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Natural Resource Stewardship and Science

Rocky Mountain Network Stream Ecological Integrity Monitoring Protocol

Narrative, Version 1.0

Natural Resource Report NPS/ROMN/NRR—2015/1101





ON THIS PAGE
Mike Britten (NPS ROMN) and Jason Smith (NPS GRKO) sample the Clark Fork River at GRKO, 2008.
Photograph by: NPS, B. Schweiger

ON THE COVER
Kurt Chowanski (VIP) samples Reynolds Creek in GLAC, 2009.
Photograph by: NPS, B. Schweiger

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Natural Resource Report NPS/ROMN/NRR—2015/1101

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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Standard Operating Procedures (SOPs)

This report is linked to the following Standard Operating Procedures (SOPs), which can be found in Schweiger et al. (2015 a). In addition, at the time of publication, a detailed Quality Assurance Performance Plan (QAPP) was under review by the US Environmental Protection Agency (Schweiger, In Review).

SEI SOP 1: Pre- and Post-Season Workflow

SEI SOP 2: Pre- and Post-Sample Event Activities

SEI SOP 3: Sample Tracking

SEI SOP 4: Verification of Site Status and Sample Reach Layout

SEI SOP 5: *In Situ* Water Physiochemistry

SEI SOP 6: Water and Sediment Physiochemistry

SEI SOP 7: Discharge

SEI SOP 8: Physical Habitat

SEI SOP 9: Periphyton

SEI SOP 10: Macroinvertebrates

SEI SOP 11: Sentinel Sample Events

SEI SOP 12: Field Sheet Scanning

SEI SOP 13: Processing SEI Discreet Field and Laboratory Data

SEI SOP 14: Processing *In Situ* Water Physiochemistry Logger

SEI SOP 15: Processing HOBO Water Temperature Loggers

SEI SOP 16: Photo Management

SEI SOP 17: Data Analysis

SEI SOP 18: Revising the Protocol

In addition, the following ROMN shared data management, administrative, and equipment SOPs apply to the SEI protocol and may be obtained from the ROMN website:

ROMN SOP: Admin Safety Preparations and Training

ROMN SOP: Permitting

ROMN SOP: Training

ROMN SOP: Seasonal Hiring

ROMN SOP: Park Logistics

ROMN SOP: End of Season

ROMN SOP: GSA Vehicle Leasing

ROMN SOP: Specimen Tracking and Vouchering

ROMN SOP: Using a Digital Camera

ROMN SOP: Using the Garmin GPS 76csx

ROMN SOP: Using Electronic Data Recorders

ROMN SOP: Field Communications

ROMN SOP: SPOT Transponder

ROMN SOP: Folder Structure and File Naming

ROMN SOP: Archive Format Standards for Network Data

ROMN SOP: YSI Logger

ROMN SOP: HOBO Logger

ROMN SOP: Photo Management

ROMN SOP: Database Design

Revision History

Version #	Date	Author	Change Description	Reason	New Version #

Version numbers increase incrementally by hundredths (e.g., version 1 .01, version 1.02, etc.) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0, . . .). The previous version number, date of revision, author of the revision, and the reason for making the changes are recorded along with the new version number.

This document is the first published version the protocol. Creation of this protocol began in 2007. Major changes in the early internal drafts and the reasons for each change are available from the ROMN Data Manager.

The ROMN Data Manager will be notified of any changes to the Protocol Narrative or SOPs so that the new version number can be incorporated in the metadata of the project database.

New versions will be posted on the ROMN website.

Executive Summary

The Rocky Mountain Inventory & Monitoring (I&M) Network (ROMN) includes a wide range of environments ranging from mountain peaks to deciduous forests to western grasslands. The six parks of the network include Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), Little Bighorn Battlefield National Monument (NM), Florissant Fossil Beds NM, Great Sand Dunes National Park and Preserve (NPP), and Rocky Mountain NP.

Here, we present a protocol to monitor Stream Ecological Integrity (SEI) within five network parks (GLAC, ROMO, GRKO, LIBI and potentially GRSA). The overall goals for long-term ecological monitoring of ROMN streams focus on documenting the status and trend in stream condition, understanding the causes of change in stream condition, and assisting in the application of these data to park management.

Under budget scenarios and management needs as of 2015, we expect to conduct and report on park-scale surveys only in GLAC and ROMO every 10 years. We will report on objectives specific to data derived from annual sample efforts at sentinel sites in GLAC, ROMO, GRKO, LIBI and potentially GRSA every fifth year, staggered by park. Continuously logged hydrologic and water physiochemistry data will be reported on more frequently. ROMN will consider altering this schedule with changes in budget, resource condition and/or management needs.

Generalized SEI monitoring objectives include the following:

1. Determine status in a suite of response measures at the park scale (in GLAC and ROMO) and at all sentinel sites.
    a. Important water and sediment chemistry parameters like temperature, nutrients and metals
    b. Stream physical habitat features like sediment composition and riparian cover
    c. Macroinvertebrate and diatom bioassessment metrics
2. Determine the long-term trend in the condition of select stream responses.
3. Assess status of select responses through:
    a. Comparisons to existing and published assessment points, including any regulatory criteria, ecological thresholds or ecoregion assessment points that are relevant to ROMN park streams management,
    b. Comparisons to ecoregion assessment points derived from distributions of reference site data from within the park and/or surrounding ecoregion(s),
    c. Comparisons to baselines derived from partner or auxiliary data.
4. Relate any spatial or temporal patterns (including trend when possible) in select stream responses to important ecological and anthropogenic drivers.

To meet these monitoring objectives we have designed a multi-faceted, integrated approach. We base the bulk of our field methods on protocols developed by the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program. These methods are well established and are used by many ROMN partners. We emphasize response measures of community-level macroinvertebrate and diatom composition/structure, hydrology, geomorphology, substrates, water temperature, and qualitative or categorical indicators of condition and stress (including both anthropogenic and natural). Our assessment focuses on park-specific integrative bioassessment models with macroinvertebrate and diatoms as the response and the suite of stressor or driver covariates collected at all stream sites. The application of standardized protocols facilitates comparison of streams within an ecoregion and across ROMN and other NPS parks.

We use multiple sample design forms that address specific needs, but are also integrated through analysis and implementation of the protocol in a given park. While episodic,

large probability surveys are essential for meeting several of our objectives, most SEI monitoring in most years is restricted to sentinel sites. A focus on sentinel sites is both more realistic given our budget and may be at a scale more likely to elucidate the role of key drivers like hydrology, climate, stream temperature, and landscape structure in controlling stream condition.

Our approach to data interpretation is to evaluate each indicator by comparing SEI results to established or novel numeric assessment points. Where relevant assessment points do not exist, we estimate values using a variety of methods including models of disturbance and ecological response and derivation from reference sites in the parks' ecoregions. We interpret patterns in these comparisons using ecological literature and theory, NPS I&M and Water Resource Division guidance, NPS resource management policies, and collaborative work with ROMN partners.

We use the terms "reference" and "non-reference" to describe how an indicator relates to assessment points. A vital sign/indicator is considered to be in a reference state when the stream data fall within a range of values considered to be functional, intact or, loosely speaking, in "good condition" from an ecological or other perspective (e.g. human health). The status is considered to be non-reference if it is degraded, dysfunctional, or in a "poor" condition. Alternatively, the vital sign may be in a state that is intermediate between reference and non-reference. To avoid confusion with a strictly regulatory approach, we currently do not apply terms like "impaired" or "meets designated uses" in any interpretation by ROMN especially of our own data.

This effort has been, and will continue to be, a cooperative undertaking between ROMN staff, the Flathead Lake Biological Station, the U.S. Geological Survey, the U.S. EPA, Montana Department of Environmental Quality, Colorado Department of Health and Environment and (most importantly) park management and staff. The SEI protocol represents the efforts of many dedicated scientists and resource managers.

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This first complete version of the Rocky Mountain Network (ROMN) Stream Ecological Integrity (SEI) Monitoring Protocol was prepared by ROMN and Flathead Lake Biological Station (FLBS) staff based on input and information from many people. Errors are the responsibility of ROMN staff.

The ROMN Technical Committee laid the groundwork for this protocol and continues to provide vision and guidance for our long-term inventory and monitoring program. Thanks to the current and past members of the committee: Isabel Ashton, Stan Austin, Mark Biel, Ben Bobowski, Fred Bunch, Tara Carolin, Jeff Connor, Ken Czarnowski, Chris Ford, Therese Johnson, John Mack, Paul McLaughlin, Jack Potter, Jason Smith, Melana Stichman, Michael Stops, Phyllis Pineda-Bovin, Terry Terrell, Kathy Tonnessen, Judy Visty, Leigh Welling, Phil Wilson, Rick Wilson, and Chris Ziegler.

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The Network worked closely with statisticians and ecologists at Colorado State University (Scott Urquhart), the EPA (Tony Olsen, Thomas Kincaid), from several other I&M Networks (notably, Steve Garman now at USGS and Tom Philippi of NPS) and other external academics (especially Robert Gitzen from South Dakota State) to develop our sample designs and power models. We are grateful for the significant amount of (often gratis) advice and help these individuals have offered.

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Finally, we gratefully acknowledge two careful and detailed peer reviews, one from Dave Peck from the US EPA and one anonymous reviewer from the NPS Inventory and Monitoring Program. These greatly improved the protocol.

Introduction

The National Park Service Inventory and Monitoring Program

The purpose of the National Park Service (NPS) Inventory & Monitoring (I&M) Program is to develop and provide scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems. As part of the NPS's effort to improve park management through greater reliance on scientific knowledge, a primary role of the I&M Program is to collect, organize, and make available natural resource data and to contribute to the Service's institutional knowledge by facilitating the transformation of data into information through analysis, synthesis, and modeling of specific key vital signs. The I&M Program defines the term "vital sign" as a subset of physical, chemical, and biological elements and processes of park ecosystems that is selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Fancy et al. 2009).

The five goals of the I&M Program are to (Fancy et al. 2009):

1. Inventory the natural resources and park ecosystems under NPS stewardship to determine their nature and status.
2. Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments.
3. Establish natural resource inventory and monitoring as a standard practice throughout the NPS system that transcends traditional program, activity, and funding boundaries.
4. Integrate natural resource inventory and monitoring information into NPS planning, management, and decision making. Share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

These goals are accomplished through park-wide inventories and long-term monitoring programs. In establishing a service-wide natural resources inventory and monitoring program, the NPS created networks of parks that are linked by geography and shared natural resource characteristics. Working within networks improves the efficiency of inventory and monitoring because parks are able to share budgets, staffing, and other resources to plan and implement an integrated program.

The Rocky Mountain Inventory and Monitoring Network (ROMN) is comprised of six NPS parks: 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 (Figure 1). Through a comprehensive three-year scoping process, ROMN and its partner parks and scientific collaborators identified 12 high-priority vital signs for focused, long-term monitoring. The vital signs include wet and dry deposition; weather and climate; water chemistry; surface water dynamics; freshwater communities; invasive/exotic aquatic biota; groundwater dynamics; stream communities; invasive/exotic plants; vegetation composition, structure, and soils; focal species (beaver, elk, grizzly bear, and GRSA endemic insects); and landscape dynamics (Britten et al. 2007). By monitoring these vital signs in network parks, ROMN aims to efficiently provide comparable long-term ecological health information across broad latitudinal and elevation gradients from the southern to the northern Rocky Mountains.

The Stream Ecological Integrity (SEI) protocol presented here directly addresses five of ROMN's 12 high priority vital signs including water chemistry, surface hydrology, aquatic biota, and invasive/exotic aquatic biota. Three other high-priority vital signs are indirectly linked with the SEI protocol including landscape dynamics, wet and dry

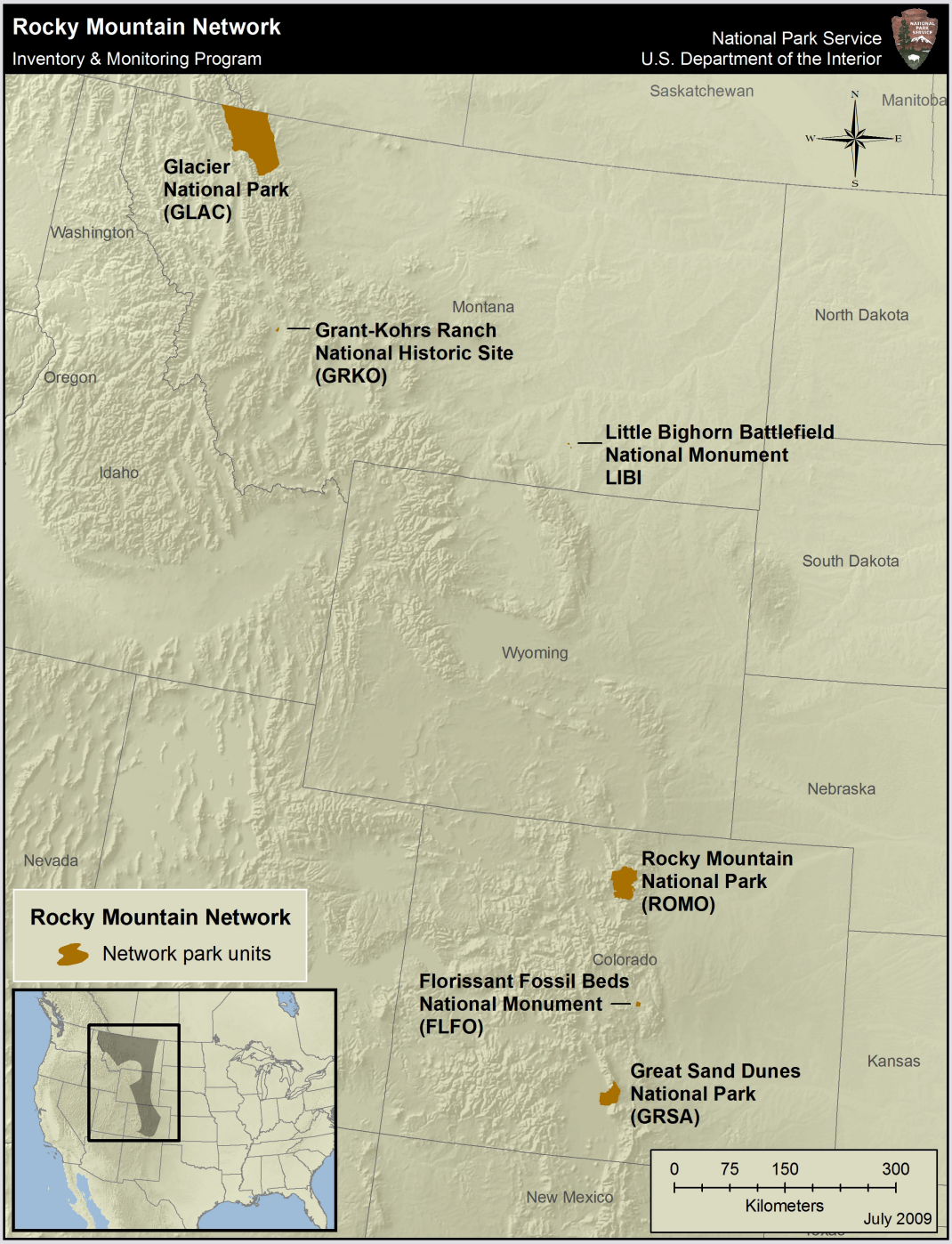


Figure 1. National park units in the Rocky Mountain Inventory and Monitoring Network. The stream ecological integrity protocol will be implemented in five units: Glacier National Park, Rocky Mountain National Park, Great Sand Dunes National Park and Preserve, Grant-Kohrs Ranch National Historic Site, and Little Bighorn Battlefield National Monument.

deposition, and weather and climate. SEI monitoring will be conducted in up to five parks: GLAC, ROMO, GRKO, LIBI and potentially GRSA. Implementation details vary by park and are discussed further below.

In this document, we present a protocol that will serve as the basis for the long-term monitoring of streams in ROMN parks. The document is organized following standards established by the NPS I&M program (Oakley et al. 2003; Fancy et al. 2009), and is comprised of two parts (plus appendices). The first is the protocol narrative (this document), which provides an overview of the monitoring protocol, the rationale for the specific design elements and monitoring components included, summaries of field and analytical methods, overviews of data management, and an administrative plan for long-term implementation. The second consists of specific standard operating pro-

cedures (SOPs) that provide instructions for executing field, analytical, and select administrative components of the protocol.

Although considerable effort has been made to provide a defensible and effective monitoring approach given time and resource constraints, future developments will likely necessitate modification of the methods presented here. We include a revision history log where all modifications with rationale in future versions of the protocol are recorded (changes in draft internal versions are available upon request).

Stream Definition and Classification

There is a rich history of defining and classifying aquatic systems (e.g., Davis 1899; Strahler 1957; Vannote et al. 1980; Frissell et al. 1986; Rosgen 1994; Maxwell et al. 1995) with flowing, standing, and transitional habitat treated independently and in a landscape context (i.e., jointly with terrestrial systems). Classifications range in scale from continental watersheds to channel unit delineation of specific habitat types (e.g., riffles and pools). Classification of aquatic systems such as streams allows a better understanding of the processes that formed the systems as well as the ability to predict future behavior from hydrogeomorphology, the ability to extrapolate specific biophysical information or relationships from one system to another of like position within the classification, and the capacity for a consistent and reproducible frame of reference.

What is a "Stream"?

Our general definition of "streams" is aquatic habitat with flowing water present continuously throughout a year (regardless of weather conditions). The subsurface (streambed) of streams lies below the groundwater table and may be fed by either groundwater or surficial runoff. Perennial streams are only dry in periods of hydrologic drought, where the groundwater table recedes below a streambed. Finally, the flora and fauna of streams includes organisms whose life cycles require a fully aquatic environment for a year or more. We do not include any non-natural systems, such as constructed ditches or canals. As of publication we also do not include non-perennial, intermittent, or ephemeral streams in SEI monitoring, although these habitats can be very important in ROMN parks (especially in alpine areas). We usually use "stream" to refer to any size perennial system, such that larger streams, often thought of as "rivers," are also included as streams in our monitoring. Occasionally we will use "river" if a water body is colloquially referred to in this way.

Stream Order

Most SEI sample designs treat streams in a park as a continuous resource (see below), but we do incorporate stream order as a well-known classification of stream type in some sample design aspects and in some analyses. Stream order is based on the position of a reach within a stream network or stream order (Strahler 1957), with the numeric value of stream order describing the hierarchy in which stream segments are arranged. For example, when two stream segments of the same order join, the new segment they create is the next highest order (with a first order stream having no other streams intersecting it). If a stream happens to be a lower order than that of the intersecting stream, the first channel assumes the higher order, and so on. In general, an nth order stream is a tributary formed by two or more streams of order (n-1) and streams of lower order.

Stream order can covary with multiple geophysical and biological attributes of channels. For example, the geomorphology described by a stream order is expressed in multiple scaling laws that link the geometric properties of fluvial drainage networks seen in attributes of a stream reach or network, such as drainage area, network density, etc. Perhaps the simplest covariate with stream order is channel size (expressed in multiple ways such as discharge, width, volume, etc.). Channel size is a fundamental component of many of the seminal concepts of stream ecology, such as the river continuum concept (Vannote et al. 1980) that can serve to organize and predict aquatic condition as described by the ROMN framework.

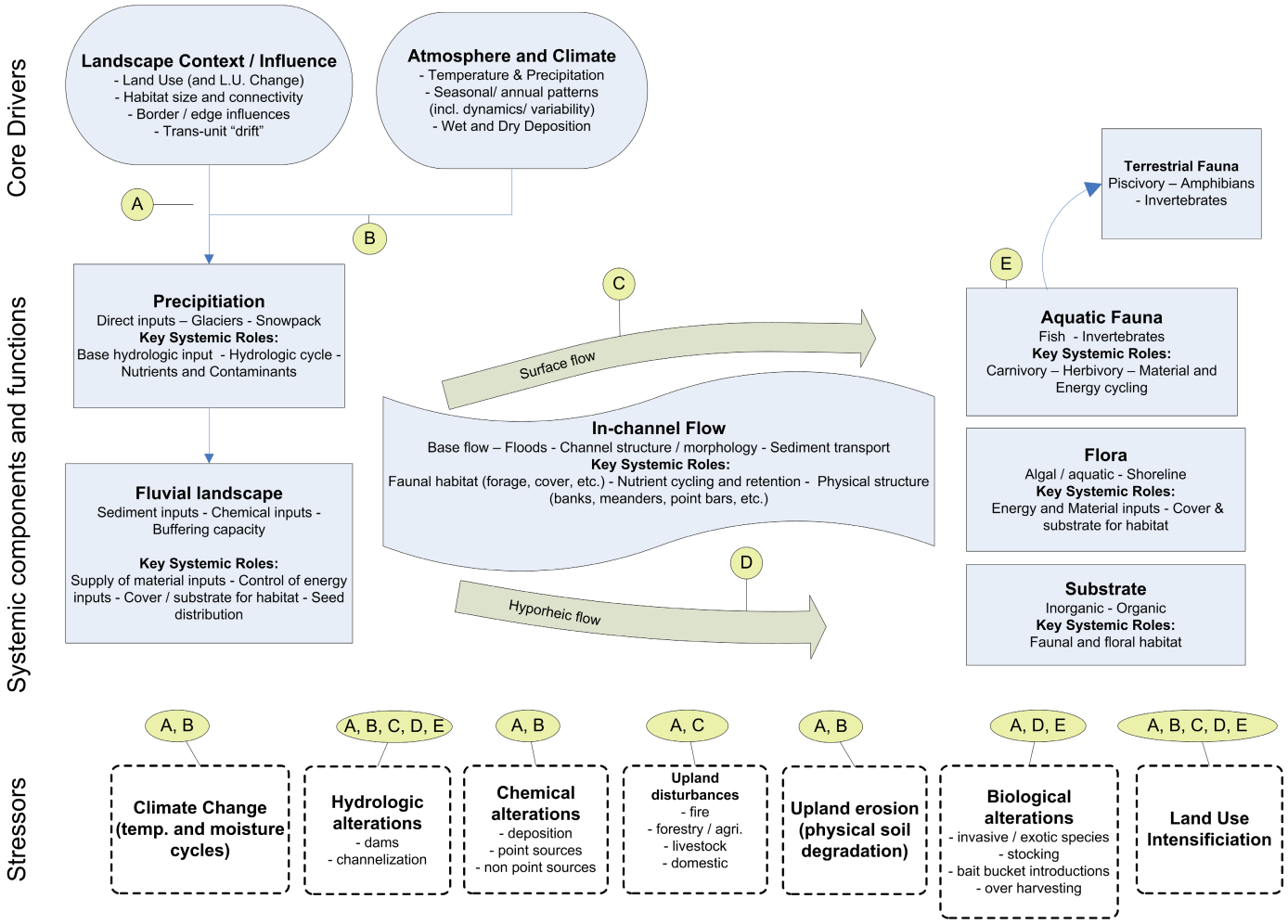


Figure 2. ROMN stream ecosystem characterization model. The conceptual diagram identifies core drivers of pattern and process (ovals at the top of the figure), major components of streams (rectangles on the left and right of the figures), and known or anticipated stressors that drive changes in the processes and patterns that define a community or ecosystem (dotted-line boxes at the bottom of the figure). Connections between stressors, drivers and system components are indicated with lettered identifiers within comment balloons. Note that these are not state-transition or energy-material flow models; they do not explain the details of component-driver interactions, rather they conceptualize the systems at a level critical for scoping and design. These models depict the major components and drivers of a system and connect changes to the environment (stressors) with systemic effects by relating controlling elements (before the arrow in the balloons) with the system effects (after the arrow in the balloons).

Stream Conceptual Diagram

To help visualize and understand the major components, ecosystem functions, and drivers and stressors of streams we developed a general stream characterization diagram (or "conceptual model;" Figure 2). Figure 2 provides a framework for understanding the relationship between streams and surrounding park lands, as well as current and anticipated issues potentially impacting streams in ROMN parks. [Note that Figure 3 also provides a simple conceptual treatment of stream ecosystems with a focus on the expected impacts of climate change.]

Rationale and Justification for Stream Monitoring

There are several reasons behind the choice to conduct long-term stream monitoring in ROMN parks. In general, streams and rivers are fundamental components of the ecological and cultural context of the network parks (Stottlemyer et al. 1997; Hauer et al. 2000; Mast et al. 2005; Hauer et al. 2007). They are often what visitors come to see, what they remember when they leave, or in the case of GRKO and LIBI, form an important backdrop to the historical or cultural events preserved by the park. Perhaps most important-

ly, the NPS recognizes that aquatic resources are some of the most critical and biologically important resources in the national park system and that they are vulnerable to degradation from activities both within and external to parks.

