that can have detrimental effects on wetland condition and function. Post-fire environments are prone to erosion; severe events (e.g., heavy rain before vegetation re-establishment) can lead to heavy sediment loading in wetland and aquatic systems.

A.5.2 Human activities

Hydrologic alteration, such as diversion of surface waters, wells for access to groundwater, and, in some cases, land-filling, is the primary anthropogenic stressor causing wetland loss and dysfunction. These activities have direct impacts on wetland distribution and function.

Nutrient loading also can have critical impacts on wetland function. Sources of excess nutrients include emissions from industrial and energy processes, automobiles, and agricultural and domestic run-off. Some pollutants are toxic (e.g., heavy metals from mine tailings), whereas others may appear benign or beneficial to the system while actually causing a fundamental disruption of primary production patterns, nutrient budgets, and species composition (e.g., eutrophication due to excess nitrogen availability).

Disturbances including fire, forestry, mining, agriculture, livestock grazing, and other domestic and industrial developments in the uplands of a watershed often have direct, deleterious effects on wetland conditions. Changing the topography or vegetation structure within the uplands of a watershed directly affects the storage and flow of water through that watershed. Removal of vegetation (e.g., associated with roads, logging, and grazing) destabilizes the surface environment, resulting in increased erosion (i.e., sediment loading in the downslope wetland and aquatic systems). In addition, human activities often have wide-ranging effects on biotic communities. Land-use conversions to agricultural or domestic applications generally bring non-native species to an area. Extermination of local, native species (e.g., beaver and wolves) is also a legacy of human use that may affect wetland conditions (see below).

A.5.3 Biotic processes

The local extirpation of beavers has been a critical biotic modification of stream and wetland systems in the Rocky Mountain region. The hydrologic manipulation provided by beaver activities has immediate effects on the local water table both upstream and downstream from a dam, as well as long-term effects on the hydrology and geomorphology of entire valleys and stream systems. Therefore, the population dynamics and landscape distribution of beavers have critical effects on the distribution, function, and condition of mountain wetlands. Extirpation of large carnivores (except in GLAC) also may be responsible for a decline in shrub stature and production in wetlands, because the presence or absence of carnivores affects the behavior of large ungulates, especially elk. Heavy use of wetlands by elk leads to significant biomass removal and has a cumulative effect on the condition of vegetation. Because ungulates prefer to eat new growth (branch leaders and new sprouts), ongoing heavy use can reduce reproductive success of shrubs and trees; this results in damage and population decline (documented in Kawaneechee Valley of ROMO; Westbrook et al. 2006; D. Cooper, pers. comm.).

The presence of water and nutrient-rich surface soils, coupled with periodic disturbances (e.g., hydrologic, animal, human) make wetlands a favorable landscape type for exotic species invasions. Tamarisk and Russian olive are woody invaders of wetlands, especially riparian systems. Numerous other wetland invaders are also common—for example, purple loosestrife (*Lythrum*), toadflax (*Linarea*), and leafy spurge (*Euphorbia*)—and the list of "new arrivals" is steadily growing as human uses facilitate transportation and establishment of many species. Biotic integrity, as indicated by multiple measures (e.g., species richness and relative composition of native, annual, and invasive species) is a primary component of wetland condition and function; terefore, the introduction of exotic species and loss of natives is a systemic, management, and monitoring concern for ROMN wetlands.

The position of wetlands at the interface between upland and aquatic systems makes the interaction of hydrology, soil, and biota their defining attribute. Species composition and distributions, as well as functional characteristics, are fundamentally connected to the hydrologic regime; therefore, biotic processes of wetlands are fundamentally connected to physical processes.

A.6 Literature Cited

Bailey, R. G. 1976. Ecoregions of the United States [Map]. Ogden, Utah: USDA Forest Service.

Baron, J. S., H. M. Reuth, A. M. Wolfe, K. R. Nydick, E. J. Allstott, J. T. Minear, and B. Moraska. 2000. Ecosystem responses to nitrogen deposition in the Colorado Front Range. Ecosystems **3**:352–368.

Bedford, B. L., M. R. Walbridge, and A. Aldous. 1999. Patterns in nutrient availability and plant diversity of temperate North American Wetlands. Ecology **80**(7):2151–2169.

Berkman, H. E., and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes **18**:285–294.

Billings, W. D., and L. C. Bliss 1959. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. Ecology **40**(3):388–397.

Blair, J. M., T. R. Seastedt, C. W. Rice, and R. A. Ramundo. 1998. Terrestrial nutrient cycling in tallgrass prairie. Pages 222–243 *in* A. K. Knapp, J. M. Briggs, D. C. Hartnett, and S. L. Collins, eds., Grassland dynamics: long-term ecological research in tallgrass prairie. Oxford: Oxford University Press.

Blanch, S. J., G. G. Ganf, and K. F. Walker. 1998. Growth and recruitment in Vallisneria americana as related to average irradiance in the water column. Aquatic Botany **61**:181–205.

Bowman, W. D., T. A. Theodose, and M. C. Fisk. 1995. Physiological and production responses of plant-growth forms to increases in limiting resources in alpine tundra: implications for differential community response to environmental change. Oecologia **101**(2): 217–227.

Cabana, G., and J. B. Rasmussen. 1994. Modeling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature **372**:255–257.

Chutter, F. M. 1972. Empirical biotic index of quality of water in South African streams and rivers. Water Research **6**(1):19–25.

Clements, W. H., D. S. Cherry, and J. Cairns Jr., 1988. Impact of heavy metals on insect communities in streams: A comparison of observational and experimental results. Can. J. Fish. Aquat. Sci. **45**:2017–2025.

Cooper, D. J., and R. E. Andrus. 1994. Patterns of vegetation and water chemistry in peatlands of the west-central Wind River Range, Wyoming, USA. Canadian Journal of Botany/Revue Canadienne De Botanique **72**(11):1586–1597.

Detling, J. K. 1998. Mammalian herbivores: Ecosystem-level effects in two grassland national parks. Wildlife Society Bulletin **26**:438–448.

Fedkiw, J. 1989. The evolving use and management of the nation's forests, grasslands, croplands, and related resources, USDA-Forest Service, General Technical Report RM-175, September.

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

Frank, D. A., and S. J. McNaughton. 1992. The ecology of plants, large mammalian herbivores and drought in Yellowstone National Park. Ecology **73**:2043–2058.

Galat, D. L., and R. Lipkin. 2000. Resorting ecological integrity of great rivers: Historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia **422**: 29–48.

Giannico, G. R., and S. G. Hinch. 2003. The effect of wood and temperature on juvenile coho salmon winter movement, growth, density, and survival in side-channels. River Research and Applications **19**:219–231.

Goldman, C. R. 1988. Primary productivity, nutrients, and transparency during the early onset of eutrophication in ultraoligotrophic Lake Tahoe, California–Nevada. Limnology and Oceanography **3**:1321–1333.

Gozlan, R. E., S. Mastrovillo, F. Dauba, J. N. Torenq, and G. H. Copp. 1998. Multi-scale analysis of habitat use during late summer for 0+ fishes in the River Garonne (France). Aquatic Sciences **60**:99–117.

Graumlich, L. J. 1991. Sub-alpine tree growth, climate, and increasing CO2: An assessment of recent growth trends. Ecology **72**(1):1–11.

Gray, L. J., and W. K. Dodds. 1998. Structure and dynamics of aquatic communities. Pages 177–189 *in* A. K. Knapp, J. M. Briggs, D. C. Hartnett, and S. L. Collins, eds., Grassland dynamics. New York: Oxford University Press.

Hartley, E. A. 1976. Man's effects on the stability of alpine and subalpine vegetation in Glacier National Park, Montana. Ph.D. dissertation, Duke University, Durham, N.C.

Herkert, J. R. 1993. Habitat establishment, enhancement and management for forest and grassland birds in Illinois. Technical Publication 1. Springfield, Ill.: Illinois Division of Natural Heritage.

______. 1994. The effects of habitat fragmentation on midwestern grassland bird communities. Ecological Applications **4**:461–471.

Herlihy, A. T., P. R. Kaufmann, and M. E. Mitch. 1990. Regional estimates of acid mine drainage impact on streams in the mid-Atlantic and southeastern United States. Water, Air, & Soil Pollution **50**(1–2):91–108.

Hessl, A. E., and Baker, W. L. 1997. Spruce-fir growth form changes in the forest–tundra ecotone of Rocky Mountain National Park, Colorado, USA. Ecography **20**(4):356–367.

Hobbs, N. T., D. S. Schimel, C. E. Owensby, and D. J. Ojima. 1991. Fire and grazing in tallgrass prairie: Contingent effects on nitrogen budgets. Ecology **72**:1374–1382.

Hynes, H. B. N. 1983. Groundwater and stream ecology. Hydrobiologia **100**(1):93–99.

Jackson, P. L. 1998. Spatial changes in alpine treeline vegetation patterns along hiking trails in Glacier National Park, Montana. M.S. thesis. Oregon State University, Corvallis, Oregon.

Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. Ecological Monographs **64**:45–84.

Jones, K. B., D. T. Heggem, T. G. Wade, A. C. Neale, D. W. Ebert, M. S. Nash, M. H. Mehaffey, K. A. Hermann, A. R. Selle, S. Augustine, and others. 2000. Assessing landscape condition relative to water resources in the western United States: A strategic approach.

Environmental Monitoring and Assessment **64**(1):227–245.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Can. Spec. Publ. Fish Aquat. Sci. **106**:110–127.

Keane, R. W., P. Morgan, and J. P. Menakis. 1994. Landscape assessment of the decline of Whitebark pine (Pinus albicaulis) in the Bob Marshall Wilderness Complex, Montana, USA. Northwest Science **68**(3):213–229.

Klasner, F. L., and D. B. Fagre. 2002. A half-century of change in alpine treeline patterns at Glacier National Park, Montana, USA. Arctic, Antarctic and Alpine Research **34**:49–56.

Knopf, F. L., and F. B. Samson. 1996. Conservation of grassland vertebrates. Pages 273–289 *in* F. L. Knopf and F. B. Samson, eds., Ecology and conservation of Great Plains vertebrates. New York: Springer-Verlag.

Kohshima, S. 1987. Glacial biology and biotic communities. Pages 77–91 *in* S. Kawano, J. H. Connell, and T. Hidaka, eds., Evolution and coadaptation in biotic communities. Kyoto, Japan: University, Kyoto.

Kuchler, A. W. 1975. Potential natural vegetation of the conterminous United States [Map]. New York: American Geographical Society.

Likens, G. E. 2000. A long-term record of ice cover for Mirror Lake, New Hampshire: Effects of global warming? Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie **27**:2765–2769.

Lloyd, A. H., and L. J. Graumlich. 1997. Holocene dynamics of treeline forests in the Sierra Nevada. Ecology **78**(4):1199–1210.

Magnuson, J. J., D. M. Robertson, B. J. Benson, R. H. Wynne, D. M. Livingstone, T. Arai, R. A. Assel, R. G. Barry, V. Card, E. Kuusisto, N. G. Granin, T. D. Prowse, K. M. Stewart, and V. S. Vuglinski. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. Science 289:1743–1746.

Manier, D. J., and N. T. Hobbs. 2006. Large herbivores influence the composition and diversity of shrub-steppe communities in the Rocky Mountains, USA. Oecologia **146**:641–651.

Marnell, L. F. 1986. Impacts of hatchery stocks on wild fish populations. Pages 339–347 *in* R. H. Stroud, ed., Fish culture in fisheries management. Bethesda, Md.: American Fisheries Society.

Marr, J. W. 1977. The development and movement of tree islands near the upper limit of tree growth in the southern Rocky Mountains. Ecology 58:1159–1164.

Matthews, W. J. 1988. Patterns in freshwater fish ecology. New York: Chapman and Hall. (Second printing, May 1998, Kluwer Academic Press.)

Moyle, P. B., H. Li, and B. A. Barton. 1986. The Frankenstein effect: Impact of introduced fishes in North America. Pages 415–426 *in* R. H. Stroud, ed., Fish culture in fisheries management. Bethesda, Md.: American Fisheries Society.

Nelson, E. J. and D. B. Booth. 2002. Sediment sources in an urbanizing, mixed land use watershed. Journal of Hydrology **264**:51–68.

Niyogi, D. K., W. M. Lewis, Jr., and D. M. McKnight. 2002. Effects of stress from mine drainage on diversity, biomass, and function of primary producers in mountain streams. Ecosystems **5**:554–567.

Ojima, D. S., W. J. Parton, D. S. Schimel, and C. E. Owensby. 1990. Simulated impacts of annual burning on prairie ecosystems. Pages 118–132 *in* S. L. Collins and L. L. Wallace, eds., Fire in North American tallgrass prairies. Norman, Okla.: University of Oklahoma Press.

Osmundson, D. B., R. J. Ryel, V. L. Lamarra, and J. Pitlick. 2002. Flow–sediment–biota relations: Implications for river regulation effects on native fish abundance. Ecological Applications **12**:1719–1739.

Parkhill, K. L., and J. S. Gulliver. 2002. Effect of inorganic sediment on whole-stream productivity. Hydrobologia **472**:5–17.

Paul, M. J. and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics **32**:333–365.

Pedersen, J. A., M. A. Yeager, and I. H. Suffet. 2002. Characterization and mass load estimates of organic compounds in agricultural irrigation runoff. Water Science and Technology **45**(9):103–110.

Peterson, D. L., T. J. Sullivan, J. M. Eilers, S. Brace, D. Horner, K. Savig, and D. Morse. 1998. Assessment of air quality and air pollutant impacts in National Parks of the Rocky Mountains and northern Great Plains. Technical Report NPS D-657. Denver, Colo.: National Park Service.

Poff, N. L, J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Ritcher, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience **47**:769–784.

Rahel, F. J., C. J. Keleher, and J. L. Anderson. 1996. Potential habitat loss and population fragmentation for cold water fish in the North

Platte River drainage of the Rocky Mountains: Response to climate warming. Limnology and Oceanography **41**:1116–1123.

Richter, B. D., D. P. Braun, M. A. Mendelson, and L. L. Master. 1997a. Threats to imperiled freshwater fauna. Conservation Biology **11**:1081–1093.

Ruzycki, J. R., D. A. Beauchamp, and D. L. Yule. 2003. Effects of introduced lake trout on native cutthroat trout in Yellowstone Lake. Ecological Applications **13**(1):23–37.

Sauer, C. O. 1950. Grassland climax, fire, and man. Journal of Range Management **3**:16–21.

Schlesinger, W. H. 1997. Biogeochemistry: An analysis of global change. Second edition. San Diego, Calif.: Academic Press.

Scott, M. L., G. T. Auble, and J. M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications **7**(2):677–690.

Seastedt, T. R. 1988. Mass, nitrogen, and phosphorus dynamics in foliage and root detritus of tallgrass prairie. Ecology **69**:59–65.

______. 1995. Soil systems and nutrient cycles on the North American prairie. Pages 157–174 *in* A. Joern and K. H. Keller, eds., The changing prairie. Oxford: Oxford University Press.

Seastedt, T. R., W. D. Bowman, T. N. Caine, D. McKnight, A. Townsend, and M. W. Williams. 2004. The landscape continuum: A model for high-elevation ecosystems. BioScience **54**(2):111–121.

Smith, V. 1998. Development of a priority area restoration and protection plan for a moderately sized agricultural watershed in southwestern Wisconsin. In Rivers, the future frontier. Proceedings of the 1998 Symposium April 28–May 3, 1998. Anchorage, Alaska: River Management Society.

Soulsby, C., A. F. Youngson, H. J. Moir, and I. A. Malcolm. 2001. Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: A preliminary assessment. Science of the Total Environment **265**(1–3):295–307.

Stanford, J. A., and J. V. Ward. 1993. An ecosystem perspective of alluvial rivers: Connectivity and the hyporheic corridor. Journal of the North American Benthological Society **12**:48–60.

Stottlemyer, R., C. A. Troendle, and D. Markowitz. 1997. Change in snowpack, soil water, and streamwater chemistry with elevation during 1990, Fraser Experimental Forest, Colorado. Journal of Hydrology (Amsterdam) **195**(1–4):114–136.

Taylor, J. N., W. R. Courtenay, Jr., and J. A. McCann. 1984. Known impacts of exotic fishes in the continental United States. Pages 322–373 *in* W. R. Courtenay, Jr., and J. R. Stauffer, eds., Distribution, biology, and management of exotic fishes. Baltimore: Johns Hopkins University Press.

Tranquillini, W. 1979. Physiological ecology of the alpine timberline. New York: Springer-Verlag.

Walsh, S. J., D. R. Butler, T. R. Allen, and G. P. Malanson. 1994. Influence of snow patterns and snow avalanches on the alpine treeline ecotone. Journal of Vegetation Science **5**:657–672.

Weitzel, R. L. 1979. Periphyton measurements and applications. In R. L. Weitzel, ed., Methods and measurements of periphyton communities: A review. Special Technical Publication 690. American Society for Testing and Materials.

Westbrook, C. J., D. J. Cooper, and B. W. Baker. 2006. Beaver dams and overband floods influence groundwater–surface water interactions of a Rocky Mountain riparian area. Water Resour. Res. 42:W06404, doi:10.1029/2005WR004560.

Williams, M. W., M. Losloben, N. Caine, and D. Greenland. 1996. Changes in climate and hydrochemical responses in a high-elevation catchment in the Rocky Mountains, USA. Limnol. Oceanog. **41**(5):939–946.

World Meteorological Organization (WMO). 2004. Cited in text as 2003 The Integrated Global Atmospheric Chemistry Observations (IGACO) Report of IGOS-WMO-ESA (September). WMO TD No. 1235. http://www.wmo.ch/web/arep/gaw/gawreports.html.

Wolfe, A. P., J. S. Baron, and R. J. Cornett. 2001. Anthropogenic nitrogen deposition induces rapid ecological changes in alpine lakes of the Colorado Front Range (USA). Journal of Paleolimnology **25**(1):1–7.

Wolman, M. G., and R. Gerson. 1978. Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surface Processes **3**:189–208.

Ziemer, R. R., and T. E. Lisle. 1998. Hydrology. In R. J. Naiman and R. E. Bilby, eds., River ecology and management: Lessons from the Pacific Coastal Ecoregion. New York: Springer-Verlag.

Appendix B
Vital Signs Development

B.1 Preliminary Vital Signs

Two methods were used to create the initial set of preliminary Vital Signs (VS) for the ROMN. These are briefly summarized below.

B.1.1 Literature search

We surveyed existing regional monitoring programs (primarily USGS, USFS, and EPA), ongoing NPS monitoring, academic research programs, and multiple other NPS Networks to generate a list of preliminary VS relevant to possible ROMN monitoring objectives. These were classified by the National VS framework (see Chapter 3) and resulted in approximately 600 preliminary VS. This list is not given here due to its size, but may be obtained upon request.

B.1.2 Survey

We also conducted an e-mailed survey of over 70 ROMN collaborators prior to each Vital Sign workshop. In essence, this was an informal "Delphi" survey to obtain input from experts regarding the design of VS monitoring in the ROMN parks. The Delphi method has been used elsewhere as an approach for obtaining input on the design of resource monitoring programs (e.g., Davis 1997; Oliver 2002a,b). Participants were asked to evaluate and prioritize potential indicators or suites of indicators on the basis of several criteria. These criteria were also used in the VS workshops and the associated database - so they are described below. Figure B.1.2 shows the form that was sent to each participant in the survey.

The survey was repeated at the conclusion of each workshop to allow personal "votes" on VS after each workshop participant had been through the collaborative process of the workshop.

Table B.1.2 gives the combined results of the four surveys. This list contains 38 largely unique Vital Signs and represents 71 sets of responses from 63 people. Vital Signs were ordered in the list based on multiple metrics (each participant used the criteria described below – we then had to rank these across all participants). In summary we used the frequency a given VS was ranked by a participant and a weighting scheme that emphasized the top 3 choices (weights were #1 = 0.4, #2 = 0.25, #3 = 0.20, #4 = 0.10, #5 = 0.05). This was normalized to a scale of 0 – 1.0, with 1 being the highest or most important VS.

ROMN Vital Sign Nomination

Goals:
The goal of this survey is to identify a set of candidate Vital Signs that we will discuss during our upcoming workshop. Having this list will save time and ensure that we are able to utilize your expertise to the fullest. At this stage, please consider this effort to be very generalized ("brainstorming") in nature. Your professional experience and gut feeling has immense value and will be a key part of developing our program!

Vital Sign Framework:
To provide a context for each Vital Sign (VS), we are using a hierarchical NPS-wide VS Framework presented in Table 2 (attached below). Using the VS framework places each VS in an ecosystem or ecological process category. The Levels in Table 2 do not have explicit definitions, rather they are intended to facilitate roll-ups that are required for reports to OMB and Congress, impose a logical structure to VS lists, and attach an obvious name or intuitive meaning to Vital Signs.

In some cases, the Level 3 category will be equivalent to a Vital Sign and in others more detail is needed and a Level 4 is required. In cases where Level 3 is sufficient, the Level 3 and Level 4 categories will be identical. It may be necessary (but unlikely) to create a new Level 3 in the hierarchy presented in Table 2, but this must functionally nest within existing Level 2 and 1 classes. The examples in Table 1 may clarify how the VS Level categories are used. In this case, the VS are "Air Quality - Ozone" and "Whitebark Pine Forest Biological Integrity" (respectively) as generated from the synthesis of Levels 1 - 4.

Table 1. Example VS. See Table 2 below for a complete list of Levels 1-3.

Level 1	Level 2	Level 3	*Level 4 (you add)*	*Example Measures (you add)*
Biological Integrity	Focal Species or Communities	Forest vegetation	*Whitebark Pine Forest*	*Stand age counts, canopy structure, patch size*
Air and Climate	Air Quality	Ozone	*Ozone*	*Atmospheric ozone concentration, foliar ozone damage*

Vital Sign Criteria:
We have provided a general set of criteria in Table 3 (attached below) that you can use to evaluate your potential lists of candidate VS. This process will be dealt with in more detail in the workshops.

Items We Need From You
Please list, in order of priority from highest to lowest, the following 3 sets of Vital Signs (VS).

1. The most important VS to monitor.
2. The best set of 3 VSs.
3. The best set of 5 VSs.
4. Optional description for each VS.

For each VS you list, please include a Level 3 category (from Table 2), your (new) Level 4 category (usually the VS) and some example field measures for each VS. We have also included an ***optional*** detailed VS description form you can fill in that will clarify and better describe each VS you propose. THIS IS AN OPTIONAL STEP AND YOU MAY FILL IT IN AS MUCH OR AS LITTLE AS YOU LIKE. It will allow you to (for example) better define the habitat or process of interest, provide relevant details about each VS, etc. *Describing important candidate VS for ROMN will be continued in the VS workshops.*

Please direct questions to Mike Mike_Britten@nps.gov (with a cc to Billy_Schweiger@nps.gov)

Please send your responses electronically to Brent_Frakes@nps.gov
If you prefer to print and fill out a hard copy, please send to Brent Frakes at 1201 Oakridge Drive, Ft. Collins CO 80525

ROMN Vital Sign Nomination Form

Nominator: ____

TOP VITAL SIGN TO MONITOR:

Level 3 Category (From Table 2)	Level 4 Category (new)	Example Measures (new)

TOP 3 VITAL SIGNS:

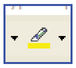
Level 3 Category (From Table 2)	Level 4 Category (new)	Example Measures (new)

TOP 5 VITAL SIGNS:

Level 3 Category (From Table 2)	Level 4 Category (new)	Example Measures (new)

Optional VS Description

Instructions:
Please copy or duplicate this 3 page form for each VS you wish to describe. Type comments directly in each copy and use the highlight tool for selection of categories provided. The last page is also optional and allows you to rank each of your VS (in a relative sense, using the classes in Table 3 above)

The highlight tool is on your toolbar and looks like: 

Level 3 Category (From Table 2)	Level 4 Category (new)	Example Measures (new)

Parks this VS is applicable to:

FLFO GRKO GLAC GRSA LIBI ROMO

Monitoring Questions Related to This VS

Drivers/Stressors the VS Responds to

Highlight levels (Word tool is above) of ecological organization most important for this VS

Sub-Individual Individual Population Guild
Assemblage Community Ecosystem Landscape
Rocky Mountain Region Broader Scale

Highlight spatial scale(s) should this VS be monitored?

Less than Park-Wide Park-Wide Park and Local Buffer State
Rocky Mountain Region Continent Global

At what temporal scale(s) should this VS be monitored?

Continual Daily Monthly Annually Every Other Year
Every 5 Years Every 10 Years Other________________

Level of Spatial Variability of this VS

Unknown Low Medium High

Level of Temporal Variability of this VS

Unknown Low Medium High

Measurement Error of this VS

Unknown Low Medium High

What are the reasons for and types of measurement errors for this VS

List the important associated (related) vital signs to monitor with this candidate VS. What are important measurements to take along with the related VS?

List important species to monitor from a conservation/management perspective (Note: This only applies to ecological organizations that are less than a population)

List species that are common enough for the Network to reasonably (cost-wise) expect to monitor (Note: This only applies to ecological organizations that are less than a population)

What is/are the main spatial sampling strata for this VS?

Site Patches Park Region Other_______________

What is/are the type/structure of the sample design?

Targeted (Ad Hoc) Targeted (Model Driven) Probability

Suggest important design considerations, including the spatial extent, for monitoring the candidate vital sign?

Discuss the measurements for this candidate vital sign, including the units

What is the estimated annual total cost for monitoring this VS?

Unknown $1 $10 $100 $1,000
$10,000 $100,000 $1,000,000

Please comment on your cost estimate and factors that influence cost to monitor this VS

List programs or references for within and outside of Parks (include names and contact information when possible)

Optional Evaluation of VS

Level 3 Category (From Table 2)	Level 4 Category (new)	Example Measures (new)

The relative information availability for this VS is:
Unknown Low Medium High

Comments:

The ecological significance of this VS is:
Unknown Low Medium High

Comments:

The management significance of this VS is:
Unknown Low Medium High

Comments:

The feasibility and cost of Implementation for this VS is:
Unknown Low Medium High

Comments:

The data utility and application for this VS is:
Unknown Low Medium High

Comments:

The relative number and quality of existing data and programs is:
Unknown Low Medium High

Comments:

Figure B.1.2. ROMN vital sign survey form.

Table B.1.2. Candidate vital signs: surveys.