Ecological Considerations

The mission of the NPS I&M Program and ROMN is to provide long-term ecological monitoring data and information for a suite of stream "vital signs" to park managers to assist them in preserving park streams and rivers unimpaired for the enjoyment of current and future generations. ROMN has implemented the SEI protocol to monitor several important vital signs including water quality and chemistry, surface water dynamics, invasive/exotic aquatic biota, and freshwater communities (Britten et al. 2007). Understanding and managing streams and rivers is best accomplished by treating them as complete hydrologic systems within a watershed where the natural processes that deliver water, sediment, and woody debris are maintained and human disturbances are minimized. Important natural processes for healthy stream system functioning include flooding, stream migration, and associated erosion and deposition that results in natural habitat features such as floodplains, cutbanks and river bluffs, riparian habitats, accumulations of woody debris, terraces, gravel bars, riffles, and pools. ROMN monitoring aims to provide data and understanding of the hydrologic systems within ROMN parks and the natural processes that streams and rivers support.

While regulatory considerations (summarized below) provide an important context for SEI monitoring, the emphasis of long-term ecological integrity monitoring within the protocol is a key distinction from stream monitoring conducted by States or other federal agencies like the EPA.

Ecological Integrity

We focus on the ecological integrity of streams. Ecological integrity is the capacity to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region (Karr 1991). It is a complex, multidimensional concept and usually a single indicator is insufficient to characterize it. Therefore, we use an integrated set of response measures, including community-level macroinvertebrate and diatom composition/structure, hydrology, geomorphology, substrates, water temperature, and qualitative or categorical indicators of condition and stress (including both anthropogenic and natural). We use qualitative or categorical indicators of condition and stress to help understand patterns in these responses and develop bioassessment models of stream condition. Macroinvertebrate and diatom data are primarily used to generate multi-metric and multivariate indices of stream ecological integrity (EPA 2002; Jones 2004; Faber-Langendoen et al. 2006; Rocchio 2007; Lemly and Rocchio 2009). We are also developing park-scale models using novel methods developed for the ROMN wetland protocol (Grace et al. 2012; Schoolmaster et al. 2012, 2013a,b).

Ecological integrity may not be the primary goal of park natural resource management, particularly at historical parks and historic sites where cultural resource management may take precedence. Moreover, it may not provide project-specific results for a single, focused issue in a park ("effectiveness monitoring"). ROMN will work with parks to develop approaches that are specific to each park and the key issues affecting stream condition in a given system, integrating the broader, longer-term concepts within ecological integrity with more case-specific needs.

Threats to Streams

Stressors with important ecological consequences that can influence streams include climate change and invasive (usually non-native) species in riparian and channel habitats.

NPS vital signs monitoring is a long-term effort. Therefore, it should effectively respond to long-term changes in stream condition given shifting climate regimes. Changes in stream hydrology due to climate changes over the past fifty years in the West are well documented (Barnett et al. 2008) and these

changes are expected to continue. Physical, chemical, and biological characteristics of aquatic ecosystems act as indicators of impacts due to climate change (McKnight et al. 1997). Even modest temperature increases in the western United States may cause significant changes to the hydrologic cycle, manifested as earlier snowmelt, earlier ice-out on lakes, reduced summer baseflow (Dettinger et al. 2004), a lower snowpack volume at lower to mid elevations (Knowles et al. 2006), and increased flooding due to rain-on-snow events in winter (Heard 2005), especially when coupled with dramatic precipitation events such as in the spring of 2011. Hydrographs (i.e., the magnitude and timing of spring run-off) will likely shift to earlier floods. These changes will, in turn, likely affect the seasonal dynamics of stream and riparian biota (Palmer and Bernhardt 2006).

While more proximate, classic stressors impact many ROMN streams, climate change may be the most important direct and indirect stressor over the long term; however, many of the effects of climate change may take some time to appear, and most will be confounded with other sources of stress. Therefore, the SEI protocol is designed to measure a broad spectrum of stressors that might impact stream condition across multiple time scales, so that we can attempt to tease apart these patterns.

As summarized in Ashton (2010) and Figure 3, climate change may significantly impact ROMN aquatic resources and likely make it more difficult to achieve water quality standards nationwide (Field et al. 2007). While there are likely to be regional variations, projected effects across the West include loss of glaciers, less snow, earlier peak flows, less streamflow, warmer water temperatures, more frequent droughts, and more intense storms (Figure 3). While there is high confidence that climate change will alter freshwater ecosystems, numerous uncertainties exist. Many of the projected changes are based on precipitation changes, which are inherently more difficult to model than temperature. Moreover, the magnitude and frequency of extreme events such as droughts and floods are unpredictable, and these will have large impacts on water resources. The interacting effects of other stressors, such as pollution, ultraviolet light, diseases, and environmental toxins, with climate change are unknown. Moreover, the ramification of changes in food-web structure and dynamics caused by the loss of some species and the expansion of others is unclear. Finally, and perhaps most importantly, the threat to water resources posed by increasing human demand is difficult to quantify. ROMN feels that this is one of the primary reasons why a comprehensive approach to long-term monitoring of these important resources in our parks is required as this may be the best way to sort out these uncertainties.

Climate-induced changes in the hydrological cycle and multiple proximate direct disturbances often lead to changes in species distribution, including invasion by taxa that can threaten native or endemic species and the stability of aquatic ecosystems (Rahel and Olden 2008). We include simple methods that quantify the presence and abundance of a select list of invasive taxa developed with park staff. These methods should not replace more specific protocols that may be implemented by a park or other collaborators.

The Montana Department of Fish, Wildlife and Parks (MT FWP) and Colorado Parks and Wildlife (CPW) maintain lists of species of concern in their respective states (MT FWP 2012; CPW 2013). Most of these taxa are vertebrates (that we do not collect) or plants (see below). Aquatic invertebrates on the list in Montana include the zebra and quagga mussel (*Dreissena polymorpha* and *Dreissena rostriformis*), the New Zealand mudsnail (*Potamopyrgus antipodarum*), and the rusty crayfish (*Orconectes rusticus*). Aquatic invertebrates on the list in Colorado include the zebra and quagga mussel, the New Zealand mudsnail, the rusty crayfish, and three water flea species (*Daphnia lum-*

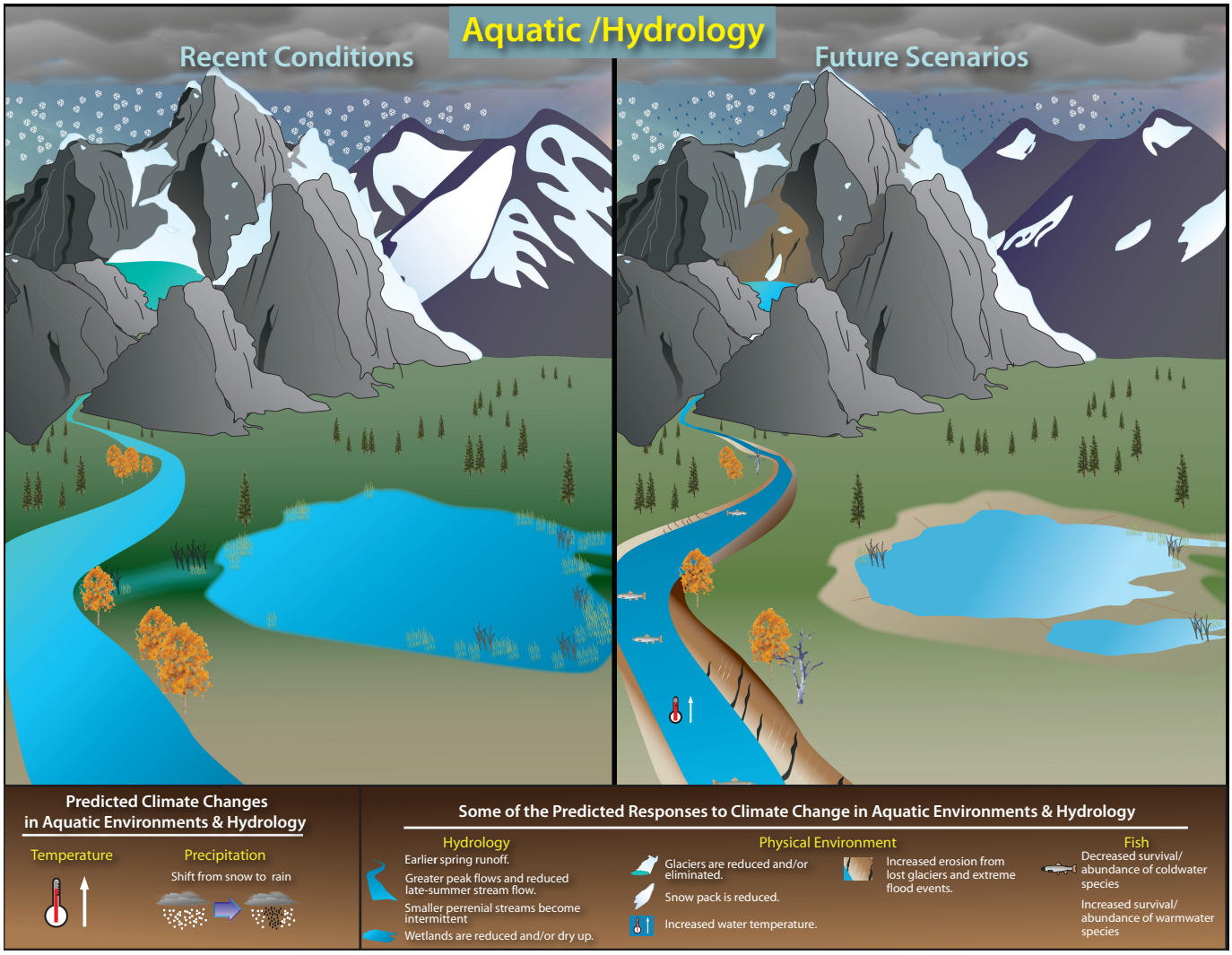


Figure 3. Conceptual diagram of generalized expected dynamics in stream ecosystems due to climate change. From: Ashton (2010), originally created and provided by Rob Bennetts (NPS).

holtzii, *Cercopagis pengoi*, and *Bythotrephes longimanus*). Several of these species do or could occur in ROMN parks.

Riparian corridors are often ideal habitat for invasive plants. These species may have impacts on community structure and can alter soil and water chemistry. Moreover, invasion into riparian areas is often a useful indicator of general disturbance (often anthropogenic, at least in part). Target invasive plants were developed in concert with staff from all ROMN parks. These lists include taxa that are ecologically varied, easy to identify, truly invasive, ecologically or economically harmful, and some of which are also included in regional surveys conducted by ROMN partners (Ringold et al. 2008). Twelve to fifteen taxa were selected for survey along stream sites in each ROMN park. Another important species of concern (although not on a state list yet) is the diatom *Didymosphenia geminata*, commonly referred to as didymo or rock snot.

Regulatory Considerations

Streams and rivers are among the more regulated natural resources and multiple federal and state programs must be implemented by NPS and its partners to protect aquatic habitat and its many functions. NPS is required to manage all parks in accordance with the Organic Act and other laws to not derogate from the values and purposes for which these various areas have been established (NPS 1970). Under the General Authorities Act, all resources, including water resources of a park, are protected by the Department of the Interior/National Park Service. Only

an act of Congress can change this fundamental responsibility of the NPS.

NPS Laws, Regulations and Policies for Streams

The NPS Organic Act, the Code of Federal Regulations, and NPS Management Policies (NPS 2006) broadly require park management to maintain, rehabilitate, and perpetuate the inherent integrity of aquatic resources and processes. NPS policies direct park managers to work with the appropriate partners (e.g., the Crow Tribe, Montana Department of Environmental Quality [MT DEQ], the Colorado Department of Public Health and Environment [CDPHE] and the EPA) to obtain the highest-possible standards for park waters within the framework of the Clean Water Act and to maintain or restore water quality. For smaller "flow through" parks, like GRKO or LIBI, this is complex given the small length of stream or river and their watersheds within these parks. Moreover, the nested location of LIBI in the Crow Reservation (see below) creates a unique context for monitoring, managing, and protecting the Little Bighorn River in LIBI.

Clean Water Act

The Clean Water Act, first promulgated in 1972, is designed to maintain and restore the chemical, physical, and biological integrity of the nation's waters including waters in national parks. As part of the Act, Congress recognized the primary role of the states and tribal nations in managing and regulating water quality. Section 313 of the Clean Water Act requires that all federal agencies comply with the requirements of state law for water quality management, regardless of other jurisdictional status or landownership. State agencies implement the protection of water quality for the waters of the state under the authority granted by the Clean Water Act through best management practices and water quality standards, as the foundation of water quality-based pollution control. Water quality standards define the goals for a waterbody by designating its uses, setting criteria to protect those specific uses, and establishing provisions, such as antidegradation policies to protect waterbodies from pollutants. The state's anti-degradation policy is a three-tiered approach to maintaining and protecting various levels of water quality. Minimally, the existing uses of a water segment and the quality level necessary to protect the uses must be maintained. The second level provides protection of existing water quality in segments where quality exceeds the fishable/swimmable goals of the Clean Water Act. The third level provides protection of the state's highest quality waters where ordinary use classifications may not suffice; these are classified as Outstanding Resources Waters.

Under section 303(d) of the Clean Water Act, states, territories, and authorized tribes are required to develop lists of impaired waters (summarized for ROMN parks in Table 1). These are waters that are too polluted or otherwise degraded to meet the water quality standards set by states, territories, or authorized tribes. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop Total Maximum Daily Load (TMDL) for these waters. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards.

Outstanding Resources Waters and National Wild and Scenic Rivers

All non-front country waters, or waters wholly within GLAC, ROMO, and GRSA are Outstanding Resource Waters (ORW). This is a desirable designation to acquire for NPS parks with significant water resources management responsibilities. ORW are not allowed to have any degradation or permanent change in the water quality resulting from new or increases in point-source discharge (i.e., State of Montana Administrative Code Title 17, Chapter 30; MT DEQ 2002). This means that, apart from non-significant activities, the state may not authorize any degradation of ORW and the state should prohibit, to the greatest extent practicable, changes to the existing water quality of those waters. In general, these streams and rivers must be afforded the greatest protection feasible under state law.

Finally, two forks of the Flathead River in

Table 1. Summary of designated waters in ROMN parks as of February 2013 (NPS 2013).

Waterbody Type	Stream Miles	303(d) Impaired Stream Miles	Miles Adjacent	303(d) Impaired Adjacent Miles	Lake Acres	303(d) Impaired Acres	ORW?	303(d) in watershed?	Beneficial Use Class
GRKO									
Perennial Stream/River	4.85	3.45	0.059	0.059	--	--	No	Yes	C1
Intermittent Stream/River	3.22	0	0	0	--	--		--	
Canal	3.63	0	0.101	0	--	--		--	
Lake/Reservoir	--	--	--	--	19.49	0		No	
GLAC									
Perennial Stream/River	1439.78	5.76	109.96	4.52	--	--	Yes	Yes	A1 (N/M Fork Flathead); ORW
Intermittent Stream/River	1260.75	0	0	0	--	--		--	
Canal	0	0	0	0	--	--		--	
Lake/Reservoir	--	--	--	--	26,967.31	0		No	
GRSA									
Perennial Stream/River	55.14	0	0.005	0	--	--	Yes	Yes	cold-water aquatic life class 1, recreation 1a, agriculture, water supply; ORW
Intermittent Stream/River	244.75	0	0	0	--	--		--	
Canal	22.69	0	0	0	--	--		--	
Lake/Reservoir	--	--	--	--	69.87	0		No	
LIBI									
Perennial Stream/River	0	0	3.2	0	--	--	No	No	B2
Intermittent Stream/River	1.97	0	0	0	--	--		--	
Canal	0	0	0	0	--	--		--	
Lake/Reservoir	--	--	--	--	0	0		No	
ROMO									
Perennial Stream/River	482.94	190.66	14.48	1.48	--	--	Yes	Yes	cold-water aquatic life class 1, recreation 1a, agriculture, water supply; ORW
Intermittent Stream/River	283.12	102.02	0	0	--	--		--	
Canal	16.65	0.80	0	0	--	--		--	
Lake/Reservoir	--	--	--	--	1,119.08	440.72		No	

"C1", "A1," and "B2" are beneficial use classes for Montana parks. Source data include 1:24k scale National Hydrography Dataset (NHD; USGS 2013a) and State summaries of 303(d) impairment status (MT DEQ 2012b; CDPHE 2013a,b,c). Stream miles or lake area are restricted to the park's boundaries. "Adjacent" refers to waterbodies that share a boundary with a park. "Lake" refers to any non-flowing water resource. "Intermittent" includes any type designated as ephemeral in NHD source data. "Beneficial use class" names vary by State. Table 2 presents summaries of impairment causes as completed or in progress TMDLs being developed by the States or EPA. Identifying adjacent features may include some level of subjectivity and require a certain degree of judgment by the processor. Other sources of information, such as reviewing land segment maps and contacting park staff, were utilized whenever possible to verify adjacent features. See NPS (2013) for details.

GLAC (the North Fork from the Canadian border downstream to its confluence with the Middle Fork and the Middle Fork from its headwaters to its confluence with the South Fork) are designated National Wild and Scenic Rivers (WSR; Public Law 90-542; 16 U.S.C. 1271 et seq.). These two rivers feature recreation, scenery, historic sites, unique fisheries, and wildlife such as grizzly bears and wolves. This designation preserves the outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations.

Water Quality in Indian Country

State water quality standards apply to all waters within a state, with the exception of those waters that are within Indian Country (as defined in 18 U.S.C. Section 1151), such as the Little Bighorn River in LIBI. In these cases, the tribes have jurisdiction once they develop a water quality standards program that includes designated appropriate uses, criteria, and anti-degradation policies that are approved by EPA. The Crow Tribe has yet to do this for the Little Bighorn River, so the authority still resides with EPA. At this time, EPA has not developed a program for this river, so NPS and ROMN have no accepted regulatory framework for understanding and managing LIBI water quality.

Clark Fork Superfund Project

GRKO is within the Clark Fork River Superfund Site, an area that is contaminated with arsenic and heavy metals (copper, cadmium, lead, and zinc) related to historic mining, milling, and smelting activities in the headwaters of the Clark Fork River. Tailings from these operations were transported downstream and deposited along the floodplain of the river by at least six major floods during the late 1800s and early 1900s (Smith et al. 1998). Sedimentation ponds were later built to prevent movement of tailings from the headwaters. However, the Clark Fork continues to be contaminated in two ways: by erosion of previously deposited tailings, and by direct leaching of metals from tailings into surface water and groundwater. Copper is the primary metal of concern, because it is the most toxic to aquatic life and plants in the river floodplain. Many of the probable sources of impairment in GRKO listed in Table 2(a) are likely due to these events.

In April of 2004, a Record of Decision was issued by the EPA for the remediation of contaminated areas within Reach A of the Clark Fork River, which includes GRKO (EPA 2004). General remediation efforts will include removal of larger tailing deposits (>37 m^2 in area and 60 cm in depth) followed by re-vegetation of the excavated area. Smaller tailing deposits and impacted soil and vegetation will be remediated *in situ* using lime addition, soil mixing, and revegetation. Consultants for MT DEQ will begin a draft remediation design for GRKO in 2015. The NPS has specific cleanup needs and responsibilities under the laws that govern national historic sites. The Record of Decision was expanded and modified specifically for GRKO. MT DEQ (2010) presents an interim comprehensive long-term monitoring plan for remediation actions implemented within the Clark Fork River Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site. The monitoring plan describes the requirements for: (1) annual monitoring to ensure that remediation and restoration projects are meeting established performance standards, and (2) long-term monitoring to demonstrate that over time the remediation activities are achieving the goals that were set forth in the Clark Fork Operable Unit Record of Decision (EPA 2004) and in the Monitoring and Maintenance Plan for the Clark Fork Operable Unit (MT DEQ 2010). ROMN SEI monitoring is not meant to monitor the effectiveness of ongoing remediation and restoration of the Clark Fork channel and riparian habitats within GRKO. SEI monitoring of the Clark Fork River does not replace any research remediation and restoration effectiveness monitoring or other work being undertaken by the state or other federal agencies under the auspices of the Record of Decision or the state monitoring plan.

Legal/Regulatory Status of ROMN Streams

Water use classifications for all stream segments in Montana and Colorado were

Table 2a. Summary of impairment causes and Total Maximum Daily Load (TMDL) status as of 2013 for GRKO.

Stream and Tributary Names	Probable Causes for TMDLs	Probable Source(s)	TMDL Complete?
CLARK FORK RIVER, Little Blackfoot River to Cottonwood Creek	Alteration in stream-side or littoral vegetative covers	Agriculture, Channelization	NO
	Copper	Mill Tailings	NO
	Lead	Mill Tailings	NO
	Low flow alterations	Agriculture	NO
	Nitrogen (Total)	Agriculture, Municipal Point Source Discharges	NO
	Phosphorus (Total)	Agriculture, Municipal Point Source Discharges	NO
	Physical substrate habitat alterations	Agriculture, Channelization	NO
	Sedimentation/Siltation	Agriculture	NO
	Zinc	Mill Tailings	NO

Table 2b. Summary of impairment causes and Total Maximum Daily Load (TMDL) status as of 2013 for GLAC (MT DEQ 2012b).

Stream and Tributary Names	Probable Causes for TMDLs in GLAC	Probable Source(s)	TMDL Complete?
DIVIDE CREEK, headwaters to mouth	Alterations in wetland habitats	Channelization	YES
	Other anthropogenic substrate alterations	Highways, Roads, Bridges, Infrastructure (New Construction) Site Clearance (Land Development or Redevelopment)	YES
*COAL CREEK, South Fork to mouth (North Fork Flathead)	Sedimentation/Siltation	Forest Roads (Road Construction and Use) Silvicultural Harvesting	YES
*BIG CREEK, South Fork to mouth (North Fork Flathead)	Alteration in stream-side or littoral vegetative covers	Forest Roads (Road Construction and Use) Streambank Modifications/destabilization	YES

*upstream of GLAC boundary but may influence park waters.

Table 2c. Summary of impairment causes and total Maximum Daily Load (TMDL) status as of 2013 for ROMO (CDPHE 2013 a,b,c).

Stream and Tributary Names	Probable Causes for TMDLs in ROMO	Probable Source(s)	TMDL Complete?
BIG THOMPSON RIVER, including all tributaries and wetlands in ROMO	Copper	--**	NO
*BIG THOMPSON RIVER, all tributaries (ROMO to Home Supply Canal)	Copper	--**	NO
	Cadmium	--**	NO
	Temperature	--**	NO
	Zinc	--**	NO

*downstream of ROMO boundary, but may reflect park waters.

** CDPHE does not specify.

established by MT DEQ (Administrative Rules of MT 17.30.611 as in MT DEQ 2002) and CDPHE (CDPHE 2013a,b,c). The Water Resource Division of the NPS compiles data on protected uses and any impairment status of waters in all NPS parks. Table 1 presents summary data for ROMN parks as of 2012 (NPS 2013). Table 2 lists possible causes of impairment for any stream in a ROMN park that is in need of or has a defined TMDL.

The Interpretation of SEI Data in a Regulatory Context

As emphasized in several places in this document, the primary motivation for SEI monitoring is to understand and document thelong-term ecological condition of aquatic resources in ROMN parks in order to better protect and manage them. The NPS does not have regulatory authority over waters in a park; any Clean Water Act motivated regulatory action (i.e., as driven by an exceedance of a state or EPA criterion or threshold) is the responsibility of a State, Tribe, or the EPA. However, as noted above, the Organic Act and various NPS Management Policies do require park management to maintain, rehabilitate, and perpetuate the inherent integrity of aquatic resources and processes and NPS will work with appropriate State and other Federal partners to do so.

Importance of Aquatic Resources to ROMN Parks and Surrounding Ecosystems

ROMN wilderness parks (GLAC, ROMO, and GRSA) have diverse and extensive flowing waters, generally in excellent condition—treasured for their beauty and ecological integrity (Figure 4; Long 2002).

The aquatic resources of GLAC are particularly notable. The World Wildlife Fund rates the distinctiveness of the aquatic systems in the Canadian Rockies Ecoregion (that contains GLAC) as "Continentally Outstanding" (Abell et al. 2000). Much of the Pacific Northwest region was heavily glaciated during the Pleistocene, and as a result, has few known endemic aquatic species. The Canadian Rockies ecoregion, however, served as a refugium for freshwater species during the last glaciation, and as a result GLAC's streams, rivers, and lakes and associated groundwater and wetland systems support a wealth of biodiversity from plants



Figure 4. Reynolds Creek in Glacier National Park. Photo courtesy of Glacier National Park.

including tiny diatoms (unicellular algae), to aquatic insects to amphibians, fish, birds, and mammals. Over 500 taxa of diatoms have been recorded in the park, including several unique and new to science species (Bahls 2009). Macroinvertebrates are also diverse and include endemic species such as the meltwater stonefly (*Lednia tumana*) which lives in alpine streams immediately downstream of glaciers and snowfields (Muhlfeld et al. 2011). GLAC waters provide high-quality lentic and lotic fish habitat inhabited by six native salmonids including the threatened bull trout (*Salvelinus confluentus*) and the state-sensitive west slope cutthroat trout (*Oncorhynchus clarkii lewisi*); both are indicators of high water quality. Fourteen other (non-salmonids) inhabit GLAC waters including several sculpins (*Cottus* spp.), burbot (*Lota lota*), and northern pike (*Esox lucius*) (Downs et al. 2013). This diversity of fish species is supported by a diverse and large food web, pristine water quality, and intact hydrology. The waters of the park are also home to five introduced non-native salmonids, which affect management and are of great concern to the park. Nearly every terrestrial species in the park interacts with streams and rivers at some point in their life cycles. Species of note include the Rocky Mountain tailed frog (*Ascaphus montanus*), common loon (*Gavia immer*), harlequin duck (*Histrionicus histrionicus*), American dipper (*Cinclus mexicanus*), northern water shrew (*Sorex palustris*), beaver (*Castor canadensis*), and the river otter (*Lutra canadensis*).

Rocky Mountain National Park preserves some of the finest examples of physiographic, biologic, and scenic features of the southern Rocky Mountains and is recognized as an International Biosphere Reserve. ROMO is also designated as a Global Important Bird Area. This designation recognizes the vital role of the park in the perpetuation of bird species. Drainages on the east side of ROMO form the headwaters of the Big Thompson River, Saint Vrain Creek, and Cache La Poudre River; those on the west side drain into the Upper Colorado River system. The park contains nearly 800 km of perennial streams and more than 150 lakes, most of which are above 3,000 m in the subalpine and alpine zones (Britten et al. 2007). The park's varied elevations encompass diverse aquatic ecosystems where wilderness qualities dominate. ROMO waters provide high-quality lentic and lotic fish habitat inhabited by three native salmonids including the threatened greenback cutthroat trout (*Oncorhynchus clarki stomias*), Colorado River cutthroat trout (*Salmo clarki pleuriticus*) and Yellowstone cutthroat trout (*Salmo clarki*). The waters of the park are also home to three introduced non-native salmonids that are of great concern to park management. Nearly every terrestrial species in the park interacts with streams and rivers at some point in their life cycles. Species of note include moose (*Alces alces*). elk (*Cervus elaphus canadensis*), American dipper (*Cinclus mexicanus*), beaver (*Castor canadensis*), and the river otter (*Lutra canadensis*).

The stream resource at GRSA is not as extensive as in GLAC or ROMO. However, the two primary drainages in GRSA (Sand Creek, which flows around the northwest side of the dunes, and Medano/Mosca Creeks, which flow around the southeast side; Figure 5), play a vital role in maintaining the dune fields because they deposit sand on the upwind side of the dune field where it is transported back to the dunes by prevailing winds (Chatman et al. 1997). Both streams begin high in the Sangre de Cristo Mountains and are fed primarily by snowmelt. As they flow around the edge of the dune field they begin losing water through the sand into a shallow, unconfined groundwater aquifer. All the water in both creeks, except what is lost to evapotranspiration, eventually infiltrates into the unconfined aquifer that flows under the dunes and eventually discharges at Big Spring and Little Spring Creeks on the west side of the dune field. Medano Creek and Sand Creek are also world-class examples of surge flow, a stream flowing in rhythmic waves on sand. Three elements are needed to produce the phenomenon: a relatively steep gradient to give the stream a high velocity; a smooth, mobile creekbed with little resistance; and sufficient water to create surges. In spring and early summer, these elements combine

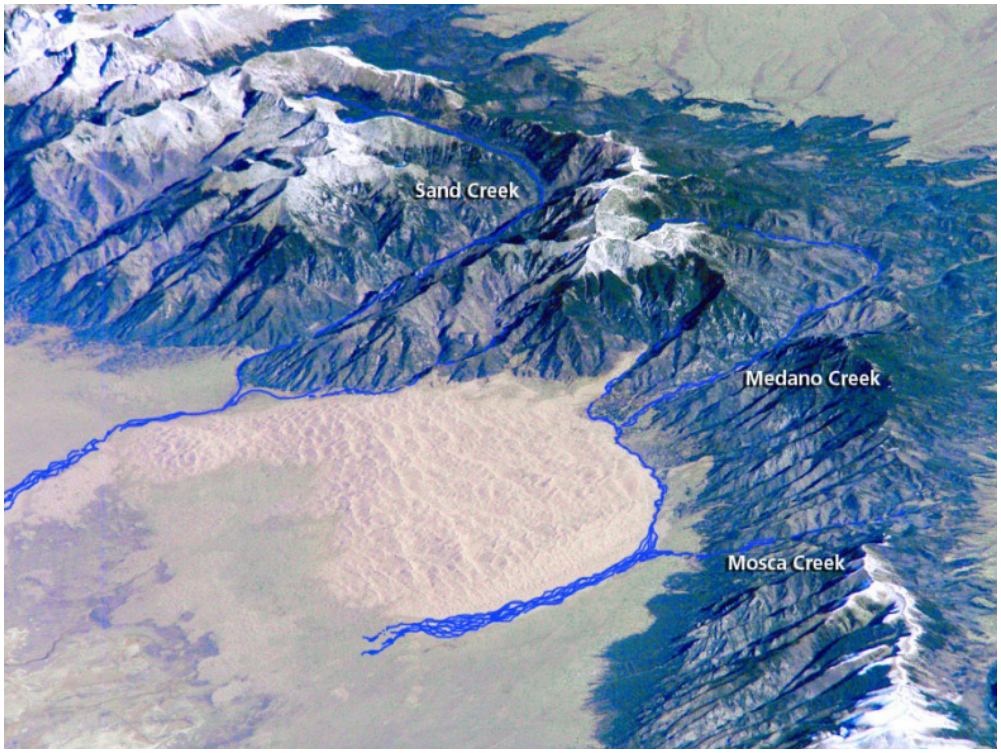


Figure 5. Sand, Medano, and Mosca Creeks in Great Sand Dunes National Park and Preserve showing the important relationship between these systems and the main dune field. Image courtesy of GRSA.

to make waves at Great Sand Dunes. While Sand Creek contains exotic trout species, such as rainbow, brook, and brown trout (*Oncorhynchus mykiss*, *Salvelinus fontinalis*, and *Salmo trutta*), Medano Creek is an important habitat for native fish species. The Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) historically occupied the Rio Grande Basin and associated drainages in southern Colorado and New Mexico. At present, it occupies about 15% of that range, mostly in the headwaters of the upper Rio Grande watershed. Medano Creek serves as an important biological refugia for this trout, because it is a closed system where exotic species cannot enter; the creek is bounded by an alpine basin at its source, and the Great Sand Dunes at its terminus. The Rio Grande sucker (*Catostomus plebeius*) is an endangered species in Colorado. These small fish have been reintroduced to forested sections of Medano Creek, and their population is still being monitored.

While LIBI and GRKO do not have the extensive and near-pristine flowing waters of ROMN wilderness parks, the Little Bighorn River and Clark Fork River and their associated hydrogeologic systems are primary resources at LIBI and GRKO, respectively. These two parks protect a small portion of these river's drainages; the rivers are integral to many of the ecological processes occurring within the parks, and they play an important role in park operations. For example, LIBI water rights allow the park to divert water from the river for fire suppression and GRKO has multiple water right claims to the use of surface water from the Clark Fork and its tributaries for flood irrigation of park lands. As discussed further below, the Clark Fork and its floodplain are part of an ongoing Superfund project to restore and mitigate impacts of acid mine drainage and heavy metal deposits (EPA 2004). This creates a complex array of ecological processes that SEI monitoring must attempt to quantify and a diverse regulatory arena that ROMN must assist the park with. Overbank flows (flooding) represent an important floodplain function for low-gradient rivers, such as the Little Bighorn and Clark Fork. This was dramatically illustrated in the spring of 2011 at LIBI when discharge on the river was near its historic peak (396 m^3/s, or about 14,000 ft^3/s; USGS 2011). During periods of overbank flow, significant detention storage of floodwaters can occur, moisture levels of floodplain soils and underlying aquifers are recharged, and fine sediments are deposited on floodplain surfaces. These, and several other



Figure 6. Slickens in the GRKO riparian corridor. Photograph by: B. Schweiger, NPS ROMN.

processes, are critical to the maintenance of a healthy river ecosystem. A primary concern regarding flooding at LIBI, however, is the potential loss of artifacts on the floodplain and riverbanks; this may require some type of stabilization to preserve potential collection sites (Schweiger et al. 2014b). Flooding at GRKO might also play an important role in mobilizing contaminated sediments (or "slickens;" Rice 2002; Rice and Hardin 2002; Figure 6).

Finally, both rivers played a central role in the historical events that LIBI preserves (Rickey 2005) and the western ranch lifestyle that GRKO commemorates as part of a living museum. The Little Bighorn was a popular summer religious rendezvous site for the various bands of the Lakota tribe involved in the Battle of Little Bighorn in 1876. River fords were significant in battle movement within the mostly non-wadeable channel. At GRKO, the six small tributary creeks and nine natural springs located on the ranch that feed into the Clark Fork River create a natural abundance of fresh water. This water, coupled with ideal topography and deep soils, provided the Grant, Kohrs, and Warren families the natural resources needed to support their domestic and ranching activities for over 150 years.

Historical Stream Monitoring in ROMN Parks

Water quality data for ROMN parks through 2004 are developed into a database, analyzed, and reported in Mast (2007). Statistical summaries of water-quality constituents are presented and compared to aquatic-life and drinking-water standards. Spatial, seasonal, and temporal patterns in constituent concentrations are also described and suggestions for future water-quality monitoring are provided. The report focuses on field properties, major constituents, nutrients, and dissolved trace elements. The majority of the data were obtained from the U.S. Geological Survey (USGS) National Water Information System and the EPA Storage and Retrieval System databases. Hydrologic interpretations are considered preliminary because data sets generally are small and data were collected periodically for different study objectives. Most importantly, data

were not collected using a survey design and no design-based analytical methods are used. Nevertheless, Mast (2007) provides a good summary of previous water chemistry-based research and monitoring within aquatic ecosystems in ROMN parks.

There have been multiple research and shorter-term monitoring efforts focused on biological and habitat responses in the aquatic ecosystems of ROMN parks; however, these have not been cataloged into a single comprehensive treatment like what Mast (2007) did for water chemistry. This is a large task that is beyond the scope of this narrative. ROMN will include summaries of the historical biological and habitat research in select publications into the future.

Monitoring Objectives

The general goals for long-term ecological monitoring of ROMN park streams focus on documenting the status and trend in condition, helping to understand the causes of change in condition, and assisting in the application of SEI results and relevant auxiliary information to park stream management. Specific objectives vary somewhat with park and stream type. In some cases, analyses and models are also park and stream type specific. Under budget scenarios and management needs as of 2015, we expect to conduct park-scale surveys over the long term only in GLAC and ROMO. ROMN will consider altering this plan with changes in management needs, resource condition, and budget.

Overview of Sample Designs and Associated Core Analyses

We use three sample design forms (presented in detail for each park below) with each linked to or driven by specific objective(s). Data generated from sites selected by different designs may be integrated via analysis for some objectives (in most cases the response designs and how data are collected at a site are identical which facilitates this).

The first SEI design type is a probabilistic or "random" survey of streams in GLAC and ROMO. Survey designs are the default design recommended within the I&M Program (Fancy et al. 2009). ROMN considers survey designs to be the most defensible way to conduct most long-term, park-wide monitoring, and many of the monitoring protocols for ROMN rely on this technique at least in part (Britten et al. 2007). Survey designs include fewer assumptions and provide more reliable and defensible parameter estimates for inference to distributed target populations than targeted or model-based approaches (Olsen et al. 1999; Schreuder et al. 2004). Surveys provide representative and defensible information because the site selection process allows unbiased estimation of both status and, with repeated visits, trend across a heterogeneous resource (Larsen et al. 1995). When design-based inference is properly applied to survey data, a survey ensures that status estimates are unbiased and provides protection from model assumption failures (Thompson 2002). The broad spatial perspective afforded by large surveys allows a unique characterization of the status and trend in stream condition. "Status" is a general term that can be estimated using multiple types of statistics such as a simple mean of some response (and its variance) or something more complex such as the percentage of the stream in a park that is above or below an assessment point as estimated from design-based algorithms and expressed via a cumulative distribution function and its confidence bounds. Status may also be described through multivariate models (i.e., ordinations) that quantify relationships among macroinvertebrate and diatom communities, water chemistry, stream habitat, and environmental or disturbance gradients.

While our episodic large surveys are essential for meeting several of our objectives, most SEI monitoring in most years is conducted at sites selected with the second SEI design form, a targeted or hand-picked "sentinel" approach. We conduct sentinel site monitoring in all ROMN parks where we do or will monitor streams. ROMN considers (Britten et al. 2007) sentinel designs to be a valid sample design form in a limited, but important, set of circumstances (Overton and Stehman 1996). Sentinel designs can be used when the ecological process of interest is "well mixed" (suggesting most any site is likely appropriate for its measure), there is a clear need to understand a specific

location in a park, or the costs for surveys are insurmountable. A sentinel site focus is more realistic given our budget and the long-term time-series generated at sentinel sites supports trend modeling and a detailed perspective of the "ecology of place" (Billick and Price 2010) at select streams. "Status" at sentinel sites is estimated using multiple types of statistics such as a simple mean of some response (and its variance). However, because sentinel sites are selected with no way of controlling for bias due to their location or context (these statistics are derived differently than those generated from survey based data and in lieu of more complex modeling or often untestable assumptions), results from sentinel status may not be statistically inferred to streams beyond the sentinel site or its immediate reach (Olsen et al. 1999). Multivariate models may also be used to estimate status but in most cases sample size limitations will reduce the effectiveness of these analyses using sentinel site data alone.

Our third design form is another targeted or model-based approach called a gradient design. Gradient sites are often located at the tails of distributions of anthropogenic disturbance or interesting environmental gradients (i.e., elevation) that can strongly affect stream integrity. Gradient sites are useful in calibrating bioassessment models and are often at locations of specific management interest to a park. We implement gradient designs only in GLAC and ROMO, although in many ways, sentinel sites (in all parks) can also be used to meet objectives linked to gradient sites.

Survey Objectives (GLAC and ROMO)

We address and report on objectives specific to data derived from survey designs in GLAC and ROMO following large survey efforts conducted approximately every ten years. The most important use of survey data is to estimate episodic park-scale status. There is great value in these status estimates and the associated modeling and interpretation. Most status estimates from survey data are generated using design-based inference to the extensive population of all streams that could be sampled in a park. In select cases, model-based or geographic information systems (GIS) driven analyses are also used to estimate park-scale status.

Reporting cycles for survey sites are approximately every 10th year, staggered by park. Statistically rigorous estimates of population scale trend from survey site data depend on the specific response (and its patterns of variation across sites and time). Some responses allow trend estimates after a single survey but some do not until two or more survey cycles of data collection have been completed (with each cycle being separated by around 10 years, see below for details). However, simpler estimates of park-scale change are conducted after the second survey cycle. Survey objectives are as follows:

1. Determine status in a suite of response measures (lists within each category are examples; for a more detailed list of responses see Table 26).
    a. Macroinvertebrate and periphyton
        i. Occurrence of important species (i.e., *Didymosphenia geminata* or "didymo")
        ii. Simple bioassessment metrics such as percent mayfly+stonefly+caddisfly, percent invasive taxa, or taxa richness
        iii. More complex metrics such as the Hilsenhoff Biotic Index (nutrients) or diatom sediment/nutrient/metals increaser indices
        iv. Synthetic bioassessment metrics such as a Multimetric Index of Biotic Integrity (MMI) or a multivariate comparison of Observed to Expected (O:E) macroinvertebrate or diatom species composition (We apply existing models derived for ecoregional-scale efforts and build novel park-specific models.)
    b. Water/sediment physiochemistry
        i. *In situ* water chemistry (i.e., pH, temperature)
        ii. Major ions (i.e., chloride, sulfate)

iii. Nutrients (i.e., nitrogen, phosphorous, carbon)

iv. Metals (i.e., arsenic, mercury, copper)

c. In channel and riparian physical habitat

i. Substrate, channel, and riparian characteristics (i.e., pool density, bankfull width/depth ratio, percent fines, areal cover and type of riparian vegetation, presence of target invasive plants)

ii. Thalweg profile (i.e., mean residual depth, relative bed stability

iii. Woody debris (density by size class within and above bankfull channel)

iv. Instantaneous stream discharge

d. Anthropogenic disturbance

i. Presence and proximity of individual stressors and composite index

2. Determine the percent change in the condition of select stream responses detailed in objective one after each cycle of a survey.

3. Determine population scale trend in the condition of select stream responses detailed in objective one when sufficient power has accrued.

4. Assess status of select responses detailed in objective 1 as follows (In some cases, estimates of change or trend may also be assessed using these tools):

a. Compare to existing and published assessment points, including any regulatory criteria, ecological thresholds or ecoregion assessment points that are relevant to ROMN park streams and their management.

b. Compare to ecoregion assessment points derived from distributions of reference site data from within the park and/or surrounding ecoregion(s). These are developed for a subset of SEI responses based on data availability and quality and the relevance of the response to stream management.

c. Compare to baselines derived from partner or auxiliary data or (preferably) SEI survey data. Baselines are developed for a subset of SEI responses based on data availability and quality and the relevance of the response to stream management.

5. Relate spatial or temporal patterns (including trend when possible) in select stream responses to important ecological and anthropogenic drivers. These models depend on scale appropriate SEI covariate and auxiliary data, with clear (and often causal) connections to SEI responses and are therefore done on an as possible basis.

Sentinel Objectives (GLAC, ROMO, GRKO, LIBI, GRSA)

We address and report on objectives specific to data derived from annual sample efforts at sentinel sites in GLAC, ROMO, GRKO and LIBI. *As of publication, SEI monitoring in GRSA was under development and may be included in future revisions of this protocol* .

The most important use of sentinel data is to estimate long-term trend at select streams in a park. Statistically rigorous estimates of site-level trend from sentinel site data depend on the specific response (and its pattern of variation across time). Some responses allow trend estimates after just a few years but some do not until over 30 years of data collection have been completed (see below for details). However, simpler estimates of annual change are possible after two years of sentinel monitoring. Annual status is also estimated at sentinel sites—important and useful, especially when the results can be expressed in the context of SEI survey results (and/or results from auxiliary data in or around a park).

All sentinel sites have water temperature loggers that collect hourly data year round. Moreover, most sentinel sites are co-located with (usually USGS) gauges that collect continuous stream discharge and often monthly (or at least quarterly) water physiochemistry. These auxiliary data often have long historic records that provide excellent opportuni-

ties for trend analyses (Mast 2007; Mills et al. 2012). Schweiger et al. (2014a, b) present detailed analyses and interpretations of such data at GRKO and LIBI. Given these data, our sentinel site objectives include estimating status and trend in water temperature, discharge and water physiochemistry. In many cases trend models are possible without waiting for data to accrue over time.

Reporting cycles for sentinel sites are approximately every fifth year, staggered by park. Continuously logged data (discharge and temperature) at select sentinel sites will be reported on more frequently (at the time of publication, this strategy was under development). Sentinel objectives are as follows:

1. Determine site-level annual change (after the second year of sampling) and long-term trend (after sufficient power has accrued) in the condition of select stream responses.
    a. Macroinvertebrate and periphyton.
        i. Occurrence of important species (i.e., didymo)
        ii. Simple bioassessment metrics such as percent mayfly+stonefly+caddisfly, percent invasive taxa, or taxa richness
        iii. More complex metrics such as the Hilsenhoff Biotic Index (nutrients) or diatom sediment/nutrient/metals increaser indices
        iv. Synthetic bioassessment metrics such as a Multimetric Index of Biotic Integrity (MMI) or a multivariate comparison of Observed to Expected (O:E) macroinvertebrate or diatom species composition (We apply existing models derived for ecoregional-scale efforts and build novel park-specific models.)
    b. Water/sediment physiochemistry
        i. *In situ* water chemistry (i.e., pH)
        ii. Major ions (i.e., chloride, sulfate)
        iii. Nutrients (i.e., nitrogen, phosphorous, carbon)
        iv. Metals (i.e., arsenic, mercury, copper)
        v. Temperature metrics (i.e., annual (water year) and monthly mean, minimum and maximum daily mean, annual seven-day minimum and maximum)
    c. In channel and riparian physical habitat
        i. Substrate, channel, and riparian characteristics (i.e., pool density, bankfull width/depth ratio, percent fines, areal cover and type of riparian vegetation, presence of target invasive plants)
        ii. halweg profile (i.e., mean residual depth, relative bed stability
        iii. Woody debris (density by size class within and above bankfull channel)
        iv. Instantaneous stream discharge
    d. Anthropogenic disturbance
        i. Presence and proximity of individual stressors and composite index
    e. Hydrology (at sites with associated gauges)
        i. Hydrologic metrics (i.e., annual (water year) total discharge, highest daily mean, maximum peak flow, annual seven-day minimum, summer discharge as a percent of total annual, and monsoon timing)
2. Determine the status at a sentinel site in the responses listed in objective one.
3. Assess the status of select responses detailed in objective 1 as follows (In some cases, estimates of change or trend may also be assessed using these tools):
    a. Compare to existing and published assessment points, including any regulatory criteria, ecological thresholds or ecoregion assessment points that are relevant to ROMN park streams and their management.
    b. Compare to novel ecoregion assessment points derived from distribu-

tions of reference site data from within the park and/or surrounding ecoregion(s). These are developed for a subset of SEI responses based on data availability and quality and the relevance of the response to stream management.

c. Compare to baselines derived from partner or auxiliary data or, in GLAC or ROMO, SEI survey data. Baselines are developed for a subset of SEI responses based on data availability and quality and the relevance of the response to stream management.

4. Relate spatial or temporal patterns (including trend when possible) in select stream responses to important ecological and anthropogenic drivers. These models depend on scale-appropriate SEI covariate and auxiliary data, with clear (and often causal) connections to SEI responses and are therefore done on an as possible basis and left unspecified here.

Assessment

A key element of the SEI protocol is interpreting the *meaning* of SEI data. Is a result suggestive of high condition or reference status and why? Does a trend in a response suggest that condition is moving towards a degraded, non-reference state, and why? Clearly, this is a critical aspect of a mature long term monitoring program. We put emphasis on working with ROMN park staff and other partners to include management relevant data interpretation in SEI results. We generally follow assessment approaches and use terminology as presented in Stoddard et al. (2006), Bennetts et al. (2007) and Mitchell et al. (2014), as these methods have become established in other federal monitoring programs. They are used in part by the State of Montana (Supplee et al. 2005) and Colorado (CDPHE 2010) and are beginning to coalesce within the NPS. Most importantly, ROMN parks have accepted our approach as a general and flexible framework for interpreting SEI data from their parks. The following section provides an overview of the key elements of SEI assessment. More details are in provided in Schweiger et al. (In preparation).

Overview

We compare our monitoring results to assessment points (defined below) using either qualitative or statistical methods (as allowed by data). We stress numeric (versus narrative) assessment points to remove as much subjectivity from the process as possible. We interpret these comparisons using ecological theory, NPS I&M Division guidance, NPS resource management policies, and collaborative work with ROMN partners, especially park staff and management. We use the terms reference, intermediate (which can have multiple levels) and non-reference to label condition states of an SEI response. The reference condition is a central concept in ROMN assessment and it is further discussed below.

Assessment Points

We largely adopt a definition of assessment points from Bennetts et al. (2007): "… assessment points represent preselected points along a continuum of resource-indicator values where scientists and managers have together agreed that they want to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns." However, we generalize the term even further and use it as a catch all for a variety of thresholds or boundaries used in monitoring and assessment. Table 3 presents brief summaries of the types of assessment points used in the SEI protocol. More details are in provided in Schweiger et al. (In preparation) including detailed references behind each type of assessment point.

Reference Condition

Assessment points establish boundaries between alternate condition states. In the simplest case, a single assessment point separates a distribution of values for some measure or metric into a range of values that correspond to "good" or intact conditions and a range of "bad" or degraded condition states. We use the term reference for an intact functional condition state and non-reference for a degraded or non-functional state (Steedman 1994; Hughes 1995; Jackson and Davis 1995; Karr and Chu 1999; Davies and Jackson 2006; Stoddard et al. 2006). More complex scenarios include interme-

Table 3. Assessment points used by ROMN to interpret SEI data. Assessment points are listed in priority order.