Level03Name	Top1	Top3	Top5	Included in a Set	Weighted Normalized Score
Land cover / Land use	25	13	7	45	1.000
Water chemistry	5	17	6	28	0.476
Weather and Climate	10	8	8	26	0.461
Invasive/Exotic plants	4	17	11	32	0.461
Wet and dry deposition	4	11	7	22	0.339
Air contaminants	5	2	4	11	0.188
Surface water dynamics	0	9	6	15	0.170
Mammals	0	9	5	14	0.162
Vegetation communities	2	4	6	12	0.155
Soil function and dynamics	2	5	3	10	0.148
Freshwater communities	2	4	0	6	0.122
Groundwater dynamics	4	0	1	5	0.118
T&E species and communities	0	5	7	12	0.111
Amphibians and Reptiles	2	2	4	8	0.100
Fire and fuel dynamics	1	3	4	8	0.096
Productivity	1	3	2	6	0.081
Aquatic macroinvertebrates and algae	0	2	9	11	0.077
Nutrient dynamics	1	2	4	7	0.070
Invasive/Exotic animals	0	4	2	6	0.070
Visitor usage	0	3	5	8	0.066
Non-point source human effects	1	1	1	3	0.048
Cultural landscapes	1	0	2	3	0.030
Ozone	0	2	0	2	0.030
Stream / river channel characteristics and processes	0	2	0	2	0.030
Terrestrial communities	0	2	1	3	0.030
Forest vegetation	1	0	1	2	0.026
Birds	0	0	6	6	0.018
Extreme disturbance events	0	0	4	4	0.015
Insect communities	0	0	4	4	0.015
Riparian communities	0	1	1	2	0.015
Visibility and particulate matter	0	0	4	4	0.015
Arctic and alpine tundra	0	1	1	2	0.015
Toxics	0	1	1	2	0.015
Grassland vegetation	0	1	0	1	0.011
Wetland communities	0	1	0	1	0.007
Windblown features and processes	0	1	0	1	0.007
Fish	0	0	1	1	0.000
Glacial features and processes	0	0	1	1	0.000

B.1.3 Vital Sign Meetings

A diverse and multi-disciplinary group of participants were invited to each workshop (Tables B.1.3-1 and B.1.3-2). As an introduction to the Montana VS Objectives workshop, Dr. Jack Stanford, Director of the Flathead Lake Biological Station, presented his perspective on the importance of long-term ecological monitoring in the Flathead River catchment. For the Colorado Workshop, Dr. Jill Baron similarly described her long-term research and monitoring in ROMO and the value and uses of the information for understanding and protecting the park.

Table B.1.3-1. Participants in the Montana Park Vital Signs Objectives Workshop, January 25, 26, and 27, 2005, Flathead Lake Biological Station, MT.

Name	Affiliation
Ben Bobowski	NPS – Grant-Kohrs Ranch NHS
Carl Bock	Univ. Colorado, Boulder
Jane Bock	Univ. Colorado, Boulder
Mike Britten	NPS – Rocky Mountain Network
Don Campbell	USGS – WRD – Colorado District – Alpine Hydrology Research Group
Tara Carolin	NPS – Glacier NP
Steve Corn	USGS – BRD – Aldo Leopold Wilderness Research Unit
Bonnie Ellis	Univ. Montana – Flathead Lake Biostation
Dan Fagre	USGS – Rocky Mountain Science Center – West Glacier Field Station
Brent Frakes	NPS – Rocky Mountain Network
Steve Gniadek	NPS – Glacier NP
Andy Hansen	Montana State Univ.
Cathie Jean	NPS – Greater Yellowstone Network
Bob Keane	USFS – Fire Science Lab
Kim Keating	USGS – Rocky Mountain Science Center
Carl Key	USGS – Rocky Mountain Science Center – West Glacier Field Station
Dan Manier	Colorado State Univ.
Alisa Mast	USGS – WRD – Colorado District – Alpine Hydrology Research Group
Jack Potter	NPS – Glacier NP
Christina Relyea	Univ. Montana – Flathead Lake Biostation
Billy Schweiger	NPS – Rocky Mountain Network
Cyndi Smith	Parks Canada – Waterton Lakes NP
Jack Stanford	Univ. Montana – Flathead Lake Biostation
Bob Stottlemeyer	USGS – Fort Collins Science Center
Kathy Tonnessen	NPS – Intermountain Region – Rocky Mountain Research Coordinator
John Waller	NPS – Glacier NP
Leigh Welling	NPS – Glacier NP – Crown of the Continent Research Learning Center
Mark Williams	Univ. Colorado, Boulder – Niwot Ridge Long-term Ecological Research Site
Gerry Wright	Univ. Idaho Coop. Fish and Wildlife Research Unit

Table B.1.3-2. Participants in the Colorado Park Vital Signs Objectives Workshop, March 1, 2, and 3, 2005, Estes Park, CO.

Name	Affiliation
Stan Austin	NPS – Rocky Mountain NP
Jill Baron	USGS – BRD – Fort Collins Science Center
Pam Benjamin	NPS – Intermountain Region
Pete Biggam	NPS – Inventory and Monitoring Program
Bruce Bingham	NPS – Intermountain Region – Inventory and Monitoring Program
Phyllis Bovin	NPS – Great Sand Dunes NP and Preserve
Mike Britten	NPS – Rocky Mountain Network
Mark Brunson	Utah State Univ.
Fred Bunch	NPS – Great Sand Dunes NP and Preserve
Herb Cabezas	EPA – Office of Research and Development
Dave Clow	USGS – WRD – Colorado District – Alpine Hydrology Research Group
Jeff Connor	NPS – Rocky Mountain NP
David Cooper	Colorado State Univ.
Karl Cordova	NPS – Rocky Mountain NP
Jesse Duhnkrack	NPS – Rocky Mountain NP
Brent Frakes	NPS – Rocky Mountain Network
Larry Gamble	NPS – Rocky Mountain NP
Tom Hobbs	Colorado State Univ.
Therese Johnson	NPS – Rocky Mountain NP
David Klute	Colorado Division of Wildlife
Dan Manier	Colorado State Univ.
Alisa Mast	USGS – WRD – Colorado District – Alpine Hydrology Research Group
Carol McCoy	NPS – Geological Resource Division
Kristi Morris	NPS – Air Resources Division
Erin Muths	USGS – BRD – Fort Collins Science Center
Lisa Norby	NPS – Geologic Resources Division
Kara Paintner	NPS – Biological Resource Management Division – Fire Program
Pete Penoyer	NPS – Water Resources Division
David Pillmore	NPS – Rocky Mountain Network
Ellen Porter	NPS – Air Resources Division
Carlie Ronca	NPS – Rocky Mountain NP
Renee Rondeau	Colorado Natural Heritage Program
Kate Schoenecker	USGS – BRD – Fort Collins Science Center
Terri Schulz	The Nature Conservancy – Colorado Field Office
Billy Schweiger	NPS – Rocky Mountain Network
Terry Terrell	NPS – Rocky Mountain NP
Kathy Tonnessen	NPS – Intermountain Region – Rocky Mountain Research Coordinator
Judy Visty	NPS – Rocky Mountain NP
May Kay Watry	NPS – Rocky Mountain NP
Brad Welch	NPS – Biological Resource Management Division
Rick Wilson	ROMN – Florissant Fossil Beds NM
Marie Zanowick	EPA – Region 8

B.1.4 Vital Signs Database

A critical element of the vital sign selection was use of a relational database to organize information. This database had the following goals:

- Organize the information
- Facilitate discussion
- Allow for easy reporting
- Build on past work and provide foundation for Phase III work.

To accomplish these goals, designing of the database required consideration of the back-end, or how the data was organized, and the front-end, how the data was presented to the users in the workgroup session.

B.1.4.1 Database Structure

Design of the data relationships attempted to balance normalization with function during the workgroup sessions. In total, there were 13 tables, including lookup tables, although six core tables housed the vital information (Figure B.1.4.1). Of the six tables, ***tblGroupVitalSign*** captured most of the information about each group-specific vital sign. Four related tables collected information regarding questions, methods, related vital signs (both as drivers and covariates), and related species.

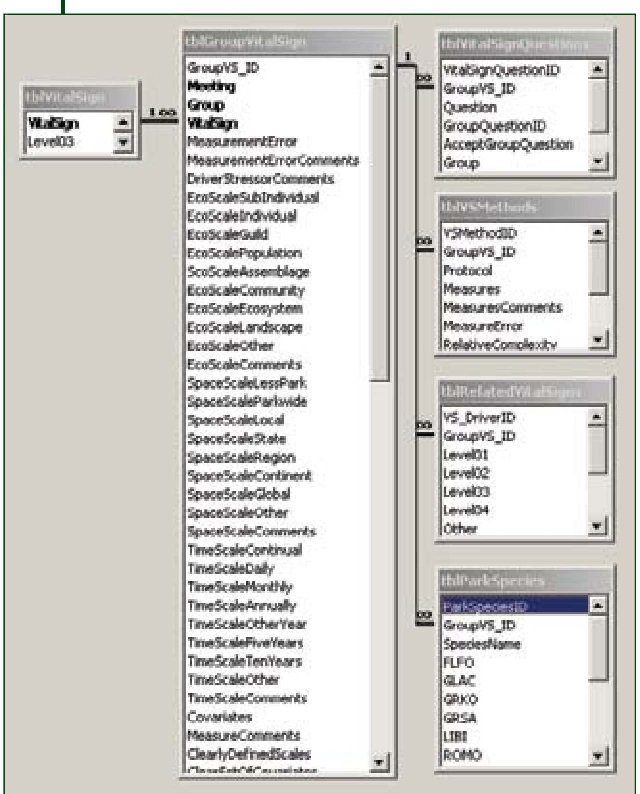


Figure B.1.4.1. ROMN Vital Signs Database table structure.

B.1.4.2 Forms

Equally important as the design of the table relationships were the forms used during the workgroup sessions. These forms had to be clear, easy-to-use, minimize data entry, and guide discussion, and provide an organizing framework.

B.1.4.2.1 Overview

The forms structured the workgroups around four basic steps (Figure B.1.4.2.1).

Step 1: Required the workgroup to select from a predefined list. Workgroups were not allowed to proceed until they specified the correct workgroup.

Step 2: This key step guided the workgroups through a series of forms to answer many different aspects of the vital sign.

Step 3: Once all of the vital signs were discussed, this step allowed the workgroup to review their answers and modify ranks given in Step 2.

Step 4: Provided some useful reporting options to allow for further discussion within and among the workgroups.

Of these four steps, Steps 2 and 4 require more discussion and are covered in the following two sections.

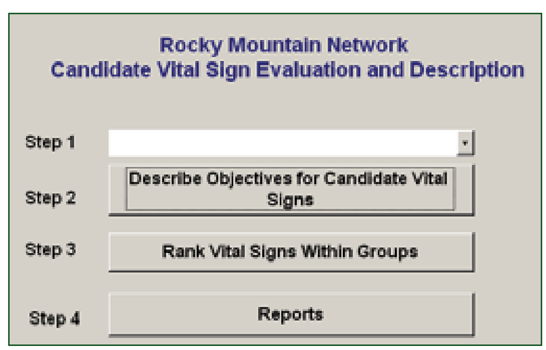


Figure B.1.4.2.1. ROMN Vital Signs Database Initial Form.

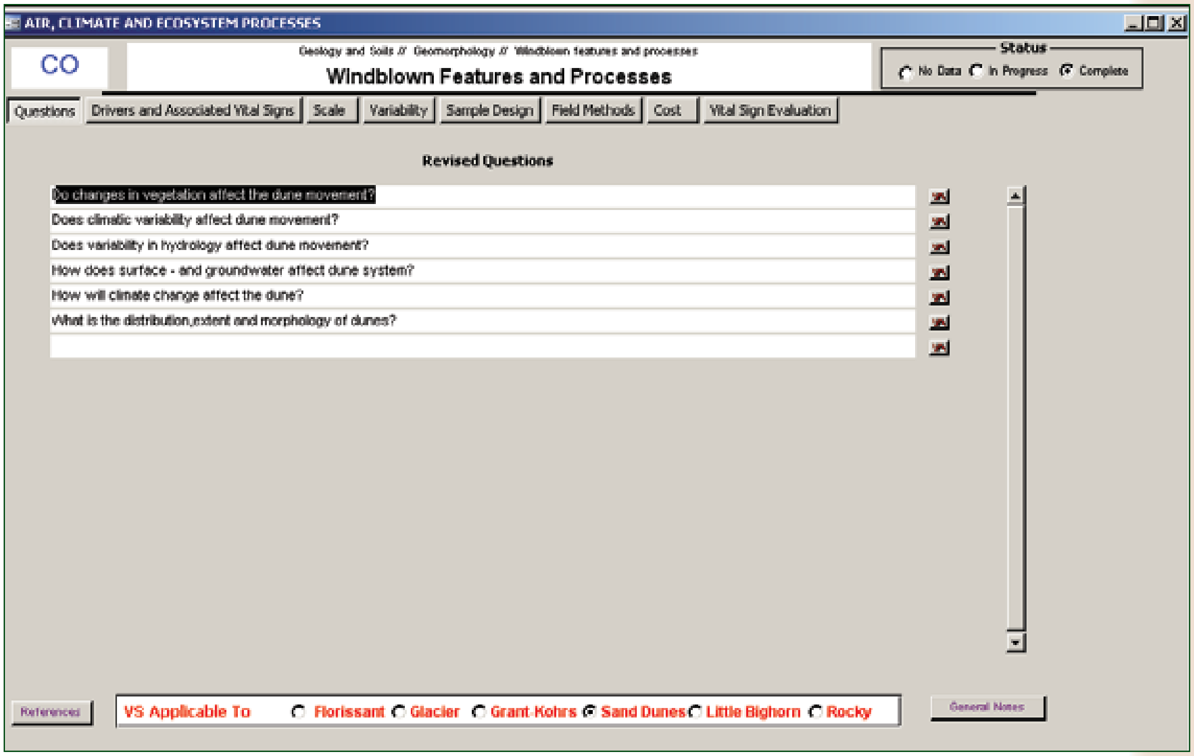


Figure B.1.4.2.2. ROMN Vital Signs Database table structure.

B.1.4.2.2 Vital Sign Descriptions (Step 2)

Step 2 provided a context for the workgroups to detail information about each vital sign. Figure B.1.4.2.2 shows that discussion focused on nine different themes that included:

- Questions – What questions or research objectives did the workgroup have regarding this vital sign
- Drivers and Associated Vital Signs – List related vital signs, either as drivers or co-variates
- Scale – Discuss the ecological scales of organization, and the spatial and temporal scales at which the vital sign should be monitored
- Variability – Relative degrees of spatial and temporal variability and how well the variability is understood
- Sample Design – Determine the type/structure of sample design and the important strata to be measured
- Field Methods – List important protocols and measures for each vital sign
- Cost – Provide a preliminary relative cost of each vital sign

The following text provides brief descriptions of each of these attributes.

B.1.4.2.3 ROMN Vital Sign Attributes

B.1.4.2.3.1 Questions

- Example / General: Compiled monitoring questions for use as examples; they may, or may not, apply to the specific VS under review.
- Revised Questions: Specific questions that express monitoring objectives of the VS. May be classic long-term monitoring in format or more akin to associated research or motivating factors (Monitoring (M) or Research (R)). These questions (or statements) helped focus groups or clarified the intention of the VS.

B.1.4.2.3.2 Drivers and Associated VS

- Other VS that are functionally, operationally, or ecologically related to the focal VS.

- Relationship Strength: Important. Ranks the relative degree which the associated VS is related in a functional and/or an operational sense to the VS under review.
- Driver / Covariate: Classifies the associated VS's relationship with the VS under review. "Drivers" are processes or components within a system that likely affect change in the focal VS. "Covariates" are VS that vary with but do not directly (putatively) cause changes in the VS. "Both" may be used when the associated VS is involved in feedback loops with the focal VS or when this relationship is more ambiguous.

B.1.4.2.3.3 Scale

Ecological Organization

- Sub-individual: Any biological component 'within' a single or multiple individuals of the same species (e.g., organ systems, genes or any component of a species genome).
- Individual: Any living thing considered to be a single genetic individual; includes aggregate measures of physiological "health" or disease load.
- Population: A group of individuals of the same species which inhabit the same geographic area.
- Guild/Assemblage: Guilds are a group of organisms that all make their living in a similar way e.g., seed-eating animals, filter-feeders, fruit eaters. Assemblages are taxonomically related species in the same geographic area
- Community: The whole of the organisms living in a specific area. Includes organisms of different species. Communities are classically described as associations of coexisting populations defined by the nature of the interactions among the populations or the place in which the association occurs.
- Ecosystem: Consists of all the abiotic factors and communities that inhabit a particular area.
- Landscape: Heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout. The spatial scale of landscapes is organism specific; landscapes generally occupy some spatial scale intermediate between an organism's normal home range and its regional distribution, but there is no absolute size for a landscape.

Groups

- Legal: Specific groups (any entity within a level of ecological organization, e.g., a specific taxa) with legal or management status. Use the comments box to specify details of the designation (e.g., Federal Endangered, TNC G1, in a Park RMP, etc.)
- Statistical: Specific groups (any entity within a level of ecological organization, e.g., a specific taxa) that are of note due to their rarity or high abundance. Use the comments box to specify details of the designation (abundant only in park habitat X, too rare to sample efficiently)

Spatial Scale

- Characterizes the area within which sample locations might be distributed to describe patterns in the VS. Should approximately match the spatial variability or structure of interest in the VS.

Temporal Scale

- Characterizes the time-frame or interval across which sample locations should be distributed to describe patterns in the VS. Should approximately match the temporal variability or structure of interest in the VS.

Variability

- Spatial: Relative score of the spatial variability of the VS (1 – low, 10 = high). The answer here should be related to the spatial scale description. Comparisons are with other VS within any workgroup or discipline and should be based on the most characteristic or important set of measures for the VS. Given the variable degree to which a VS is differentiated from its suite of measures (e.g., how 'lumped' a VS is), this score will be a very qualitative 'gut-feeling'. Include comments (e.g. regarding extent, patterns, or complexity) to clarify or classify your numeric ranking. The second score characterizes how well this spatial structure is understood (1 – low, 10 = high). This value is qualified by the same caveats as above.

- Temporal: Relative score of the temporal variability of the VS (1 – low, 10 = high). The answer here should be related to your temporal scale definitions. Comparisons are with other VS within any workgroup or discipline and should be based on the most characteristic or important set of measures for the VS. Given the variable degree to which a VS is differentiated from its suite of measures (e.g., how 'lumped' a VS is), this score will be a very qualitative 'gut-feeling'. Include comments (e.g. short-term or long-term cycles, patterns, complexity, or stochasticity) to clarify or classify your numeric ranking. The second score characterizes how well this temporal structure is understood (1 – low, 10 = high). This value is qualified by the same caveats as above.

B.1.4.2.3.4 Sample Design

Site-level

- VS assessment will describe condition or trend at only the selected location. No inference to non-sampled locations is intended or should be allowed.

Inference to non-sampled locations

- VS assessment will describe condition or trend across non-sampled locations (in addition to the sampled site). An appropriate methodology for this process is required (below).

Type of Sample Design

- Ad-hoc: No known protocol for how sites are arrayed. Often occurs with legacy sites, but may also describe scenarios where an assessment is generated from sites designed for other purposes. Valid inference beyond the site is unlikely.
- Convenience: Sites placed using access sites (e.g., a bridge), with no accommodation for this in the assessment of data generated. Valid inference beyond the site is unlikely.
- Targeted – Site Specific: Sites placed on purpose at known locations of impact or special concern. Valid inference beyond the site should not be the intent of this design.
- Targeted – Model Driven: Sites placed on purpose at locations generated by a model or with the intent to be used in a model for making inference to non-sampled sites. Valid inference beyond the site should be conducted with a model (e.g., NAWQA).
- Probability: Sites placed across the target population using a probability sample design. Valid inference beyond the site should be conducted with design-based inference (e.g., EMAP).
- Census: Sites placed across the entirety of the target population (e.g., remote sensing). A census assesses every "individual" in the population and is therefore not really sampling. Statistical testing does not apply and inference is direct.

Strata

- List geospatial (or temporal) strata that might be used to help partition variance across the target population. Most relevant for Targeted – Model Driven and Probability type designs.

B.1.4.2.3.5 Field Methods

Protocol Name

- Established or intuitive/general name for the protocol or measurement.

Measures

- List of measurement(s) taken within the protocol (e.g., cover, density, pH, concentration, rate)

Measurement Error

- Relative score of the measurement error typical for the measurement(s) being described (1 – low, 10 = high). Comparisons are with other measurements within any workgroup or discipline and should be based on the most characteristic or important set of measures for the VS (if more than one in the protocol). This score will be a very qualitative 'gut-feeling'.

Complexity

- Relative score of the field and/or analytical complexity typical for the measurement(s) being described (1 – low, 10 = high). Comparisons are with other measurements within any workgroup or discipline and should be based on the most characteristic or important set of measures for the VS (if more than one in the protocol). This score will be a very qualitative 'gut-feeling'.

B.1.4.2.3.6 Cost

Relative Cost Score

- Relative score for the costs typically incurred for the measurement(s) being described (scale is reversed: 1 – High, 10 = Low). Comparisons are with other measurements within any workgroup or discipline and should be based on the most characteristic or important set of measures for the VS (if more than one in the protocol). This score will be a very qualitative 'gut-feeling'. Comments should include dollar amounts (if possible) a qualifying scale on the cost score (e.g., whether the cost is per sample event, across an entire year, etc.). Comments should also clarify which steps in the process are included in the estimate (e.g., collecting data, analysis, etc.).

B.1.4.2.4 Vital Sign Evaluation (Step 3)

In this step, participants provided an ordinal evaluation of the vital sign based on (1) ecological significance, (2) Long-term management significance; (3) Feasibility and Cost; (4) Response Variability; (5) Existing programs and data.

B.1.4.2.4.1 Ecological Significance

The first purpose of Vital Signs monitoring is to provide information about park ecological condition, both status and trend. Vital signs must be ecologically significant and clearly justified on the basis of peer-reviewed literature and scientifically sound conceptual framework.

Ecological Significance should be evaluated using the following considerations (Numeric Score 10 if agree with > 90% of statements; 5 if agree with ~ 50% of statements; 1 agree with < 10% of statements; 0 is UNKNOWN or NA (but try and avoid this one!]:

- The Vital Sign reflects or influences an important ecosystem or key characteristic of ecosystem integrity.
- There is a demonstrated link between the Vital Sign and the ecological function or critical resource it is intended to represent or affect.
- The Vital Sign integrates ecosystem stresses over space and time, or is an overall indicator of ecosystem condition.
- The Vital Sign is a central driver of ecosystem dynamics.
- Vital Sign is anticipatory – i.e., signifies an impending change in the ecological system?
- The Vital Sign is relevant to ecological function or critical resource it is intended to represent (sound, defensible linkage)?

- The Vital Sign reflects functional status of one or more key ecosystem processes or the status of ecosystem properties that are clearly related to these ecosystem processes?
- The Vital Sign reflects the capacity of key ecosystem processes to resist or recover from change induced by exposure to natural disturbances and/or anthropogenic stressors?
- The resource being represented by the Vital Sign has high ecological importance based on the conceptual model of the system and the supporting ecological literature.

B.1.4.2.4.2 Long-Term Management Significance.

The second purpose of Vital Signs monitoring is to provide managers with the broad-based, scientifically credible information they need to make decisions and to influence others to make decisions for the benefit of park resources. Moreover, given the long-term perspective of the VS program, the time-scale of the management decisions of concern should be those that affect long-term processes or those that have implications over the long-run. Ultimately, VS are useful only if they can provide information to support long-term management decision (including decisions by other agencies and organizations that benefit park resources) or to quantify the success of past decisions. A useful VS must produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom are able to recognize the implications of the indicator's results for protecting and managing a park's ecological systems (including physical and biological processes as well as the composition and structure of the park's natural resources.)

Long-term Management Significance should be evaluated using the following considerations (Numeric Score 10 if agree with > 90% of statements; 5 if agree with ~ 50% of statements; 1 agree with < 10% of statements; 0 is UNKNOWN or NA (but try and avoid this one!]:

- The Vital Sign has high long-term management importance relative to other resources and/or resource concerns or issues.
- The Vital Sign and its information have great potential to support management decisions over the long-term and/or influence outside decisions.
- The Vital Sign produces results that are clearly understood and accepted by scientists, policy makers, managers, and the public (e.g., the Vital Sign is easily communicated)?
- The Vital Sign will support monitoring and interpretation of results related to other ecosystem components and/or processes.
- The Vital Sign will contribute to larger, collaborative efforts to understand ecosystem dynamics and/or trends in resource condition.
- Monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early.
- Important. A Legal Significance criterion is part of 'Long-term Management Significance', and gives extra emphasis towards those attributes and resources that are required to be monitored by some legal or policy mandate. Additional priority should be attached to a VS if a park is directed to monitor specific resources because of some binding legal or Congressional mandate, such as specific legislation and executive orders, or park enabling legislation. This criterion is best evaluated by a small group of people familiar with legislation, GPRA goals, etc. Subject-matter experts and persons unfamiliar with legal and policy mandates should not be asked to score each potential indicator using this criterion. In many cases, a species or process that has a federal, state or local legal mandate that requires monitoring by default makes the Long-term Management Significance Score "High(10)".

B.1.4.2.4.3 Feasibility and Cost

The Vital Sign not only has to be relevant to the monitoring program in an ecological and management context but implementation also has to be feasible, practical, and affordable in the context of all the constraints and requirements that will affect the Vital Signs program. Sampling, analysis, and interpretation of vital signs must be technically feasible and cost-effective. For purposes of vital-sign evaluation, a cost-effective vital sign is defined as one with a high benefit:cost ratio – i.e., information benefits are high relative to total costs. Methods for sampling and measuring the indicator should be tested, reproducible, and cost-effective for use in a monitoring program. Sampling methods may include simple, low-tech or low-cost data collection methods, but Vital Signs that require more complex or expensive collection methods should not be precluded if they can be shown to be cost-effective, e.g. data collection every five years results in low annual cost. Consideration should be given to data collection methods, logistical requirements, data processing and information management, data quality, and costs in terms of time, money, and personnel. Logistic feasibility should include factors such as travel, training, sample transport, laboratory analyses, and the time involved to perform these tasks over the long term.

Feasibility and Cost should be evaluated using the following considerations (Numeric Score 10 if agree with > 90% of statements; 5 if agree with ~ 50% of statements; 1 agree with < 10% of statements; 0 is UNKNOWN or NA (but try and avoid this one!]:

- Monitoring methods are well-documented or are feasible to develop.
- Vital sign is relatively cost-effective to monitor (consider sampling complexity, frequency, and extent.
- Logistical requirements of monitoring can be met feasibly.
- Specialized equipment or knowledge required for data acquisition or analysis?
- Sampling window (in time) is known?
- Sampling does not significantly impact site or protected organisms? (Is nondestructive?)
- Long-term data management is feasible?

B.1.4.2.4.4 Response Variability

Vital signs must be characterized by patterns of variability that are well understood and possess a high signal:noise ratio. That is, variability attributable to anthropogenic stressors must be high relative to variability attributable to natural processes or measurement errors and it is likely that the Vital Sign will show a trend if one exists. The ideal Vital Sign is relatively insensitive to changes in conditions other than the stress of interest; i.e., changes in the Vital Sign can reliably be attributed to changes in the stressor or resource of interest. Similarly, data do not exhibit large, naturally-occurring variability and human errors of measurement and natural variability over time and space are sufficiently understood and documented.

Feasibility and Cost were evaluated using the following considerations (Numeric Score 10 if agree with > 90% of statements; 5 if agree with ~ 50% of statements; 1 agree with < 10% of statements; 0 is UNKNOWN or NA:

- The Vital Sign displays a high signal to noise ratio. It is likely to detect ecologically significant changes within a reasonable timeframe.
- The Vital Sign is responsive to stressors and/or sensitive to change in the condition of related resources.
- Factors driving spatial/temporal variability in data are understood and can be accounted for via stratification or other means? Locations in similar "condition" yield similar measurements?
- The Vital Sign is linked to multiple monitoring questions or ecosystem structure/function components.
- Possible to estimate / control measurement errors introduced by human observers and/or instruments during data collection, transport, and data analysis /

management?