Assessment Point	Definition
Management assessment point	Assessment point(s) along an SEI measure or metric response distribution as defined by or with park management. They may trigger management action (including additional sampling or research). They are often set to avoid undesirable ecosystem changes and enable more proactive management responses. They may represent a **desired condition**. They may be focused on a **historical or cultural context**. They can be more **narrative** in structure but an assessment point that cannot be quantified numerically may present challenges in the assessment process. Importantly, they may be one in the same as any of the assessment points given below (i.e., take the same value as an ecoregional assessment point if management in a park sees this as useful). Commonly used in the SEI protocol.
Criterion (standard, critical load)	Assessment point(s) established for decisions that have an explicit connection to a regulatory policy. These are usually based on human health or environmental effects and generally represent the lower limits of the acceptable range in a condition gradient (or the boundary of non-reference). They are typically established and implemented by states or other federal agencies with authority granted by legislation like the Clean Water Act. Note that in some rare cases criteria may take precedence over a management assessment point. Importantly, the NPS does not have regulatory authority over streams under the Clean Water Act within ROMN parks including the ability to formally evaluate or determine beneficial designated uses. Any comparisons we make to state or federal criteria do not include any official statement as to whether a beneficial designated use is attained. The Organic Act and various NPS Management Policies do require park management to maintain, rehabilitate, and perpetuate the inherent integrity of streams and their ecological processes and NPS will work with appropriate State and other Federal partners to do so. Currently uncommon in the SEI protocol. States and EPA are developing more criteria for stream monitoring and assessment.
Ecological threshold	Assessment points that define a boundary at which a small change in external factors cause a rapid or abrupt change in ecosystem condition. They can be complex, and fully developed and understood examples are somewhat rare. In some cases an assessment point might be classified as an ecological threshold without a complete understanding of the dynamics and implications of the estimated threshold value. Currently uncommon in the SEI protocol.
Ecoregion threshold	Assessment point(s) derived from reference condition distributions for a response as measured at reference sites within a park or broader ecoregion. Ecoregion thresholds may be defined in an arbitrary way (i.e., a percentile) or derived via models that estimate values within the distribution that connect ecological or management meaning to the assessment point(s). Data sources for empirically generating SEI reference condition distributions include other monitoring programs such as the National Streams Condition Assessment. See text for more details. Currently uncommon in the SEI protocol, but as comparable data become available this will change.
Baseline	Assessment point(s) derived from a sufficient (in a spatial or temporal sense) 'period of record' data set. Importantly, a baseline assessment point may not necessarily bound a reference condition distribution. Rather, because source data can often include complex mixes of reference and non-reference states, baselines should be considered only in a comparative sense. If an SEI result does not fall within a baseline, it may or may not suggest the SEI data are in reference condition. Currently uncommon in the SEI protocol.

diate assessment points that bound one to many condition ranges in between reference and non-reference. Importantly, the reference condition is a distribution of states shaped by a broad spectrum of natural drivers such as climate, geography or successional dynamics. However, the distribution of non-reference condition states is structured by both direct/indirect anthropogenic stress and natural variation. We develop a solution to deconvoluting these sources of variation in Schoolmaster et al. (2012, 2013a,b).

ROMN has elected to use two variants of reference condition in the SEI protocol depending on which park is being evaluated. First, for wilderness parks (GLAC, GRSA, ROMO), we use a minimally disturbed condition (MDC). Second, for GRKO and LIBI, nested within a more anthropogenic landscape, we use a least disturbed condition (LDC). We explain these further below.

The MDC describes a reference condition of streams in the absence of significant human

disturbance and is the best approximation or estimate of true ecological integrity. However, if an MDC is estimated empirically from reference sites, there are few if any streams truly or completely unaffected by the global influence of human activity. Therefore, minimal disturbances must be allowed to structure at least a small part of the variance in an MDC (e.g., atmospheric contaminants at levels below known effects). Similarly, several authors (i.e., Dufour et al. 2008) have argued that given pervasive and fast-paced shifts in natural systems driven by large-scale climate change, a pristine state with zero anthropogenic components simply does not exist. Therefore any method, even a conceptual approach, used to derive a putatively pristine reference condition distribution will or even should include some degree of human influence.

The LDC describes a reference condition of streams as the best available condition within a landscape. It is based on a set of explicit rules that allow a higher level of human activity to influence the reference distribution (Hughes et al. 1986; Hughes 1995; Bailey et al. 2004). These rules vary by region depending on the characteristics of the landscape and degree of human use. They are often developed iteratively with the goal of establishing the least amount of ambient human disturbance in the region under study that still might be considered to generate a fair reference condition distribution. Note that because the degree of human disturbance changes over time (i.e., as either degradation continues or restoration occurs), an LDC may vary with time - this must be carefully considered in assessing monitoring data.

Deriving Reference Conditions and Associated Assessment Points

Specific assessment points and reference condition distributions are developed as part of the analysis and reporting process in close consultation with ROMN park management and other collaborators. Where relevant assessment points do not exist, we estimate values using a variety of methods including models of disturbance and ecological response and derivation from reference sites in the parks' ecoregion. Methods and the actual values are presented in select Data Summary and all Comprehensive SEI reports.

Sample Design

Sample designs define locations in space for the collection of data, sample sizes required to meet monitoring objectives and the strategy for arraying samples across time (Olsen et al. 1999). SEI monitoring objectives require estimates of status and trend at, depending on the park, both park and site scales. It can be costly to simultaneously estimate status for an extensive resource (requiring a large sample size across a park) and long-term trend (which requires repeat visits through time). Therefore, we employ a suite of three sample designs that compromise among these competing objectives.

Our three designs include (1) "random" probabilistic surveys implemented in GLAC and ROMO, (2) targeted or hand-picked sentinel designs implemented in all ROMN parks where we do or will monitor streams, and (3) targeted or model-based gradient designs used in GLAC and ROMO. Table 4 and the following sections summarize these designs and present the SEI sample sites in each park. *Note that we include additional background and detail for GLAC designs simply because we present this park's designs first.*

Glacier National Park

GLAC has many streams and rivers that are among the park's most important ecological resources. We use all three design types in GLAC to monitor streams. Between 2007 and 2015 there were 49 sites established in the park that were sampled 196 times (119 base flow events with all methods; 96 partial events with a subset of methods). Of these 49 sites, 40 were survey sites, four were sentinel sites (one site was both a survey and a sentinel site) and six were gradient sites.

GLAC Survey

A distinguishing feature of the SEI protocol in GLAC is a survey design approach to locating most stream monitoring locations. This random selection allows valid statistical inference to the population of streams in the park, with known confidence, from a relatively small sample.

Target Population

The target population explicitly identifies the resource of interest for a survey and is the resource for which quantitative estimates are developed via sampling and associated analyses. It includes criteria for determining whether a resource unit is in or out of the target population at the time of a sample event. Our target population for the GLAC

Table 4. Summary of sample designs used in ROMN SEI monitoring. Event counts are for complete sample events with partial visits in parentheses.

	Sample Designs		
Park	**Survey**	**Sentinel**	**Gradient**
GLAC	40 survey sites sampled 75(8) times from 2007-2009	4 sentinel sites sampled 37(88) times from 2008-2015	6 gradient sites sampled 7(0) times from 2007-2009
ROMO	38 survey sites sampled 46(0) times from 2014-2016*	3 sentinel sites sampled 33(73) times from 2008-2015	10 gradient sites sampled 11(0) times from 2014-2015
GRKO	--	1 sentinel site sampled 7(21) times from 2008-2015	--
LIBI	--	1 sentinel site sampled 7(19) times from 2007-2015	--
GRSA	None as of publication	None as of publication	None as of publication

*If budget allows, additional survey sites and revisits to select sites in ROMO will continue in 2016. Future surveys will attempt to sample all survey sites in GLAC and ROMO.

survey includes all sampleable, perennial at time of the sample, non-artificial (i.e., no canals or ditches), flowing (i.e., no lakes or wetland) water within the park. "Sampleable" is defined based on accessibility and administrative access (see below). Whether a site is truly perennial at the time of a sample event is sometimes difficult to determine. Moreover, this can vary across years. Whether a sites is perennial is determined in part a priori by examining data on the flow characteristics of a site from any gauge that is on the stream or via expert knowledge about a site's history. However, it must also be based on characteristics evaluated at the site at the time of the event as detailed in SEI SOP 4: Verification of Site Status and Sample Reach Layout. In summary, a perennial stream has flowing water in at least 50% of the sample reach, well-defined channel structure, specific patterns in substrates and (usually) well defined riparian vegetation. If a site does not meet the designation as safely sampleable or perennial in any given survey it is not sampled and may be replaced by another site that is perennial in order to meet sample size requirements for any given survey (there are several consequences of this change in status to the design-based estimation process as will be detailed in the analysis SOPs). We also restrict the GLAC target population to a later summer index period (see below) when most stream communities are at their peak development and most likely stressed from lower water flow, higher water temperatures and the energetic costs of reproduction. Finally, target populations are specific to the approximately three- year periods of each survey (i.e., 2007 – 2009).

Sample Population

In general, the sample population is the actual resource sampled within a survey. It is usually a subset of the more conceptual target population. Differences between the two are caused by non-response errors for a certain portion of the target population. Non-response errors include safety or compliance denials (e.g., as created by steep slopes or a sensitive cultural resource), sample frame errors (e.g., an incorrectly mapped stream), damaged or lost samples, or incorrectly collected data. Quality control and proper training can deal with some of these issues and a proper survey design can help in maintaining valid samples; however, some errors that reduce the sample population from the target are unavoidable.

Sample Frame

A sample frame is the geospatial data from which a design algorithm selects potential sample locations. Frames are typically GIS layer(s) that represent the best available approximation of the target population and often integrate environmental variable(s) known or expected to drive patterns of variability in the target population within a defined region (e.g., stream size, hydrologic gradients, or management units). Sample frames incorporate all boundaries and all attributes used within the design (e.g., accessibility class).

For the GLAC survey design, we used a modified high resolution (1:24k) stream hydrography database from the USGS National Hydrography Database (NHD; USGS 2013a) clipped to the park boundary as our sample frame. Modifications to the NHD data vary by park but generally include enhanced line topography and attributes. NHD classifies streams as perennial/intermittent, canals, or "artificial paths' (which are centerlines of large rivers or lakes). Stream order (Strahler 1952) was added to the Glacier NHD data via an analysis conducted by ROMN. All intermittent (non-perennial) streams, canals, and artificial paths within lakes were removed from the frame leaving only perennial streams within the park (see Figure 12).

Incorporating Accessibility in the Design; Cost Surface Model

Sampling in the remote wilderness settings of parks like Glacier can be difficult. Steep, rugged terrain severely limits access to many canyon bottoms and high peaks. Expense, safety, and wilderness aesthetics issues prohibit the use of helicopter transport and mountaineering practices, such as rock climbing, to reach isolated sites. Additionally, most of the park is backcountry with limited trail access. A robust survey design deals with the costs of accessing remote sites

by adjusting the probability of selecting sites in high-cost areas to be low (or even zero), limiting the number of sites in these kinds of areas.

We incorporated accessibility into the SEI survey design via a cost surface (Figure 7). Cost surfaces are derived from a GIS model (Theobald et al. 2010) that generate a grid of the estimated time required to access any point in the park. The central algorithm of the model predicts traveling speed from the slope of the terrain being crossed, modified by a series of auxiliary variables including no or reduced cost routes (roads, trails), cost-free starting locations (i.e., a backcountry campsite) and land cover type (with coefficients by type for permeability). Impassable barriers such as streams (over a certain size), lakes and a slope threshold of 35 degrees are also included in the model. Final cost values (expressed as travel time; Figure 7) were created by summarizing cost in grid cells that intersected all stream reaches in the sample frame and classifying these values into nine cost classes using a natural breaks algorithm.

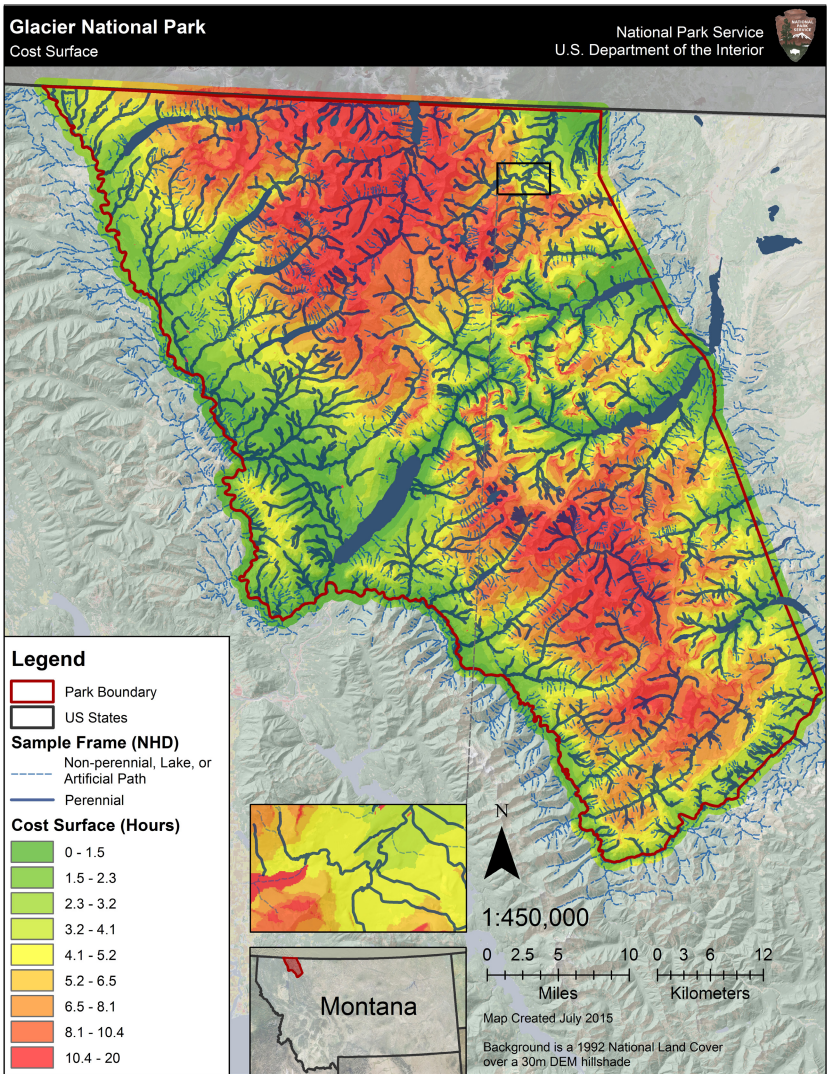


Figure 7. GLAC cost surface. Cost is in units of hours needed to access any point in the park and classified into nine classes with a natural break algorithm. Redder colors within the park represent higher cost.

Site Selection and Sample Size

We used a generalized random-tessellation stratified (GRTS) spatially-balanced algorithm to select sample sites (Stevens and Olsen 2004). The GRTS survey design approach is flexible, efficient, and statistically robust, and it can accommodate many of the difficulties commonly encountered in field sampling (e.g., sample frame errors, inaccessibility). It allows for proper inclusion of new sample sites to replace non-target sites (i.e., not a stream) or sites not sampleable due to safety or compliance issues, maintains spatial balance, and through a novel variance estimator, increases precision of status estimates (Stevens and Olsen 2003). These attributes help ensure that SEI GRTS survey designs are representative of the target population of interest, may be efficiently implemented, and allow unbiased inference from sampled sites to unsampled elements of the target population with known confidence (Hansen et al. 1983).

To provide future flexibility, the complete GRTS design selected a large number of candidate sites (395) across the park. A target sample size of 45 unique sites from this overall sample was derived following Cochran (1987; Equation 1). The methodology uses properties of proportions (as the statistic used to estimate status, e.g., "40% of resource is above an ecological threshold") and the required precision as measured by a 95% confidence interval around the estimate. The most conservative estimate of precision about a proportion is at a value of 0.50 (variance is maximized at this location in the distribution). Applying Equation 1, a sample size of 45 gives a precision of ±12% around a proportion based status estimate with an alpha of 0.05.

$$Precision = Z_{1-\propto} * 100 * \sqrt{\frac{p(1-p)}{n}}$$

Equation 1. Formula for estimating sample size (n) based on a proportion (p) and desired precision (Cochran 1987). Z=1.645 at a confidence (α) of 95%.

Estimating proportions is (statistically speaking), difficult, and confidence intervals around other statistics (like a mean) are generally smaller (Stevens and Olsen 2003). Cochran (1987) also assumes a simple random sample design. Stevens and Olsen (2003) show that GRTS designs and a novel variance estimator called the local neighborhood variance generate tighter precision around status estimates. Therefore, we expect our sample of 45 in GLAC to generate estimates around a proportion of 0.5 to be around ±9-10% (T. Olsen, pers. comm. September 2010).

The relatively simple method from Cochran (1987) is useful because sample size estimation does not require pilot data. Note that more detailed analyses are presented below that use data from the 2007 – 2009 survey to estimate the power to detect long-term trend at the park scale (as well as alternate estimates of precision around status estimates).

Allocating Samples to Stream Order and Cost Classes

The nine cost classes occurred unequally across stream orders, with a total count of 37 unique combinations. Sample size allocation to these order/cost class subpopulations was determined in an iterative fashion that reduced the range in inclusion probabilities (the chance that any site is included in the design, also known as sample weights) below a recommended maximum of around 30x (T. Olsen, pers. comm. October 2010). This was somewhat of a challenge given the large extent of stream length in the park in difficult to access first and second order streams. In most cases, if a stream order-cost class was on average beyond 10 hours of one way travel time it was not deemed a viable context for long-term monitoring and no samples were targeted to it. However, because the eventual effects on design weights also depends on the frequency of a stream order-cost class, as we iterated possible combinations of sample size allocation, higher/lower cost or more common or more rare stream orders were included. Completely restricting habitat from a survey design is usually not recommended as it excludes portions of the target population from the design permanently. However, because all final estimates were to be made to an extensive population of all streams in the park (ignoring order and cost) and no order was entirely excluded, we felt this was the most effective way to balance the costs of accessing remote areas yet include as much of the park's high cost small streams in SEI monitoring as possible (S. Urquhart pers. comm., March 2007). Finally, because we had no *a priori* interest in making estimates for any stream order and/or cost subpopulation, we ignored subpopulations when (1) replacing non-target or otherwise non-sampleable sites encountered in the field, and (2) in constructing final status estimates (in effect, deconvoluting cost and stream order from the final status estimates; T. Olsen, pers. comm. October 2010).

Realized 2007-2009 Sample Size

The total realized sample size was 40 during the initial GLAC SEI survey. The discrepancies from the target sample size of 45 were due to budget and other logistical limitations. Future surveys will rectify this by adding survey sites from the original draw (following GRTS design implementation rules). Note that select elements of the power analyses presented below are based on GLAC data (from 40 sites and are thus conservative for the intended sample size of 45).

Revisit Design: Modeling Power for Trend Detection and Precision of Status

A revisit design specifies sample size and how samples are allocated across time (MacDonald 2003). It describes the assignment of sites to panels (or sets of sites) and how they are visited (annually, multiple times within a year, every nth year, visited a set number of times then dropped, or visited on an alternating schedule through time). Panel designs can provide balanced replication of sites over time so that spatial and temporal effects may be modeled and trend may be accurately estimated.

In general, power analyses test the ability of a revisit design to detect an effect given that the effect actually exists (the probability of not making a Type-II error of failing to detect a real trend). Our approach also generates estimates of the precision of status

estimates as the standard error (SE) for a mean and how this varies over time. The power analyses presented here are primarily intended to help understand the implications of our 'affordable' revisit design and sample size as specified following Cochran (1987; see above). They provide a "reality check" on the ability to meet SEI monitoring objectives through an understanding of the confidence with which estimates of condition (status) and the ability to detect trends may be made. However, we do investigate select alternate revisit designs (with different sample sizes) to better understand tradeoffs among trend and status estimation and operational reality (useful especially should budget constraints change in the future). Importantly, we are not conducting (controversial) *post hoc* power analyses as we are not evaluating the ability to test any hypothesis using data from the 2007-2009 GLAC survey. Rather the GLAC data are treated as pilot data to estimate key parameters needed for the power models.

An overview of the five main steps in our power analysis approach and results for GLAC survey-based monitoring follows. We use methods developed in Urquhart et al. (1993, 1998), Larsen et al. (1995, 2001), and Urquhart and Kincaid (1999). We have applied versions of these tools in Manier et al. (2011) and an unpublished update to Schweiger et al. (2015b). We illustrate the application of these methods to sentinel site monitoring in sentinel design sections below.

Step 1: Developing linear models for select SEI responses and their components of variance

Our approach requires estimates of four sources of variation that can have effects on the ability to detect trend and on the precision of status estimates. These include variation due to year, stream site (also known as the population variance), the interaction between site and year and the residual (or all other unaccounted for variation). Each of these sources of variation influences the variance in the slope (or trend) of a response and this in turn affects the detection of trend by its influence on the precision with which trend may be estimated (Larsen et al. 2001). Equation 2 illustrates the relationship between variance in a slope and the multiple sources of variance as estimated via variance components (Larsen et al. 1995).

$$Var(slope) = \frac{\frac{\sigma^2_{\text{site}}}{N_{\text{site}}} + \sigma^2_{\text{year}} + \frac{\sigma^2_{\text{year*site}} + \frac{\sigma^2_{\text{residual}}}{N_{\text{revisit}}}}{N_{\text{site}}}}{\sum(Y_t - \tilde{Y})^2}$$

Equation 2. Components of variation as used in linear models. From Larsen et al. (1995).

To estimate variance components, we constructed linear mixed models using real data for six response measures from a diverse suite of indicator types (i.e., chemical, biological, habitat) collected from 2007-2009 or 2010 at GLAC survey sites. While all six are useful and important measures in an ecological or management sense, we focused on examples that were either highly variable (across time and/or space) or not (determined by relative values of coefficients of variation) and some of the measures used for power models may not be ones we would focus reporting on. Finally, we selected measures that had enough replicates across years and sites such that all (or most) sources of variation could in fact be estimated. The distribution of each response was examined graphically and with a Shapiro test and transformed as needed to meet assumptions of residual error homoscedasticity and normal distribution.

A set of covariates were selected for possible inclusion in the models based on our expert opinion on the ecological or geophysical gradient that might covary with one or more of the six responses. These included site elevation, watershed size, stream order and instantaneous stream flow. For biological responses we also included percent of substrate as sand or finer and a measure of relative bed stability (Kaufmann et al. 1999). Model selection (or which covariates to include or not) was conducted largely by evaluating the ecological significance and individual contribution of each possible covariate to a model via Akaike Information Criteria (AIC) and (to a lesser degree) a covariate's p-value in the ANOVA table. We also used forward and backwards stepwise regression with AIC and a Bayesian Information Criterion (BIC) as the selection crite-

ria when choices based on our ecological knowledge or of each possible individual covariate were ambiguous (Gurka 2006; Schabenburger 2007). The distribution of each covariate was examined as above and transformed as needed.

Following recommendations from S. Urquhart and L. Starcevich (pers. comm. 2007 and 2013, respectively) Type III linear mixed ANOVA models were formed from the covariates obtained in the ad hoc or stepwise model selection approach and site, year, and site-by-year interaction as random effects (Table 5). In select cases, a Restricted Maximum Likelihood (REML) model was required to estimate the random terms in a model given patterns in sample distribution across the main effects. To test the significance of the main effects, error terms were constructed via Satterthwaite's method of denominator synthesis (1946) that contained all the same sources of random variation except for the variation of the respective effect of interest. Note that the GLAC data set is unbalanced across within and among year revisits. This does not change the models but it does complicate the calculations (Larsen et al. 2001). Finally, the models do not incorporate design properties (sample weights; see Kincaid et al. 2004). However, sample weights are not likely correlated with any trend in our response measures (Urquhart and Kincaid 1999) and so this likely has a marginal effect on the final models. All analysis was done in R (R Development Core Team 2014) using the lmerTest library and in Statistica version 12 (StatSoft, Inc. 2013).

Step 2: Determining the 'affordable total sample size'

Ultimately SEI sample size is a function of the available resources in the ROMN program (Britten et al. 2007). This is allocated among all our protocols and parks in a way that maximizes the information return ("science") per unit dollar. This interaction of budget and required precision was used to help set *a priori* total unique sample size within the GLAC survey (an N of **45**, see above). Nevertheless, as noted above, power analysis is still very important (maybe even more so) in determining the consequences of the affordable sample size and it can allow fine tuning of complex panel structures that optimize capacity within budget constraints.