- Vital Sign is quantitative, objective, and repeatable?
- Vital Sign has a high precision of measurement?
- Vital sign is able to discriminate differences among sites along a known condition gradient?
- Measurement errors introduced by human observers and/or instruments during data collection, transport, analysis, and management can be controlled and estimated;

B.1.4.2.4.5 Response Variability

While the lack of monitoring data supportive or identical to the Vital Sign should not eliminate the Vital Sign (e.g., some Vital Signs will be novel or specific to a NPS application), if all else is equal, evaluations should favor Vital Signs that will integrate into an existing NPS or other agency monitoring effort. Constraints in funding and personnel, as well as logistical difficulties, will greatly limit sample sizes and the number of places where the NPS Vital Signs program can sample. The ability to compare data over time (temporally) as well as among places (spatially) with other monitoring efforts is a key to interpreting and understanding the results of the Vital Signs monitoring. Wherever possible, parks should use or modify existing, well-tested sampling protocols to promote data comparability and cost effectiveness.

Existing Programs and Data should be evaluated using the following considerations (Numeric Score 10 if agree with > 90% of statements; 5 if agree with ~ 50% of statements; 1 agree with < 10% of statements; 0 is UNKNOWN or NA (but try and avoid this one!]:

- Vital sign already is monitored within park?
- Vital sign already is monitored outside park?
- Baseline data available? Inside park and/or outside park?
- Data readily available or shared? Can be obtained from elsewhere free of charge?

B.1.4.2.5 Database Reporting (Step 4)

Reporting options were numerous to allow users and workgroups to view information in a number of formats, views, and levels of aggregation (Figure B.1.4.2.5).

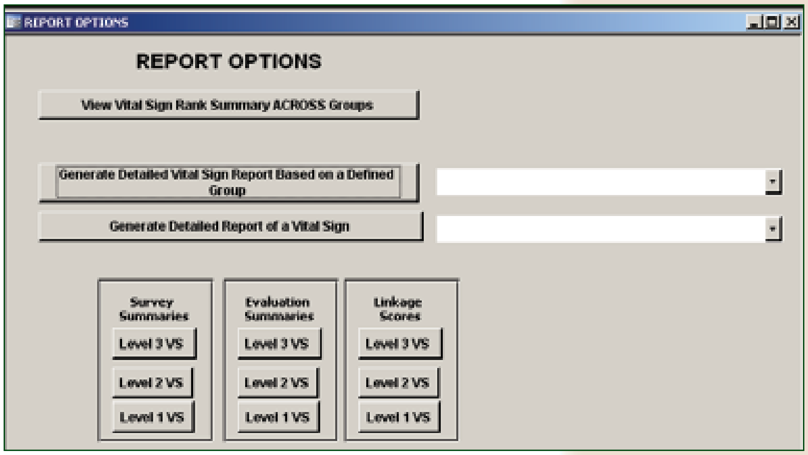


Figure B.1.4.2.5. ROMN Vital Signs Database reporting options.

B.1.5 Candidate Vital Signs from Workshops

Candidate Vital Signs derived from the workshops are given in Table B.1.5. Because these included a starting point of survey results this table also includes information from the surveys. For brevity, we do not present these within the national hierarchical framework (but this structure can be provided by the Vital Sign Objectives database). This list contains 117 candidate Vital Signs and (for most Vital Signs) a score within each of the five criteria categories plus a weighted mean summary score. While this list is not the final set of Vital Signs selected for ROMN, they have value in that they contain many Vital Signs that may become important in the future for ROMN efforts or are being measured and assessed by our partners and are therefore possible "shared" Vital Signs for the ROMN. It is essential that we recognize these Vital Signs as many were described as important, but perhaps beyond our means to effectively implement. Publishing these lists - even though they are not fully described here and on the surface may appear overwhelming - will help accomplish this.

Table B.1.5. Candidate vital signs from the workgroups.

Vital sign	Norm Score	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	Ecological Significance	Management Significance	Relative Cost (10 = low)	Response Variability	Existing Monitoring Efforts	Meeting
Beavers	0.95	-	x	-	x	-	x	10	10	8	10	7	CO
Water chemistry	0.95	x	x	x	x	x	x	10	10	7	10	8	MT
Water chemistry	0.94	x	x	x	x	x	x	10	10	7	8	9	CO
Core weather and climate	0.94	x	x	x	x	x	x	10	10	5	10	9	CO
Groundwater dynamics	0.93	-	-	-	x	-	-	10	10	8	7	8	CO
Wet and dry deposition	0.93	-	x	-	x	x	x	10	10	7	8	8	CO
Land cover / use	0.93	x	x	x	x	x	x	10	10	5	10	8	CO
Land cover / use	0.93	x	x	x	x	x	x	10	10	5	10	8	MT
High elevation lake and stream chemistry	0.92	-	x	-	x	-	x	10	10	6	8	8	CO
Benthic macroinvertebrates	0.92	x	x	x	x	x	x	10	10	5	8	9	MT
Land cover/land use for wildlife	0.92	x	x	x	x	x	x	10	10	5	9	8	CO
Land cover/land use for wildlife	0.92	x	x	x	x	x	x	10	10	5	9	8	MT
Windblown Features and Processes	0.91	-	-	-	x	-	-	10	10	5	8	8	CO
Elk	0.91	-	x	-	x	-	x	10	10	4	7	10	CO
Water Quality	0.90	x	x	x	x	x	x	9	10	7	9	8	MT
Exotic aquatic/rip./wet. plants, animals, pathogen	0.89	x	x	x	x	x	x	10	10	6	5	8	CO
Hydrology	0.89	x	x	x	x	x	x	9	9	8	9	9	MT
Fire Regime and Change From Natural Variability	0.88	x	x	x	x	x	x	10	10	7	5	6	CO
Landscape composition	0.88	x	x	x	x	x	x	10	10	5	5	8	MT
Fish assemblages	0.88	x	x	x	x	x	x	7	10	8	10	10	CO
Fish assemblages - maintaining natural community	0.88	x	x	x	x	x	x	7	10	8	10	10	MT
Surface water hydrology	0.88	x	x	x	x	x	x	10	9	8	5	8	CO
Rip and wet multi-scale physical biological char.	0.87	x	x	x	x	x	x	10	10	6	5	6	CO
Ground water hydrology	0.87	x	x	x	x	x	x	10	9	5	8	7	CO
Air Contaminants	0.86	x	x	-	x	-	x	10	10	10	5	1	CO
Endemic Insects	0.85	-	-	-	x	-	-	10	8	7	7	8	CO
Permafrost and Pattern Ground	0.85	-	x	-	x	-	x	10	10	5	5	5	CO
Fire regime	0.84	x	x	x	x	x	x	9	10	3	8	7	MT
Invasive plants	0.84	x	x	x	x	x	x	9	9	5	8	8	CO
Core weather and climate	0.84	x	x	x	x	x	x	10	7	5	10	9	MT
Wet and dry deposition	0.83	x	x	x	x	x	x	8	9	7	8	9	CO
Grizzly bear	0.83	-	x	-	-	-	-	8	10	5	7	8	MT
Historical context	0.82	x	x	x	x	x	x	9	10	5	8	3	MT
Exotic plants	0.82	x	x	x	x	x	x	9	10	4	9	3	MT
Climate	0.82	x	x	x	x	x	x	10	8	7	4	8	CO
Groundwater levels and surface water hydrology	0.82	x	x	x	x	x	x	10	10	2	3	7	CO
Surface water dynamics	0.81	x	x	x	x	x	x	10	8	8	5	5	MT
Indicators of climate change	0.81	x	x	x	x	x	x	10	10	5	1	5	CO
At risk biota	0.81	x	x	x	x	x	x	9	9	5	5	8	CO
Distribution and abundance of invasive animals	0.80	x	x	x	x	x	x	8	9	8	8	5	CO

Table B.1.5. Candidate vital signs from the workgroups, cont.

Vital sign	Norm Score	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	Ecological Significance	Management Significance	Relative Cost (10 = low)	Response Variability	Existing Monitoring Efforts	Meeting
White pine blister rust (non-native)	0.80	-	x	-	x	-	x	8	8	7	9	8	CO
Landscape diversity	0.80	x	x	x	x	x	x	9	9	5	4	8	CO
Solute Mass Balance	0.79	x	x	x	x	x	x	9	8	5	7	8	CO
Health and distribution of communities of concern	0.79	x	x	x	x	x	x	10	8	2	9	5	MT
Aquatic physical habitat	0.79	x	x	x	x	x	x	9	7	9	7	7	CO
human impacts	0.79	x	x	x	x	x	x	9	9	5	6	5	MT
Fire and fuels compared to natural range	0.79	x	x	x	x	x	x	9	9	4	5	7	CO
Human Population	0.78	x	x	x	x	x	x	7	10	5	3	10	CO
Native Trout	0.76	-	x	x	x	x	x	7	9	5	7	8	CO
Ungulates	0.76	-	x	-	x	-	x	8	8	6	7	7	MT
Algae, plankton, zooplankton assemblages	0.76	-	x	-	x	-	x	10	5	6	9	8	CO
Grey wolf	0.75	-	x	-	-	-	x	8	8	5	7	7	MT
Type, Distribution and Intensity of Visitor Use	0.75	x	x	x	x	x	x	7	10	5	7	3	CO
Visibility and particulates	0.75	-	x	-	x	-	x	5	10	7	8	7	CO
Ecosystem Productivity	0.74	x	x	x	x	x	x	10	5	5	6	10	MT
Vegetation Communities	0.73	x	x	x	x	x	x	8	8	5	6	6	CO
Soil function and dynamics	0.73	x	x	x	x	x	x	10	5	5	10	5	MT
Seston (organic: algae, plankton, zooplankton, etc	0.72	-	x	-	x	-	x	10	5	3	8	8	MT
Benthic macroinvertebrate assemblages	0.71	x	x	x	x	x	x	7	7	5	8	9	CO
Stream physical habitat	0.70	x	x	x	x	x	x	10	4	9	5	7	MT
Landscape structure	0.69	x	x	x	x	x	x	8	7	7	3	7	MT
Upland soil function	0.69	x	x	x	x	x	x	8	6	5	7	8	CO
Wet and dry deposition	0.69	x	x	x	x	x	x	8	8	5	4	4	CO
Air Quality	0.68	x	x	x	x	x	x	7	7	5	5	9	MT
Predators - important	0.67	-	x	-	x	-	x	8	7	5	7	3	CO
Dark Night Sky	0.67	x	x	x	x	x	x	6	7	9	8	5	CO
Soundscape	0.67	x	x	x	x	x	x	7	8	6	5	3	CO
Breeding Landbirds	0.67	x	x	x	x	x	x	4	9	7	5	9	CO
Climate	0.66	x	x	x	x	x	x	9	4	8	5	8	CO
Glacial Features and Prcocesses (Alpine and Rock)	0.64	-	x	-	x	-	x	7	7	5	5	5	CO
Air Quality Effects	0.64	x	x	x	x	x	x	7	7	5	5	5	CO
Small / Medium Mammals	0.64	-	x	-	x	-	x	10	5	4	4	3	CO
Elk	0.63	-	x	-	x	-	x	8	7	3	4	4	MT
Winter track surveys	0.63	-	x	-	-	-	x	6	7	7	4	7	MT
T, E, & rare aquatic/wetland/riparian populations	0.63	-	x	x	x	-	x	5	10	3	2	5	CO
Visitor Usage	0.62	x	x	x	x	x	x	7	7	6	1	6	CO
Status of rare / endemic plant populations	0.62	x	x	x	x	x	x	7	7	3	5	5	MT
Boreal toads	0.61	-	x	x	-	-	x	3	8	8	5	10	CO
Toxics	0.61	x	x	x	x	x	x	7	9	1	1	3	MT
Breeding landbirds	0.61	-	x	x	-	x	-	5	7	7	5	7	MT

Table B.1.5. Candidate vital signs from the workgroups, cont.

Vital sign	Norm Score	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	Ecological Significance	Management Significance	Relative Cost (10 = low)	Response Variability	Existing Monitoring Efforts	Meeting
Disturbance and Recovery Processes	0.61	x	x	x	x	x	x	8	6	5	5	2	CO
Soil Biogeochemistry	0.61	x	x	x	x	x	x	8	6	2	7	3	CO
Biogeochemistry	0.61	x	x	x	x	x	x	8	6	2	7	3	MT
ozone	0.60	-	x	-	x	-	x	5	5	10	5	10	CO
Amphibians	0.60	-	x	-	-	-	x	5	5	8	7	10	CO
Productivity	0.59	x	x	x	x	x	x	7	6	3	5	5	MT
Birds of Prey	0.58	-	x	-	x	-	x	6	7	3	5	5	CO
Bald eagle productivity	0.58	-	x	x	-	-	x	4	7	8	3	8	MT
Paleontology	0.57	x	-	-	-	-	-	1	10	5	8	5	CO
Fluvial landscape	0.56	x	x	x	x	x	x	8	5	1	6	4	MT
Amphibians	0.51	-	x	-	-	-	x	3	5	8	5	10	MT
Fuels	0.50	x	x	x	x	x	x	4	7	3	4	5	MT
Bighorn sheep	0.48	-	x	-	x	-	x	3	6	8	4	5	MT
Bighorn sheep	0.48	-	x	-	x	-	x	3	7	5	3	5	CO
Common loon	0.42	-	x	-	-	-	-	3	3	8	3	10	MT
Mule Deer	0.41	-	x	-	-	-	x	3	3	7	3	10	CO
Cultural landscapes	0.38	x	x	x	x	x	x	1	7	8	0	2	CO
Harlequin duck	0.36	-	x	-	-	-	-	3	3	7	2	6	MT
Reptiles	0.32	-	-	-	x	x	-	3	3	7	2	2	CO
Wet and dry deposition													MT
Ozone Concentrations													MT
Stream / River Channel Characteristics and Process													CO
Lake Features and Processes													CO
Status of rare / vertebrate populations													MT
Invasive plants													MT
Pathogens													MT
Riparian plant communities													MT
Surface water - ground water interaction													MT
Status of rare / endemic plant populations													MT
Dams, diversion and channel modification													MT
Stream / wetland hydrologic function													MT
Water chemistry core													MT
Wetland type x: (e.g., springs, seeps, hanging gar													MT
Sandsheet seeps, wetlands and playas													MT
Riparian habitat													MT
Status of rare / endemic invertebrates													MT
Soil: physical/chemical/biota													CO
Non-point sources													MT
Invertebrates (mollusks)													MT

Table B.1.5. Candidate vital signs from the workgroups, cont.

Vital sign	Norm Score	FLFO	GLAC	GRKO	GRSA	LIBI	ROMO	Ecological Significance	Management Significance	Relative Cost (10 = low)	Response Variability	Existing Monitoring Efforts	Meeting
Channel - floodplain interaction													MT
Bird communities; group X													MT
Alpine fens and wetlands													MT
Extreme disturbance events													CO
Seston (phytoplakton - lotic)													MT
Population status of indicator invertebrates													CO
Mammal communities; carnivores													MT
Ungulate monitoring													MT

Appendix C
Supplemental Information on Sample Design

C.1 Design Types

The following sections provide information about judgment designs, model-based designs, probability designs, and hybrid designs supplemental to that included in Chapter 4 of this monitoring plan.

C.1.1 Judgment designs

Judgment designs employ expert knowledge to varying degrees in the selection of sampling locations (Gilbert 1987). For example, monitoring sites are often placed based only on biological intuition or experience with a particular resource. Similarly, convenience-based judgment designs use only accessibility (e.g., bridges on streams) to place monitoring sites. While professional judgment has some value, and access is an important consideration in monitoring programs, studies have shown that unknown selection bias is common with most of these kinds of designs (Stehman and Overton 1994; Stoddard et al. 1998; Olsen et al. 1999), and the ROMN will not use this approach. We will incorporate factors that improve efficiency of sampling (e.g., access) into more robust design types.

We also consider designs that have no known, discernible rationale, or those with a historic basis that does not match a current ROMN monitoring objective, to be judgment in form. The trade-offs of incorporating historical monitoring designs (and their data) into the ROMN program must be carefully examined. In many cases, historical data is often not worth the shortcomings of the design used to collect it. Therefore, we will only integrate or use the design of historical programs in our monitoring when the benefit is demonstrably real.

There are two scenarios that may allow a more defensible use of a judgment design. First, resources or ecological processes of interest that are known to be "well-mixed" (Urquhart et al. 1998) or spatially homogeneous relative to the scale of monitoring (e.g., regional-scale weather dynamics measured at the scale of a park) might be sampled with sites placed based on expert judgment. Because there is little variability at the scale of a site, location may have less of an effect on the measured responses.

Second, resources or ecological processes with a known geospatial context that is small relative to the effort required to validly sample it (e.g., a specific, well-defined wetland, or administratively defined resources such as stream segments on a state's 303(d) list) may be sampled with sites targeted to these resources. We will use these kinds of judgment designs when required or when it is clear that they may be more efficient than an alternative design (Hirsch et al. 2006). However, the assumptions involved in these approaches are rarely tested, and can remain unknown sources of bias in the design and its analyses (Jassby 1998; Stow et al. 1998).

C.1.2 Model-based designs

Model-based designs use an explicit model to place sample locations in space and time. The models often are statistical (e.g., spatial, ANOVA, regression, principal components, ordination), relating sample to population characteristics and attempting to find sites in space that best augment a set of existing sites (see Nanus et al. 2003). Alternatively, process models explicitly represent physical and biological phenomena and direct the design to place sites at location(s) that will best support data collection to improve understanding of a process or resource state (Gilliom et al. 2006). For example, the USGS hydrologic flux and loading models require sites at basin outflows or nick points based on the assumption that these locations integrate or average conditions within a basin (Langland et al. 2004; Cohn et al. 1989). Classic experimental designs are typically model-based, for example, randomized block designs or gradient studies.

C.1.3 Probability designs

C.1.3.1 Generalized Random Tessellation Stratified design (GRTS)

GRTS designs have become the standard for many monitoring programs, including the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) program (Messer et al. 1991), and are used in water-quality monitoring programs by all but two U.S. states (T. Olsen, pers. comm.). The EMAP design team has completed and put in place more than 400 GRTS designs during the last 10 years for multiple types of resources and monitoring goals (e.g., Paulsen et al. 1998; Schweiger et al. 2005). GRTS designs are also being used by nearly all other NPS I&M networks for a broad spectrum of vital signs in both terrestrial and aquatic systems.

Many ROMN monitoring objectives require sample designs that integrate resource classification or spatial structure in the resource of interest into the design. For example, rare or special-interest resources, administrative boundaries, or geophysical variables such as elevation zones or stream order often require integration into probability designs in order for monitoring data to account for any variability in response across these boundaries. GRTS designs can use either stratification or unequal probability of selection to accomplish this.

Stratification involves explicitly distinguishing regions or strata within a resource of interest and creating separate sample designs for each of these strata. With a stratified design, the probability of selecting sites is independent across strata, site replacement occurs within strata, and all estimates are done separately by strata (they may be combined eventually). Strata are artificial constructs defined prior to sample selection; they should change very slowly, if at all, over the duration of a monitoring program, regardless of conditions on the ground (Geissler and McDonald 2003).

With unequal probability of selection, the probability of selecting sites is a function of an attribute of population elements such as size. Elements are grouped into subpopulations based on their attributes (e.g., stream size). Selection of sites across subpopulations is not independent, replacement of sites can occur across subpopulations, and estimates can be done for single or combined subpopulations. Subpopulations can be defined *a priori* or created after sampling based on observed patterns of variability on the responses.

Both stratification and unequal probability GRTS designs can be useful in increasing precision of estimates (by creating more homogeneous populations) as well as the efficiency of sampling. However, stratification must be almost perfect (i.e., must completely reflect reality) for it to increase precision (Stevens 1997), and is generally less flexible than unequal probability of selection. Therefore, most ROMN designs avoid explicit strata.

C.1.4 Hybrid designs

Many design types may be combined or used in concert in a variety of ways, creating hybrid design forms. For example, several ROMN objectives require a sentinel design in order to understand site-specific processes (e.g., nutrient loadings over a water year at a site) and probability designs to monitor the status of a target population (e.g., valid inference of nutrient status and trend to the entire park). The final analysis must integrate these two data sets in an informative way; thus, the design process is more efficient if the designs are treated together rather than separate. In many cases, this integration continues with the analysis of data collected from a hybrid design of sentinel and probability sites (Overton et al. 1993). A similar analytical process is used to integrate ROMN probability designs with historic and/or ongoing monitoring that is not based on probability design.

It is also common to employ elements of model-based design within a probability structure (known as model-assisted designs). For example, many probability designs are augmented by models (e.g., geospatial or multivariate) that classify or create the strata or subpopulations to be sampled. The modeling seeks to reduce the variance across the strata or subpopulations and therefore improve the precision of estimators. Good classification can improve precision, but improper or poor classification will decrease precision (Stevens 1997).

C.2 Target populations, sample frames, and sample populations

This section provides supplemental information on the relationship between target populations, sample frames, and sample populations.

Ideally, a sample population and sample frame would be equivalent to the target population for which inference is to be drawn. Unfortunately, numerous constraints exist that often preclude this from occurring. Therefore, in some situations, units within a sample frame and/or a target population are not included in the sampled population. This can lead to significant non-response issues in environmental surveys.

In a strict sense, the sample population is the resource monitored. 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.

The sample population should be clearly described in all analyses or assessments. Assumptions could be made about lack of real ecological differences from the sampled and target populations, but in the absence of supporting data or a good model, this moves sampling and analysis away from the probability design paradigm and back into the less-defensible model-based or even judgment world. Note that for all judgment and many model-based designs, the target and sample populations are actually equal, and are both limited to the sampled units only. In lieu of modeling, any direct inference is limited to the sites sampled, with little valid capacity for describing the measured responses beyond these sites.

C.3 Key design evaluation concepts

This section provides additional information on the criteria the ROMN uses to evaluate a design's capacity to estimate status and trend.

C.3.1 Status

C.3.1.1 Fit to monitoring goals and representativeness

For ROMN sentinel designs, fit to objectives and overall adequacy of the design are defined largely by the quality of the expert opinion or model used to set up the design. We present assessments of this sort in specific protocols. For censuses, the only real way to test a design is to confirm that the census was complete—a difficult task.

The ROMN's primary qualitative criterion for assessing the adequacy of a probability sample design is the degree to which a design's structure and basis lead to a representative, efficient sample across space. The development of the GRTS design was motivated in part by the need for a design that combined the representativeness of a simple random design with the spatial balance of a systematic approach. In comparisons between simple random, systematic, and GRTS designs, GRTS has been shown to outperform other probability designs under all design scenarios (e.g., clumped or distributed resources, stratified designs, unequal probabilities of selection designs; Stevens and Olsen 2004). Because GRTS designs are operationally efficient as well, this approach is optimal for quantifying the status of ROMN vital signs.

C.3.1.2 The linear model and variance components tool

The linear model and variance components approach can be applied to status estimation (Kincaid et al. 2004). The tool requires the same input as with power for trend estimation (initial conditions, variance components, effect size or percent change, trend, estimates of spatial and temporal structure, sample sizes within an explicit panel structure, and an acceptable alpha level). Within the context of this model, status is equal to the mean response of a response measure over all years without a trend (i.e., when the slope of the trend line is zero). If the trend slope is not zero, then status is the response mean projected along the trend line (curve) to a defined year or sampling interval (Urquhart et al. 1993). By treating status in this way, the same investigation of the effect of variance components and initial conditions used for trend detection can be applied to status estimation, with the relevant output of the model being the precision of a status estimate expressed as its standard error (SE), instead of power for trend.

Another useful implication of the model is that it is possible to generate conglomerate status estimates by combining single-period status estimates (often with smaller sample sizes) across years. Essentially, the model estimates the year effects, and all sites are adjusted to the latest year to create a combined status estimate (S. Urquhart, pers. comm.). The idea is similar to the well-established adjusted treatment means procedure in the analysis of covariance (Cochran 1957; Thigpen and Paulson 1974). It does require a panel structure with linkage of site revisits (connectedness) to allow estimation of all differences in year effects. The ROMN carefully uses this aspect of the model to create multi-year status estimates, but only in concert with an explicit statement of the target sample population created by the approach, and only when it does not lead to intuitively egregious results.

The formal statistical and analytical basis for this work can be found in Urquhart et al. (1993), Larsen et al. (1995), and Kincaid et al. (2004). The tool the ROMN used to assess status estimates and their implication for designs is the same as with trend (although slightly modified to output SE of status; R. Gitzen, pers. comm.). Hypothetical results and relevant interpretation are presented below.

C.3.1.3 Simple approximation tool

In many cases, the information required to parameterize the linear modeling tool discussed above is not readily available, yet designs still must be specified for status estimation as best as we can. A general approximation is available (under specific conditions) that can often serve as a useful starting point.

The approach follows Cochran (1987), and determines precision (here defined as a z-distribution confidence interval) given a user-defined proportion (as the status estimate) and sample size. Proportions (and their cumulative frequency distributions) are a common way that status results can be reported, and the ROMN often will use proportions to express empirical results from a survey design relative to a threshold (e.g., "in 2009, 50 +/– 10% of the perennial stream length in ROMO was above the threshold for ammonia contamination"). Table C.3.1.3 presents example results from the method (confidence intervals for various sample sizes, two example proportions, and two alpha levels). Approximate sample sizes may be derived from Table C.3.1.3 based on a desired confidence interval and given proportion (e.g., "park management feels that estimates must be no more than ±10%"). The value of the proportion is typically not known prior to monitoring; however, a conservative estimate (e.g., where sample size must be largest) can be obtained by assuming the proportion to be 50%, which corresponds to the maximum variance.

The results from this method are conservative for several reasons. The method assumes that the design is a simple random sample. While the ROMN does not use this type of design, the results are conservative for a GRTS de-

Table C.3.1.3. Precision and sample size in estimates of selected proportions.*

		N = 25	*N* = 50	*N* = 100	*N* = 400	*N* = 1,000
Precision with 90% confidence						
Assumed proportion	20%	±13	±9	±7	±3	±2
	50%	±17	±12	±8	±4	±3
Precision with 95% confidence						
Assumed proportion	20%	±16	±11	±8	±4	±3
	50%	±20	±13	±10	±5	±3

*precision = Z1-α * 100 * Sqrt[p(1-p)/n]; Z value determined by alpha level, following Cochran (1987).

Table modified from EPA (2006).

sign. Proportions are statistically difficult to estimate (T. Olsen, pers. comm.), so the sample sizes suggested by this method will be conservative for other statistics (e.g., a mean). Finally, simulation studies show that a novel variance estimator developed for the GRTS design (the local neighborhood variance, discussed in Chapter 7; Stevens and Olsen 2003) further reduces precision around an estimate up to 60% from those shown in Table C.3.1.3 (i.e., it will make the confidence intervals smaller for the same sample size or require smaller samples to reach the same confidence). With all of these considerations, our initial use of this method suggests that ROMN status estimates require sample sizes in the range of 35–50 per reporting unit to generate a confidence interval around ±10% (often used as a standard precision level in monitoring; Barbour et al. 1999).