Step 3: Allocating sample size into panel designs

We developed our realized or "implemented" revisit design (Table 6) based on a balance between operational constraints and the power of the design to detect trend and provide precise status estimates. There is an almost limitless range of possible panel designs for a given sample size and no existing optimization approach, so the choice of panel designs to compare to our implemented revisit structure was somewhat ad hoc (and we purposely kept this simple and concise). We picked two designs for comparison that were within our budget, had similar annual and total unique sample effort over a three- to four-year period, but were different in terms of how they allocated samples across panels (but importantly, neither would currently "work" in the overall ROMN program). These include a partially augmented, serially alternating panel design ("design 2") and a simple annual revisit panel (all sites revisited every year; "design 3"). Our implemented panel design is somewhat unique but is similar in some respects to the partially augmented, serially alternating design but with a complete break in sample effort for five years (note that sentinel site monitoring occurs every year in GLAC). This allows ROMN effort to be focused on other large surveys in other protocols and/or parks during these years. The statistical and monitoring literature suggests that partially augmented, serially alternating designs offer the best compromise between estimating status and trend (Urquhart et al. 1993, 1998; Larsen et al. 1995, 2001). It is a linked or connected approach (in an experimental design sense) because some plots are measured in consecutive years and revisit panels overlap with other panels. Connectivity provides the possibility of always estimating year effects, if present, as well as annual means and differences or contrasts among them. The third design has a single panel of sites revisited annually and is intended largely as a baseline for comparison. It is not possible to have the same exact annual and total unique sample sizes in all designs so we used sample effort

Table 5. Linear mixed models used to derive variance components for power analyses. See text for details. Covariates selected via expert opinion and stepwise model selection. Site, year, and site-by-year interaction treated as random effects. Degrees of freedom (df) were constructed following Satterthwaite's method (1946). AIC = Akaike Information Criteria; Coef. Var. = coefficients of variation.

Parameter	Descriptive Summary and Model Details	Source	df	Sum of Squares	Mean Squares	p	Variance Component	%
Total Suspended Sediment (mg/l)	• Figure code: ln_TSS • log transformed • AIC = 186.70 • Adjusted R^2 = 0.75 • Mean = 1.0* • Coef. Var. = 222.08 • No covariates • Type III ANOVA	site	39	105.04	2.69	0.00	0.593	28.2
		year	2	8.33	4.17	0.00	0.139	6.6
		site:year	15	30.53	2.04	0.00	0.882	41.9
		residuals	23	11.34	0.49		0.493	23.4
Specific Conductance (us/cm)	• Figure code: ln_SC • log transformed • AIC = -99.30 • Adjusted R^2 = 0.96 • Mean = 1.0* • Coef. Var. = 57.59 • 1 covariate • Type III ANOVA	discharge	1	0.62	0.62	0.00		
		site	36	23.33	0.65	0.00	0.307	95.6
		year	3	0.03	0.01	0.53	0.000	~0.0
		site:year	13	0.21	0.02	0.32	0.002	0.7
		residuals	17	0.22	0.01		0.013	4.0
Chlorophyll a (mg/m²)	• Figure code: ln_chlor a • log transformed • AIC = 257.24 • Adjusted R^2 = 0.11 • Mean = 1.0* • Coef. Var. = 165.56 • 1 covariate • REML	stream order	1	6.75	6.75	0.01		
		site	38	36.68	0.97	0.33	0.057	3.3
		year	2	3.60	1.80	0.13	0.385	22.3
		site:year	15	8.14	0.54	0.81	0.000	~0.0
		residuals	31	25.65	0.83		1.285	74.4
Mountain MMI (0-100, no units)	• Figure code: mtn index • not transformed • AIC = 419.42 • Adjusted R^2 = 0.89 • Mean = 70.36 • Coef. Var. = 17.32 • 1 covariate • Type III ANOVA	percent sand+fines	1	571.40	571.44	0.00		
		site	39	10012.80	256.74	0.00	144.275	76.4
		year	2	398.30	199.15	0.00	18.837	9.9
		site:year	13	391.80	30.14	0.17	7.359	3.9
		residuals	16	293.20	18.32		18.324	9.7

*All means are from the first year of the period of record unless response is log transformed when 1.0 is used by default (Larsen et al. 1995).

Table 5. Linear mixed models used to derive variance components for power analyses. See text for details. Covariates selected via expert opinion and stepwise model selection. Site, year, and site-by-year interaction treated as random effects. Degrees of freedom (df) were constructed following Satterthwaite's method (1946). AIC = Akaike Information Criteria; Coef. Var. = coefficients of variation, cont.

Parameter	Descriptive Summary and Model Details	Source	df	Sum of Squares	Mean Squares	p	Variance Component	%
Diatom Sediment Increasers (%)	• Figure code: ln_sediment increasers • log transformed • AIC = 419.42 • Adjusted R2 = 0.89 • Mean = 1.0* • Coef. Var. = 149.78 • 3 covariates • REML	percent sand+fines	1	1.53	1.53	0.15		
		relative bed stability	1	0.66	0.66	0.32		
		discharge	1	2.45	2.45	0.07		
		site	32	68.74	2.15	0.02	0.677	44.3
		year	2	0.35	0.18	0.76	0.031	2.0
		site:year	13	14.53	1.12	0.17	0.162	10.6
		residuals	10	6.14	0.61		0.658	43.1
Percent Residual Pools (%)	• Figure code: prp100 • log transformed • AIC = -219.43 • Adjusted R2 = 0.94 • Mean = 1.0* • Coef. Var. = 19.71 • 1 covariate • Type III ANOVA	in_q_cms	1	1.65	1.65	0.00		
		site	39	1.24	0.03	0.00	0.015	70.8
		year	2	0.08	0.04	0.00	0.004	17.0
		site:year	13	0.03	0.00	0.53	0.000	0.0
		residuals	18	0.05	0.00		0.003	12.6

*All means are from the first year of the period of record unless response is log transformed when 1.0 is used by default (Larsen et al. 1995).

Table 6a. Evaluated revisit designs for GLAC SEI survey.* Implemented GLAC survey design revisit structure.

Panel/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Survey Panel 1	15	3	3								15	3	3		
Survey Panel 2		15	3	3								15	3	3	
Survey Panel 3			15	3	3								15	3	3
Within season revisits	3	3	3	3	3						3	3	3	3	3
Unique N	15	30	45												
Total Sample Events	18	21	24	9	6	0	0	0	0	0	18	21	24	9	6
Cumulative 4 year effort	18	49	73	81											

Table 6b. Evaluated revisit designs for GLAC SEI survey.* Design 2: partially augmented, serially alternating design.

Panel/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Survey Panel 1	15				11				11				11		
Survey Panel 2		11				11				11				11	
Survey Panel 3			11				11				11				11
Survey Panel 4				11				11				11			
Survey Panel 5	4	4			4	4			4	4			4	4	
Survey Panel 6		4	4			4	4			4	4			4	4
Survey Panel 7			4	4			4	4			4	4			4
Survey Panel 8				4				4				4			
Within season revisits	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Unique N	15	30	45	60											
Total Sample Events	17	21	21	21	17	21	21	21	17	21	21	21	17	21	21
Cumulative 4 year effort	17	38	59	80											

Table 6c. Evaluated revisit designs for GLAC SEI survey.* Design 3: annual revisit design.

Panel/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Survey Panel 1	17	17	17	17	13	13	13	13	13	13	13	13	13	13	13
Within season revisits	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Unique N	17														
Total Sample Events	20	20	20	20	16	16	16	16	16	16	16	16	16	16	16
Cumulative 4 year effort	20	40	60	80											

*Values in the cells are expected sample sizes within each panel. Values in cells are sample sizes. Empty cells have no sample events. Within season and across year revisits are of the same sites (i.e., site revisited twice in each of 2007, 2008, and 2009). As detailed in the text, the realized sample sizes in the first implementation of the survey (2007-2009) was only 40. Future years will adjust sample effort to the values shown here. The designs repeat indefinitely through time.

over a four-year period as the limiting factor and required it to be approximately equal across all designs. Our power analysis and (at least in the initial stages of) implementation also include within season revisits. These are important for better understanding the impacts of seasonality and other sources of variation as well as fine tuning our index period (see below). These sample events may be dropped (or increased) as we learn more about temporal patterns and sources of variation in SEI data.

Step 4: Setting the detectable trend

The minimally detectable difference (MDD) is the smallest population-level trend in a response that can be detected by a given design. It is a key parameter in power analysis (and monitoring in general). We express the MDD as a percentage or an annualized rate of change as the power models we use (see below) require that the slope of the trend be in units of percent change per unit time, rather than as a change in concentration per unit of time (Stoddard et al. 1996). An annual rate gives the long term proportional change (e.g., 30% change from Year 1 to Year 10) on an annual basis. It is equivalent to the slope of a regression line in a log-linear model of a logged response versus time.

Ideally, an MDD would be derived as an estimated population-level trend in a response from pilot data or be provided as explicit and numeric guidance from park management. However, because we did not have either of these we used a hypothetical MDD of 2%. This value is likely significant enough to be of interest to land managers, but conservative enough to provide resolution of possible differences in proposed revisit designs. A 2% annualized trend equates to an 18% total increase over 10 years, or for example, an increase in the measured percent of Glacier's stream beds covered in fine substrates from about 6% (as measured in 2007; Schweiger et al. 2015a) to 7.2% in 2017 (which would then exceed a tolerance level of around 7% for many species of macroinvertebrates; Bryce et al. 2010). Designs capable of detecting small trends will do better in detecting larger trends in the same resource, so power should be improved when rates of change are more rapid. We show this by also modeling an annualized rate of 5%. Note that at this rate, the fine sediments level seen in 2007 would increase above the threshold in around 5 years. Moreover, because we do not have real or management-based MDD, we consider only increasing annualized change (a positive trend) as this is a conservative strategy. Gerrodette (1987) shows that a decreasing trend is easier to detect than an increasing value.

Step 5: Estimating power for trend and standard error for status

The derivation of the equations for power to detect trend are presented in detail in Urquhart et al. (1993, 1998) and Larsen et al. (1995, 2001). We modify R functions developed and provided by T. Kincaid from the U. S. Environmental Protection Agency (EPA) and B. Gitzen from South Dakota State University. The R code is available from ROMN upon request.

Parameters in the power analysis include the variance components as detailed in Table 5, an initial mean value (set to 1 when the response measures is log transformed, otherwise the mean for all sample events in year one of sampling), a matrix of sample events (the panel or revisit design under test), and two correlation coefficients. These correlations include a site correlation across years and a year autocorrelation. Their value can impact power estimates, but we do not have sufficient data to effectively estimate these parameters using GLAC 2007-2009 survey data. Urquhart et al. (1993, 1998) and Stoddard et al. (1996) suggest that the value of the year autocorrelation is expected to be 0 (or at least less than 0.25) and spatial autocorrelation to be around 1.0 for most environmental response measures. We follow these guidelines and set these parameters 0 and 1 respectively (Larsen et al. 1995).

We lack a test to statistically compare power for trend or standard error for status across different runs of the models. Therefore, we compare output based on the number of years needed to develop an 80% power for trend detection (this value is an established threshold (Jackson et al. 2000) and may also be thought of as equivalent to a probability of a false negative result of 20%). There is

no analogous criterion for standard error of status, so we qualitatively evaluate standard error curves relative to one another. For both power and standard error, values are absolute (meaning that there is no statistical error around them) – facilitating simple comparisons like ours.

Results

The literature behind our approach has a rich discussion of how each parameter can impact power for trend and design decisions. We restrict the comparisons presented here to a small subset of the parameters in the models, focusing on the aspects that we either have control over (i.e., panel design, response measures used) or that we do not, yet can have a strong impact on results (i.e., total unique sample size). In each case, we hold constant all other parameters such that differences are only due to the parameter in question. Our goal is to present the key implications of our design choice at GLAC so most discussion centers on the implemented revisit design.

Effect of response measure

Figure 8 presents power for trend and SE for status curves for select response measures using the implemented panel design in GLAC and a hypothetical MDD of 2%. All other parameters were estimated from GLAC pilot data as shown in Table 5 or held constant across responses.

Three responses (specific conductance, the percent residual pools per 100m and the mountain MMI index for macroinvertebrates) show a similar pattern in the ability to detect a trend with the threshold of 0.80 being crossed around the 11th or 12th year of monitoring (or during the second survey implementation in GLAC planned for around 2017). Specific conductance and residual pools also show a consistent small standard error. We exclude the standard error curve for the mountain MMI index for macroinvertebrates because it had non-logged starting mean values and thus a different range (but the temporal pattern is more or less the same as the responses shown). Three responses (middle Rockies sediment diatom increaser index, chlorophyll a and total suspended sediment) show a similar but very different pattern than the three measures above in the ability to detect a trend with the threshold of 0.80 either never being crossed or not until around the 30th year of monitoring. Chlorophyll a and total suspended sediment initially have large standard errors around the mean (again with a starting value of 1.0). After around 20 years of monitoring these settle to values between 0.3 and 0.4. As above, we exclude the standard error curve for the middle Rockies sediment diatom increaser index because they had non-logged starting mean values and thus a different range (but similar pattern).

These results show the negative impacts of a higher year or site-by-year interaction variance component and how responses that have high site variance components reach acceptable power quicker (0.8 in less than 10 years) and have consistently low standard errors (Table 5). The choice of what to measure at SEI sites is determined by many aspects other than power for trend detection and precision of estimates of status. However, if a response measure has poor statistical attributes it may be a less-effective indicator.

Effect of panel design

Panel structure details (when to sample sites, revisit sites, and sample size to a lesser degree) are the primary elements of revisit design choice under our control. Figure 9 presents example power for trend and SE for status curves for three designs (Table 6) using two responses – one variable (chlorophyll a) and one non-variable (specific conductance), an MDD of 2% and all other parameters as in Table 5 or held constant.

Differences for power for trend and standard error for status using the non-variable specific conductance were small among the three revisit designs analyzed. The implemented design reached (almost) 80% power marginally quicker than the other two designs during the 4th year of monitoring (vs the 5th or 6th for designs 2 or 3). All three gave standard errors less than 0.2 from nearly the beginning of monitoring. Power for trend and standard error for status using the highly variable chlorophyll a response were also similar but very different than for specific conductance. No design reached

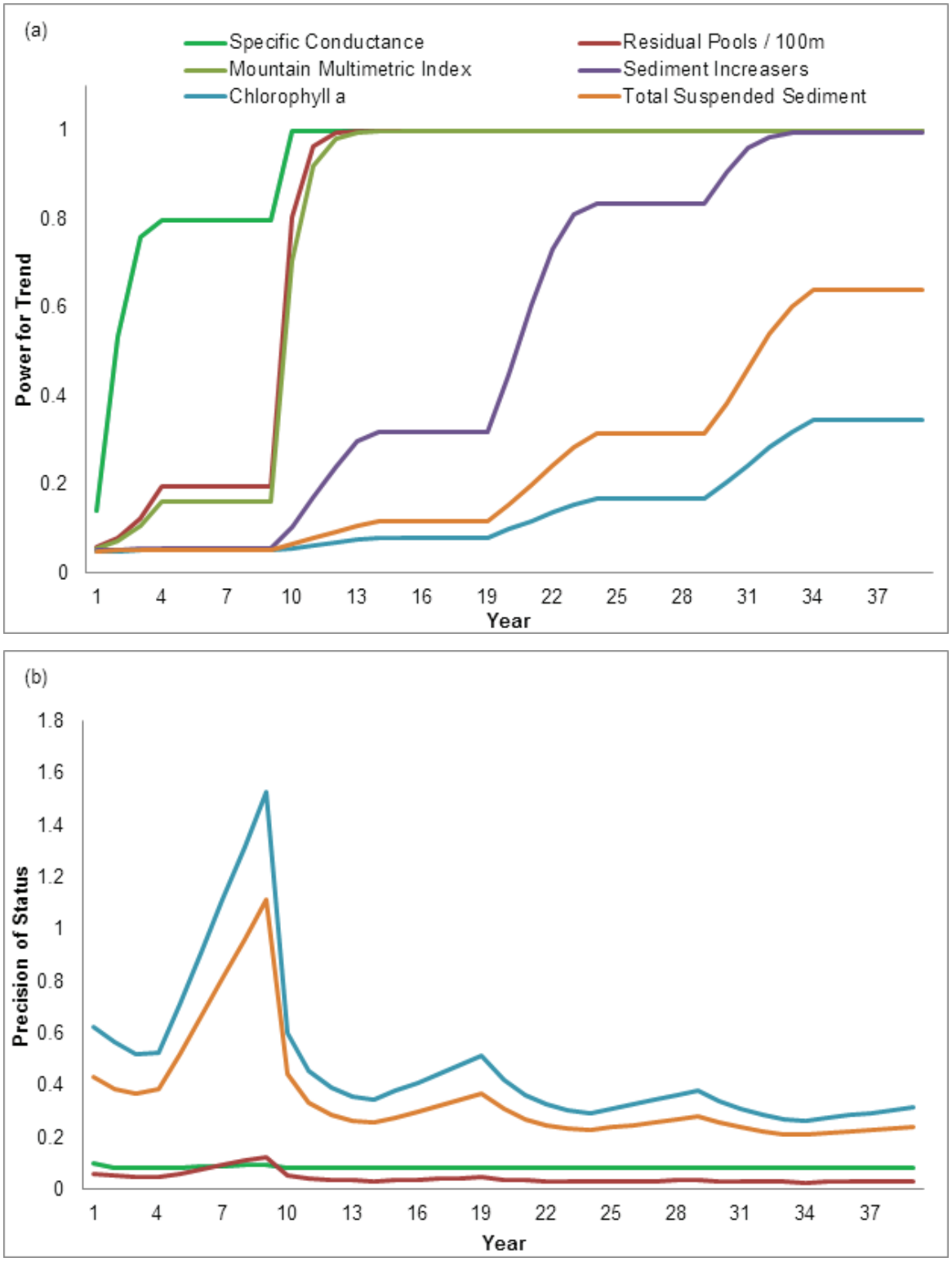


Figure 8. Effect of response measure on (a) power to detect a trend of 2% and (b) on the standard error of the mean (status). Models use the GLAC SEI implemented revisit structure and a sample size of 45. Variance components for each response are in Table 5. Standard error curves for the Mountain Multimetric Index and Sediment Increasers are not shown in (b) given a different scale of response due to different initial values. Note that the legend for both panels is in (a).

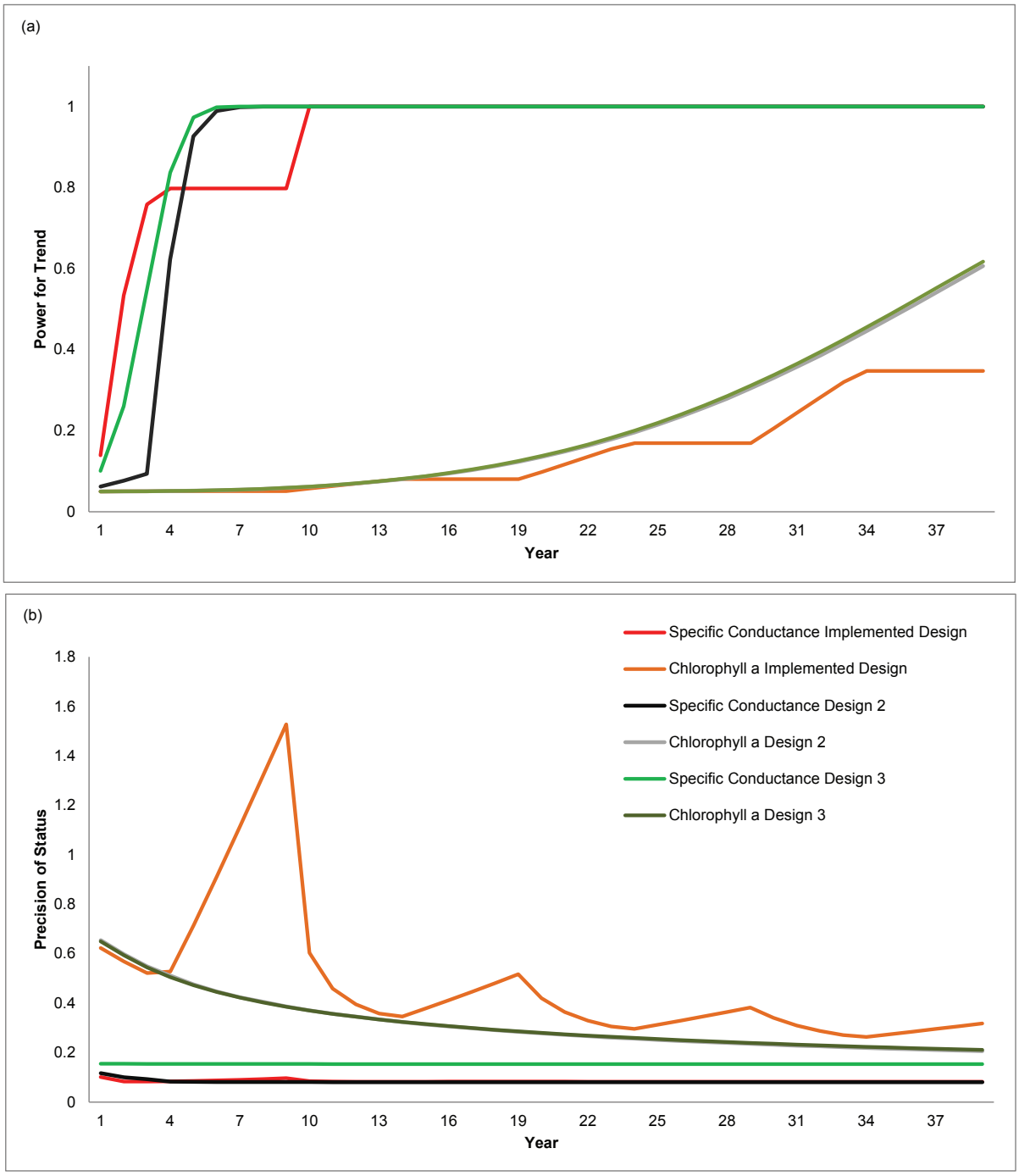


Figure 9. Effect of panel design on (a) power to detect a trend of 2% and (b) on the standard error of a mean (status). Models use a variable (chlorophyll a) and non-variable (specific conductance) response. Variance components for each response are in Table 5. Note that the legend for both panels is in (b).

80% power within 40 years, with the implemented design having the slowest accumulation. All three needed over 30 years for SE values to fall below 0.4.

Again these results clearly show the importance and negative impacts of a higher year or site-by-year interaction variance component and how responses that have high percentages of their variance structure at the site level reach acceptable power quicker and have consistently low standard errors (Table 5). However, the implemented design does have marginally better accumulation of power to detect trend in a response with a high proportion of its total variance within the year variance component.

Effect of total sample size

Figure 10 presents power for trend and SE for status curves using sample size at the affordable level and at twice this, the implemented panel design, two example responses using two responses – one variable (middle Rockies sediment diatom increaser index) and one non-variable (mountain MMI index for macroinvertebrates), an MDD of 2% and all other parameters as in Table 5 or held constant.

In general, differences in power for trend and standard error of status were surprisingly small with a 2x increase in sample size above the affordable size (especially with the mountain MMI index which is less variable than the diatom sediment increaser index, see Table 5). Sample size is intuitively the aspect of a design that would seem to be 'the most important' in determining its qualities. Yet, in long-term monitoring design sample size is neither a simple design specification to determine nor often the most important (above a certain minimum N). As shown in other results here, 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 if a revisit, whether it is within a sampling interval (year) or an inter-annual revisit, and (3) whether status or trend is more important.

Effect of minimal detectable difference

Figure 11 presents power for trend curves using an MDD of 2% and 5%, the implemented panel design – one variable (middle Rockies sediment diatom increaser index) and one non-variable (percent residual pools), sample size at the affordable level and with all other parameters as in Table 5 or held constant.

The magnitude of the effect size has is one of the largest impacts on ability to detect trend (but no effect on the SE around status estimates). For both percent residual pools and the middle Rockies sediment diatom increaser index, a 5% MDD has markedly higher power than a 2% MDD. The higher MDD allows an 80% power in about half the number of years as the 2% MDD. Unfortunately, we do not know what the true trend in these (or any SEI response) is as our current data set is not long enough to derive a meaningful realized trend estimate at the population level nor has the park or ROMN developed meaningful effect sizes for SEI responses. However the 2% MDD is likely conservative and our estimates of how well our implemented design will do is reasonable.

Summary of capabilities of implemented GLAC survey revisit design

The details of the implemented GLAC survey revisit design were driven largely by ROMN operational reality. However, the results of our modeling suggest that depending on the response (and the magnitude of its site and year variance components), our implemented sample design will be capable of detecting reasonable MDD (2%) within (in a few cases) the first survey period or often during the second survey. Status estimates should also be reasonably precise in a relatively short time and on par with the a priori and more general precision estimates developed following Cochran (1987). However, some responses will take several surveys (separated by 10 years) to accrue sufficient power to detect a trend of 2%. If the trend in a response is steeper (5%) it is easier to detect.

Neither the partially augmented, serially alternating structure (Design 2) nor an annual revisit (Design 3) performed meaningfully better with responses with high relative site variance components. No design (con-

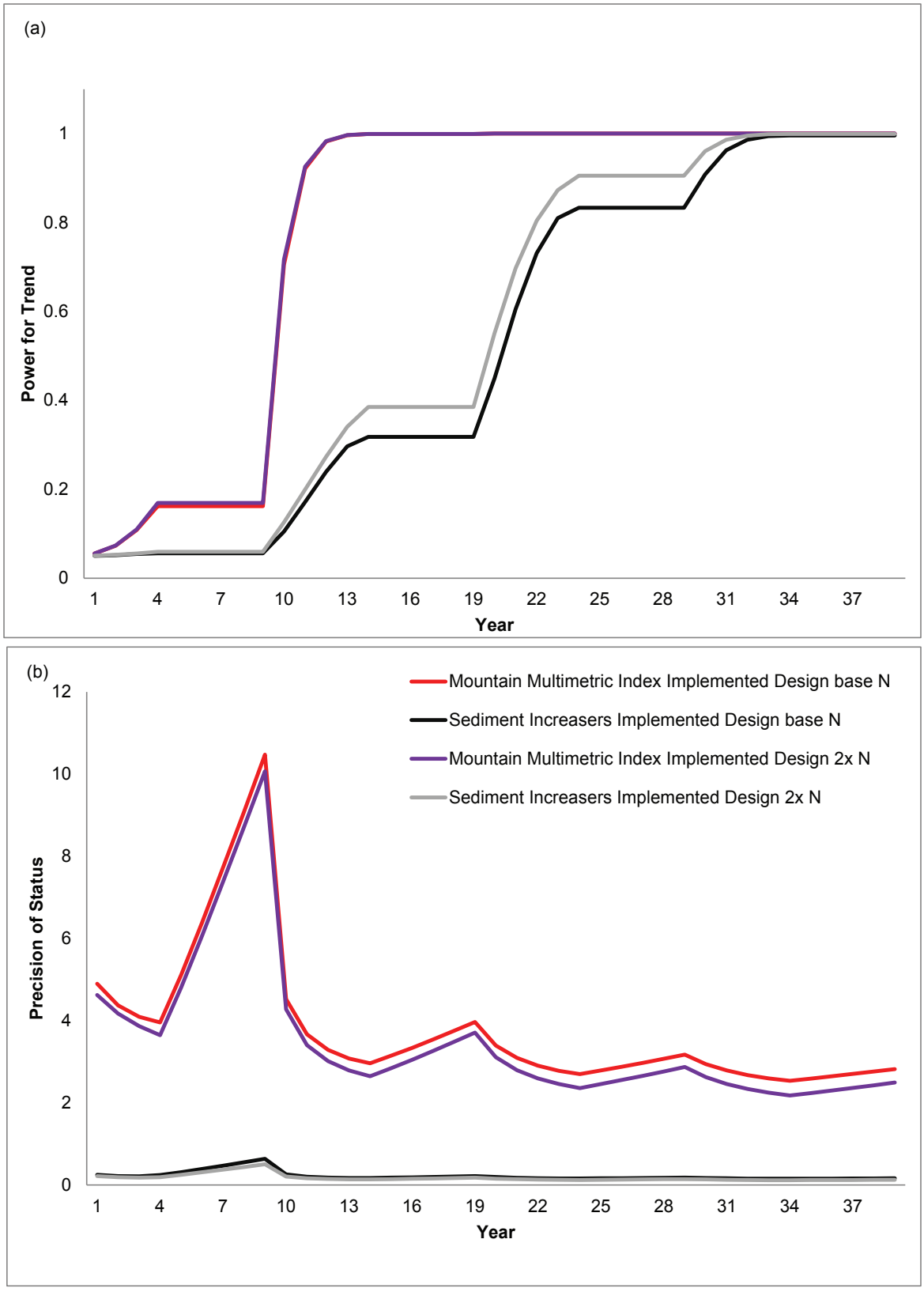


Figure 10. Effect of sample size on (a) power to detect a trend of 2% and (b) on the standard error of a mean (status). Models use example biological response variables. Variance components for each response are in Table 5. Note that the large differences in SE between the two sets of curves are due to different initial values in the response measures. Note that the legend for both panels is in (b).

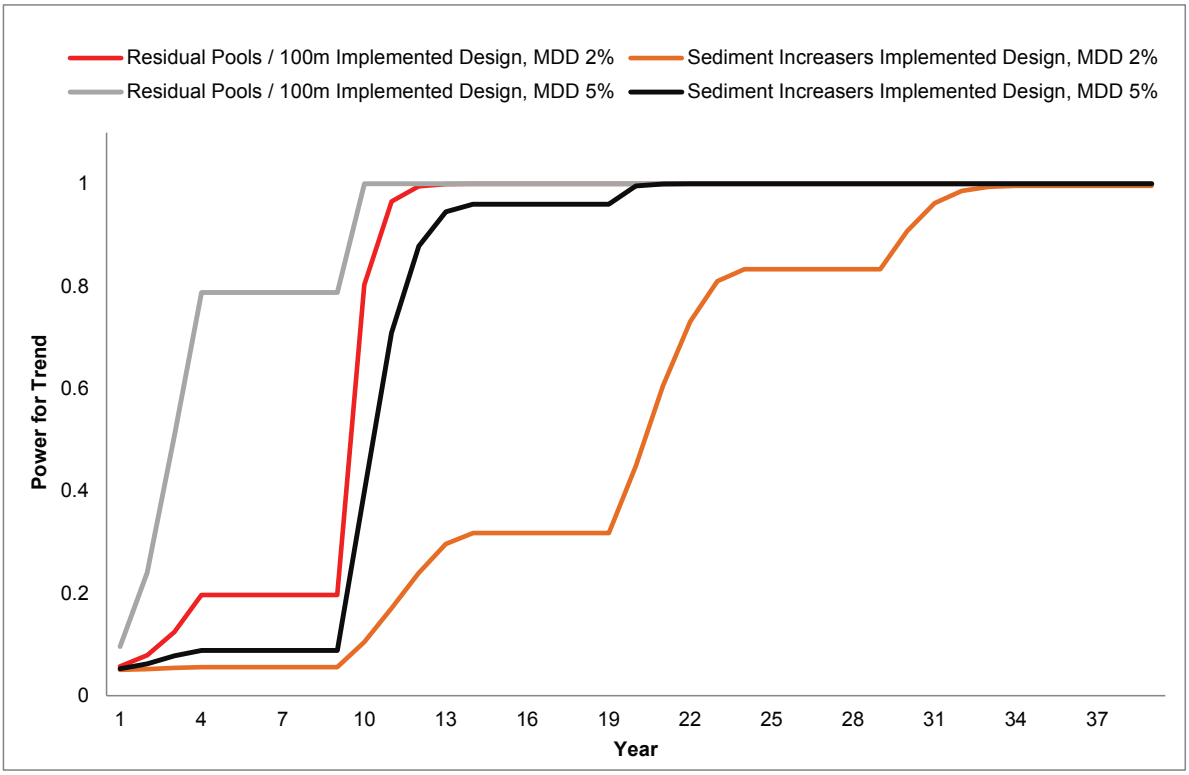


Figure 11. Effect of the minimal detectable difference (MDD) on power to detect a trend using the implemented revisit design and two example response variables. Variance components for each response are in Table 5. Note that changes in the MDD have no effect on the precision of SE estimates and this figure is omitted.

strained by a total sample size the network might afford) was capable of detecting trend in responses with high year or interaction variance. Unfortunately, when a year effect exists the only solution for the estimation of trend is to continue monitoring over the long term. If year effect exists, 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. 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. However, year effects can be circumvented or controlled through 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 can improve power within each subpopulation due to the decreased variance across all sites. If year effects are likely to be important, identifying and monitoring possible controlling factors become as important as monitoring the core responses.

GLAC Survey Sites

Table 7 and Figure 12 present SEI survey sites sampled in GLAC during 2007-2009.

GLAC Sentinel

GLAC sentinel monitoring uses a different design and analysis approach than the survey to allocate sites across space and events across time. The most important distinguishing features are (1) an expert opinion or judgment-based selection of stream site locations, (2) multiple samples at each site per year (summarized in the Methods Section below), and (3) no intention to make inference beyond the site or immediate stream reach without complex modeling or assumptions.

Target and Sample Populations

The target population for sentinel site monitoring is the stream site (which for some responses is a variable length stream reach,

Table 7. GLAC SEI survey sites and sample events from 2007 to 2015 (partial sample events are in parentheses). If budget allows, the GLAC survey size will be increased to 45 in future years.

		Sample Events by Year														
Site ID	Stream Name	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	Lat.	Long.	Stream Order	Catch. Area (km^2)	Elev. (m)
SEI-002	North Fork Flathead River	--	1(0)	--	--	--	--	--	--	--	1(0)	48.874	-114.369	5	2075.8	1134
SEI-003	Belly River	--	1(0)	--	--	--	--	--	--	--	1(0)	48.868	-113.726	4	28.0	1497
SEI-004	Nyack Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.544	-113.560	4	62.0	1338
SEI-005	Quartz Creek	2(0)	2(0)	2(0)	--	--	--	--	--	--	6(0)	48.750	-114.184	4	122.8	1171
SEI-006	Starvation Creek	2(0)	2(0)	2(0)	--	--	--	--	--	--	6(0)	48.973	-114.357	3	37.5	1339
SEI-007	Mineral Creek	--	2(0)	1(0)	--	--	--	--	--	--	3(0)	48.763	-113.821	4	54.5	1180
SEI-008	Lincoln Creek Tributary	--	1(0)	--	--	--	--	--	--	--	1(0)	48.535	-113.879	3	11.1	1114
SEI-009	North Fork Flathead River	--	1(0)	--	--	--	--	--	--	--	1(0)	48.652	-114.171	6	3362.6	1034
SEI-010	Boundary Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.992	-114.018	1	5.1	1548
SEI-011	Hudson Bay Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.627	-113.522	3	17.1	1535
SEI-012	Middle Fork Flathead River	--	1(0)	1(0)	--	--	--	--	--	--	2(0)	48.320	-113.626	6	1606.1	1110
SEI-013	N. Fork Flathead River G. Rim	0(2)	1(4)	--	--	--	--	--	--	--	1(6)	48.485	-114.102	6	4040.3	955
SEI-014	Belly River	--	2(0)	1(0)	--	--	--	--	--	--	3(0)	48.930	-113.715	5	141.8	1423
SEI-015	Appistoki Creek	--	2(0)	2(0)	--	--	--	--	--	--	4(0)	48.484	-113.355	2	6.1	1627
SEI-016	Ole Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.389	-113.381	3	21.7	1601
SEI-017	Bowman Lake Tributary	1(0)	--	--	--	--	--	--	--	--	1(0)	48.832	-114.174	2	3.4	1416
SEI-018	Bowman Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.800	-114.241	4	132.2	1161
SEI-020	Thompson Creek Tributary	--	1(0)	--	--	--	--	--	--	--	1(0)	48.564	-113.628	3	9.7	1268
SEI-022*	N. Fork Flathead R. Border	1(0)	2(0)	1(2)	0(4)	1(3)	1(3)	1(3)	1(3)	1(3)	9(21)	48.994	-114.466	5	1125.2	1207
SEI-023	McDonald Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.700	-113.813	5	206.7	1056
SEI-025	Howe Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.576	-114.007	2	9.6	1103
SEI-027	Red Eagle Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.667	-113.494	4	93.5	1418

*Site was initially selected by the survey design but then also used as a sentinel site.

Table 7. GLAC SEI survey sites and sample events from 2007 to 2015 (partial sample events are in parentheses). If budget allows, the GLAC survey size will be increased to 45 in future years, cont.

		Sample Events by Year														
Site ID	Stream Name	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	Lat.	Long.	Stream Order	Catch. Area (km^2)	Elev. (m)
SEI-032	Railroad Creek Tributary	--	1(00	--	--	--	--	--	--	--	1(0)	43.396	-113.255	2	13.4	1496
SEI-033	Waterton River	--	--	1(0)	--	--	--	--	--	--	1(0)	48.863	-113.916	3	29.1	1445
SEI-034	Akokala Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.852	-114.287	4	70.7	1200
SEI-037	McGee Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.629	-114.080	3	24.0	1095
SEI-041	Camas Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.636	-113.980	3	66.3	1157
SEI-049	Dutch Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.691	-113.994	2	22.5	1274
SEI-091	South Fork Cut Bank Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.583	-113.348	1	1.8	1755
SEI-093	Rubideau Creek Tributary	--	1(0)	--	--	--	--	--	--	--	1(0)	48.499	-114.018	1	1.4	995
SEI-095	Saint Mary River	--	1(0)	--	--	--	--	--	--	--	1(0)	48.662	-113.640	4	59.0	1409
SEI-097	Waterton River	--	--	1(0)	--	--	--	--	--	--	1(0)	48.855	-113.929	3	23.9	1461
SEI-098	Parke Creek	2(0)	2(0)	2(0)	--	--	--	--	--	--	6(0)	48.870	-114.264	3	24.1	1289
SEI-100	McDonald Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.645	-113.850	5	278.7	996
SEI-101	Camas Creek	2(0)	2(0)	2(0)	--	--	--	--	--	--	6(0)	48.632	-114.106	4	198.6	1054
SEI-104	Middle Fork Flathead River	--	1(0)	--	--	--	--	--	--	--	1(0)	48.372	-113.673	6	1694.7	1092
SEI-105	Camas Creek	2(0)	2(0)	1(0)	--	--	--	--	--	--	5(0)	48.669	-113.926	3	43.6	1194
SEI-108	Nyack Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.457	-113.755	4	202.0	1026
SEI-109	Apgar Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.532	-114.001	3	9.4	978
SEI-129	Quartz Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.817	-114.164	4	66.4	1280

*Site was initially selected by the survey design but then also used as a sentinel site.

see below). In sentinel designs, the target population is usually functionally the same as the sample population as there is often no difference in the actual array of sites sampled from what was expected *a priori*. As noted in several places in this protocol this creates a very different inferential context than with a survey design that has a series of consequences on analyses and interpretation of sentinel site data.

Sample Frame

Because sentinel designs do not rely on an algorithm (like GRTS) to select locations, a sample frame is not technically needed. However, GIS data similar (or identical) to SEI survey design sample frames may be used to locate sentinel sites. Using the same frame for both survey and sentinel designs is advantageous in linking the two design forms.

Site Selection

ROMN did not use any sort of model or computer-based algorithm to locate GLAC sentinel stream sites. Rather, sentinel sites were located subjectively based on a suite of criteria developed by ROMN staff, collaborators (especially scientists who have been working in GLAC streams for decades) and GLAC staff. Most importantly, sentinel sites are located based on an expectation that the site is important and useful for understanding site specific patterns in stream condition over time. This can be based on previous monitoring at a site - often sentinel sites are co-located with historic or ongoing monitoring or research on streams (especially with USGS or similar stream discharge gauges). While by definition I&M monitoring is not to be used for short-term effectiveness monitoring (Fancy et al. 2009), often sentinel sites can be placed in locations where park restoration activities have or will occur (as these sites often have known long-term issues such as metal or sedimentation pollution, changes in temperature regimes that can be important and/or need to be better understood). Finally, we locate sentinel sites in places that are more accessible given the frequency at which we collect data in sentinel sites (but recognize that this can lead to a biased condition given higher visitor usage or proximity to localized stressors).

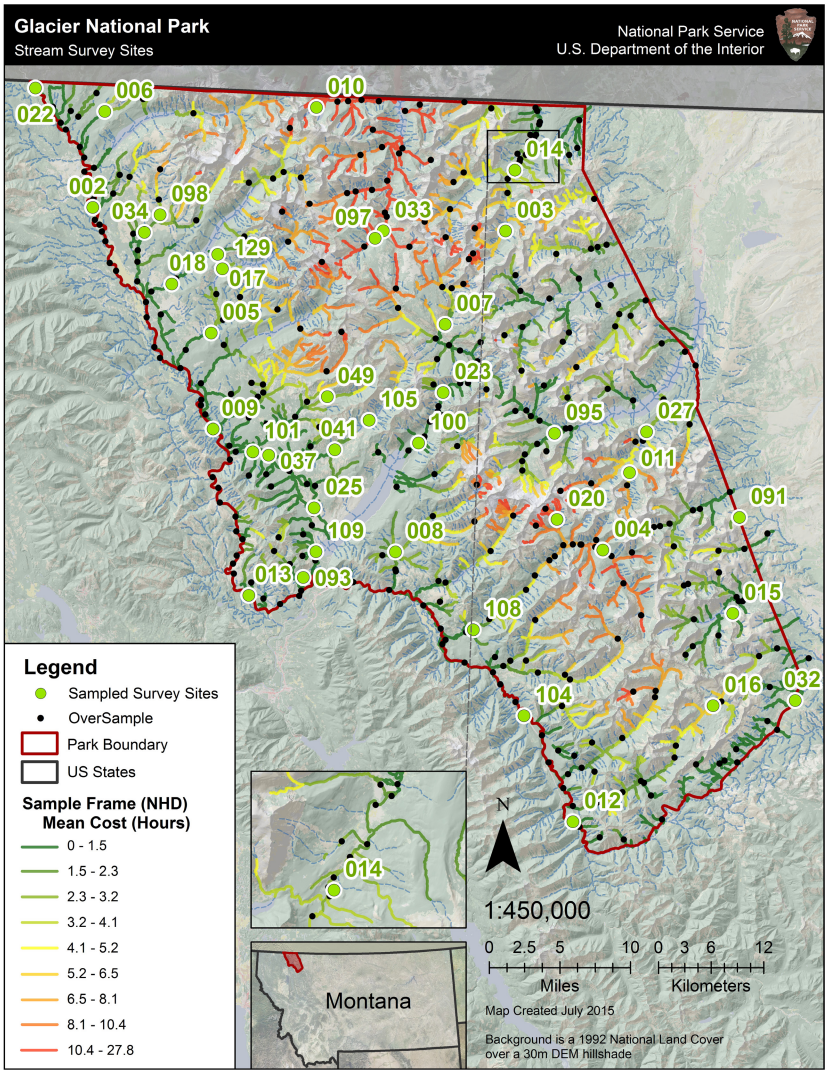


Figure 12. GLAC SEI survey sites and sample frame. Sites sampled in 2007-2009 are labeled. Small black dots are oversample sites. The sample frame stream layer is color coded by cost - redder streams have higher access times.

In summary, key criteria used to select SEI sentinel sites include the following (not in any priority order):

1. Allocation of sites across important stream types in GLAC such as larger floodplain rivers, higher elevation small streams, mid-order steeper gradient streams in constrained valleys, and mid-order broader valley bottom/meandering streams
2. Allocation of sites across geographic classes (elevation, topography, park region)
3. Representativeness of a site for stream type(s) and/or geographic context (For example, is a particular alpine stream typical in its hydrology, substrates, etc.?)
4. Uniqueness - somewhat in contrast to criteria three - of a complex (For example, is a particular stream ecologically important

or interesting in a way that will help the long term monitoring and management of streams in GLAC in general?)

5. Use of existing stream monitoring locations (especially with established stream gauges)
6. Management importance or utility of a stream for the park (i.e., as a restoration site, usefulness for visitor interpretation, etc.)

Revisit Design: Modeling Power for Trend Detection and Precision of Status Estimates

The methods we use to estimate power to detect a trend and precision of status estimates at GLAC sentinel sites are conceptually similar to those applied to survey sites (above). However, the models are simpler and the options for possible revisit designs more constrained (primarily because there is only one site per sentinel location).

As with survey sites, the power analyses presented here are primarily intended to help understand the implications of the 'affordable' and implemented revisit design and sample size in GLAC. We do investigate select alternate revisit designs to better understand tradeoffs among trend and status estimation and operational reality. The five main steps in the approach are more or less the same as for the survey design models and we only summarize meaningful differences here.

Step 1: Developing linear models for select responses and their components of variance

Following Larsen et al. (1995) two general components of a response's variation at a single sentinel site are important: 1) year to-year differences in condition (a year effect), and 2) the combination of within-year natural variability and measurement error (residual variation). Equation 3 gives these components of variance and their relationship with variation in sentinel site trend. Several publications present various techniques for trend detection at single sites (e.g., see reviews in Berryman et al. 1988). Most of these methods do not deal with the fundamental limits to trend detection capability that arise from year and residual sources of variation. However, power to detect trend at single sites is still constrained by the limits placed by these variance components.

$$Var(\hat{\beta}) = \frac{{\sigma^2}_{\text{annual}} + \left(\frac{{\sigma^2}_{\text{index}}}{r}\right)}{\sum(X_i - \bar{X})^2}$$

Equation 3. Components of variation as used in single site linear models. From Larsen et al. (1995).

We again constructed linear mixed models to estimate these two variance components. However, for sentinel sites we used water chemistry data from USGS gauges associated with the North Fork of the Flathead and the Swiftcurrent Creek sentinel sites (for other sentinel sites in GLAC without gauges we will conduct power models when we have sufficient SEI data and/or we must assume that patterns are more or less the same at these locations). While the USGS data were not generated by the SEI protocol and do not include biological or physical habitat responses, they are high quality data, are based on a protocol comparable to SEI, and most importantly have a sufficient period of record to allow a more meaningful estimate of variance components (especially the year effect that would be difficult to estimate with the limited SEI data available at time of publication). There are also published trends (Mast 2007; Mills et al. 2012) in these responses that we connect our power results to (see below). To bracket possible scenarios we used responses that were variable or not. We included discharge as a covariate in all models. The period of record and sample density within a year varied with response. In the rare cases where USGS samples occurred in winter and/or more than four times a year we did not subset data to spring, summer and fall months (as sampled in the SEI protocol). We felt this was acceptable as obtaining the best estimates of each variance component was more important than mirroring the SEI revisit design (but our power models do use the implemented revisit design as the default, see below). The distribution of variables was examined graphically and with a Shapiro test prior to modeling and transformed as needed to meet assumptions of residual error homoscedasticity and normal distribu-

tion. All other details are as described above for the GLAC survey models.

Step 2: Determining the 'affordable total sample size'

As with the GLAC survey, SEI sample size is a function of the available resources in the ROMN program (Britten et al. 2007). For sentinel sites this was a total of four sample events per year, with three partial water and sediment chemistry only events and at base flow when all methods were conducted (see below).

Step 3: Allocating sample size into panel designs

The implemented sentinel revisit design was simple with four events per year sampled on the limbs of the hydrograph during late spring to early fall. The choice of panel designs to compare to this was limited to monthly year round sampling (N = 12).

Step 4: Setting the detectable trend

The minimally detectable difference (MDD) is the smallest population level trend that can be detected by a given design. While robust trend estimates are available for several USGS water chemistry parameters at two GLAC sentinel sites (Mast 2007; Mills et al. 2012) the nonparametric form of the slope (known as a Sen slope) and their units of concentration per unit time do not allow direct incorporation as an MDD in our power analyses. Therefore we again use 2% as a default MDD and compare results to a 5% trend.

However, if the data used for the USGS trend models meet all assumptions of linear regression (and generally they do), the nonparametric Sen slope trends are unbiased estimators of a parametric regression slope (Wang and Yu 2005). This allows qualitative comparison of the trend in a parameter at our sentinel sites as in Mast (2007) or Mills et al. (2012) to a slope from a linear fit of a decreasing (or increasing) series of data points at the MDD rate (2%, 5%) as the dependent variable and year as the predictor. The initial value for the response is the mean concentration in the first year of the data set. While somewhat inexact, this allows interpretation of our power models in the context of an estimated real trend in a parameter at a site.

Step 5: Estimating power for trend and standard error for status

The derivation of the equations for power to detect trend are presented in detail in Urquhart et al. (1993, 1998) and Larsen et al. (1995, 2001). Parameters in the power analysis include a year and residual variance components (Table 8), an initial mean value (set to 1 when the response measure is log transformed, otherwise the mean for all sample events in year one of sampling), a matrix of sample events (the panel design under test), and site and year correlation coefficients. The site correlation across years defaults to 0.0 (there is only one site). The year autocorrelation is directly estimated from the USGS data with a lag value of 1.

Results

We focus our interpretation here on the effect of variation across years in a response, the role of a conservative (2%) and less so (5%) MDD, and the contrast between the implemented revisit design versus a design with monthly samples. In each case, we hold constant all other parameters such that differences are only due to the parameter in question. Our goal is to present the key implications of our sentinel design choice at GLAC so most discussion centers on the implemented revisit design.