C.3.2 Trend and effect size

Trend is a raw measure of effect size; as such, it is intuitively more similar to response measures and therefore easier to visualize and interpret. "Proportional change" or "annual rate" are typically used in place of "effect size" when describing trend. The annual rate for a given proportional decline (e.g., 30% change from Year 1 to Year 10) can be derived using $N_c = N_0 e^{rt}$ (where N = value in a response measure at initial (0) and final (c) times; t = interval over which decline occurs, and r = annual rate). For example, solving this equation translates a 30% decline over 10 years to an annual rate of roughly 3.5%. This annual rate is equivalent to the slope of a line that defines net trend.

Change or trend in a response measure can occur both at the site and the population scale. Substantial research has been conducted on site-specific trend detection (e.g., form of trend, best tools to detect trend; Esterby 1993; Thomas 1996; Gibbs et al. 1998). For example, a substantial amount of the literature on water-quality trend detection describes methods of accommodating the particular behavior of chemical constituents in water, such as non-normal distributions, seasonal patterns, missing values, relationships with other variables (e.g., flow), censored data (below detection limits), and spatial and temporal autocorrelation (see Hirsch et al. 1982, 1991; El-Shaarawi 1993; Zetterqvist 1991; Jassby and Powell 1990; Loftis et al. 1989). These efforts emphasize the important influence that variability exerts on ability (power) to detect trends across time at a site. However, they do not distinguish between all the forms of variation that are critical for the cost-effective development of multi-site monitoring designs focused on population-scale inference. In essence, none of these efforts have approached the problem of assessing trend from the perspective of a sample survey, and if applied as such, they would likely mis-specify ROMN long-term monitoring designs.

C.3.2.1 Figure 4.4.1.2

Actual power for trend estimation employs a more complex derivation of the equation in Figure 4.4.1.2 (see Chapter 4); the statistical and analytical basis, assumptions, and justifications for this approach are well documented (see Urquhart et al. 1993; Larsen et al. 1995; Urquhart and Kincaid 1999; and Larsen et al. 2004 for examples).

The model assumes that if any trend is present, linear trend will be present (Urquhart and Kincaid 1999). Power for detecting this form of trend evaluates the likelihood of distinguishing whether a slope (i.e., annual change) of a specified magnitude in the mean value of a response measure across a network of sites differs from zero. The model assumes that time is viewed discretely (e.g., annually) and the target population is finite (Urquhart et al. 1998). However, the underlying ideas can be extended to continuous structures needed to cover, for example, the sampling of points along streams or in an alpine upland habitat (Stevens 1997).

C.3.2.1 Population 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 linear model and variance components approach (Urquhart et al. 1993, 1998; Larsen et al. 1995) and the Complex Survey Design Simulator (CSDsim; Garman et al. in prep.).

The linear model and variance components tool. The variance components tool requires input of the initial condition (i.e., a mean of a the response measure across all sites), each variance component (see Figure 4.4.1.2 and Table 4.4.1.2, Chapter 4), the effect size or percent change (expected, known, or hypothetical annual change), estimates of spatial and temporal structure (e.g., variability and correlation among sites), sample sizes within an explicit panel structure (e.g., one of the panel forms in Table 4.3.2, Chapter 4), and an acceptable alpha (Type-I error). In the simplest case, this approach is static, in that parameters are not allowed to change within a run of the model. However, it is easily applied, robust, and well supported as a tool for developing panel designs to estimate population status and trend.

All input parameters are derived external to the model. These values could come from data collected during ROMN protocol-development projects (see Chapter 9), results from similar monitoring programs (which may be at a different scale or in a different location), scientific literature, best professional judgment, or a range of values that bracket expected conditions.

Output includes power for trend (and standard error of status) values for each sampling interval (year) over the monitoring period specified by the panel design. Example output and interpretation is given below. The tool was developed in the R programming language and provided by T. Kincaid from the EPA. The R code is available from the ROMN or T. Kincaid upon request.

The CSDsim tool. This tool incorporates the same key concepts (linear models and variance components) as the tool described above, but differs 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). This tool is potentially more flexible and may be a more realistic approach, but it is not as well tested or developed at this time; therefore, the ROMN expects to use both approaches for guidance.

Three user-specified population parameters are required: the mean and standard deviation of the response measure across all sites, the mean and standard deviation of trend or slope across all sites, and the mean and standard deviation of the root mean square error (i.e., the variability about a trend line). Initial values at each site are generated using the mean, its standard deviation, and a normal random variate. Annual observations are then generated to conform to the slope and root mean square error assigned to a site. Assignment of parameter values to a site occurs in two ways. The default is independent, random assignment—that is, without explicit correlation among parameter values or among plots. The second method employs user-specified spatial patterns (e.g., clumped or dispersed) of the relative spatial arrangement of values.

A user-specified survey design is next implemented to extract sample observations based on the specified panel structure (i.e., the number of plots and the revisit design). The site locations can be generated via a simple random, systematic, or GRTS design. A Monte Carlo approach applies the survey design for a user-specified number of replications, where each replication selects different combinations of plot locations. For each replication, sampled observations of the indicator value act as output that then can be used to generate variance components (see Table 4.4.1.2) and power for trend using the variance components tool discussed above. Additionally, examples of known population and sample-derived values for slope and status can be compared across replicate runs of CSDsim. This provides insight into the ability of a survey design to estimate population conditions. The output from CSDsim is similar to what is produced by the linear model discussed above. Results and interpretation using CSDsim are only presented in ROMN protocols. The tool was developed in the visual C++ programming language and provided by S. Garman from the Northern Colorado Plateau I&M network. The C++ code is available from ROMN or S. Garman upon request.

C.3.2.2 Site trend

The temporal pattern of ecological response measures across time at a single site incorporates two components of variation: within-sample interval (e.g., year) and across years (see Figure 4.4.1.2). Separation of these two sources of variability is important for establishing how many samples must be taken across time in order to detect a trend. Within-interval variability is a function of whether a temporal window or an index period is used for measurements (and how well this controls non-trend variability), the natural variability of the indicator within the selected period, variation and errors in the measurement protocol, and the number of samples allocated to describing that indicator. Variability in the estimates from single sites across years is one of the important components of variation relevant for trend detection at an individual site. 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.

C.3.3 Evaluating designs for status and trend

Choices among design alternatives rarely are based on a single design feature like power for trend detection or the SE of status estimates. Therefore, we use the linear modeling tool presented above to evaluate designs for both trend and status 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 of status estimates. The CSDsim tool is similar in application and result, but all input parameters are simulated.

Figure C.3.3 provides hypothetical results that illustrate key patterns in power for trend and SE of status with different design specifications. Real results of this form are presented in ROMN protocols. Each frame includes several curves of power for trend and SE of status derived by varying one of the inputs into the linear model while keeping all others constant (i.e., effect size, sample size, year-to-year variance, and panel structure). The following sections discuss the key patterns in Figure C.3.3. and their implications (for a complete interpretation, see Urquhart et al. 1993, 1998; Larsen et al. 1995; Urquhart and Kincaid 1999).

As a guide to general interpretation of the patterns in Figure C.3.3, for power, more is better, with a standard rule of thumb of 80% often used as a threshold. For SE, smaller is better, but there really are not any distribution-free criteria (i.e., the value of a given status estimate is important). Note that the SE of a mean is related to a confidence interval (CI = M ± (z * SE) where M is the mean or status and the z-score is determined from a normal distribution based on the specified alpha level, allowing a linkage to the results of the simple approximation presented above.

C.3.3.1 Effect size (Figure C.3.3, frame 1)

The magnitude of the effect size (e.g., an annualized trend or a minimally detectable change size as measured by the slope of the line) has one of the largest impacts on ability to detect trend, but no effect on the SE around status. The example simulation in frame 1 of Figure C.3.3 demonstrates that for a nearly indiscernible trend of 0.005 per year (a 5% change over 10 years), there is essentially no capacity to reveal trend in the default design. As the trend increases to 30% and 60% over 10 years, the power of the design quickly increases. In other words, for a fixed design form and suite of variance components, larger trends are easier to detect.

Unfortunately, the effect size often is not knowable; thus, it is difficult to examine its influence on a design effectively, *a priori*. Data from a well-developed pilot phase or examples from the literature might be used to suggest the expected amount of change in a resource, or what a minimally detectable change should be. Models may be developed that predict an expected change in a response measure under various scenarios (e.g., Stoddard et al. 1996). Alternatively, the expected effect size might be specified as some level of change that is unacceptable

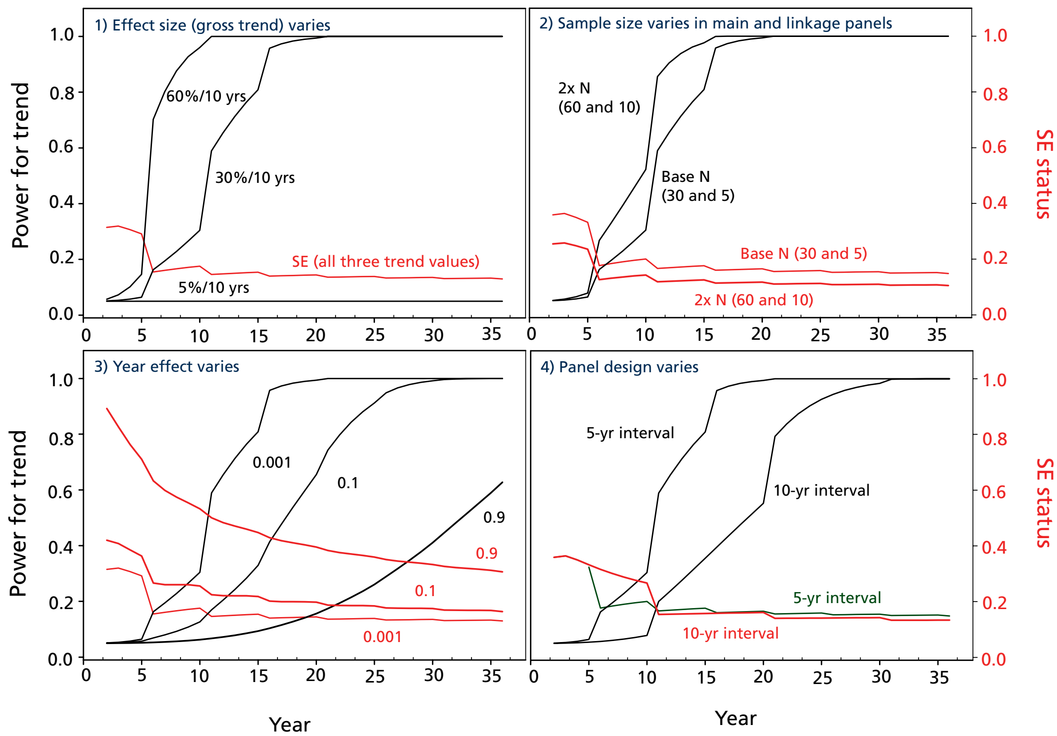


Figure C.3.3. Example output of variance components model.

All input to the models is constant, except as follows: Frame 1 varies effect size (5%, 30%, and 60% gross trend over 10 years).

Frame 2 varies sample size per panel (same panel design but a range of 2x for the N within a panel).

Frame 3 varies the year variance component (0.001, 0.1, 0.9).

Frame 4 varies the panel design using a 5-year or 10-year interval between the main panels ([(1-), (2-)] and [(1-), (2-)]).

The default values used in the models are: Initial mean = 1; Annual rate (trend) = 3.57% (30% over 10 years); Site variance component (VC) = 1; Year VC = 0.001; Site x Year VC = 0.1; Residual VC = 0.5; Site correlation =1; Year correlation = 0; and Alpha = 0.05. See text for interpretation.

for management reasons (e.g., it will not meet a park's desired future condition) and the sample design set up to ensure that this level of change is detectable.

C.3.3.2 Sample size (Figure C.3.3, frame 2)

Sample size, in the context of a complex, long-term monitoring design, is not a simple design specification to determine. Sample size must be considered in the following contexts: (1) when sites are visited in a panel structure, (2) whether a sample is a unique (or new) site or a revisit, and (3) if a revisit is within a sampling interval (year) or an inter-annual revisit. Figure C.3.3, frame 2 shows that, all else being equal, a doubling of sample size increases power for trend and decreases the SE of status, as would be expected. However, when compared to the patterns in the other three frames of Figure C.3.3, this large increase in effort has a smaller relative effect on both trend and status than other variables in a design scenario. In general, collecting a larger sample size within a sample interval will improve status estimates, while more revisits to sites across time will improve power for trend. Moreover, panel designs incorporating planned revisits across the entire period of the study (e.g., spaced across multiple years) have higher power for trend detection than plans using only revisits close in time.

Revisiting sites across time has an important implication for design specification. In multi-site monitoring, the total variance of trend estimates among samples is usually large, and the proportion attributable to site effect is substantial (e.g., individual wetlands often differ much more than locations within a wetland). If one sample of sites was taken at one time and another independent sample taken at another time, the site component of variance would be included in the variance of each sample (i.e., there would be a better spatial distribution to estimate status). However, if each site is considered a "block," and sites are periodically revisited, the site component of variance disappears from the variance of a slope (Urquhart et al. 1993, 1998). Revisiting sites across years eliminates site-to-site variation in the same way that self-pairing in experimental studies eliminates the variation introduced across subjects. The positive implications of this (i.e., trend becomes much more discernible) suggest that all ROMN designs must have revisits to some sites across time. While some of these revisits must be spread across time, many will be in the smaller panels that connect the design (linkage panels). These sites are visited in consecutive years and allow estimation of annual variability.

However, a design cannot only specify revisits to a small number of sites. Status is important as well; thus, some number of unique sites must be included in a design. Revisits only reduce the influence of the residual variance component on trend detection capability, while adding additional sites reduces the effect of both the residual and the interaction variance components. Therefore, when resources are fixed, sampling additional sites, rather than revisiting sites, is always an improvement (unless the interaction term is zero). The amount of benefit derived from adding sites to the sample is related to the relative magnitudes of the two variance components. An increase in the number of sites visited also increases the possibility of identifying subpopulations with common trend characteristics, as a result of the larger sample size. As the period of monitoring increases, it becomes feasible to evaluate trends at individual sites specified by a GRTS design.

C.3.3.3 Year effect (Figure C.3.3, frame 3)

The effects of design features on status and trend can be managed through design and sample size choices—except for the year-effect variance component (Urquhart et al. 1993; 1998). The year effect is the variation of the target resource (response) across years for all sites in a target population; it is not the variation in an indicator across years at a single site. If a trend is present, year variance is the deviation away from the trend line (or curve) after trend is accounted for. Frame 3 in Figure C.3.3 shows three power for trend and SE for status curves across a range of year effects. Small year effects (e.g., 0.001) allow reasonable power and SE after 10–12 years. However, as the year effect increases (to 0.1 and 0.9), the time required to reach 80% power or attain acceptable SE increases dramatically.

If a year effect exists even in small amounts, the sample size of an analysis reverts to the number of years for which there are data, and the number of visits and/or numbers of sites have no practical effect on trend detection (i.e., in the equation in Figure 4.4.1.2, the year-variance component is not divided either by the total number of unique sites or the number of revisits in a year). If the year effect is large, no amount of design manipulation can overcome its effect on trend detection. The only real recourse is to monitor for a longer period of time to accrue sufficient power (in the equation in Figure 4.4.1.2, a longer monitoring period increases precision by increasing the denominator). In some cases, it can be cost-effective to visit a site other than on a yearly basis (i.e., to skip some years) with little loss in trend-detection capability (Larsen et al. 2001).

However, year effects can be circumvented or controlled in a variety of other ways. Measures and methods that are more immune to year effects can be used (Stoddard et al. 1996; Kaufmann et al. 1999; Kincaid et al. 2004). Classification of sites into subpopulations whose variance structures differ (Stoddard et al. 1996) can improve power within each subpopulation due to the decreased variance across all sites. Finally, we can identify logically sound factors with which year variation is correlated and use these to remove the year effect with a linear model (Larsen et al. 2001, 2004). If year effects are likely to be important, identifying and monitoring possible controlling factors become as important as monitoring the indicators themselves.

C.3.3.4 Panel form (Figure C.3.3, frame 4)

Most ROMN panel structures (including the default design used in Figure C.3.3) use a partially augmented, serially alternating split panel (Urquhart and Kincaid 1999). These design forms are the most effective compromise between emphasis on spatial and temporal variation, and they enable different types of change to be detected (e.g., both individual trend and net or population trend). Split panel design also helps balance the need for repeated site visits and the impacts incurred by field-sampling procedures, because most sites are "rested" for extended periods (several years) between sampling events. These rest intervals also facilitate cost-effective rotation of effort across ROMN parks and protocols (see Chapter 9). Finally, in contrast with an always-revisit panel form (e.g., the same set of sites visited every year), a split panel form will increase the number of unique sites over the same time period, providing better status estimates.

The panel structures in frame 4 of Figure C.3.3 differ only in the interval between the main, sample-size-rich panels (from 5 to 10 years) and the required number of linkage panels (5 and 10). The total unique sample size also (unavoidably) varies, so it is somewhat difficult to interpret the pattern according to panel structure alone. However, power for trend increases and SE for status decreases more slowly with time for the form with 10 years separating the main panel revisits, emphasizing the importance of site revisits. It takes about 10 years longer for the long interval design to reach 80% power. After all main panel sites have been revisited once, the SE curves are indistinguishable.

C.4 Literature Cited

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. Second edition. Washington, D.C.: U.S. Environmental Protection Agency; Office of Water. EPA 841-B-99-002.

Cochran, W. G. 1957. Analysis of covariance: Its nature and uses. Biometrics **13**(3) (Special issue on the analysis of covariance):261–281.

______. 1987. Sampling techniques. New York: John Wiley and Sons.

Cohn, T. A., L. L. DeLong, E. J. Gilroy, R. M. Hirsch, and R. M. Wells. 1989. Estimating constituent loads. Water Resour. Res. **25**(5):937–942.

Draper, N. R., and H. Smith. 1967. Applied regression analysis. Third edition. New York: John Wiley & Sons.

El-Shaarawi, A., 1993. Environmental monitoring, assessment and prediction of change. Environmetrics **4**:381–398.

Esterby, S. R. 1993. Trend analysis methods for environmental data. Environmetrics **4**:459–481.

Garman, S. L., B. Schweiger, C. Lauver, R. Bennetts, E. Crowe, T. Mau-Crimmins, and D. Manier. In prep. A simulator for evaluating complex survey designs (CSDsim): Technical documentation. NPS Intermountain Region Technical Report.

Geissler, P. H., and T. L. McDonald. 2003. Sampling designs for national park monitoring. Paper presented at the bi-annual meeting of the George Wright Society, Protecting Our Diverse Heritage: The Role of Parks, Protected Areas, and Cultural Sites, April 17.

Gibbs, J. P., S. Droege, and P. Eagle. 1998. Monitoring populations of plants and animals. BioScience **48**:935–940.

Gilbert, R. O. 1987. Statistical methods for environmental pollution. New York: Van Nostrand Reinhold.

Gilliom, R. J., J. E. Barbash, C. G. Crawford, P. A. Hamilton, J. D. Martin, N. Nakagaki, L. H. Nowell, J. C. Scott, P. E. Stackelberg, G. P. Thelin, and D. M. Wolock. 2006. Pesticides in the nation's streams and ground water, 1992–2001. Reston, Va.: U.S. Geological Survey Circular 1291. http://ca.water.usgs.gov/pnsp/pubs/circ1291/.

Hirsch, R. M., R. B. Alexander, and R. A. Smith. 1991. Selection of methods for the detection and estimation of trends in water quality. Water Resour. Res. **27**:803–813.

Hirsch, R. M., J. R. Slack, and R. A. Smith, 1982. Techniques of trend analysis for monthly water quality data: Water Resour. Res. **18**:107–121.

Hirsch, R. M., P. A. Hamilton, and T. L. Miller. 2006. U.S. Geological Survey perspective on water-quality monitoring and assessment. J. Environ. Monit. **8**:512–518.

Jassby, A. D. 1998. Interannual variability at three inland water sites: implications for sentinel ecosystems. Ecological Applications **8**:277–287.

Jassby, A. D., and T. M. Powell. 1990. Detecting changes in ecological time series. Ecology **71**:2033–2052.

Kaufmann, P. R., P. Levine, E. G. Robison, C. Seeliger, and D. V. Peck. 1999. Surface waters: Quantifying physical habitat in wadeable streams. Washington, D.C.: U.S. Environmental Protection Agency. Report nr EPA/620/R-99/003.

Kincaid, T. M., D. P. Larsen, and N. S. Urquhart. 2004. The structure of variation and its influence on the estimation of status: Indicators of condition of lakes in the northeast, U.S.A. Environmental Monitoring and Assessment **98**(1/3):1–21.

Langland, M. J., P. J. Phillips, J. P. Raffensperger and D. L. Moyer. 2004. Changes in streamflow and water quality in selected nontidal sites in the Chesapeake Bay basin, 1985–2003. Reston, Va.: U.S. Geological Survey Scientific Investigations Report.

Larsen, D. P., N. S. Urquhart, and D. L. Kugler. 1995. Regional-scale trend monitoring of indicators of trophic conditions of lakes. Water Resources Bulletin **31**:117–140.

Larsen, D. P., T. M. Kincaid, S. E. Jacobs, and N. S. Urquhart. 2001. Designs for evaluating local and regional scale trends. BioScience **51**(12):1069–1078.

Larsen, D.P., P. R. Kaufmann, T. M. Kincaid, and N. S. Urquhart. 2004. Detecting persistent change in the habitat of salmon-bearing streams in the Pacific northwest. Canadian Journal of Fisheries and Aquatic Sciences **61**(2):283–291.

Loftis, J. C., R. C. Ward, R. D. Phillips, and C. H. Taylor. 1989. An evaluation of trend detection techniques for use in water quality monitoring programs. Corvallis, Ore.: U.S. EPA Environmental Research Laboratory. EP.4160013-891037.

Messer, J. J., R. A. Linthurst, and W. S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environ. Monit. Assess. **17**:67–78.

Nanus, L. D. H. Campbell, G. P. Ingersoll, D. W. Clow, M. A. Mast. 2003. Atmospheric deposition maps for the Rocky Mountains. Atmospheric Environment **37**:4881–4892.

Olsen, A. R., J. Sedransk, D. Edwards, C. A. Gotway, W. Liggett, S. L. Rathburn, K. H. Reckhow, and L. J. Young. 1999. Statistical issues for monitoring ecological and natural resources in the United States. Environ. Monit. Assess. **54**:1–45.

Overton, J. M., T. C. Young, and W. S. Overton. 1993. Using 'found' data to augment a probability sample: Procedure and case study. Environ. Monit. Assess. **26**(2/3):65–83.

Paulsen, S. G., R. M. Hughes, and D. P. Larsen. 1998. Critical elements in describing and understanding our nation's aquatic resources. J. Am. Water Resour. Assoc. **34**:995–1005.

Schweiger, E. W., D. W. Bolgrien, T. R. Angradi, and J. R. Kelly 2005. Environmental monitoring and assessment of a great river ecosystem: The Upper Missouri River pilot. Environmental Monitoring and Assessment **103**:21–40.

Stehman, S. V., and W. S. Overton. 1994. Environmental sampling and monitoring. Pages 263–306 *in* G. P. Patil and C. R. Rao, eds., Handbook of statistics. New York: Elsevier Science B.V.

______. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics **8**:167–195.

Stevens, Jr., D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Evironmetrics **14**:593–610.

______. 2004. Spatially balanced sampling of natural resources. J. Am. Stat. Assoc. **99**:262–278.

Stoddard, J. L., N. S. Urquhart, A. D. Newell, and D. L. Kugler. 1996. The Temporally Integrated Monitoring of Ecosystems (TIME) project design: Detection of regional acidification trends. Water Resour. Res. **32**:2529–2538.

Stoddard, J. L., C. T. Driscoll, J. H. Kellogg, and J. S. Kahl. 1998. Can site-specific trends be extrapolated to a region? An acidification example for the northeast. Ecological Applications **8**(2):288–299.

Stow, C. A., S. R. Carpenter, K. E.Webster, and T. M. Frost. 1998. Long-term environmental monitoring: Some perspectives from lakes. Ecological Applications **8**:269–276.

Thigpen, B., and A. Paulson. 1974. A multiple range test for analysis of covariance. Biometrika. **61**:479–484.

Thomas, L. 1996. Monitoring long-term population change: why are there so many analysis methods? Ecology **77**:49–58.

Urquhart, N. S., and T. M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological, and Environmental Statistics **4**:404–414.

Urquhart, N. S., W. S. Overton, and D. S. Birkes, 1993. Comparing sampling designs for monitoring ecological status and trends: impact of temporal patterns. Pages 71–88 *in* V. Barnett, ed., Statistics in the environment. Sussex, England: John Wiley & Sons, Ltd.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications **8**(2):246–257.

Zetterqvist, L., 1991. Statistical estimation and interpretation of trends in water quality time series. Water Resources Research **27**:1637–1648.

Appendix D
Data and Information Management Plan

D.1 Introduction

D.1.1 Purpose

Reliable data and information are essential to managing the national parks, and collecting natural resource information is the first step toward understanding national-park ecosystems. When collected using rigorous methods, maintained through sound management practices, and transmitted to park managers in a useable format, that information can also form the basis for sound management decisions.

Preserving information requires the establishment and maintenance of reliable data and information management practices. Without planning, data are easily corrupted, misplaced, or misunderstood, and information can be quickly lost through staff turnover, lack of effective communication, and changes in hardware, software, and data archive formats. Any good set of facts, whether collected last week or 20 years ago, must also provide enough information about itself (i.e., metadata) to ensure its preservation and meaningful use.

D.1.2 Scope

This plan is not limited to facts or data contained in the tables, fields, and values that make up a dataset. Its larger purpose is to describe the process for generating, preserving, documenting, and transmitting the context that helps data become information and makes it valuable and interpretable. As such, this plan covers both data—commonly defined as "facts or pieces of information" in scientific or academic literature—and information, defined variously as "1. knowledge communicated or received concerning a particular fact or circumstance" to "7. computer data at any stage of processing, as input, output, storage, or transmission" (Merriam-Webster 2006). In other words, this plan is not just concerned with the management of data and facts; it also intends to ensure that facts become information (e.g., interpretation of the data via analyses and reports). Therefore, it addresses pieces of information, the processing and preservation of those pieces, and the communication of knowledge derived from those pieces.

This plan applies to the Rocky Mountain Network (ROMN), one of 32 NPS networks nationwide, which connects six park 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 core network staff is located in Fort Collins and Estes Park, Colorado. While the Internet and other modern telecommunication technologies have greatly facilitated contact between the multiple entities of the network, direct personal communication remains critical in establishing common goals, locating and resolving misunderstandings, and setting priorities. Figure D.1.2 shows the physical relationship of the network office and the six parks and displays the major airports, roads, and geographic barriers, that affect geographic connectivity among the network entities.

The primary audience for this plan includes developers and users of network information. Developers include network staff, park professional staff, other NPS staff, and external collaborators. Users include network park managers and staff from all divisions, network staff, Intermountain Region managers and staff, Washington Area Service Office (WASO) managers and staff, and the public.

D.1.3 Goals and objectives

The goals of our information management system are to ensure the quality, interpretability, security, longevity, and availability of ecological data and related information resulting from resource inventory and monitoring efforts.