Figure 13 and Figure 14 presents power for trend and SE for status curves for select responses at the North Fork and Swiftcurrent sites, respectively. In general, patterns are similar to those seen in survey site power models. First, the absolute magnitude of the year variance component matters, with sulfate consistently showing slower accumulation of power and higher SE than the other responses at either site. Second, revisit design matters, with monthly samples always giving quicker accumulation of power to detect a trend and lower SE at both sites, for all responses and for both MDD. However, the effect of an increase in sample size to 12 per year over the implemented design of four samples per year did not matter as much as patterns in the other parameters we examined. Note that monthly samples do have

Table 8. Linear mixed models used to derive year variance components for sentinel site power analyses. Year treated as a random effect. Degrees of freedom (df) were constructed following Satterthwaite's method (1946). Coef. Var. = coefficients of variation from untransformed data. A mean of 1.0 is used for log transformed responses by default (Larsen et al. 1995). A Sen slope trend in mg/l/year from published results is shown where available with slope from a linear fit between year and an increasing or decreasing series at 2% shown for comparison. POR = Period of record, var. comp. = variance component.

Parameter	Descriptive Summary and Model Details	Source	df	Sum of Squares	Mean Squares	p	Variance Component	%
North Fork								
Sulfate* (mg/l)	• Log transformed • Mean = 1 • Adjusted R^2 = 0.42 • Coef. Var. = 35.09 • Year autocor. = 0.70 • Type III ANOVA	discharge	1	5.84	5.84	0.00		
		year	27	7.68	0.28	0.00	0.031	23.98
		residual	139	13.82	0.10		0.099	76.02
Specific Cond. (us/cm)**	• Log transformed • Mean = 1 • Adjusted R^2 = 0.71 • Coef. Var. = 16.48 • Year autocor. = 0.41 • Type III ANOVA	discharge	1	5.88	5.88	0.00		
		year	35	1.40	0.04	0.00	0.003	25.18
		residual	290	2.90	0.01		0.010	74.82
Swiftcurrent								
Specific Cond.* (us/cm)**	• Not transformed • Mean = 1 • Adjusted R^2 = 0.40 • Coef. Var. = 18.54 • Year autocor. = 0.08 • Type III ANOVA	discharge	1	0.11	0.11	0.00		
		year	8	0.21	0.03	0.00	0.002	32.49
		residual	131	0.42	0.00		0.003	67.51
Nitrite+Nitrate** (mg/l)**	• Log transformed • Mean = 1 • Adjusted R^2 =0.31 • Coef. Var. = 62.77 • Year autocor. = 0.88 • Type III ANOVA	discharge	1	0.06	0.06	0.00		
		year	8	0.09	0.01	0.00	0.001	16.73
		residual	131	0.36	0.00		0.003	83.27

*From Mills et al. (2012): trend mg/l/y = -0.076 (-2% MDD ~ -0.071), p = 0.003, POR for trend and var. comp.: 1974-1993.

** From Mills et al. (2012): trend mg/l/y = 0.194 (2% MDD ~ 8.21), p = 0.095, POR for trend and var. comp.: 1974-2008.

*** From Mast (2007): trend mg/l/y = -0.56 (-2% MDD ~ -1.37), p = 0.07, POR for trend and var. comp.: 1982-2005.

**** No trend available, used hypothetical trend of 2%, POR for var. comp.: 2001-2011.

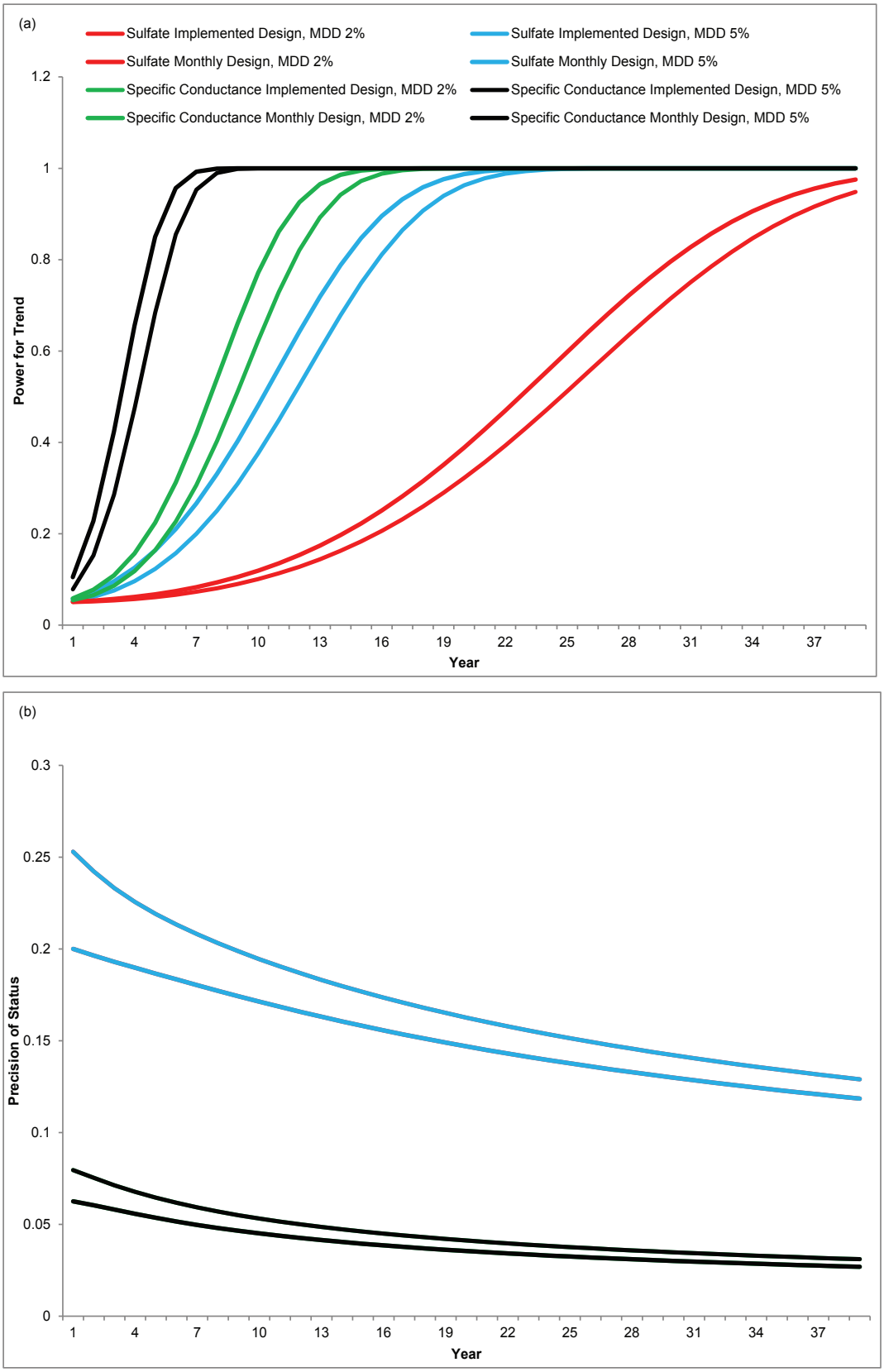


Figure 13. Effect of response measure, revisit design and the minimal detectable difference (MDD; 2% or 5%) on (a) power to detect the trend and (b) the standard error of the mean (status) at the N. Fork of the Flathead sentinel site (see Table 8). The "Implemented" design is 4 samples per year (in the spring through fall). The "Monthly" design is 12 samples per year. Note that because MDD has no effect on standard error some curves overlap in panel b and are not visible. Note that the legend for both panels is in (a).

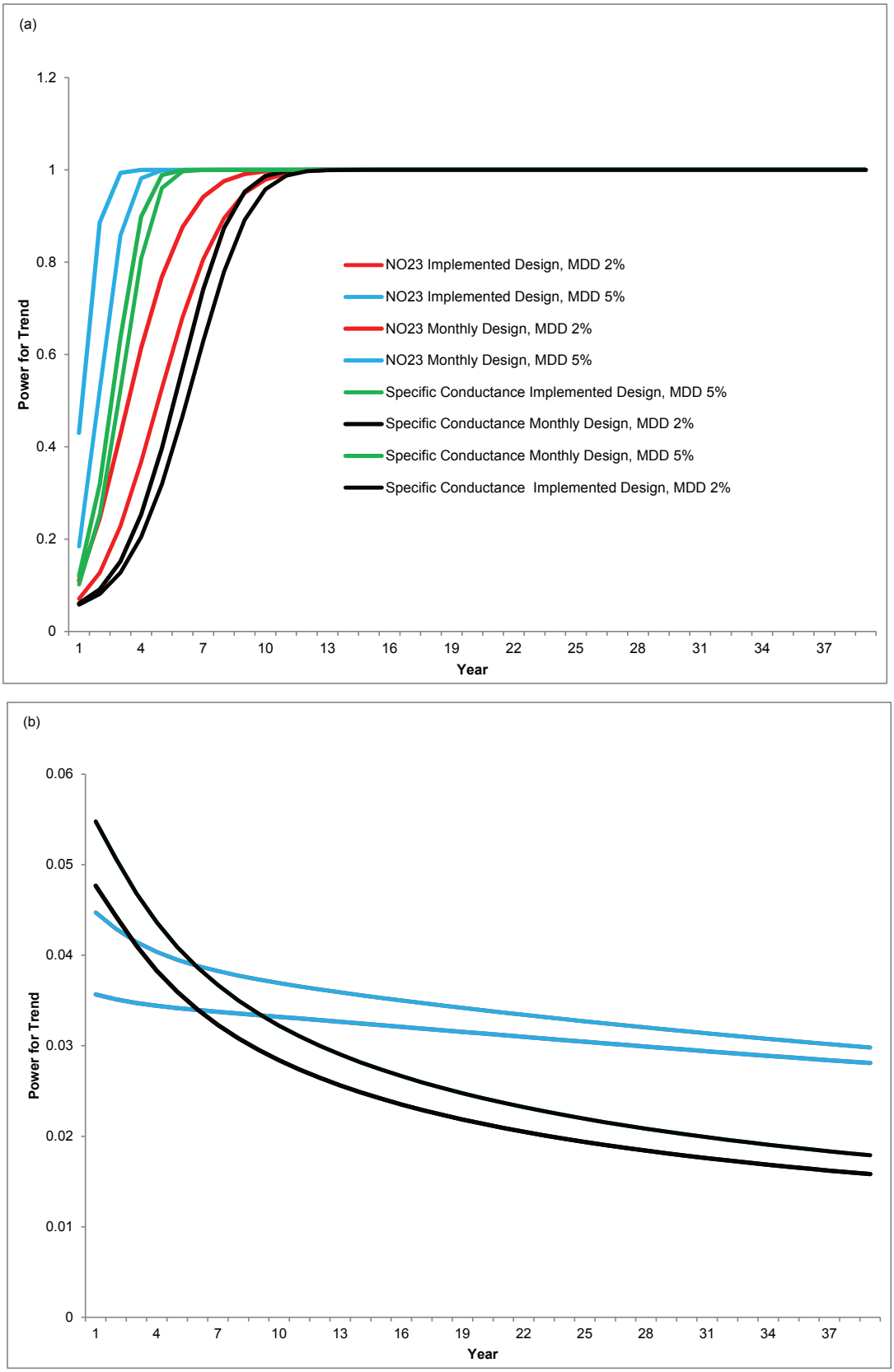


Figure 14. Effect of response measure, revisit design and the minimal detectable difference (MDD; 2% or 5%) on (a) power to detect the trend and (b) the standard error of the mean (status) at the Swiftcurrent sentinel site (see Table 8). The "Implemented" design is 4 samples per year (in the spring through fall). The "Monthly" design is 12 samples per year. Note that because MDD has no effect on standard error some curves overlap in panel b and are not visible. Note that the legend for both panels is in (a).

benefits not discussed here such as better estimates of seasonal patterns. Third, power to detect an MDD of 5% accrues more quickly, especially for sulfate in the North Fork.

In contrast with the survey power models shown above we have some sense of how the annualized percent change MDD used in our power models compare to estimated trends for select parameters. A 2% annual decrease in sulfate corresponds to a slope of -0.071 – very close to the Sen slope estimated in Mills et al. (2012). This suggests that our power model using 2% as the MDD approximates a real pattern in sulfate at the North Fork site from 1974 to 1993.In contrast, we are likely not estimating a real trend in specific conductance at this location as a 2% MDD is approximately 42 times greater than the Sen slope measured by Mills et al. (2012). Finally, a 2% MDD for specific conductance at Swiftcurrent is approximately three times greater than the estimated value in Mast (2007), suggesting our expectation for power and SE are closer to estimated trend values for this response and site from 1982 to 2005.

As with our survey in GLAC, the details of the implemented GLAC sentinel revisit design were driven largely by operational reality. Nevertheless, the results of our modeling suggest that depending on the response used (and the magnitude of its year variance components), our implemented revisit design at GLAC sentinel sites may be capable of detecting hypothetical MDD (2%) in as soon as three years but in some cases this may take up to around 30 years. Status estimates should be reasonably precise in a relatively short time for parameters with lower yearly variation. However, if trends are in fact much lower than an annualized rate of 2% per year our results may be optimistic. In general our results show the negative impacts of a higher year variance component where the only real solution is to extend the monitoring period (i.e., wait for more years to pass).

GLAC Sentinel Sites

Sentinel sites in GLAC include the North Fork of the Flathead at the park border, Ole Creek in the southwestern corner of the park, Reynolds Creek at the top of Logan Pass, and Swiftcurrent Creek on the east side of the park (Figures 15 and 16; Table 9).

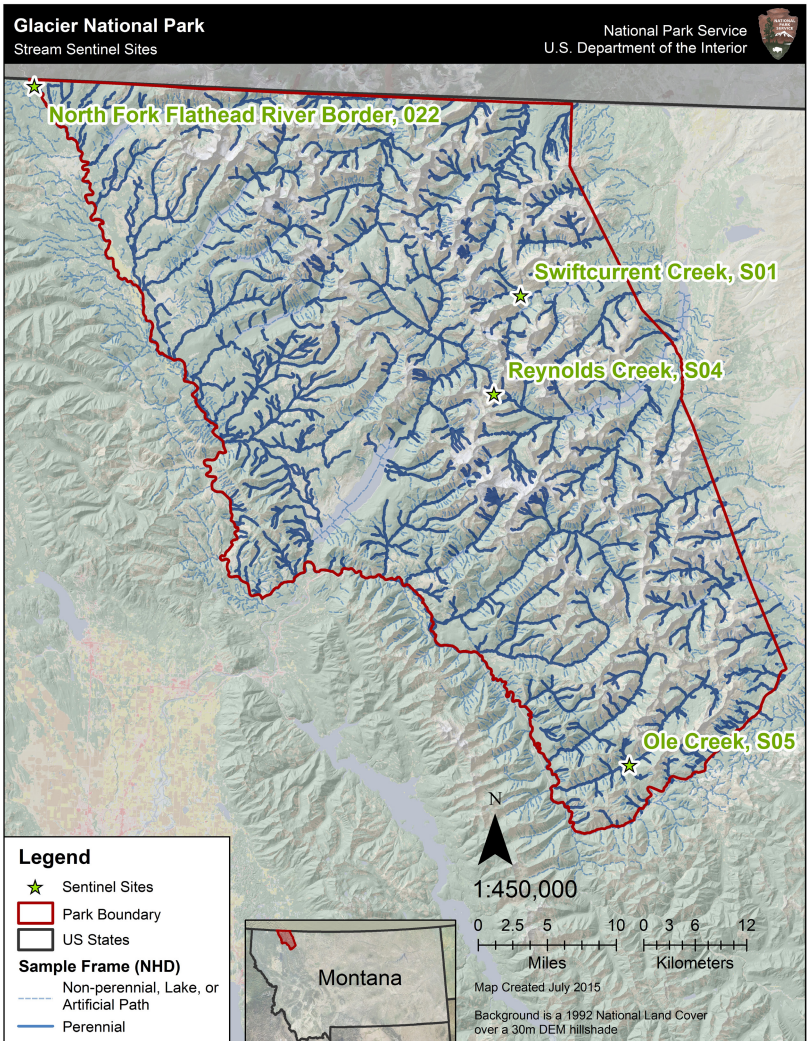


Figure 15. GLAC SEI sentinel sites. Figure 16 shows each site at a finer scale.

GLAC Gradient

The GLAC gradient design is similar to the sentinel design in several aspects including (1) an expert opinion or judgment-based selection of stream sites, and (2) no intention to make inference beyond the sites or the sentinel stream complex. However, the criteria used to locate gradient sites differ from those used to identify sentinel sites. Data from gradient sites are primarily used to characterize stream condition at the extremes of anthropogenic and natural drivers that influence stream ecology. Therefore, sites are targeted to streams we expect to be under stress or in pristine condition relative to the complete population of streams in the park.

Site Selection

Gradient sites were located subjectively based on a suite of criteria developed by ROMN staff, collaborators (especially

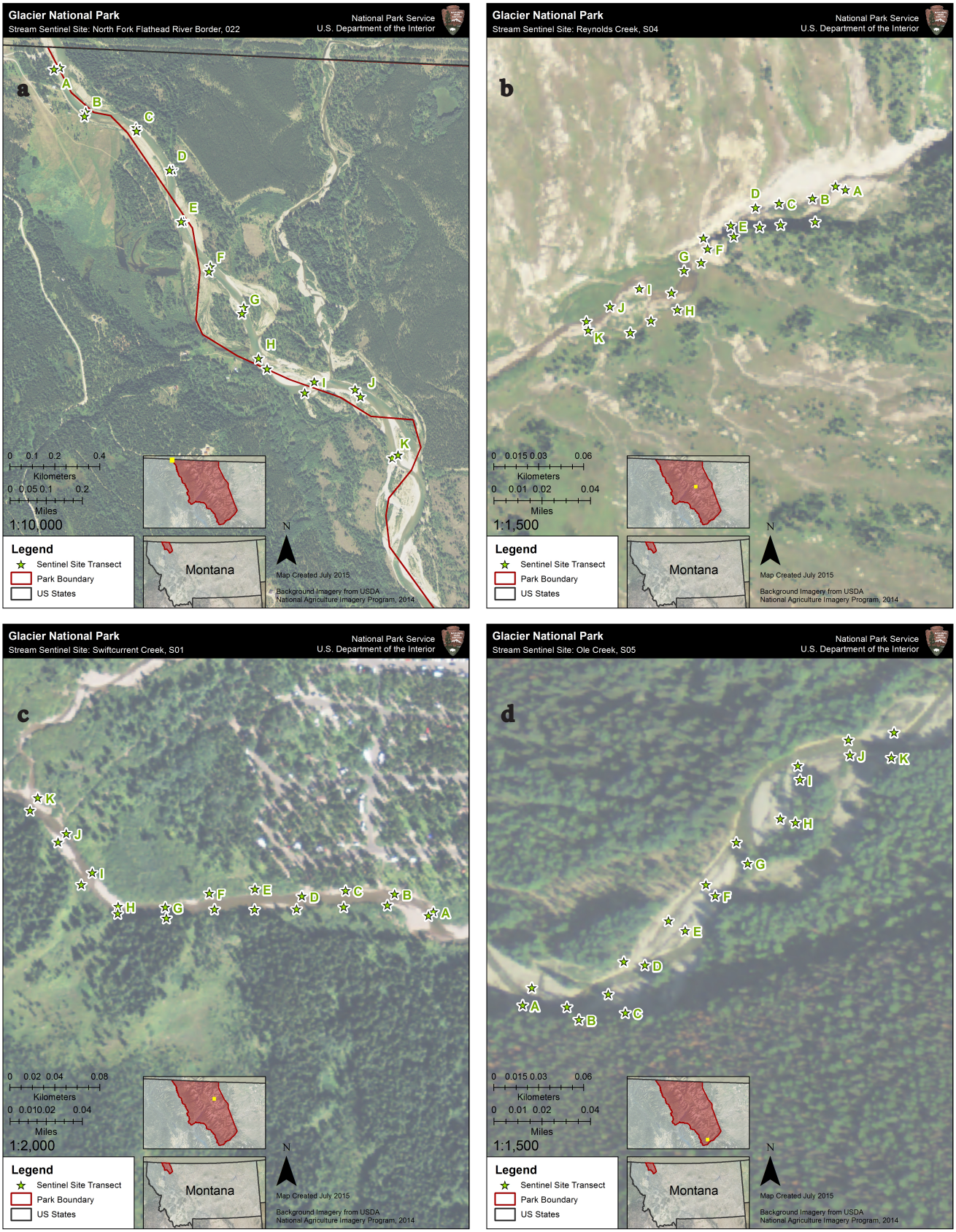


Figure 16. GLAC SEI sentinel sites: a) North Fork of the Flathead (Site 022, also a survey site), b) Reynolds Creek (site S04), c) Swiftcurrent Creek (site S01), and d) Ole Creek (Site S05).

Table 9. GLAC SEI sentinel sites and sample events from 2007 to 2015 (partial sample events are in parentheses).

Site ID	Stream Name	Sample Events by Year										Lat.	Long.	Stream Order	Catch. Area (km^2)	Elev. (m)
		2007	2008	2009	2010	2011	2012	2013	2014	2015	Total					
SEI-022*	N. Fork Flathead R. Border	1(0)	2(0)	1(2)	0(4)	1(3)	1(3)	1(3)	1(3)	1(3)	9(21)	48.994	-114.466	5	1125.2	1207
SEI-S05	Ole Creek	--	--	1(1)	1(3)	1(3)	1(3)	1(3)	1(3)	1(3)	7(19)	48.795	-113.680	4	21.5	1505
SEI-S01	Swiftcurrent Creek	1(0)	1(0)	1(2)	1(3)	1(3)	1(3)	1(3)	1(3)	1(3)	9(20)	48.692	-113.716	3	2.5	1305
SEI-S04	Reynolds Creek	--	1(0)	1(1)	1(2)	1(2)	1(2)	1(1)	1(2)	1(3)	8(13)	48.307	-113.484	3	77.6	1984

*Site was initially selected by the survey design but then also used as a sentinel site.

scientists who have been working in GLAC streams for decades) and most importantly GLAC staff. Some criteria were the same as those used to locate sentinel streams (not in any priority order):

1. Allocation of sites across important stream types in GLAC
2. Allocation of sites across geographic classes (elevation, topography, park region)
3. Use of existing stream monitoring locations (especially with established stream gauges)

However, because gradient sites were intended to capture stream condition either under direct anthropogenic disturbance (or alternatively lacking local stressors), two additional criteria were used. No model was used to score potential sites on these criteria other than the author's and our collaborators' expert opinions.

4. Past or ongoing regulatory classification as an impaired stream reach (i.e., on the state's Clean Water Act 303d list, see Table 1)
5. Proximity of stream to relatively localized extant or historic (potential) human disturbances such as roads or visitor facilities

Target and Sample Populations

The target population for gradient sites is the site. The target population is usually functionally the same as the sample population. This is different than the target/sample population for the survey design and has a series of consequences on analyses and interpretation of gradient site data.

Sample Frame

Because gradient designs do not rely on an algorithm (like GRTS) to select locations, a sample frame is not technically needed. However, GIS data similar (or identical) to SEI survey design sample frames may be used to locate gradient sites. Using the same frame for survey, sentinel and gradient designs is advantageous in linking the design forms.

Revisit Design

There is no intention to use gradient sites to estimate status or detect trend therefore the gradient revisit design is purely a function of budget and logistical constraints and no power modeling was performed.

GLAC Gradient Sites

Table 10 and Figure 17 show the six gradient sites across the park and select attributes of each site.

Table 10. GLAC SEI gradient sites and sample events from 2007 to 2015 (partial sample events are in parentheses).

Site ID	Stream Name	Sample Events by Year										Lat.	Lon.	Stream Order	Catch. Area (km²)	Elve. (m)
		2007	2008	2009	2010	2011	2012	2013	2014	2015	Total					
SEI-G01	Divide Creek	1(0)	1(0)	--	--	--	--	--	--	--	2(0)	48.745	-113.432	3	39.1	1380
SEI-G02	Coal Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.690	-114.197	3	210.5	1043
SEI-G03	Canyon Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.507	-114.141	6	77.0	977
SEI-G04	Big Creek	1(0)	--	--	--	--	--	--	--	--	1(0)	48.603	-114.165	6	214.3	1012
SEI-G06	Fish Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.547	-113.983	2	42.9	963
SEI-G07	Kennedy Creek	--	1(0)	--	--	--	--	--	--	--	1(0)	48.860	-113.550	4	47.6	1622

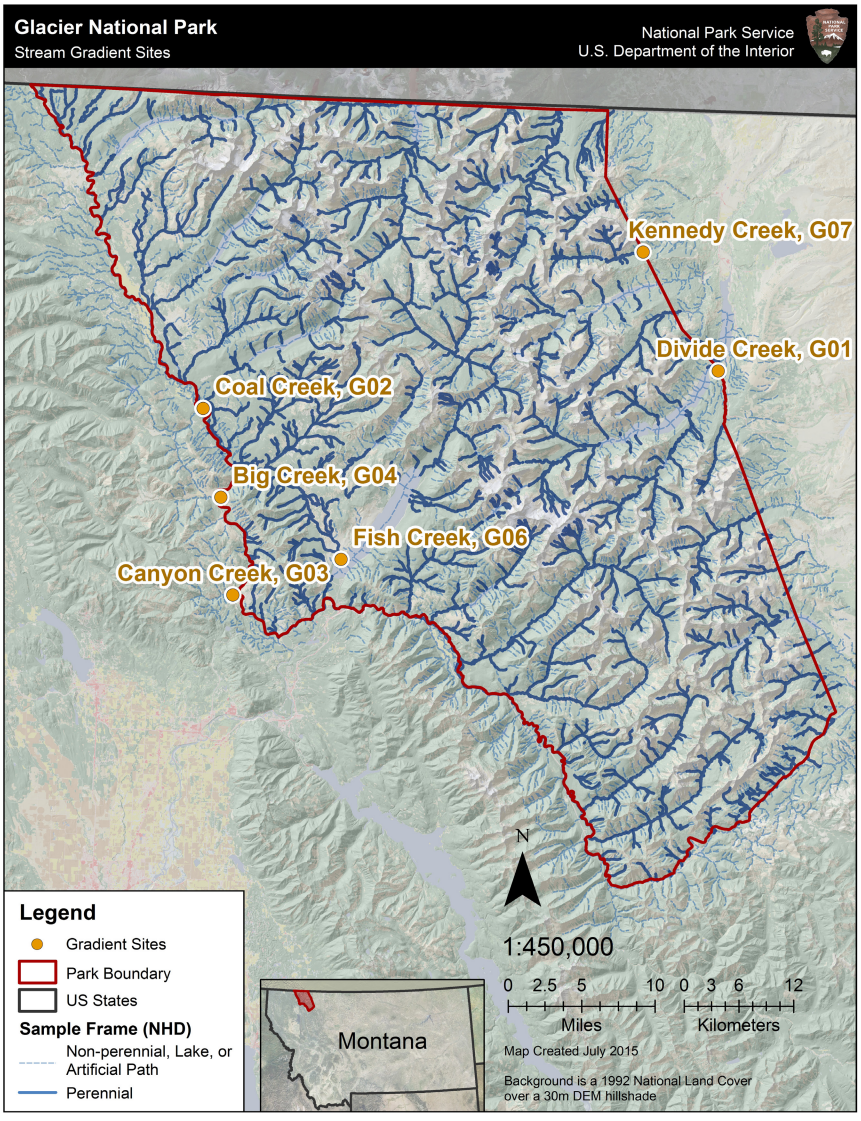


Figure 17. GLAC SEI gradient sites.

Rocky Mountain National Park

ROMO has many streams and rivers that are among the park's most important ecological resources. We use all three design types in ROMO to monitor streams. Between 2008 and 2015 there were 51 sites established in the park and sampled 163 times (90 base flow events with all methods; 73 partial events with a subset of methods). Of these 51 sites, 38 were survey sites, three were sentinel sites (one sentinel site had two distinct locations treated separately in some situations) and ten were gradient sites.

Note that we present less background on the ROMO sample designs (and for subsequent parks) as this detail is given above with the GLAC designs.

ROMO Survey

A distinguishing feature of the SEI protocol in ROMO is a survey design approach to locating most stream monitoring locations. This random selection allows valid statistical inference to the population of streams in the park with known confidence from a relatively small sample.

Target and Sample Population

Our target population for the ROMO survey includes all sampleable, perennial at time of the sample, non-artificial (i.e., no canals or ditches), flowing (i.e., no lakes or wetland) water within the park. We also restrict the ROMO target population to a later summer index period specific to approximately three-year periods of each survey (i.e., 2014 – 2016). In general, the sample population is the actual resource sampled within a survey. It is usually a subset of the more conceptual target population.

Sample Frame

The sample frame at ROMO consisted of a modified high resolution (1:24k) stream hydrography database from the USGS National Hydrography Database (NHD; USGS 2013a) clipped to the park boundary. Modifications included enhanced line topography and attributes such as stream order (see Figure 19). As at GLAC, we incorporated accessibility into the SEI survey design via a cost surface (Figure 18). Final cost values (expressed as travel time) were created by summarizing cost in grid cells that intersected all stream reaches in the sample frame and classifying these values into nine cost classes using a natural breaks algorithm.

Site Selection and Sample Size

We used a generalized random-tessellation stratified (GRTS) spatially-balanced algorithm to select survey sites (Stevens and Olsen 2004). To provide future flexibility the GRTS design selected a large number of candidate sites (1650) across the park. A target sample size of 45 unique sites from

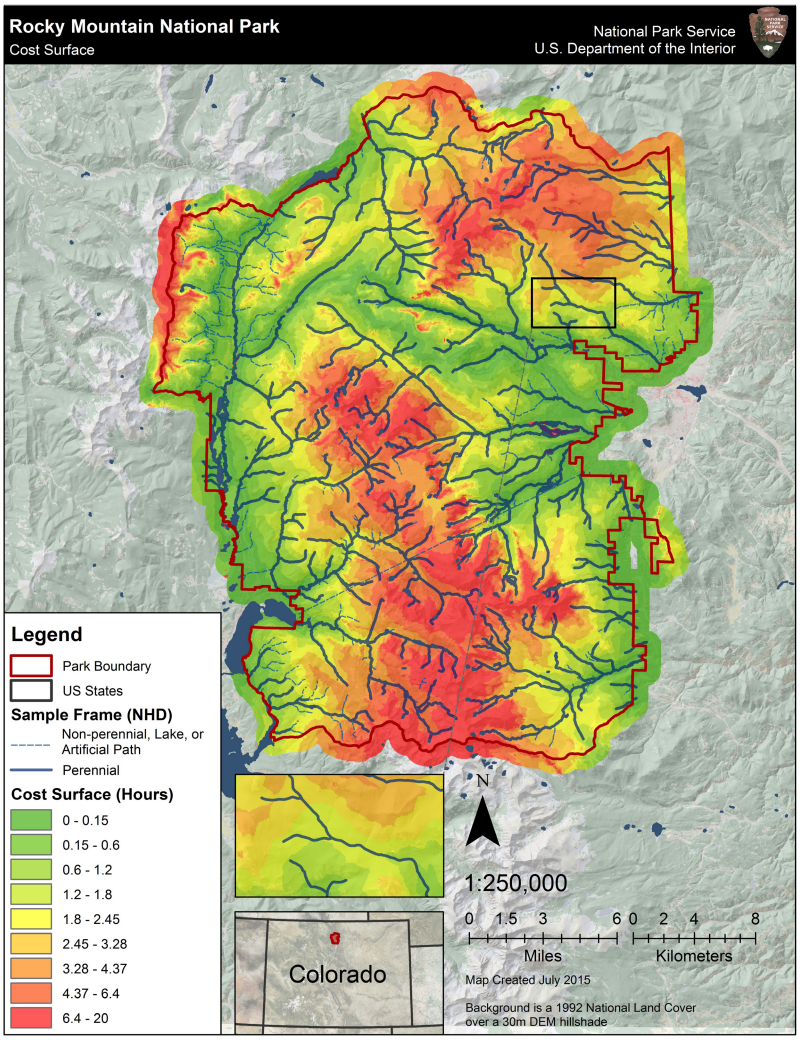


Figure 18. ROMO cost surface. Cost is in units of hours needed to access any point in the park and classified into nine classes with a natural break algorithm. Redder colors within the park represent higher cost.

this overall sample was derived following Cochran (1987; see above for a summary of the *a priori* sample size estimation approach as applied in GLAC).

Allocating Samples to Stream Order and Cost Classes

One difference from the GLAC survey design was a simplification of the original nine cost classes to three. This reduced the complexity of the stream order/cost class combinations and allowed all stream reaches in the park to be included in the design. However, it also likely selected stream sites that were very high cost (as of publication we were still completing the ROMO survey so this was under evaluation). Sample size allocation to these order/cost class subpopulations was determined in an iterative fashion that reduced the range in inclusion probabilities below a recommended maximum of around 30x (T. Olsen, pers. comm. October 2010). As in GLAC, because we had no a priori interest in making estimates for any stream order and/or cost subpopulation, we ignored cost or order subpopulations when (1) replacing non-target or otherwise non-sampleable sites encountered in the field, and (2) in constructing final status estimates (in effect, deconvoluting cost and stream order from the final status estimates; T. Olsen, pers. comm. October 2010).

Realized 2007-2009 Sample Size

As of publication the total realized sample size through the first two years of the ROMO survey was 38. Depending on budget, we expect to add around seven unique sites to this in the third year of the survey. Future surveys will also attempt to sample the full 45 sites.

Revisit Design: Modeling Power for Trend Detection and Precision of Status

As of publication, no power models had been performed using ROMO survey data. Future models will be primarily intended to help understand the implications of the 'affordable' or implemented revisit design (which is the same as in GLAC with 15 unique sites sampled per year over three years with within and across year revisits to three of these sites repeated every 10 years, see Table 6). In general, we expect patterns in power to detect trends and SE around status estimated with this design to be similar to that seen in GLAC and for the general conclusion of future power modeling in ROMO to support the implemented revisit design.

ROMO Survey Sites

Figure 19 and Table 11 present SEI survey sites sampled in ROMO during 2014-2015.

ROMO Sentinel

ROMO sentinel monitoring uses a different design and analysis approach than the survey to allocate sites across space and events

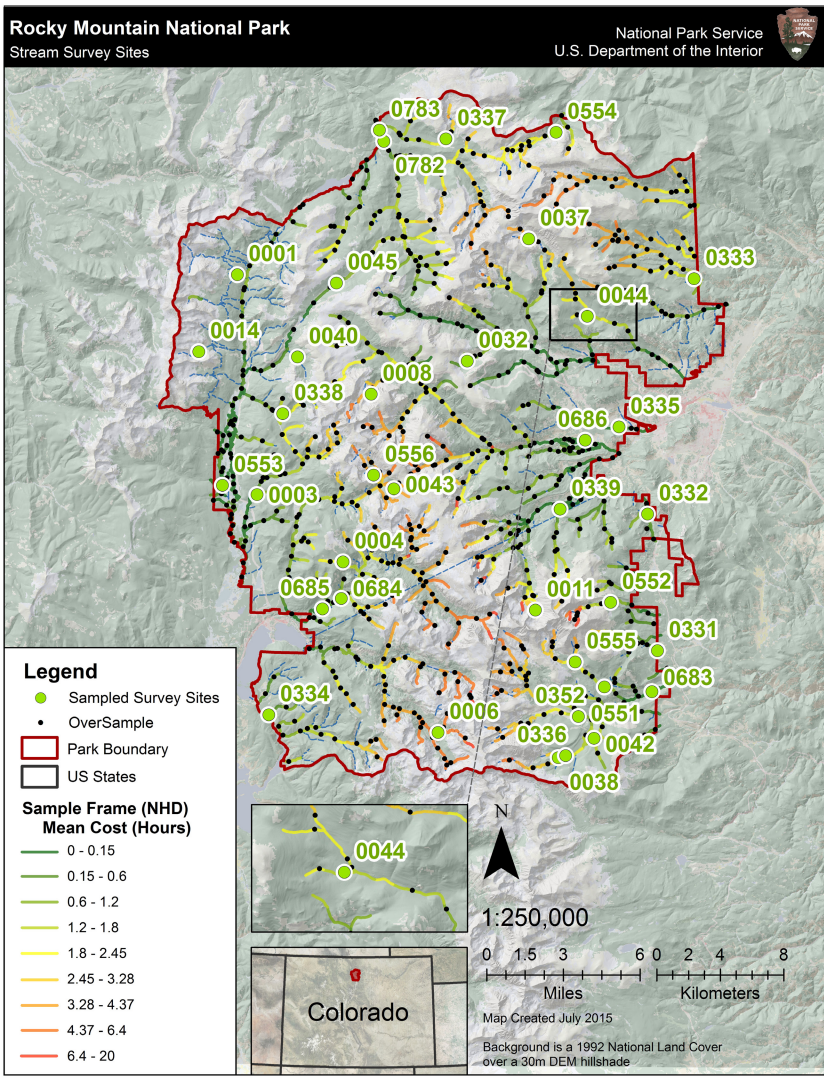


Figure 19. ROMO SEI survey sites and sample frame. Sites sampled in 2014-2015 are labeled. Small black dots are oversample sites. The sample frame stream layer is color coded by cost - redder streams have higher access times.

Table 11. ROMO SEI survey sites and sample events from 2014 to 2015 (partial sample events are in parentheses). If budget allows, the ROMO survey size will be increased to 45 with additional revisits to select sites in 2016.

		Sample Events by Year							
Site ID	Stream Name	2014	2015	Total	Lat.	Lon.	Stream Order	Catch. Area (km^2)	Elev. (m)
SEI_0001	Little Dutch Creek	1(0)	--	1(0)	40.448	-105.855	1	*tbd*	2994
SEI_0002	West Creek Trib upper	--	1(0)	1(0)	40.452	-105.534	1	*tbd*	2749
SEI_0003	Onahu Creek Trail Trib	1(0)	--	1(0)	40.324	-105.840	1	*tbd*	2731
SEI_0004	North Inlet Trib A	1(0)	--	1(0)	40.286	-105.776	1	*tbd*	3134
SEI_0006	Paradise Creek Trib	--	1(0)	1(0)	40.189	-105.704	1	*tbd*	3249
SEI_0008	Little Rock Lake Trib	--	1(0)	1(0)	40.381	-105.756	1	*tbd*	3418
SEI_0011	Green Lake Trib	--	1(0)	1(0)	40.259	-105.633	1	*tbd*	3441
SEI_0014	Opposition Creek	--	1(0)	1(0)	40.404	-105.884	1	*tbd*	3267
SEI_0032	Sundance Creek	2(0)	2(0)	4(0)	40.400	-105.685	1	*tbd*	3207
SEI_0037	Roaring River	1(0)	--	1(0)	40.471	-105.642	1	*tbd*	3410
SEI_0038	Cony Creek Trib	1(0)	--	1(0)	40.175	-105.616	1	*tbd*	3162
SEI_0040	Beaver Creek	--	1(0)	1(0)	40.402	-105.811	1	*tbd*	3182
SEI_0042	North Saint Vrain Creek Trib	1(0)	--	1(0)	40.185	-105.587	1	*tbd*	3084
SEI_0043	Haynach Lake Trib2	--	1(0)	1(0)	40.327	-105.738	1	*tbd*	3342
SEI_0044	Black Canyon Creek	--	1(0)	1(0)	40.426	-105.596	1	*tbd*	2852
SEI_0045	Lower Cache la Poudre	--	1(0)	1(0)	40.444	-105.782	1	*tbd*	3194
SEI_0331	Horse Creek	1(0)	--	1(0)	40.237	-105.542	2	*tbd*	2668
SEI_0332	Aspen Brook	2(0)	2(0)	4(0)	40.314	-105.550	2	*tbd*	2595
SEI_0333	West Creek Trib lower	--	1(0)	1(0)	40.448	-105.517	2	*tbd*	2486
SEI_0334	Pole Creek	1(0)	--	1(0)	40.199	-105.829	2	*tbd*	2550
SEI_0335	Beaver Brook	1(0)	--	1(0)	40.364	-105.572	2	*tbd*	2445
SEI_0336	Cony Creek	1(0)	--	1(0)	40.177	-105.610	2	*tbd*	3125
SEI_0337	Casade Creek	--	1(0)	1(0)	40.526	-105.702	2	*tbd*	3240
SEI_0338	Timber Creek	--	1(0)	1(0)	40.370	-105.821	2	*tbd*	3086
SEI_0339	Boulder Brook	1(0)	--	1(0)	40.316	-105.615	2	*tbd*	2705
SEI_0352	Ouzel Creek	1(0)	--	1(0)	40.199	-105.603	2	*tbd*	2917
SEI_0551	Hunters Creek	1(0)	--	1(0)	40.216	-105.581	3	*tbd*	2950
SEI_0552	Roaring Fork	1(0)	--	1(0)	40.264	-105.575	3	*tbd*	3195
SEI_0553	Bowen Gulch	1(0)	--	1(0)	40.329	-105.866	3	*tbd*	2701
SEI_0554	South Fork of Cache la Poudre	--	1(0)	1(0)	40.531	-105.620	3	*tbd*	3046
SEI_0555	Hunters Creek	--	1(0)	1(0)	40.230	-105.603	3	*tbd*	3097
SEI_0556	Haynach Lake Trib	--	1(0)	1(0)	40.335	-105.754	3	*tbd*	3252
SEI_0683	North St Vrain Creek	1(0)	--	1(0)	40.213	-105.546	4	*tbd*	2550
SEI_0684	North Inlet1	1(0)	--	1(0)	40.265	-105.777	4	*tbd*	2616
SEI_0685	North Inlet2	2(0)	2(0)	4(0)	40.259	-105.791	4	*tbd*	2602
SEI_0686	Big Thompson	1(0)	--	1(0)	40.356	-105.596	4	*tbd*	2457
SEI_0782	Cache la Poudre River1	--	1(0)	1(0)	40.525	-105.748	5	*tbd*	2947
SEI_0783	Cache la Poudre River2	--	1(0)	1(0)	40.531	-105.751	5	*tbd*	2924

across time. The most important distinguishing features are (1) an expert opinion or judgment-based selection of stream site locations, (2) multiple samples at each site per year (summarized in the Methods Section below), and (3) no intention to make inference beyond the site or immediate stream reach without complex modeling or assumptions.

Target and Sample Populations

The target population for sentinel site monitoring is the stream site (which for some responses is a variable length stream reach, see below). In sentinel designs, the target population is usually functionally the same as the sample population as there is often no difference in the actual array of sites sampled from what was expected *a priori.*

Sample Frame

Because sentinel designs do not rely on an algorithm (like GRTS) to select locations, a sample frame is not technically needed.

Site Selection

ROMN did not use any sort of model or computer-based algorithm to locate ROMO sentinel stream sites. Rather, sentinel sites were located subjectively based on a suite of criteria developed by ROMN staff, collaborators (especially scientists who have been working in ROMO streams for decades) and ROMO staff. In comparison to the GLAC sentinel site allocation, more sites were located in streams within the park that had ongoing long-term and large-scale restoration projects.

In summary, key criteria used to select SEI sentinel sites include the following (not in any priority order):

1. Use of existing stream monitoring locations (especially with established stream gauges)
2. Management importance or utility of a stream for the park (i.e., as a restoration site, usefulness for visitor interpretation, etc.)
3. Allocation of sites across important stream types in ROMO such as larger floodplain rivers, higher elevation small streams, mid-order steeper gradient streams in constrained valleys and mid-order broader valley bottom/meandering streams
4. Allocation of sites across geographic classes (elevation, topography, park region)
5. Representativeness of a site for stream type(s) and/or geographic context (For example, is a particular alpine stream typical in its hydrology, substrates, etc.?)
6. Uniqueness - somewhat in contrast to criteria three- of a complex (For example, is a particular stream ecologically important or interesting in a way that will help the long term monitoring and management of streams in ROMO in general?)

Revisit Design: Modeling Power for Trend Detection and Precision of Status Estimates

As of publication, no power models had been performed using ROMO sentinel data. Future models will be primarily intended to help understand the implications of the 'affordable' or implemented revisit design (which is the same as in GLAC with four visits per year to each site). In general, we expect patterns in power to detect trends and SE around status estimated with this design to be similar to that seen in GLAC and for the general conclusion of future power modeling in ROMO to support the implemented revisit design.

ROMO Sentinel Sites

Sentinel sites in ROMO include the North Fork of the Flathead at the park border, Ole Creek in the southwestern corner of the park, Reynolds Creek at the top of Logan Pass, and Swiftcurrent Creek on the east side of the park (Figures 20 and 21; Table 12).

ROMO Gradient

The ROMO gradient design is similar to the sentinel design in several aspects including (1) an expert opinion or judgment-based selection of stream sites, and (2) no intention to make inference beyond the sites or the sentinel stream complex. However, the

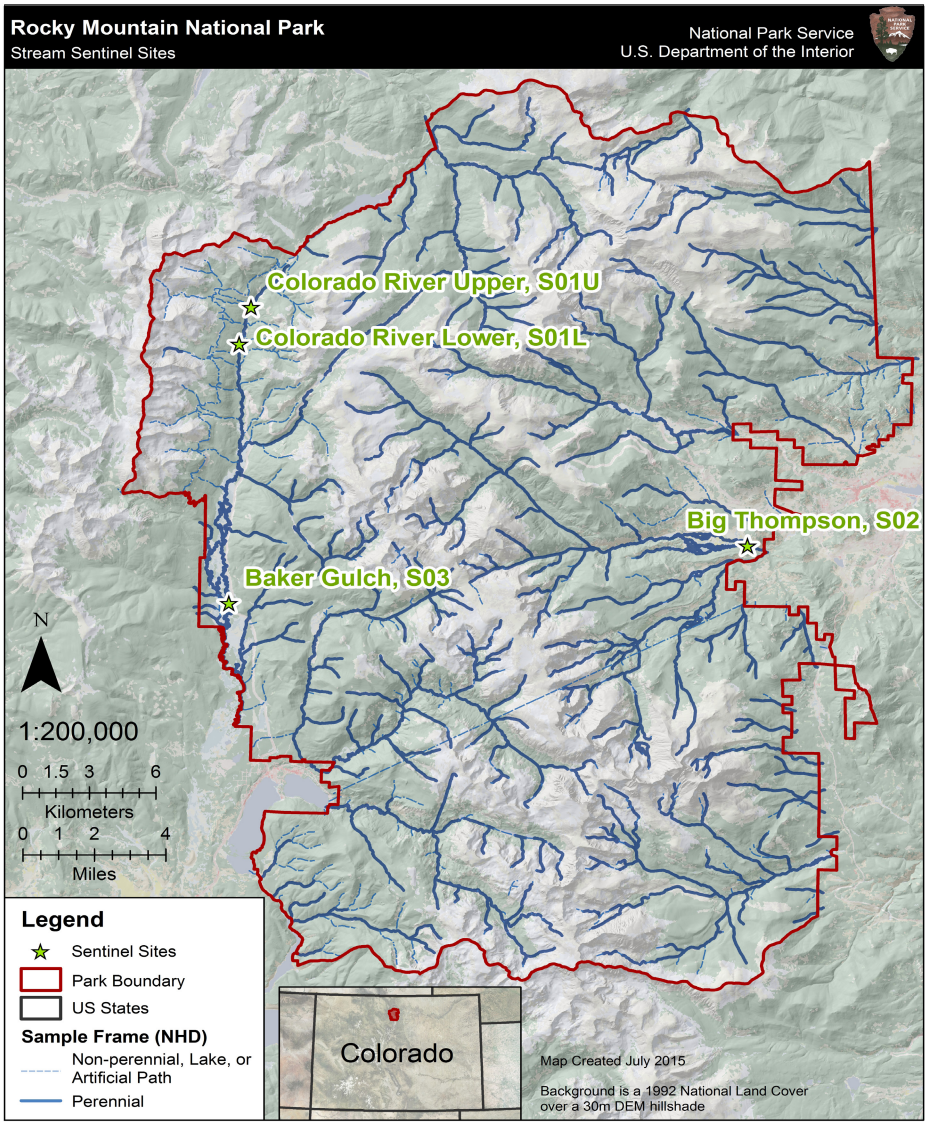


Figure 20. ROMO SEI sentinel sites. Figure 21 shows each site at a finer scale.

Table 12. ROMO SEI sentinel sites and sample events from 2010 to 2015 (partial sample events are in parentheses). Note the Upper and Lower Colorado River site are treated as one site in some contexts.

		Sample Events by Year											
Site ID	Stream Name	2010	2011	2012	2013	2014	2015	Total	Lat.	Lon.	Stream Order	Catch. Area (km²)	Elev. (m)
SEI-S01L	Colorado River Lower	1(0)	1(3)	1(3)	1(3)	1(3)	1(3)	6(15)	40.438	-105.852	4	*tbd*	2834
SEI-S01U	Colorado River Upper	1(0)	1(3)	1(3)	1(3)	1(3)	1(3)	6(15)	40.454	-105.846	4	*tbd*	2873
SEI-S02	Big Thompson River	--	--	--	--	1(3)	1(3)	2(6)	40.354	-105.584	4	*tbd*	2456
SEI-S03	Colorado River Baker	--	--	--	--	--	1(3)	1(3)	40.325	-105.856	4	*tbd*	2674
SEI-S04	*Icy Brook**	--	--	--	--	--	--						

*Icy Brook is expected to be added to the ROMO sentinel site list in 2016.



Figure 21. ROMO SEI sentinel sites: a) Colorado River Lower (Site S01L