Quality. The ROMN will take measures during all phases (project development, data acquisi-

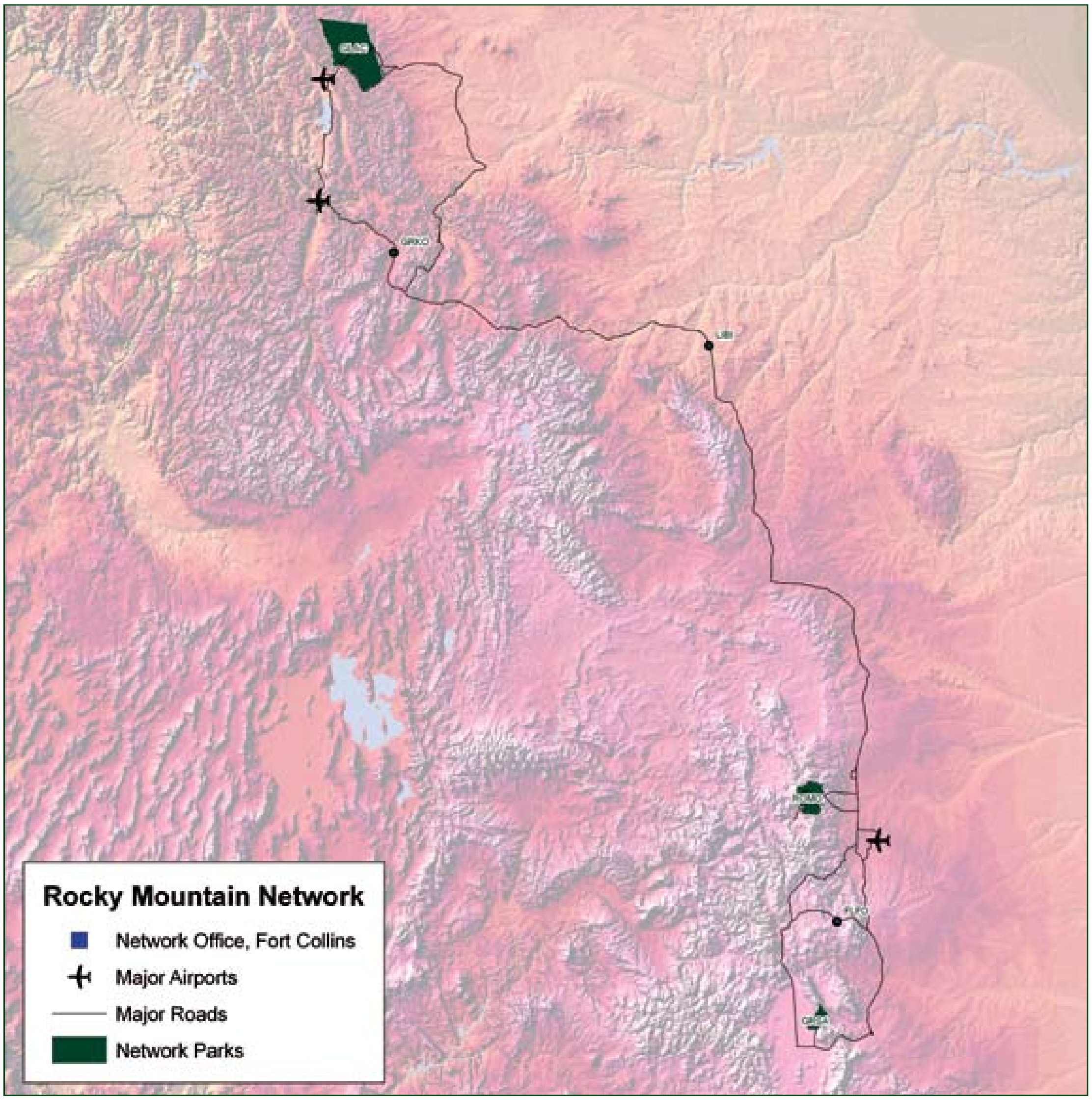


Figure D.1.2. Location of Rocky Mountain Network office relative to each of the network parks.

tion, 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. The ROMN 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.

The objectives that support these goals are as follows:

- To acquire and/or generate the data that the ROMN needs to achieve its goals;
- To compile that data into sets (information) and ensure its accuracy and logical consistency;
- To provide the documentation critical to maintaining the long-term interpretability of the acquired and compiled information;
- To determine the sensitivity level of the information;
- To properly archive the information;
- To properly catalogue the information and report it to the network parks and the public; and
- To provide information to the appropriate audiences in the correct format.

D.1.4 Organization

This plan and all of its related documents are organized hierarchically into three levels (Figure D.1.4). Organizing the plan hierarchically and having it directly accessible to network staff via the web ensures that:

- The entire Data and Information Management Plan is broad in scope yet offers substantial detail to accomplish tasks consistently;
- Staff have direct, immediate access—from the office and on the road—to the document they require, particularly the Standard Operating Procedures (SOPs);
- The plan, or any one of its components, can be updated as needed (those updates immediately affect the management of all network information);
- Updated schedules are accommodated by this plan, the operation narratives, and SOPs (while SOPs will regularly change, especially due to changes in hardware and software, the general framework for managing data will evolve more slowly); and

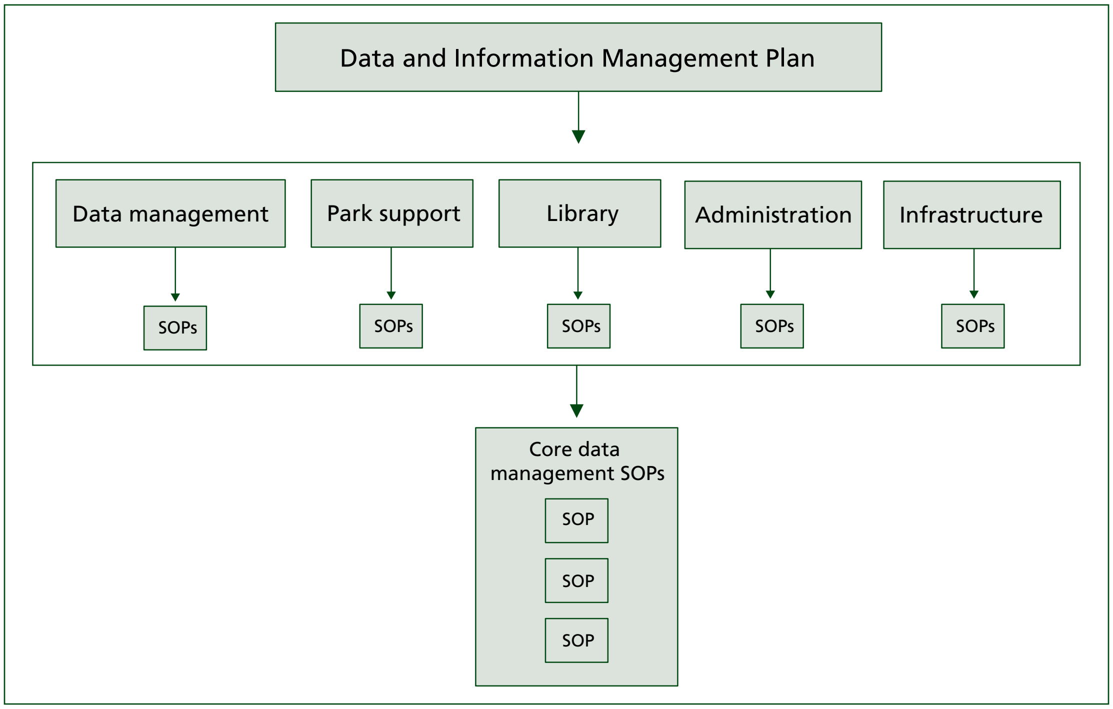


Figure D.1.4. Hierarchy of information management plan, network operations, and standard operating procedures.

- If a printed copy is required, the very latest version is immediately and always available.

D.1.4.1 Level One

Level One is this plan, which contains the information management philosophy (models), regulations, guidelines, and general data-management roles and responsibilities employed by the ROMN. This level is the most comprehensive, as it is applicable to all data-related actions within the network, but contains little detail regarding data management.

D.1.4.2 Level Two

Level Two consists of network operation narratives. Because the types of data and information, and the associated skills and personnel that manage that information, differ within the network, it is useful to divide the network into core operations relative to managing data and information (see Section D.3). For instance, the software and skills used to manage payroll and travel information differ significantly from those used to manage grassland protocols and associated data. Each operation narrative describes the more specific and distinct data-related functions (i.e., unique software, hardware and process steps) performed by each operation. (The concept of an operation is further defined in Section D.2, and Section D.3 provides a brief description of the ROMN operations. The complete operation narratives are available at the network's Intranet site (NPS–ROMN 2007o).)

Table D.1.4.3. List of standard operating procedures (core SOPs).

Operation	Standard operating procedure
Administrative	Obtaining Project Funding
Data Management	Approving Information for Distribution
	Archive Format Standards
	Cost Surface Model
	Data Analysis
	Data Management Guidelines for Protocol Development
	Developing GPS Basemaps
	Digitizing Documents
	Directory Structure
	Documentation
	Establishing and Naming Sites and Markers
	Field Season Data Handling
	File Naming Conventions
	GPS Operation Standards
	NPSpecies Update
	Photo Management
	Project Manager Application
	Protecting Sensitive Resources
	Quality Assurance and Control
	Request Research Permit
	Research Permit System Viewer
	Software Development
	Specifications for Project Deliverables
	Using GPS-Photo Link
	Using Sharepoint Services For Network Communication
Infrastructure	Network Backup
	Web Page
Library	Using Procite

D.1.4.3 Level Three

While operation narratives provide a framework for managing network information, specification of data-management steps is critical to ensuring that all tasks are performed consistently. Thus, the final level of organization is the standard operating procedures (SOPs) (Table D.1.4.3). The SOPs describe the detailed steps necessary to accomplish a data- or information-related task. For example, an SOP may specify exactly how to digitize a document according to network specifications for resolution and color. SOPs can range in their level of detail, but will—when followed—produce consistent results. Finally, SOPs represent the implementation of the policies described in this plan, therefore enforcing these policies through action. All SOPs are found at the network's Intranet site (NPS–ROMN 2007o).

In some cases, SOPs are written for a particular network operation. For instance, an SOP for backing up the network's server is specific to the Infrastructure Operation; no other operations will refer to this SOP. In other cases, SOPs may apply to two or more operations. For instance, the SOP that defines digital file-naming conventions applies to all network operations. SOPs common to multiple operations are known as core SOPs, and are produced by the Data Management Operation (NPS–ROMN 2007e).

D.2 Conceptual Framework for Managing Data and Information

This chapter describes four models that represent the conceptual framework for managing all network information. The first model, a conceptual model for data management, describes each data-stewardship step (Figure D.2.1). Each step is integral to each phase of a project and operation. Beyond the network, Figure D.2.4 provides a model for how information is ultimately integrated with other national systems.

D.2.1 Data management conceptual model

Figure D.2.1 shows a general model for data management. This model is a framework for regularly managing data at any point in time and with any task.

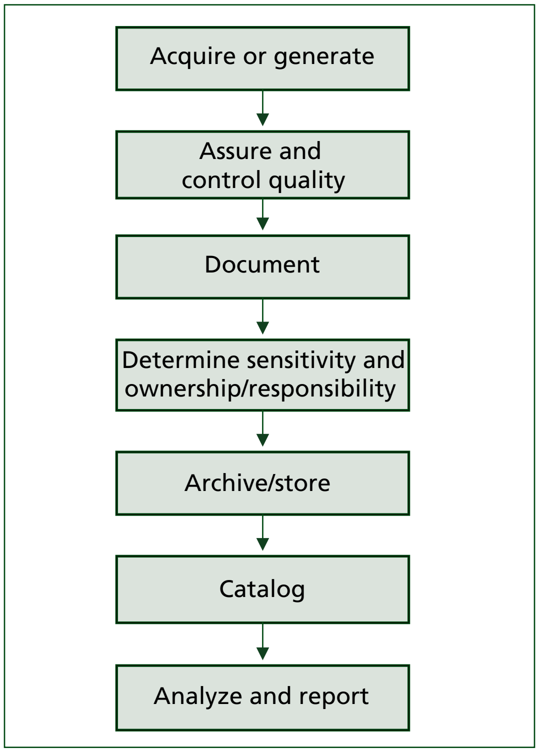


Figure D.2.1. Data management conceptual model.

These stewardship steps include:

Acquire and/or Generate. The scope of information to be acquired or created and maintained must be defined. Without a clear vision of scope, the network may be overloaded with unnecessary and/or irrelevant information or not collect critical information.

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. Examples include limiting answers on a form to a pre-defined lookup list or designing field forms that are easy to read and help field crews to identify and record the observations that are needed. Quality control (QC) involves checking the data that has been collected for accuracy and completeness to minimize the risk of producing poor quality data. Examples include verifying that all temperatures were recorded in Celsius, that all field sheets are dated and properly completed, and that information entered into computerized forms matches the original field sheets. Data of inconsistent or poor quality can result in incorrect interpretations and conclusions.

Document. The careful documentation of datasets, the data source(s), and the methodology by which the data were collected or acquired is essential for preserving information over the long-term. Documentation also establishes the basis for the appropriate use of the data in resulting analysis and products. In many cases, documentation refers to metadata, which can be defined as information about the content, quality, condition, and other characteristics of data. However, documentation also applies to other types of information, including reports. For example, some final reports, particularly legacy reports, may have an incomplete title page, making it difficult to discern an author or year of publication. In this case, creation of a more complete title page would suffice for adequate documentation.

Determine Sensitivity and Ownership. While the free flow of information often benefits parks, there are cases in which information can be used to harm their natural resources or, in cases of distributing proprietary materials without permission, hurt the National Park Service. Sensitivity is defined according to whether the use of information by unauthorized individuals will threaten a park's natural and/or cultural resources, 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 elucidates whether the network or one of the parks is the ultimate authority over a dataset or information source. This includes not only the distinction between private and public information, but also whether the responsible party is the network, park or another.

Archive and Store. Archiving and storage refers to how information is physically organized. Where the information is physically housed depends on a number of factors, including its format, sensitivity, ownership, and content. Integral to properly housing the information are protections from disaster, malice, and degradation. Archiving and storage applies to hardcopy and digital information, drafts, and final versions. It should be emphasized that archiving, in the context of this plan, is more generalized than the meaning associated with museum collections.

Catalog. Cataloging refers to how information—datasets, reports, maps, projects, ideas—is logically organized. Information may be stored and protected, but in the absence of a logical method for its discovery and retrieval, it may never be used. In some cases, cataloging may be directly connected to the documentation process (e.g., metadata), although cataloging may also be discrete.

Analyze and Report. Analysis involves the examination of information elements and their relations. Reporting involves the export of information, whether it is the analyzed product or original form.

It is important to note that these tasks are neither mandatory nor linear. During any type of data-management task, one or all could apply in any order. Nevertheless, there is a general logic to presenting these tasks in the order shown above.

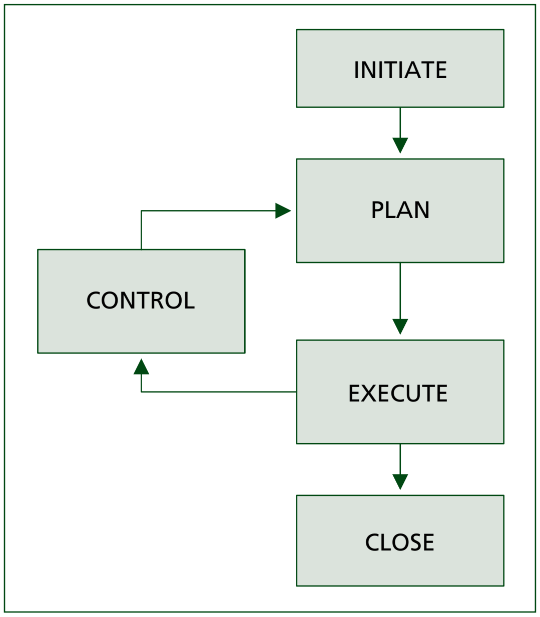


Figure D.2.2. General project life-cycle model.

D.2.2 Project life-cycle model

The data management model assists in building the foundation for a project, which is defined as a temporary endeavor undertaken to create a unique product (PMI 2004). Projects can be divided into five primary stages, each of which is characterized by some or all of the data-management components described above and implemented by staff involved in the project. Figure D.2.2 outlines the conceptual model for the project life-cycle.

Initiate. This is when many of the preliminary decisions are made regarding project scope and objectives. In addition, funding sources, permits, and compliance are all addressed in this phase. Primary responsibility rests with project leaders and program administrators. Although this phase lacks specific data-management activities, it is important that data managers remain informed of projects at this phase. This is especially true as timelines for deliverables are finalized. All contracts, agreements, and permits should include standard language that describes the formats, specifications, and timelines for project deliverables.

Plan. During this phase, details are worked out regarding how data will be acquired, processed, analyzed, reported, and made available to others. The project leader is responsible for the development and testing of project methodology, or modifying existing methods to meet project objectives. It is critical that the project leader and the data manager work together throughout this phase. This dialogue will help to build and reinforce good data management throughout the project, especially during the crucial stages of data acquisition, processing, and retrieval. By beginning collaborative development as soon after project approval as possible, data integrity and quality can be assured most easily. An important part of this collaboration is the development of the data model (i.e., database structure) and data dictionary, where the specifics of database implementation and the parameters that will be collected are defined in detail. Devoting adequate attention to this aspect of the project is possibly the single most important part of assuring the quality, integrity and usability of the resulting data. Once the project methods, data design, and data dictionary have been developed and documented, a database can be constructed to meet project requirements.

Execute. During the project implementation phase, data are acquired, processed, error-checked and documented. This is also when products such as reports, maps, GIS themes, and other products are developed and delivered. The project leader oversees all aspects of implementation, from logistics planning to data acquisition, report preparation, and final delivery. Throughout this phase, data-management staff functions primarily as facilitators, providing training and support for database applications, GIS, GPS, and other data processing applications; facilitation of data summarization, validation, and analysis; and assistance with the technical aspects of documentation and product development.

Control. For short-term projects, change control will be built in to the project scope of work and will include SOPs for modifying project objectives, methodology, and products, as well as to document change. For long-term, multi-year projects, annual summary reports will be produced to summarize results and document the work (including changes).

Close. Upon project closure, records are updated to reflect the status of the project and its associated deliverables in a network project-tracking application. For monitoring protocols, careful documentation of all changes is required. Changes to methods, SOPs, and other procedures are maintained in a tracking table associated with each document. Major revisions may require additional peer review. During this phase, data products, reports, and other deliverables are integrated into national and network databases, metadata records are finalized and posted in clearinghouses, and products are distributed or otherwise made available to their intended audience. Another aspect of integration is merging data from a working database to a master database maintained on the network server. This occurs only after the annual working dataset has been certified for quality by the project leader. Certain projects may also have additional integration needs, such as when working jointly with other agencies for a common database.

Projects can vary in their length and complexity, which will affect the effort involved in managing data. Long-term projects will often require a higher level of documentation, peer review, and program support. From a data-management standpoint, a primary difference between short- and long-term projects is an increased need to control for change to ensure internal data compatibility over time.

Projects have particular relevance to the monitoring program because each field season of monitoring can be effectively treated as a project. Using the concepts of project management to coordinate field efforts will provide project managers with the tools and framework to ensure that a season's monitoring activities are well-organized and efficient in the generation of information.

D.2.3 Operation life-cycle model

Following project close-out, data are managed under a broader framework: the operation, defined as ongoing and repetitive work with a primary objective of sustaining the business, or in this case, the network (PMI 2004).[†] Both the data management model (Figure D.2.1) and project life-cycle model (Figure D.2.2) inform

[†] We chose to name these ongoing data management activities as "operations" instead of other terms (e.g., protocols, functions, tasks, programs) because the term is common to project management terminology, is not as easily confused with other definitions and uses within the NPS and the I&M program, but is still specific in meaning. Nevertheless, we recognize the limitations of this title.

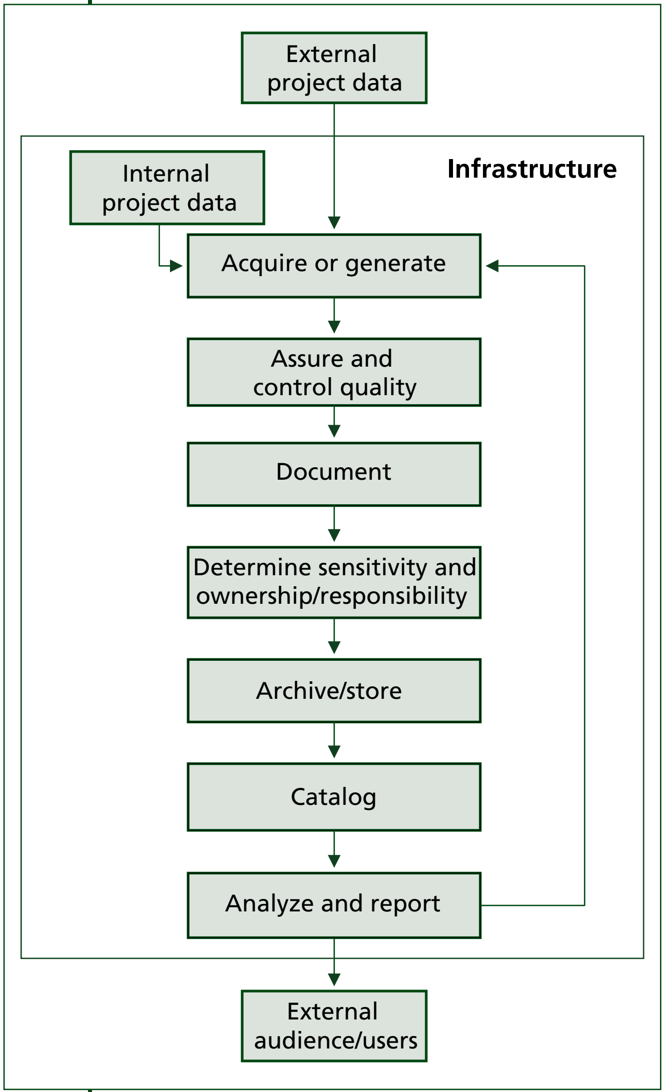


Figure D.2.3. Operation life-cycle model.

how the data-management component of an operation can be conceptualized in the operation life-cycle model (Figure D.2.3). This model borrows its structure from the data management model and incorporates the project as the data-producing element. It describes a system for continually and systematically processing, integrating, and managing data during and following project termination. Just like the data life-cycle model, each step is neither mandatory nor linear; however, this model is generally applicable to all data-related operations defined by the network. This model also includes the infrastructure, or the physical medium—local area network, hardware and software—that makes the management of data and information possible.

The operation life-cycle model emphasizes a number of other key points beyond the integration of the data and project life-cycles. First, it shows that each operation is a self-contained system with distinct entry and exit points. This ensures that provisional data are not accidentally or inappropriately used by others; data are invisible to external users until they reach a defined process step. Additionally, it shows how reported data and information may feed back into the information system and require management. For instance, reports regarding the inventory of information are treated as another item to be inventoried. Monitoring reports must also relate back to the original field information. Finally, the operation life-cycle model shows that information must be continually processed and managed for the network to function properly. Failure to incorporate any one of these steps, either individually or systematically, into an information management system, compromises both data and information over the long-term.

The operation concept has particular relevance to monitoring because each monitoring protocol, once implemented, should ultimately be treated as a unique operation. This model, therefore, provides a common framework for how all protocols should function.

D.2.4 Integration of network, park, and national systems

Unfortunately, the current configuration of the WASO and regional systems creates some confusion in terms of ownership/responsibility and where official data and reports reside. The ROMN will make every effort 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 D.2.4 provides an enterprise-level model of how information generated within the network is ultimately shared with WASO, the parks, and other audiences. Because most of the information generated by the network will be from monitoring (and not other miscellaneous projects), the narrative is specific to monitoring data and information.

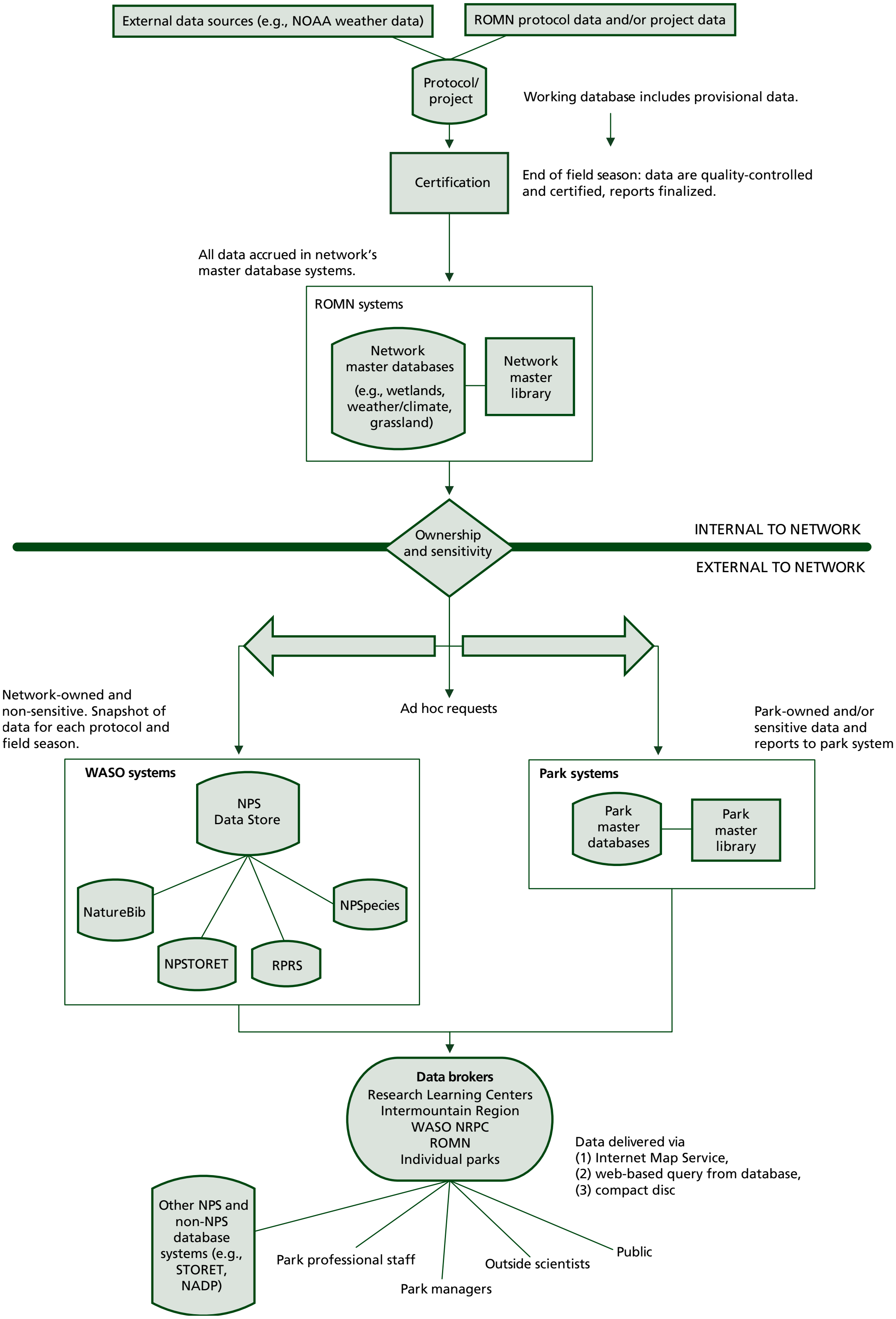


Figure D.2.4. Integration of network, park, and WASO data systems.

Each field season of a monitoring protocol is treated as a project in which data are collected, managed, and tracked in a working database. During project close-out, or at the end of the field season, the data are certified, or quality-controlled, and reports are created as a result of data analysis.

Annually, information is integrated into the larger operations. All certified data are integrated and accrued into the network's master vital signs datasets. At this point, the data are made available to the other network operations for integrative analysis.

External sharing of data depends on both ownership/responsibility and sensitivity. Non-sensitive data and reports owned by the network will be provided annually to the NPS national systems as a snapshot; data and the associated analyses will be delivered as a final product for that particular field season. Park-owned and/or sensitive data will be provided to the parks, whose managers have the ultimate responsibility to decide what action they will take regarding its distribution.

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

D.3 Network Data Operations

This section describes the data operations integral to the support of the ROMN. The ROMN recognizes the following operations:

The ***Data Management Operation*** (NPS–ROMN 2007e) has two primary responsibilities. First, it is charged with the development, implementation, enforcement, and maintenance of this plan and its associated documents and standard operating procedures (see next section). 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. This operation is similar to the Data Management Operation, in that it manages the master information for the network. However, because the processes and skills required for managing data and documents are different, the two are split.

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

The ***Infrastructure Operation*** (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 the maintenance of the network's Internet and Intranet web pages and oversight of its Sharepoint space.

The ***Administrative Operation*** (NPS–ROMN 2007a) includes the management of information related to purchasing, travel, personnel management, and funding sources.

As might be expected, the division among the operations is not entirely discrete. For instance, the Library and Data Management operations both are data and information repositories; the key differences are in how the information in the repository is formatted and used, and in the software catalog used to manage the repository. Nevertheless, classifying the network according to operations has helped to clarify systems for managing data and information that borrow from the data, project, and operation life-cycle models in Section 2. It has also enabled the ROMN to identify clear sets of processes that encapsulate the critical functionalities necessary for success.

The functions of the Library Operation serve to demonstrate how each operation implements the data management model (NPS–ROMN 2007j). Foremost, the library supports one of the fundamental needs of the network: access to final documents related to the network, its parks, or the National Park Service, as well as to natural resource information pertinent to the network's vital signs.

In the Library Operation, information, including reports and books, are ***acquired*** if they fit in to the scope of the collection. The network may receive these reports from outside sources, including researchers, or from internal sources, including project funding by the NPS. Initially, network staff must determine the ***quality*** of the document and whether it is suitable for the library collection. Quality checking may include following established NPS procedures or just checking to ensure that the document is citable (e.g., author, year, title and publisher) and that none of the pages are missing. In cases where a suitable title page is missing or is vague, it may be necessary to add extra documentation to specify the title, author, or publication date. The network must in some way determine ***sensitivity*** and ***ownership*** of the document; this will determine whether the document is free for all to view or is located for privileged access only. Once ***archived*** either digitally or as a hard copy, the document must be ***cataloged***, often through the use of such applications as NatureBib (NPS 2006e). Ultimately, the network will ***report*** on the collection, by distributing the document online or as a synthesized report such as a collections list. The operation's infrastructure is the medium (or context) within which information about the Library Operation flows, and includes the computer, hardware, software, local area network, file cabinets, and shelving.

D.4 Rocky Mountain Network Data Management Model

This section provides details about how the Rocky Mountain Network will implement the data management conceptual model (see Section D.2.1).

D.4.1 Acquire and/or Generate

The purpose of this section is to define the scope of information the network will acquire and/or create. Both national and network policies affect the scope of collection. National policies are those that apply to all activities within the NPS, and may originate with the agency's director or other entities of the federal government, including Executive Orders. Network policies are those developed internally by the ROMN. A network policy should never conflict with a national policy and should be general enough to apply to all network operations.

D.4.1.1 National guidance

National policies establish the scope of collection for all NPS activities, included those related to inventory and monitoring. Director's Order 19 (NPS 2001a) provides general guidance on the management of all NPS records; its Appendix B details what types of records should be maintained and for how long. Because administrative records are included in data and information that must be managed by this plan, the following sections of Appendix B (NPS 2001b), which specify which records are to be collected and managed, are particularly relevant:

- Natural resources records (Section N). Records and reports are considered permanent if they pertain to plant and animal life, the management of natural resources and their areas, research programs and partnerships, geologic features, pollution and environmental quality, weather and climate, pest and weed control, or soil.

- Fiscal records (Section F). Most fiscal records, including budgeting and payroll, are considered temporary and should be purged after three years.
- Personnel records (Section P). Records related to employees, including performance and work schedules are considered temporary and to be purged between two and three years.
- Property (Section S). Property and office supply records are temporary and should generally be removed after three years.

Another key policy is the Inventory &Monitoring Program Statement of Purpose (NPS 2006b). Appendix A of this document specifies the types of park-specific information to be acquired and managed, either directly or indirectly, by the networks:

- Legacy datasets and reports;
- Species information;
- Digital vegetation maps;
- Digital cartographic data;
- Digital soils maps;
- Digital geology maps;
- Water resources inventories;
- Water chemistry and flow information;
- Regional air quality monitoring stations, pollution sources, and data; and
- Precipitation and meteorological data.

D.4.1.2 Network guidance

In addition to the national policies, the ROMN has defined its own set of policies applicable to all network operations. The guidelines that apply to information acquired from other sources state that the network will only acquire and manage information that:

- Directly or indirectly supports the defined vital signs and/or facilitates the inventorying of natural resources at or around the network parks;
- Either has basic documentation that identifies the meaning of the information, its source and quality (metadata), or those elements can be documented. The information source can be another document, individual, or agency, as long as it is possible to refer back to this source. Information may be unpublished or incomplete as long as its meaning is defined, its source is identified, and some measure of its quality (its reliability) can be assigned;
- Is one of the following information formats: book, report, gray literature, periodical, journal article, NPS reference material, dataset, or map; and
- Is not a voucher specimen collected at a network park, that is, the network will not house, manage, or curate specimens.

In summary, the network is unable to acquire and manage all types of information. Referring to national and network policies provides guidance as to the types of information, including content and format, on which the network will focus.

D.4.2 Quality Assurance and Quality Control

Inaccurate, erroneous, or corrupt data or information can be worse than no information at all. Quality Assurance/Quality Control (QA/QC) mechanisms are designed to prevent error, which is the difference between an observed value, the recorded value, and the actual value. Inadequate QA/QC can result in three types of error. One type is commission, caused by data-entry or transcription errors, or malfunctioning equipment. These errors are common, generally identifiable, and can be effectively reduced with appropriate QA mechanisms built into the data-acquisition process, as well as QC procedures applied after the data have been acquired. Another type of error is omission, resulting from missing values or insufficient documentation of legitimate data values, which could affect the interpretation of those values. These errors can be resolved through QA procedures to identify missed values and QC procedures for documenting the steps of a data-collection process. Finally, errors of logical consistency refer to the inconsistency of relationship among different features. Examples include trees that shrink through time, roads found on lakes, and other illogical measurements. These logical errors may result from inconsistencies in measurement and scale or differing definitions of the variables being measured. They can also be the result of errors of commission. Logical errors are the most difficult to detect because they are often context-sensitive and subtle. For instance, trees can shrink in size following a fire and roads can occasionally be found over lakes as bridges (and under lakes during an unusually wet year!). Proper QC procedures will help identify measures that may be logically inconsistent.

D.4.2.1 National guidance

National guidance related to information quality is found primarily in NPS Director's Order 11B (NPS 2002). This order specifies that data must be:

- **Reliable.** Information must be developed from reliable data sources and quality must be ensured at each stage of information development (NPS 2002);
- **Accurate and timely.** All information will be accurate, timely, and reflect the most current data available. All information sources will be documented (NPS 2002).

D.4.2.2 Network guidance

In addition to the national guidance, the ROMN requires that data be:

- **Verified** to establish the truth, accuracy, or reality of data (e.g., data verification checks for errors of commission). Examples of this include development of database picklists that prevent transcription errors and cross-checking field forms with computer entries.
- **Validated** to check for errors of logical consistency. Validation is most easily accomplished by working with the protocols and projects to develop queries that test for illogical answers.
- **Made decipherable** so that it can be fully interpreted without ambiguity. This protects directly against errors of omission. Ensuring that data are easily interpreted and unambiguous is only possible if all supporting information (i.e., methods, codes, and data relationships) are clear and understandable.

Likewise, the network will assure and control quality through the implementation of the following SOPs:

- Standard file-naming conventions (NPS–ROMN 2007h): Provides consistent rules for how to name any digital file, accommodate data versions, and differentiate between draft and final;
- Standard directory structure (NPS–ROMN 2007f): Provides consistent rules for how the structure is to evolve through time;
- QA/QC Procedures (NPS–ROMN 2007k): Provides specific step-by-step guidance on how to effectively QA/QC network information.

D.4.3 Document

Careful documentation is crucial to long-term information preservation.

D.4.3.1 National guidance

Executive Order 12906 (EO 12906) mandates all federal agencies to:

- Fully document all new geospatial data collected or produced, either directly or indirectly, using Federal Geographic Data Committee standards (FGDC 2006);
- Document, to the best practical extent, all geospatial data previously collected. This policy applies to all legacy geospatial data.

The Federal Geographic Data Committee (FGDC 2006) provides guidance on a number of standards, including those specific to the information generated by the network:

- Content Standard for Digital Geospatial Metadata (CSDGM): The objectives of the standard are to provide a common set of terminology and definitions for the documentation of digital geospatial data. The standard establishes the names of data elements and compound elements (groups of data elements) to be used for these purposes, the definitions of these compound elements and data elements, and information about the values that are to be provided for the data elements.
- Federal Geographic Data Committee (FGDC) Biological Data Profile: The objective of the profile is to provide a common set of terminology and definitions for the documentation of biological data through the creation of extended elements and a profile of the FGDC Content Standard for Digital Geospatial Metadata.

A final requirement, from the NPS GIS Committee (NPS 2006d), requires that all GIS data layers be described using FGDC standards (FGDC 2006) and the NPS Metadata Profile (NPS 2006c).

D.4.3.2 Network guidance

In addition to the national policies, the network will:

- Ensure that all documents, including reports, news articles, and letters, in final form (i.e., not draft) will have a cover page that clearly indicates the author(s), year of publication, title, and publisher;
- Document all tabular datasets, regardless of whether they meet the FGDC standards (FGDC 2006) for geospatial datasets;
- When possible, bundle all datasets, reports, protocols, metadata, and any other supporting documents as one archive;
- Use XML as the common documentation format; and
- Build documentation into all stages of a project life-cycle model.

These national and network policies are implemented through the following SOPs:

- Documentation (NPS–ROMN 2007g): Specifies how to document datasets, documents, and photographs, and how to bundle them together to preserve context and the supporting documentation necessary for the interpretation of the datasets.
- Project Manager (NPS–ROMN 2007m): Provides the means to keep notes of a project. Theses notes may contribute to the documentation of a dataset.
- Archive Format Standards (NPS–ROMN 2007c): Provides basic guidance for creating archives intended for long-term storage and distribution of network data.

D.4.4 Determine sensitivity and ownership

Network staff will need to regularly evaluate information for conflicts related to sensitivity and ownership.

D.4.4.1 National guidance

At the national level the following rules and regulations apply to, and must be included in, all agreements with outside parties for research, monitoring, or protocol development. In short, these guidelines ensure that all data acquired via public funding belong to the people of the United States. U.S. Office of Management and Budget (OMB 1999) guidance, particularly sections 36 "Intangible Property" and 48 "Contract Provisions", mandates that the NPS:

- Reserve a royalty-free, nonexclusive and irrevocable right to reproduce, publish, or otherwise use the work for Federal purposes, and to authorize others to do so (Section 36);
- Has the right to obtain, reproduce, publish or otherwise use the data first produced under an award; and authorize others to receive, reproduce, publish, or otherwise use such data for Federal pur-

poses (Section 36);

- Shall request, and the recipient shall provide, within a reasonable time, the research data (Section 36); and
- Shall include contract provisions or conditions that allow for administrative, contractual, or legal remedies in instances in which a contractor violates or breaches the contract terms in relation to data ownership (Section 48).

The Freedom of Information Act (FOIA; USDOI 2006) restricts general public accessibility to:

- Geological and geophysical information and data concerning wells;
- The nature and specific location of (a) endangered, threatened, rare, or commercially valuable species, (b) minerals or paleontological objects, or (c) objects of cultural patrimony;
- The nature and location of any archaeological resource for which the excavation or removal requires a permit or other permission; and
- The specific location of any significant caves.

FOIA also specifies that all non-sensitive information be fully accessible to the public.

D.4.4.2 Network guidance

At the network level, there is an additional level of policy with regard to the ownership and sensitivity of data. Determining whether data falls under the purview (ownership) of the network or of one of the member parks is essential because it determines which organization has the responsibility to make this information available to the public and who will respond to questions concerning its source, meaning, accuracy, and implications. To preserve ownership, the network will ensure that:

- Copyrighted documents (e.g., publications resulting from research in parks) will not be posted or distributed unless written permission is provided by the copyright holder;
- Data generated in a park, by park staff, or via park-funded research projects remains the property of the park. Use of the information will be granted to the network in cases where it supports resource inventory and monitoring; however, public release of the information will be reserved to the park;
- Data acquired or generated by the network outside of the member parks is the property of the network. These data will be available to park staffs via internet, intranet, and/or other means;
- Information developed from analysis and summarization by network staff or cooperators is the property of the network;
- The network will not distribute anything it does not own unless its dissemination has been previously approved by its constituent parks, and any other information owner or copyright holder;
- All cooperative or interagency work will be conducted as part of a signed collaborative agreement. Every cooperative or interagency agreement or contract involving the network will cite OMB Circular A-110 (OMB 1999) under the Reports and Deliverables Section of all agreements and contracts; and
- Cooperative or interagency agreements or contracts must include a clearly defined list of deliverables and products. Details on formatting and media types that will be required for final submission must be included. Typical products include, but are not limited to, field notebooks, photographs (hardcopy and digital), specimens, raw data, and reports. All reports and deliverables will follow the current version, at the time of the agreement, of the network specifications for project deliverables (NPS–ROMN 2007n).

The issue of sensitivity will be interpreted according to which organization will be most damaged by the accidental dissemination of sensitive information. To maintain sensitive information, the network will ensure that:

- Decisions involving the sensitivity of data (i.e., threatened, endangered, rare, or commercially valuable park resources) remain the responsibility of the relevant park;
- Reports, maps, analytical documents, or datasets will not be released by the network to the general public without approval by the relevant park's assigned agent; and
- Information to be used in pending litigation will be treated as sensitive.

Sensitivity and ownership policies are implemented through the Approving Information for Distribution (NPS–ROMN 2007b) standard operating procedure, which provides decision points for whether data are sensitive and/or copyrighted and whether it is suitable for public distribution or available to select individuals only.

D.4.5 Archive and Store

The network will develop a storage system to accommodate a large volume of information. In most cases, the information will be in digital format, but analog copies—especially of historic documents—are sometimes the primary source of information. Where information is secured also depends on whether it relates to sensitive species and/or locations.

D.4.5.1 National guidance

The NPS differentiates between records and mission-critical records. Records are all documentary materials, including books, electronic data, maps, moving images, papers, photographs, and sound recordings, made or received by the National Park Service during the transaction of public business (NPS 2001a).

Mission-critical records are those records that are most necessary for fulfillment of the NPS mission (NPS 2001a). Mission-critical records are permanent records that will eventually become archival records. They should receive the highest priority in records-management activities, and resources and should receive archival care as soon as is practical in the life of the record. Mission critical records include:

- All records of natural and cultural resources and their management that contain information that affects the future management of the resource,
- General management plans and other major planning documents that record basic management philosophies and policies, or that direct park management and activities for long periods of time,
- All land records regarding legal title, rights, and usage of NPS lands; and
- Any records that directly support the specific legislated mission of a park unit in addition to, or distinct from, the overall NPS mission.

In addition, national guidance directs the NPS to:

- Follow the Records Retention Schedule. All NPS records must be retained for the amount of time specified by the NPS Records Retention Schedule. The schedule for all types of documents is covered in Director's Order 19-B (NPS 2001b);
- Store all records in areas that have the lowest possible risk of damage (NPS 2001a); and
- Permanently maintain original copies of natural resources information, including records related to animal and plant life. Document copies are to be held for 30 years and then transferred to the National Archives (NPS 2001b Section N).

D.4.5.2 Network guidance

Network data maintenance, storage, and archiving procedures aim to ensure that data and related documents and materials (digital and analog) are protected against loss, environmental hazards, catastrophe, and human malice; and archived in a manner that expedites recovery. Implementation instructions for the archiving policies are found in the following SOPs:

- Directory Structure (NPS–ROMN

2007f): Ensures that files are consistently, logically organized and easily accessible by all network staff.

- Network Backup (NPS–ROMN 2007d): Outlines steps to ensure that all digital information found on the network server is protected from accidental and deliberate loss.
- Photo Management (NPS–ROMN 2007l): Details how photographs are to be managed.
- Archive Format Standards (NPS–ROMN 2007c): Describes the steps for bundling data, photographs, and documents together into one zipped archive.

D.4.6 Catalog

Although there is not a single master cataloging system for data discovery, the network will use such systems when appropriate, with the goal of simplifying the search process.

D.4.6.1 National guidance

National guidance directs the NPS to:

- File in a manner that is coherent, organized, and not random, haphazard, or handled solely by individual employees (NPS 2001b);
- Use NatureBib (NPS 2006e) to track natural resource bibliographic citations;
- Use NPSpecies (NPS-2006g) to track the scientific information on the biodiversity of all organisms in all national park units;
- Use the NPS Data Store (NPS-2006f) to catalog metadata and associated geospatial data; and
- Use ANCS+ (NPS-2006a) to catalog museum collections.

D.4.6.2 Network guidance

The network will:

- Keep up-to-date records such that the data can be easily accessed and their heritage and quality easily learned;
- Use Project Manager (NPS–ROMN 2007m) to track all network projects and their related files; and
- Use the FGDC-compliant metadata in xml format to track all datasets.

Further implementation of the network's cataloging policies are found in the following SOPs:

- Standard file-naming conventions (NPS–ROMN 2007h): Provides consistent rules for how to name any digital file, accommodate data versions, and differentiate between draft and final; and
- Standard directory structure (NPS–ROMN 2007f): Provides consistent rules for how the structure is to evolve through time

D.4.7 Analyze and Report

Some common purposes of ROMN analysis include:

- Determining patterns/trends in status and trend;
- Discovering explanatory mechanisms, characteristics and correlations among information;
- Providing context or scale for a particular pattern or trend;
- Recommending changes to information management; and
- Presenting information in a manner that is readily communicated.

D.4.7.1 National guidance

National guidance directs the NPS to:

- Report all non-sensitive geospatial metadata to the National Geospatial Data Clearinghouse (EO 12906); and
- Report all water quality data collected to NPSTORET (NPS 2006h), the NPS equivalent to EPA's STORET, according to the guidelines from the NPS Water Resources Division.

D.4.7.2 Network guidance

The network will:

- Use sound scientific analyses that are defensible in peer review and court. These must be definitive and defensible to shortstop public misperceptions and prevent or curtail costly interruptions to the agency's management investments;
- Use the Internet and Intranet as the main mechanisms for distributing information;
- Promptly provide all reports to park natural resource managers, the network's Technical Committee (TC), and Board of Directors;
- Prepare reports that are understandable and useful to its primary audience: park resource managers, administrators, facilities managers, interpreters, and public affairs officers;
- Use graphical methods, when possible, that promote the understanding and interpretation of the information;
- Only release datasets and reports that have been subjected to full QA/QC;
- Distribute information with appropriate documentation that accurately and clearly defines the information and establishes the data as a product of the NPS I&M program; and
- As much as possible, use presentations, posters, and brochures for communication.

These guidelines are implemented through the following SOPs:

- Archive Format Standards (NPS–ROMN 2007c): Specifies how information is to be bundled for distribution.
- Quality Assurance and Control (NPS–ROMN 2007k): Ensures that all information is checked for quality and accuracy.
- Documentation (NPS–ROMN 2007g): Details how to adequately document datasets, photographs and documents that are intended for distribution.

D.5 Rocky Mountain Network Project Life-Cycle Model

This section details the network's vision for project management, given a lack of national standards and policies (see Section D.2.2). This section is written for all projects, recognizing that they can range in level of complexity, network input, and time. When possible and practical, it follows the Project Management Institute standards and terminology for project management, as articulated in the Project Management Body of Knowledge, PMBOK (PMI 2004). The steps and critical elements will aid in creating projects that successfully accomplish their goals, are realistically scheduled and budgeted, and are relatively easy to manage. These steps and elements will always be considered, and should be adopted at every possible opportunity.

D.5.1 Initiate

Projects exist to fulfill a need, for example: to create a database to contain the data collected during grassland monitoring, to plan for a season's field operations, to make more efficient use of office space, or to develop general and specific safety protocols for field crews. These needs can be developed from several sources—internally (vital signs monitoring), requested via the park support operation, or from other sources (WASO). In all cases, it is important to clearly identify the primary beneficiaries from the proposed project.

A network lead will be assigned to work with the beneficiaries in developing the background for the project and a general scope of work and objectives. The network lead will serve as the ROMN's primary representative and point of contact. In most cases, this person will also serve as the project manager. The general scope of work constitutes a statement of what is intended to be accomplished, a general budget for the project, and a simple description of what deliverables it will have. This will result in a descriptive document, or "charter," accepted by the parties involved.

The final phase of the initiation step involves competing for funding. The details of the various funding sources are included in respective SOPs for Administrative Operation. However, in a broader sense, every allocation of network resources, including personnel time and travel, will be included in the calculation. The competition for resources and funding will involve establishing priorities and taking the resulting list of projects in order.

D.5.2 Plan

The network differentiates between minor and major projects. Projects that involve significant allocation of either staff time (>160 hours total) or money (>$5,000) will be considered major projects. If a major project is funded, a team will be created involving park contacts (if the project involves the parks) and third-party contacts (if they are involved either as working crew or beneficiaries). This team is responsible for producing a detailed scope of work and objectives, including a clear, concise statement of what is to be accomplished, detailed budgets, and a complete list of deliverables. In addition, any contracts, agreements, research permits, or permissions required by the project should be completed and signed.

Many kinds of projects may reach this stage. Those that are repetitive will be covered in individual SOPs, such as the Software Development SOP (NPS–ROMN 2007p) or annual field work for each protocol, Field Season Data Handling (NPS–ROMN 2007r). However, most projects, major or minor, require documents and resources developed in the planning process to be available during the implementation phase. If other, minor projects (such as database development) are created that must be completed before implementation of a major project, sufficient time must be allocated.

In every case, a schedule for the project will be created. Minor projects will only require a simple timeline. Major projects will benefit from a work breakdown structure (WBS), PERT (Program Evaluation and Review Technique) charts or Critical Path Method (CPM) plotting. These control techniques greatly aid in keeping projects on time and on target. Useful examples of these tools are found in the PMBOK (PMI 2004).

D.5.3 Implement

Project execution and control make up the implementation step. Execution consists of carrying out the tasks defined in the planning phase. Control consists of feedback to the schedule to account for variances from expected accomplishment goals as well as errors and omissions in the planning phase (e.g., the field team needs three tapes instead of one or there is no place to record water temperature in the field form). It will be necessary for the project manager to assess the feedback from the execution phase and make any necessary modifications to ensure project completion. In cases where significant variances exist and modifications are required, it will be necessary to document these changes.

D.5.4 Close

The following items, when available, are required at project close:

- Final reports
- Datasets and metadata
- Other defined project deliverables

D.5.5 Organization

To accommodate the project life-cycle model and clearly distinguish finalized information from planning and field work, all information for a particular project will be organized in a manner that clearly represents the various project phases, thereby preserving the temporal element to the creation of information and preventing planning/preliminary information from being confused with the final version.

D.6 Roles and Responsibilities

Data management is a process characterized as much by attitudes and habits as by infrastructure, standards, and procedures. Although primary responsibility resides with the data managers, good data stewardship cannot be accomplished by data managers alone; it is truly a collaborative endeavor that involves many people with a broad range of tasks and responsibilities. As such, a valid data-management system must be

Table D.6. 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.

developed and continually modified to meet the needs of everyone with a role in coordinating, generating, maintaining, and using natural resource information in its many forms. This is a diverse group made up of network and park staff and other cooperators (Table D.6). A successful data-management system is maintained by reinforcing communication, awareness, and acceptance among everyone with responsibilities related to the origin, quality, disposition, and use of the data.

Although numerous positions share responsibility for data management, the chief personnel involved with data management include the network coordinator, project manager, and data manager. The network coordinator interacts with project leaders to ensure that timelines for data entry, validation, verification, summarization/analysis, and reporting are met. The project manager is responsible for the complete oversight of his/her respective project, including being involved in each step of the project and communicating with the data manager regarding network standards. The data manager is responsible for the development, maintenance, and enforcement of all data-management policies and procedures within the network, which requires being up-to-date with national policies and also understanding what is reasonable for network staff to follow. The data manager is also responsible for assisting and guiding the project manager during all stages of a project, from planning and database design to organizing and managing the project information, to reporting. Finally, the data manager is responsible for working with the network coordinator to ensure that adequate resources are made available for the management of all project- and network-level data.

D.7 Conclusion

The purpose of the ROMN Data and Information Management Plan is threefold. First, it provides a general framework and vision, articulated by the models described in Section D.2. The plan further describes each of the data management model steps and any associated national and/or network policies. Finally, the plan provides a hierarchical structure that accommodates both vision and detail. The plan is general, theoretical and visionary, while each operation and its respective SOPs are practical and detailed.

D.7.1 Implementation

Because this plan reflects and formalizes the information management processes that have evolved in the network since its inception, implementation will be immediate. However, it will occur as an ongoing evolution as a product of learning, testing, refining, and technology changes. This plan is seen as a living, changing, tool to aid in preserving and protecting the information required for successful long-term monitoring of the network's constituent parks. Therefore, more SOPs, representing specific, data-related tasks, will be developed, tested, and adopted to reflect this evolution. We anticipate that there will be bottlenecks, the identification and elimination of which is an important element in the implementation of this plan.

Short-term (years 1–3) goals for implementation include:

- Ensuring that all network staff understand the core plan and operations,
- Empowering network staff to provide feedback, and
- Developing draft and working SOPs that reflect the policies established in this plan.

Long-term (years 3+) goals for implementation include:

- Streamlining and standardizing the plan and SOPs within the network,
- Sharing SOPs and concepts among other networks, and
- Adapting the plan and SOPs to changing technologies and accepted practices.

D.7.2 Review and revision

To determine whether these procedures are followed through time, the plan, operations, and SOPs have a periodic evaluation cycle. This plan, which describes the conceptual models, operations, and policies, will be slowest to

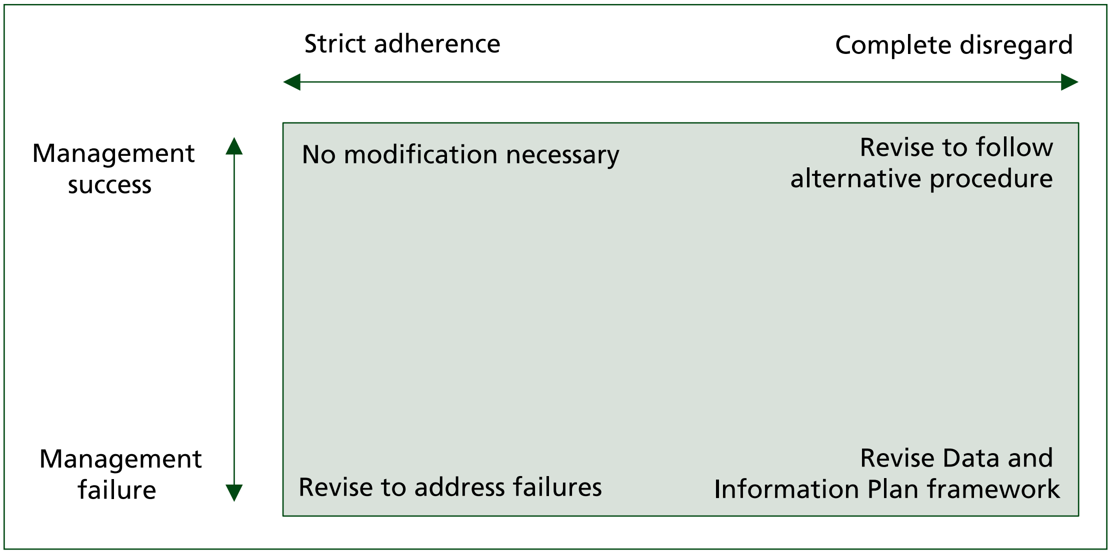


Figure D.7.2. Continuum of possible outcomes to the implementation of the Data and Information Management Plan, operations, and SOPs.

change and, therefore, will require the least-frequent review. In contrast, SOPs, which are detailed and written to specific hardware, software, and data formats, will require frequent review and revision. How often the documents describing the network operations are modified falls somewhere in between.

During these evaluations, staff will review the documents for two qualities: adherence to the procedures and overall success of managing the information. Figure D.7.2 provides a continuum of possible scenarios and actions following the review, in which the X-axis reflects how closely staff followed the policies and procedures and the Y-axis indicates the ultimate success of managing the information.

Because all of the network documents will be regularly updated, it will be essential to account for changes via versioning. Every document will contain a version number. Version numbers will be incremented by one (e.g., Version 1.3 to Version 2.0) each time there is a significant change in process and/or changes affect the interpretation of the data. Version numbers will be incremented after the decimal (e.g., Version 1.6 to Version 1.7) when there are changes to grammar, spelling, or formatting, or minor changes in process that do not affect the interpretation of the data. In addition, each document will contain a modification date and "change log" table which tracks the following:

- Original Version Number: Indicates which version was modified;
- Date of Revision: The date the new revision is approved by network staff;
- Revised By: Primary author/contact;
- Changes: Description of changes, including how it will affect the interpretation of data;
- Justification: Why the change was necessary; and
- New Version #: Indicates the new version number (this ensures that there are not any gaps in notation between versions).

The change log for this document is found in Section D.9.

D.7.3 Relationship with the monitoring plan

On a final note, this plan is intended to be a stand-alone document in support of the network, the monitoring plan, and each monitoring protocol the network produces. Chapter 6 of the network monitoring plan is a brief synopsis of data and information management. Each monitoring protocol will also include a data-management section detailing how to protect and preserve the pieces of information that are collected. As much as possible, these sections will reference the core data-management SOPs.

D.8 Definitions

Books: Any bound publication with a designated Library of Congress number.

Data: The original information collected from the field.

Decipher: To make out the meaning of despite indistinctness or obscurity; to interpret the meaning of.

Error: the difference between an observed or calculated value and a true value; specifically, variation in measurements, calculations, or observations of a quantity due to mistakes or to uncontrollable factors. Alternatively, the amount of deviation from a standard or specification (Merriam-webster 2006).

GIS data: Spatial and tabular information that is of a format that can be read and projected directly onto a digital map. Formats include, but are not necessarily limited to, shapefiles, coverages, relational database tables, geodatabase feature classes and tables, tab-delimited text files, grids, geo-tifs, MrSid, and Imagine images.

Information technology: The infrastructure needed to move large quantities of digitized information in an efficient and secure manner from one place or person to another.

Information: Knowledge communicated or received concerning a particular fact or circumstance. Alternatively, computer data at any stage of processing, as input, output, storage, or transmission (Random House 1997).

Journal articles: Peer-reviewed articles that are distributed through periodicals.

NPS reference materials: Publications created by the NPS for general reference.

Operation: A system of related procedures that function to support the fundamental needs of the network. An operation is implemented through a protocol or other document giving a general description of its elements and functions, linked to standard operating procedures.

Periodicals: Published with a fixed interval between issues. Frequently have an editor and a series of reports/articles from separate authors. NPS bulletins fall under this category.

Protocol: A plan for carrying out a scientific study or patient's treatment. Alternatively, a set of rules governing the format of messages that are exchanged between computers (Random House 1997).

Quality assurance: A program for the systematic monitoring and evaluation of the various aspects of a project, service, or facility to ensure that standards of quality are being met (Merriam-Webster 2006), generally used to refer to methods of ensuring quality during data generation and acquisition.

Quality control: An aggregate of activities (as design analysis and inspection for defects) designed to ensure adequate quality especially in manufactured products (Merriam-Webster 2006), generally used to refer to checking acquired data for accuracy and completeness.

Quality: Degree of excellence; superiority in kind (Merriam-webster 2006)

Reliable: Giving the same result on successive trials.

Reports and gray literature: Documents that summarize research or are completed to fulfill legal or procedural requirements (e.g., NEPA or planning documents).

Standard Operating Procedure (SOP) – Detailed step-by-step methodology to accomplish a specific data-management task.

Validate: To support or corroborate on a sound or authoritative basis.

Verify: To establish the truth, accuracy, or reality of (Merriam-webster 2006).

D.9 Change History

Table D.9 provides the ability to document change to the plan. All documents, including those related to operations and specific SOPs, will contain this table.

Table D.9. Change history for the ROMN Data and Information Management Plan.

Original Version #	Date of Revision	Revised By	Changes	Justification	New Version #
1.0					

D.10 Literature Cited

Executive Order 12906 (EO 12906). 1994. Coordinating geography data acquisition and access: The national data infrastructure. http://govinfo.library.unt.edu/npr/library/direct/orders/20fa.html. Last accessed June 25, 2007.

Federal Geographic Data Committee (FGDC). 2006. Standards publications. http://www.fgdc.gov/standards/standards_publications/index_html. Last accessed June 25, 2007.

Merriam-Webster. 2006. Webster's collegiate dictionary. http://www.m-w.com/.

National Park Service (NPS). 2001a. Directors Order #19: Records management, National Park Service. http://www.nps.gov/refdesk/DOrders/DOrder19.html. Last accessed June 25, 2007.

——. 2001b. Director's Order #19-B, Records disposition schedule, National Park Service. http://data2.itc.nps.gov/wapc/records/nps19app-b.pdf. Last accessed June 25, 2007.

——. 2006a. Automated National Catalog System (ANCS+), National Park Service http://www.cr.nps.gov/museum/publications/ancs.html. Last accessed June 25, 2007.

——. 2006b. Natural resources inventory and monitoring statement of purpose, NPS-75. http://www.nature.nps.gov/nps75/nps75.pdf. Last accessed June 25, 2007.

——. 2006c. Metadata tools and editor, National Park Service. http://science.nature.nps.gov/nrdata/tools/. Last accessed June 25, 2007.

——. 2006d. Natural resource GIS standards, National Park Service. http://science.nature.nps.gov/nrgis/standards/standards.cfm Brent—this link doesn't work, at least from the Internet. Is the following link a comparable substitute, or is this an Intranet site? http://science.nature.nps.gov/nrgis/standards.aspx. Last accessed June 25, 2007.

——. 2006e. NatureBib, National Park Service. https://science1.nature.nps.gov/naturebib/nb/simple/clean. Last accessed June 25, 2007.

——. 2006f. NPS Data Store, National Park Service. http://science.nature.nps.gov/nrdata. Last accessed June 25, 2007.

——. 2006g. NPSpecies, National Park Service. https://science1.nature.nps.gov/npspecies/web/main/start. Last accessed June 25, 2007.

——. 2006h. Vital signs water quality data management and archiving, NPSTORET, National Park Service. http://www.nature.nps.gov/water/infoanddata/index.cfm. Last accessed June 25, 2007.

National Park Service–Rocky Mountain Network (NPS–ROMN). 2007a. Administrative operation, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_AdministrativeOperation.pdf.

——. 2007b. Approving information for distribution, standard operating procedure, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_DMO_ApprovingInformationForDistribution.

——. 2007c. Archive format standards for network data, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_DMO_ArchiveFormatStandards.pdf.

——. 2007d. Backing up the network's digital information, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_IFO_NetworkBackup.pdf.

——. 2007e. Data management operation, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DataManagementOperation.pdf.

——. 2007f. Directory structure, version 1.0, Rocky

Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_DirectoryStructure.pdf.

——. 2007g. Documentation, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_Documentation.pdf.

——. 2007h. File naming conventions, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_FileNamingConventions-SOP.pdf.

——. 2007i. Infrastructure operation, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_InfrastructureOperation.pdf.

——. 2006j. Library operation, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_LibraryOperation.pdf.

——. 2007k. Quality assurance and control, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_QAQC.pdf.

——. 2007l. Photograph management, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_DMO_PhotoManagement.pdf.

——. 2007m. Project manager application, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_PrjectManagerApplication.pdf.

——. 2007n. Project deliverable specifications, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_ProjectDeliverableSpecs.pdf.

——. 2007o. Rocky Mountain Network Intranet, National Park Service. http://www1.nature.nps.gov/im/units/romn/index.cfm], November 2006.

——. 2007p. Software development, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ROMN/DATAMAN/ROMN_DMO_SoftwareDevelopment.pdf.

——. 2007q. Park support operation, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/Data/ ROMN/DATAMAN/ROMN_ParkSupportOperation.pdf.

——. 2007r. Field season data handling, version 1.0, Rocky Mountain Network, National Park Service. http://www1.nrintra.nps.gov/im/units/romn/.

Project Management Institute (PMI). 2004. A guide to the project management body of knowledge (PMBOK® guide). Third Edition. Newtown Square, Pa.: Project Management Institute.

U.S. Environmental Protection Agency (EPA). 2006. STORET. http://www.epa.gov/STORET/.

U.S. Office of Management and Budget (OMB). 1999. Uniform administrative requirements for grants and agreements with institutions of higher education, hospitals, and other non-profit organizations. Circular A-110, section 36-intangible property. http://www.whitehouse.gov/omb/circulars/a110/a110.html. Last accessed June 26, 2007.

U.S. Department of the Interior. 2006. Freedom of Information Act program, U.S. Department of the Interior. http://www.doi.gov/foia/. Last accessed June 26, 2007.

Appendix E
Supplemental Information on Analysis and Reporting

This appendix provides information about Rocky Mountain Network analysis and reporting techniques supplemental to that included in Chapter 7 of this monitoring plan.

E.1 Analytical Constraints of Single-site Monitoring

The primary constraint with single-site, sentinel monitoring is the inability to infer results easily from single sites to other non-sampled locations. While correct specification of monitoring objectives should negate this (e.g., the objectives clearly will state that the results apply to a single site alone; Hirsch et al. 2006), incorrect analyses of data from sentinel designs have led to several classic and severe issues, most notably inappropriate inference of water-quality status by states under Clean Water Act monitoring (EPA 1994). The explicit incorporation of objectives, sample design, and analytical solutions by the ROMN will avoid this.

E.2 Ecological Process Objectives (Sentinel Designs)

Model selection algorithms facilitate a data-based choice among competing models. Akaike's Information Criteria (AIC; Akaike 1973) treats the model-selection process as a problem in optimization of the balance between model fit and precision (Spendelow et al. 1995). The statistical foundation for this approach has been well described (e.g., Anderson et al. 1994); however, it is not perfect. Buckland et al. (1997) proposed a procedure to account better for the uncertainty of model selection for deriving parameter estimates based on an average of several plausible models, rather than a single chosen one. This approach weights the models according to AIC values; the most plausible models receive the highest weight, while the least plausible models receive little or no weight. The ROMN will use model averaging for estimating parameters of interest when the parameters are derived from a selected model where alternative models exist.

E.3 Constraints and Benefits of Model-based Analysis

Model-based analysis is familiar to ecologists and resource managers (Gregoire 1998). It employs traditional estimation or statistics where variation in measurement values and the structure of the model itself establishes the validity of inference or prediction (Stevens 1994). Advantages of model-based analysis include both very general and precise inference, often from limited data. Such inference can borrow strength from the model: the model structure provides the framework for the inference, and the precision of the inference is judged relative to the model. Thus, if the model for the design is good, inference or the predictions generated from the model may be representative of the larger target population.

However, the model must take into account any selection bias associated with the sample units, and this often is not done or is unknowable. The problem is quite simple: the model must hold for both sampled and non-sampled units, and with selection bias there is less confidence that the model will hold for all non-sampled units. Therefore, if the model is not a good description of reality, the inference may have little resemblance to the true population characteristics. Similarly, precision is judged relative to the model and there may be no indication that the inference is substantially in error. Nevertheless, model-based analysis can be very useful.

Perhaps the most important benefit of a model-based approach is the capacity for predictive inferences (Olsen et al. 1999). Our initial years of monitoring may not enable useful models as we continue to understand relationships amongst drivers and response variables. However, in the future, a model-based approach may better enable the ROMN to move from a purely descriptive approach to a more scientific (e.g., quasi-experimental) approach to monitoring that can provide advantages for understanding the system and predicting the outcome of management decisions (Yoccoz et al. 2001).

As with single-site analysis, inference of population status and trend from a sentinel-design and model-based analysis is potentially flawed, or at least problematic, because some sites will not be considered for selection and this bias has unknown consequences on all inference. Depending on the location of sites not included in a design and the characteristics of the natural resources at these sites, considerable bias may result, and ROMN objectives may be limited or unattainable (Olsen et al. 1999). Moreover, one cannot explicitly determine the likelihood that a given site will be included in the sampling; hence, there is no basis for bias correction.

E.4 Change Detection

Principal component analysis and spectral mixture analysis are techniques that compare spectral signatures across a region similarly to indices; in these cases, the indices are a multi-dimensional combination of spectral reflectance data. These analyses are useful because they are generally automated techniques with little observer bias or dependence on the quality of auxiliary data; however, they generally do not specify the changes that occur, and may require threshold development (Lu et al. 2004). Spatial models and analyses that integrate geographic information (including spatially defined indices, field and auxiliary data) and remote-sensing data (e.g., satellite imagery) are important tools for change-detection applications because they support interpretation of data across large, heterogeneous regions (e.g., geostatistical models) while providing information content with type classifications.

E.5 Park-scale Status and Trend Objectives (Probability Designs)

Design-based inference is fundamentally different than model-based approaches. In a design-based approach, expectations are taken over all possible sets of samples; in the model-based approach, expectations are with respect to some assumed underlying stochastic process (the model). In both, data are a subset of a realization of some stochastic process. However, in the design-based approach, we focus on this realization and look at what would be the average over all possible samplings of this realization. In the model-based approach, the set of locations is taken as fixed, and we consider what would be the average of the (conceptual) realizations over this set.

Design-based analyses are well documented (Horvitz and Thompson 1952; Cordy 1993; Diaz-Ramos et al. 1996; Stevens 1997), and are the foundation of long-established survey design analyses used in socioeconomics, medicine, and other fields. The 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 an ROMN vital sign. The algorithms used are beyond our scope here (see Diaz-Ramos et al. 1996).

E.6 Constraints and Benefits of Design-based Analysis

The key advantage of the design-based approach is that it minimizes the number of assumptions required to draw inference (Olsen et al. 1999). With design-based inference, generality and validity come from the design, and the inferential process from a properly executed design is unassailable and irrefutable. Design-based inference provides the clearest link to park-scale status, and is the preferred method for describing status, particularly in cases of litigation and in making complex public policy decisions. Unlike model-based estimation or statistics, it is the independence of the site selection process that establishes the validity of inferences, not variation in measurement values (Stevens 1994). Design-based inference does not depend on an assumed model of the relationship between sampled sites and the population as a whole.

However, design-based analysis does have several constraints. First, design-based analysis does not allow spatially explicit description of each member of a target population. For example, results from a survey design applied to a target population of all wetlands in ROMO are valid at the scale of this target population, but not for a specific wetland site that was unsampled by the design. In other words, survey designs are not analogous to censuses. This is an often-misunderstood aspect of survey design and its analysis. Second, survey designs and design-based inference may not readily integrate with other, non-survey design data. We present solutions to both of these issues below. Finally, design-based approaches are poorly suited for making future predictions (inference can only be made to the elements of a population included in the sample, not some future state; Schreuder et al. 2004). The ROMN will develop predictive models to address this important need.

Small-area estimation. Data obtained from surveys can be used to derive empirical, direct estimates of status for target populations at the park scale. However, survey design sample sizes in smaller areas of a target population (e.g., a specific watershed or a specific stream reach) are rarely large enough for direct estimators to provide adequate precision at these scales. To apply survey design data to specific members of a target population, we use small area estimation techniques (Ghosh and Rao 1994; Marker 1999; Rao 1999). By fitting observed values of an ROMN vital sign to a statistical model (Sarndal et al. 1992) using predictive environmental covariates (e.g., land cover), a model can be fit that predicts vital-sign data between survey sites. Traditionally, small area estimation has relied on a mixed model relating the responses of interest in the small areas to each other and to covariates. More recently, Datta et al. (1999) derived theory for multivariate and Bayesian small area estimation, Prasad and Rao (1999) improved estimation by incorporating survey design weights, and Van Sickle et al. (2004) present an application that retains survey design-derived estimates of uncertainty in all modeled output. We will use these methods to generate more robust small area estimation models for select ROMN vital signs as applicable. This will bridge the gap between survey design, population-scale monitoring, and site-specific applications of relevance to many ROMN park management concerns.

Found data. The problem of integrating survey-based data and design-based analysis with data generated from non-survey designs is discussed in Chapter 4. This is common with hybrid sample designs or when historic monitoring data must be integrated into a survey design such as GRTS, used by the ROMN.

Overton et al. (1993) and Overton (1990) provide a general procedure for augmenting an existing probability sample with data from non-probability-based surveys (found data). The procedure uses sampling frame attributes to group probability and found samples into appropriate subsets. There are some critical assumptions about the relationship between the found-data site and the assigned subpopulation; however, the found sample data observations can now be treated as a de facto probability sample (for thorough discussion of the theory supporting this technique, see Overton 1990).

While the found-data procedures may be useful, in many cases, the relative extent of the found-data subpopulation is very small (e.g., the length of stream confluence reaches relative to all other stream reaches in a park), and the influence of the found data is, therefore, very small in the population-scale inference (T. Olsen, pers. comm.). Accordingly, our use of this approach is conservative.

E.7 ROMN Thresholds

Work focused on ecological thresholds began in the 1970s (Holling 1973; May 1977), and has continued as an active area of conceptual and applied research to this day. A large body of literature exists on the subject (see Briske et al. 2005; Groffman et al. 2006; and Stoddard et al. 2006 for contemporary summaries).

Thresholds are rarely single, static values. Rather, they typically have a degree of fuzziness or variability around them (i.e., the natural range of variability of most ecological phenomena; Landres et al. 1999). Similarly, the reference or natural biological condition of a vital sign is itself a distribution. The range in reference values for a vital sign results from both sampling error and natural variability in time and in space. In other words, at any point in time, a set of sites,

all in undisturbed condition, will exhibit a range of biological condition (Stoddard et al. 2006). Because thresholds (and the variability about them) occur in a reference condition distribution, the shape of the reference condition distribution has a strong effect on our interpretation of ROMN vital signs.

Conservative application of thresholds in assessing ROMN monitoring results requires use of the range in thresholds to establish assessment points and management triggers such that park management can be alerted that the state or trending in a vital sign is approaching a threshold. This permits adaptation of the monitoring program such as more intense monitoring or research to understand better the nature and possible causes of a change. It also allows time to take management action that hopefully changes the trajectory of a vital sign and prohibits it from actually crossing a threshold.

Several approaches for defining reference conditions and thresholds have been identified in the literature (e.g., Hughes et al. 1990; Daily et al. 1997; With and King 1997; Lindenmayer et al. 1999; Rogers and Biggs 1999; Williams and Tonnessen 2000; Carpenter and Turner 2000; Stoddard et al. 2006). Methods the ROMN will use include (1) measuring vital signs at sites that are minimally or least disturbed in or around a park and using these values as thresholds or reference (Hughes 1995, Bailey et al. 2004); (2) using ambient, measured distributions of a vital sign in a park (with thresholds placed within these distributions arbitrarily at the 5^{th} or 25^{th} percentile (EPA 2000), where dose–response relationships suggest break points or where maximum species richness occurs (Stoddard et al. 2006)); (3) extrapolations from empirical models; (4) meta-analysis of existing studies (e.g., RASFI 2004); (5) simulation models; (6) interpretations of historical conditions; and (7) best professional judgment. As discussed in Chapter 9, all ROMN protocol development projects include definition of relevant assessment points and thresholds and reference conditions for each vital sign. We are also collaborating with proposed USGS research on thresholds in ROMN parks, and will take advantage of significant efforts by academic research (Hawkins 2006) as well as state and other federal agencies (Stoddard et al. 2006). In all cases, threshold delineation will be an iterative process, incorporating monitoring data as it is generated and improving threshold precision and understanding as we progress.

E.8 Multimetric and Multivariate Biological Indices

Multimetric indices have been widely modified and applied to multiple types of systems (Karr and Chu 1999; Hill et al. 2003; Simon and Lyons 1995). They are composed of a set of metrics that assesses species richness, habitat guilds, trophic guilds, tolerance guilds, reproductive guilds, abundance, and individual condition of specimens relative to ecoregional or localized gradients of disturbance. Candidate metrics undergo a series of tests, including range examination, catchment size adjustment, responsiveness, signal to noise, and redundancy tests. The metrics that change in the most predictable way with increased human influence are selected and included in a conglomerate index.

With the Observed:Expected (O:E) multivariate index, the expected taxonomic assemblage at a site is based on samples from reference sites in similar ecological settings. Values of this ratio theoretically can range from 0 to 1, with values of 1 implying reference conditions, and values less than 1 implying biological degradation. The accuracy and precision of O:E assessments depend on the quality of the model used to predict the taxa expected to occur in a sample collected from an individual site. These models describe how probabilities of capture of all taxa vary across naturally occurring environmental gradients—information from which estimates of the taxa expected at individual sites can be derived. In contrast to multimetric indices, the performance of these models does not depend on calibration against presumed stressed sites. Models are calibrated only with reference-site data. If models accurately predict the assemblage that should occur at a site under reference conditions, any deviation from these predictions is a direct measure of biological impairment.

E.9 ROMN Communication and Reporting Strategy

E.9.1 Form of ROMN reports

E.9.1.1. Web-based

A hypothetical prototype ROMN web interface is included in Figure E.9.1.1. This interface is hierarchical, modular, and includes four levels of synthesis. The highest level summarizes each protocol and/or its constituent vital signs (as applicable) over a given time period, including key conclusions of relevance to park management. These summaries point to a second level, where results are described in more detail (equivalent to 1–2 pages of narration), including key figures and tables. This level refers to level three, which provides thorough status analyses and discussions of short- and long-term trends. Finally, the fourth level is a link to the actual databases and supporting documentation (e.g., database, metadata, protocols). The synthesis or summary pages (levels one, two and three) usually will be updated on an annual basis; however, some of the database pages (level four) could be updated more frequently as data become available. More detailed, comprehensive reports that summarize multiple years of monitoring and integrate multiple protocols will follow a similar web-based format with roughly the same hierarchical structure. Both annual and comprehensive reports are available at two reporting unit scales (as applicable): (1) by individual ROMN parks and (2) for the entire ROMN. Each report also includes protocol review elements that enable ongoing improvement in the ROMN program. These reviews determine where actual procedures fall short of stated expectations and suggest revisions to a protocol.

As we develop these web-based reporting technologies we will incorporate unique applications such as web-based Internet mapping systems. We are actively collaborating with other networks and WASO to develop a robust, web-based system (NPS 2006n) for viewing, mapping, and querying of monitoring data. Eventually, the web interface will include an active map of each park with all ROMN monitoring

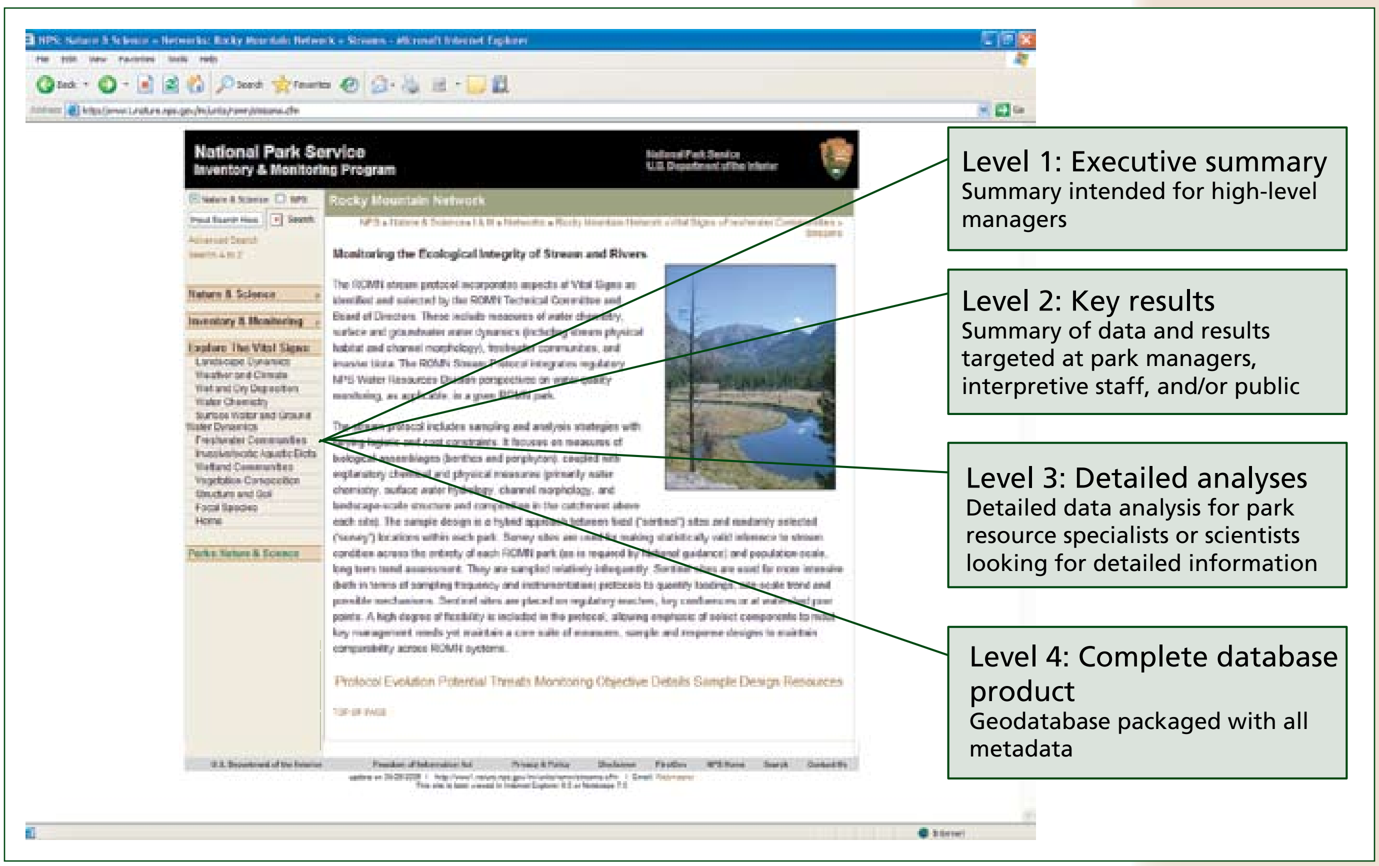


Figure E.9.1.1. Example ROMN web-site interface used for reporting monitoring results.

sites for all protocols (exact locations will be removed in publicly accessible versions). Users will be able to select sites and, using a set of queries built into application, view summaries of site-level data over a specified time period. The tool also will incorporate valid park-scale inference and model-generated results, such that the complete power of ROMN sample designs and analytical methods are not lost. Furthermore, web-based mapping also may direct users to the real-time presentation of continuous and provisional monitoring data (e.g., stream hydrology). The level of technical prowess and cost behind this reporting mechanism is substantial, and it may take time and effective collaboration within the NPS and other partners for this to come to fruition; however, it is clearly an effective way to present our results.

E.9.2 Summary of ROMN reports

E.9.2.1 Annual Administrative Report and Work Plan

An Annual Administrative Report and Work Plan (AARWP) addresses aspects of program implementation and is required to satisfy national reporting requirements. It accounts for funds and FTE expended and describes highlights, objectives, tasks, accomplishments, and products of the ROMN. Over time, AARWP reports document the administrative history of the ROMN. The AARWP is presented in a traditional report format, but made available on the ROMN Intranet.

E.9.2.2 Protocols

Rocky Mountain Network protocols are detailed, comprehensive presentations of all aspects of the monitoring for each vital sign or set of vital signs (e.g., with the integrated Stream, Wetland, and Alpine Lake Ecological Integrity protocols). They include a summary of the ecological background and management relevance for the vital sign(s). They detail the sample design for all components of a protocol (e.g., both survey and sentinel designs), including panel forms and sample sizes. They include the best available power for trend and standard error for status estimates using the anticipated sample design(s), best available variance components and effect size estimate, and two methods presented in Chapter 4. They provide all field plot layout and measurement (response design) details, including the best available performance analyses such as species–effort curves and signal:noise ratios. They summarize the specific analytical strategy for the vital sign(s), basic summary statistics, design-based inference, and all modeling that will involve the vital sign(s). They detail specific data management strategies, including all quality-assurance plans. They include various supporting but critical procedures such as safety protocols and GPS operations. All ROMN protocols will be peer-reviewed, published in a traditional report format, and made available on ROMN websites.

E.9.2.3 Protocol review reports

The efficacy of ROMN protocols will be assessed throughout the monitoring program and documented in protocol review reports. Reviews of protocol design early in the program are important to correct initial design flaws. Reviews over time will ensure continued refinement of protocols.

Reviews will be driven by the following questions, which will be answered using empirical results and from operational experience:

1. Is the protocol clear?
2. Are data collection methods as efficient as possible?
3. Do data forms capture all of the measurements?
4. Is requisitioned equipment sufficient?
5. Were as many samples measured as planned?
6. Do all sampled plots satisfy the sampling frame and design specifications?
7. Is the number of samples sufficient to meet needed precision around status estimates, or provide sufficient power to detect the specified trend or effect size?
8. Are measures at spatial and temporal resolutions sufficient for proposed assessments among indicators?
9. Is “early warning of abnormal conditions” provided (i.e., is the effect size

sufficient to alert management before substantive degradation of a natural resource)?

10. Do external data help interpret status and trends? If so, can these observations be included in the monitoring program?
11. Are data management procedures followed?
12. Do QA/QC procedures ensure error-free, quality data?
13. Are electronic data secured from loss or corruption?
14. Are electronic data stored in current versions of commonly used software?
15. Are data archived on a regular and appropriate schedule?
16. Are archived data easily accessible?
17. Does documentation ensure proper interpretation of data by a broad range of users?

Protocol review reports are presented as part of annual and comprehensive reports (see below) and, therefore, incorporated into the presentation of results on the ROMN interactive websites. They also will be summarized in a traditional report format and made available on the ROMN website. The first ROMN program review report will be prepared in FY2012, and at five-year intervals after that.

E.9.2.4 Program review reports

The efficacy of overall program effectiveness will be assessed throughout the monitoring program and documented in program review reports. Program operations will be assessed on adherence to the monitoring schedule and budgetary allocations, meeting reporting requirements, and maintaining productive relationships with ROMN park units and regional network staff, among other factors. Program effectiveness is measured in terms of how well monitoring results are communicated to target audiences and how useful the results are to decisionmakers. The program review motivates adjustments to satisfy better overall program goals and objectives. Information on program effectiveness will be determined by responses to questionnaires sent to park superintendents and resource management staff as well as internal review. The key questions asked in these reviews include:

1. Are monitoring results summarized and communicated in a useful fashion?
2. Are managers learning about the status and trends of indicators in a way that helps them make better decisions?
3. Are minimum change detection levels sufficient to meet park management needs?

Program review reports will be summarized in a traditional report format and made available on the ROMN website.

E.9.2.5 Project reports

Project reports document the objectives and methods of each ROMN-funded research, inventory, or monitoring project. If results are available, these also are presented in project reports, including any recommendations that might improve future efforts. Project reports are usually presented in a traditional report format (some cooperators may chose to use the web), but made available on the ROMN Intranet and Internet.

E.9.2.6 Annual reports

The routine preparation, on a predictable and recurring basis, of data summaries and basic interpretation can (1) foster program support by establishing a client base (Ember 1995), (2) motivate continued progress in program components, and (3) serve as the foundation for more comprehensive interpretive reports. Therefore, the ROMN will produce annual summaries of all monitoring activity and present these in the hierarchical, web-based format discussed above (they also are available in summary form in a traditional report format). Annual reports for each protocol provide a general accounting of yearly monitoring activities, issues and problems as they arise, and a status summary of measured indicators. By using the web, they can be easily scaled and presented by protocol, by park, or across the entire network. These include protocol reviews (see above) that allow

active improvement of all ROMN monitoring.

Also on an annual basis, the ROMN will provide non-sensitive and non-proprietary monitoring data and information to WASO NPS database systems (NPS Data Store, NatureBib, and NPSpecies). We will provide this information as bundled snapshot summaries for a particular field season, meaning that one year's worth of data will be distributed along with supporting protocols, reports, and any other documentation. Finally, our annual reports and the associated databases will be used by WASO in their State of the Parks reports.

E.9.2.7 Comprehensive synthesis and analysis reports

Detailed status and trend analyses and syntheses will be conducted at three-, five- or ten-year cycles. Comprehensive synthesis reports also will use the hierarchical, web-based format, but given the additional detail, each level will be correspondingly larger. They also will be available in a traditional report format and made available on ROMN websites. The comprehensive reports will include park- and network-level assessments. Park-level assessments will emphasize detecting and interpreting trends in individual vital-sign measures, and in interactions among drivers and stressors and responses measured at similar scales and across multiple scales. The latter, for example, will consider the role of broad-scale landscape pattern on plot-based measures such as upland vegetative structure. Where evidence of resource degradation exists, mitigation measures will be recommended. Network-level assessments will compare status (e.g., number of species, areal extent of patch types per time unit) and trends of vital-sign measures among ROMN parks with qualitative summaries and quantitative (where possible) methods. Comparisons with regional networks also will be considered. The latter will depend on the availability of commensurate measures. Currently, the ROMN, NCPN, SCPN, NGPN, and GRYN are informally coordinating the development and use of several protocols that will facilitate these integrated regional analyses. These include comprehensive protocol review reports (see above) that allow active improvement of all ROMN monitoring.

E.9.2.8 Other reports

Multiple other outlets for ROMN results also will be used. These include symposia, workshops, conferences, scientific journal articles and book chapters, brochures, and other interpretive aids. These all will follow the guidelines (including any peer review) specified by each outlet.

We will seek peer-reviewed publication in a wide variety of scientific journals. We view this as a crucial aspect of keeping ROMN monitoring relevant to a diverse group of collaborators and in ensuring that our protocols are cutting-edge. We will also publish in NPS specific journals. Over the past year, a publications task group has been working to revise and update the Natural Resource Publications Management Handbook. The handbook describes procedures for publishing in five natural resource series: Natural Resource Report, Natural Resource Technical Report, Scientific Monograph, *Natural Resource Year in Review,* and *Park Science*. Manuscripts published in these series must adhere to a set of minimum standards and are peer-reviewed to ensure that information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner (see http://www.nature.nps.gov/publications/NRPM).

E.10 Literature Cited

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267–281 *in* B. Petrov and F. Czakil, eds., Proceedings of the second international symposium on information theory. Budapest: Akademiai Kiado.

Anderson, D. R., K. P. Burnham, and G. C. White. 1994. AIC model selection in overdispersed capture-recapture data. Ecology **75**:1780–1793.

Bailey, R. C., R. H. Norris, and T. B. Reynoldson. 2004. Bioassessment of freshwater ecosystems using the reference condition approach. New York: Kluwer Academic Publishers.

Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins. 2005. State-and-transition models, thresholds, and rangeland health: A synthesis of ecological concepts and perspectives. Rangeland Ecology and Management **58**:1–10.

Brusven, M. A., and K. V. Prather. 1974. Influence of stream sediments on distribution of macroinvertebrates. Journal of the Entomological Society of British Columbia **71**:25–32.

Buckland, S. T., K. P. Burnham, and N. H. Augustin. 1997. Model selection: an integral part of inference. Biometrics **53**:603–618.

Carpenter, S. R., and M. Turner. 2000. Opening the black boxes: Ecosystem science and economic valuation. Ecosystems **3**:1–3.

Cordy, C. 1993. An extension of the Horvitz-Thompson theorem to point sampling from a continuous universe. Probab. Stat. Let. **18**:353–362.

Daily, G. C., P. R. Ehrlich, L. H. Goulder, J. Lubchenco, P. A. Matson, H. A. Mooney, S. H. Schneider, G. M. Woodwell, and D. Tilman. 1997. Ecosystem services: Benefits supplied to human societies by natural ecosystems. Issues Ecol. **2**:1–16.

Datta, G.S., B. Day, and I. Basawa. 1999. Empirical best linear unbiased and empirical Bayes prediction in multivariate small area estimation. Journal of Statistical Planning and Inference **75**:269–279.

Diaz-Ramos, S., D. L. Stevens, Jr., and A. R. Olsen. 1996. EMAP statistical methods manual. Corvallis, Ore.: U.S. Environmental Protection Agency, Office of Research and Development, NHEERL-Western Ecology Division. Report nr EPA/620/R-96/002.

Ember, L. R. 1995. Environmental monitoring and assessment program scaled back. Chemical and Engineering News **73**:18–23.

Ghosh, M., and J. Rao. 1994. Small area estimation: an appraisal. Statistical Science **9**:55–93.

Gregoire, T. G. 1998. Design based and model based inference in survey sampling appreciating the difference. Can. J. For. Res. **28**(10):1429–1447.

Groffman, P. M., J. S. Baron, T. Blett, A. J. Gold, I. Goodman, L. H. Gunderson, et al. 2006. Ecological thresholds: The key to successful environmental management or an important concept with no practical application? Ecosystems **9**:1–13.

Hirsch, R. M., P. A. Hamilton, and T. L. Miller. 2006. U.S. Geological Survey perspective on water-quality monitoring and assessment. J. Environ. Monit. **8**:512–518.

Hawkins, C. P. 2006. Quantifying biological integrity by taxonomic completeness: Its utility in regional and global assessments. Ecological Applications **16**(4):1277–1294.

Hill, B. H., A. T. Herlihy, P. R. Kaufmann, S. J. DeCelles, and M. A. Vander Borgh. 2003. Assessment of streams of the eastern United States using a periphyton index of biotic integrity. Ecological Indicators **2**:325–338.

Hill, D. K., and J. J. Magnuson. 1990. Potential effects of global climate warming on the growth and prey consumption of Great Lakes fish. Transactions of the American Fisheries Society **119**:265–275.

Holling, C. S. 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. **4**:1–23.

Horvitz, D. G., and D. J. Thompson. 1952. A generalization of sampling without replacement from a finite universe. J. Am. Stat. Assoc. **47**:663–685.

Hughes, R. M. 1995. Defining acceptable biological status by comparing with reference conditions. Pages 31–47 *in* W. Davis and T. Simon, eds., Biological assessment and criteria: Tools for water resource planning and decision making for rivers and streams. Boca Raton, Fla.: Lewis Publishers.

Hughes, R. M., T. R. Whittier, C. M. Rohm, and D. P. Larsen. 1990. A regional framework for establishing recovery criteria. Environmental Management **14**:673–684.

Karr, J. R., and E. W. Chu. 1999. Restoring life in running waters: better biological monitoring. Washington, D.C.: Island Press.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications **9**:1179–1188.

Lindenmayer, D. B., R. B. Cunningham, M. L. Pope, and C. F. Donnelly. 1999. The response of arboreal marsupials to landscape context: a large-scale fragmentation study. Ecological Applications **9**:594–611.

Lu, D., P. Mausel, E. Brondizio, and E. Moran. 2004. Change detection techniques. International Journal of Remote Sensing **25**(12):2365–2407.

Marker, D. A. 1999. Organization of small area estimators using a generalized linear regression framework. Journal of Official Statistics **15**:1–24.

May, R. M. 1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. Nature **269**:471–477.

National Park Service. 2006n. Great Lakes Natural Resources Gateway. http://nrintra.nps.gov/glkn/login.aspx. Last accessed October 3, 2006.

Olsen, A. R., J. Sedransk, D. Edwards, C. A. Got-

way, W. Liggett, S. L. Rathburn, K. H. Reckhow, and L. J. Young. 1999. Statistical issues for monitoring ecological and natural resources in the United States. Environ. Monit. Assess. **54**:1–45.

Overton, W. S. 1990. A Strategy for use of found samples in a rigorous monitoring design. Corvallis, Ore.: Department of Statistics, Oregon State University. Technical Report 139.

Overton, J. M., T. C. Young, and W. S. Overton. 1993. Using 'found' data to augment a probability sample: Procedure and case study. Environ. Monit. Assess. **26**(2/3):65–83.

Prasad, N. G. N., and J. N. K. Rao. 1999. On robust small area estimation using a simple random effects model. Survey Methodology **25**:67–72.

Rao, J. N. K. 1999. Some recent advances in model-based small area estimation. Survey Methodology **25**:175–186.

Resilience Alliance and Santa Fe Institute (RASFI). 2004. Thresholds and alternate states in ecological and social-ecological systems. http://www.resalliance.org/index.php?id=183.

Rogers, K., and H. Biggs. 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. Freshwater Biology **41**:439–451.

Sarndal, C. E., B. Swensson, and J. Wretman. 1992. Model assisted survey sampling. New York: Springer-Verlag.

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

Simon, T. P., and J. Lyons. 1995. Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems. Pages 245–262 *in* W. S. Davis and T. P. Simon, eds., Biological assessment and criteria: tools for water resource planning and decision making. Boca Raton, Fla.: Lewis Publishers.

Spendelow, J. A., J. D. Nichols, I. C. T. Nisbet, H. Hays, G. D. Cormons, J. Burger, C. Safina, J. E. Hines, and M. Gochfeld. 1995. Estimating annual survival and movement rates of adults within a metapopulation of Roseate terns. Ecology **76**:2415–2428.

Stevens, Jr., D. L. 1994. Implementation of a national monitoring program. J.Environ. Manag. **42**:1–29.

______. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics **8**:167–195.

Stoddard, J. L, D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: The concept of reference condition. Ecological Applications **16**(4):1267–1276.

Van Sickle, J., J. Baker, A. Herlihy, P. Bayley, S. Gregory, P. Haggerty, L. Ashkenas, and J. Li. 2004. Projecting the biological condition of streams under alternative scenarios of human land use. Ecol. Applications **14**(2):368–381.

U.S. Environmental Protection Agency (EPA). 1994. National Water Quality Inventory: 1992 report to Congress. Washington, D.C.: U.S. Environmental Protection Agency, Office of Water. EPA 841/R94/ 001.

______. 2000. Nutrient criteria technical guidance manual: Rivers and streams. Washington, D.C.: U.S. EPA Office of Water. EPA-822-B-00–002.

______. 2004. Clark Fork River operable unit of the Milltown Reservoir/Clark Fork River Superfund site record of decision. Helena, Mont.: U.S. Environmental Protection Agency Region 8.

Williams, M. W., and K. A. Tonnessen. 2000. Critical loads for inorganic nitrogen deposition in the Colorado Front Range, USA. Ecological Applications **10**:1648–1665.

With, K. A., and A. W. King. 1997. The use and misuse of neutral landscape models in ecology. Oikos **97**:219–229.

Yoccoz, N. G., J. D. Nichols, and T. Boulinier. 2001. Monitoring of biological diversity in space and time. Trends in Ecology and Evolution **16**:446–453.

Appendix F
Rocky Mountain Network Charter

Introduction

The Rocky Mountain Network (ROMN) is one of 32 vital signs monitoring Networks established by the National Park Service (NPS) as part of the Natural Resource Challenge, 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).

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.

The purpose of this charter is to define how the ROMN is organized and operates to develop and execute and Inventory and Monitoring program that is fully integrated with park resource management programs and supports the objectives of the Natural Resource Challenge.

Organization and Responsibilities

A multi-level organization structure has been identified to ensure that the ROMN implements an effective inventory and monitoring program. This organizational structure comprises a Board of Directors, Technical Committee, scientific and technical partners, and ROMN staff. The ROMN operates with guidance and oversight of the Intermountain Region I&M program and the Washington Office of Monitoring and Evaluation. This organization is consistent with the recommendations of the Associate Director, Natural Resource Stewardship and Science in an October 13, 2000 memorandum to Regional Directors (subject: New park/Network Monitoring Program: Vision and Implementation Plan).

Board of Directors

The ROMN Board of Directors provides guidance, oversight and advocacy in the development and implementation of the I&M program for the six parks of the Network. The Board is committed to fostering an atmosphere of fairness, trust, and mutual respect among the Network partners. It will pursue a holistic approach in guiding the planning and implementation of the I&M program using scientifically credible standards, while serving the needs of all Network partners.

Major Responsibilities

- Advocate an active and effective I&M program for the Network
- Provide general guidance and advice on strategies for Network inventory and monitoring

- Promote accountability for the Network I&M program and by reviewing progress and providing quality control for the ROMN
- Review and approve ROMN I&M plans, work plans and budgets, and staffing plans recommended by the Technical Committee
- Review and approve annual administrative accomplishment reports to the Intermountain Regional Office (IMR) and the Washington Office of Monitoring and Evaluation
- Provide guidance and advice on strategies and procedures for leveraging Network funds and personnel to best accomplish inventory and monitoring needs of the ROMN parks
- Ensure that the Network inventory and monitoring work is fully integrated with park resource management programs and other natural resource initiatives and programs (e.g., under the Natural Resource Challenge)
- Facilitate coordination and communication about Network inventory and monitoring activities with NPS staffs in the Network and IMR
- Identify and help develop internal and external partnerships to meet the goals of the Natural Resource Challenge and the NPS I&M Program

Membership

The ROMN Board of Directors is comprised of one representative from each ROMN member unit and the Intermountain Region's Inventory and Monitoring Coordinator (ex officio). At least two of the unit representatives will be superintendents; the other four could be designees. The Board will elect a Chairperson responsible for facilitating Board business. The Chair will rotate at two-year intervals. In the event of administrative change, the Board will elect a new Chair. The ROMN Program Manager and Chair of the Technical Committee are staff to the Board of Directors.

Meetings

The Board will confer at least twice per year. These meetings may be by teleconference or face to face. Additional conferences or meetings may be called by any member at any time. One meeting, usually held in December or January, will be held to review and approve the Annual Work Plan and Budget. The second, held towards the end of the fiscal year, will focus on review and approval of the Annual Administrative Report.

Funding for travel to meetings may be requested and provided from ROMN Program funds on an as-needed basis. The ROMN Program Manager and the Chair of the Technical Committee will assist the Chair of the Board in scheduling and organizing meetings.

Alternates, Quorums and Decision Making

Any Board member who cannot attend a meeting of the Board may assign an alternate who shall have full voting authority. Five Board members constitutes a quorum. Every effort will be made by the Board members to reach unanimity on all significant decisions. When this is not possible, concurrence by four of the six members constitutes a majority decision. Decisions will be recorded in the meeting minutes and sent to all members in a timely fashion.

Technical Committee

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.

A key function of the Technical Committee is to carefully consider and make consensus recommendations for ROMN strategies and procedures to the Board of Directors. This includes reviewing and recommending ROMN reports, work plans and budgets, and other products for Board approval.

As inventory and monitoring results are developed, the Technical Committee will have an important role in developing and communicating alternatives for park management, based on monitoring results and information.

Major Responsibilities

- Advocate an active and effective I&M program for the Network
- Provide specific guidance and advice on strategies for Network inventory and monitoring
- Review and recommend annual budget accounting report to Board of Directors
- Review and recommend ROMN I&M plans, work plans and budgets, and staffing plans to the Board of Directors for Approval
- Review and recommend annual administrative accomplishment reports to the Board of Directors for approval
- Provide guidance and advice on strategies and procedures for leveraging Network funds and personnel to best accomplish inventory and monitoring needs of the ROMN parks
- Participate on hiring panels for ROMN staff
- Communicate and collaborate on I&M efforts with ROMN partners including park staffs and scientific and technical partners

Membership

The Technical Committee consists of the lead person responsible for natural resource management for each park, the directors of the Crown of the Continent and the Continental Divide Research Learning Centers, and the NPS Rocky Mountains – Cooperative Ecosystem Studies Unit representative and science coordinator.

The ROMN Program Manager serves as staff to the Technical Committee, and ROMN staff participate in Technical Committee meetings to provide technical and scientific information on ROMN activities.

Meetings and Communication

The Technical Committee will meet twice each year, usually in the fall and the spring. Meetings will alternate between Colorado and Montana. Funding for travel to meetings may be requested and provided from ROMN Program funds on an as-needed basis. The ROMN Program Manager and the Chair will schedule and organize meetings.

The Technical Committee will conduct continuing business and communication by e-mail, conference call and other means as necessary. The Technical Committee will hold regular monthly conference calls (as of April 9, 2007, these are held the second Wednesday each month from 10:00-11:00AM MST) with the Program Manager and other Network staff.

Alternates, Quorums and Decision Making

Any Technical Committee member who cannot attend a meeting may assign an alternate. Five Technical Committee members constitute a quorum. The ROMN Technical Committee will seek consensus for all decisions and recommendations to the Board of Directors. Decisions will be recorded in the meeting minutes and sent to all members in a timely fashion.

The Technical Committee will elect a Chairperson responsible for facilitating Committee business. This includes serving as liaison to the Board of Directors and working closely with the Program Manager on Committee business. The Chair will serve for a two-year term and may not serve consecutive terms. In the event of administrative change, the Technical Committee will elect a new Chair.

Scientific and Technical Partners

A sound and credible scientific basis for ROMN inventory and monitoring is critical for program success. The ROMN will collaborate with scientific and technical partners whenever possible and appropriate to plan and conduct inventory and monitoring. Likewise the Network will work cooperatively with scientists and technical partners in the analysis, reporting and communication of Network results.

The ROMN will ensure that all Network plans and products are scientifically and technically reviewed before completion and publication and distribution. Peer review procedures are described in the Vital Signs Monitoring Plan and follow guidance from the NPS Office of Monitoring and Evaluation and the Intermountain Region I&M Program.

An independent science review panel advised the ROMN during the development of its Vital Signs Monitoring Plan. Broad goals for the panel included providing scientific review of ROMN I&M plans, helping the ROMN coordinate its I&M efforts with other groups (especially academic institutions), and identifying opportunities for the ROMN to partner with other I&M efforts. The panel was temporary; its role ended upon final publication of the ROMN Vital Signs Monitoring Plan in September 2007.

Rocky Mountain Network Staff

A small group of employees perform the ROMN program's "core activities." Permanent ROMN staff includes the Program Manager, Data Manager, and Ecologist. The Network has a permanent but less than full-time need for administrative assistance which is currently provided by a term Administrative Assistant shared among Intermountain Region I&M Networks. ROMN staff oversee and implement ROMN I&M program and projects.

The ROMN Program Manager is responsible for planning and developing the ROMN program, managing the overall program, communicating and coordinating with the many people and groups that make up the Network, supervising ROMN staff, and ensuring adequate program review. The Program Manager works closely with the Technical Committee and the Board of Directors, and is the primary ROMN contact and liaison with other NPS programs and offices as well as outside agencies. The Program Manager facilitates Technical Committee conference calls and meetings and works with the Technical Committee Chairperson to facilitate Board of Directors meetings. The Program Manager 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 ROMN 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 (currently a less than half-time term position shared with the other Intermountain Region Networks) 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.

Guidance and Network Operations

The ROMN follows guidance from the Washington Office of Monitoring and Evaluation and the Intermountain Region I&M Program. The ROMN Vital Signs Monitoring Plan, prepared in consultation with the Technical Committee and approved by the Board of Directors, Intermountain Region, and Washington Office of Monitoring and Evaluation guides the long-term monitoring program of the Network. The Plan is the foundation for the ROMN program and identifies what Vital Signs will be monitored and why, the protocols that will guide monitoring, how data will be managed and reported, etc. The plan includes a component for Water Quality Monitoring as specified in guidance from the

NPS-Water Resources Division. The Plan also includes detailed information on ROMN administrative procedures, the Network budget (including long-term budget projections), staffing options, and monitoring schedule.

The ROMN Program Manager prepares the Annual Administrative Report and Work Plan (AARWP) for Technical Committee review and Board of Directors approval annually. The AARWP is the key annual work planning, accomplishment reporting, and accountability document/process for the ROMN and the I&M program.

Funding

ROMN funds are Natural Resource Challenge 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 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. Any additional funds managed by the ROMN are also managed and accounted for using the AARWP process.

Amendments

Board of Directors and Technical Committee members may propose changes to this Charter at any time. Any change will be in the form of an amendment and will not take effect until all signatories have agreed to and signed the amendment. The Regional I&M Coordinator will be notified of proposed and adopted amendments. All ROMN members and the Regional I&M Coordinator will be provided at least a 30-day notice of proposed amendments before they take effect.

NPS D-71, August 2007

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov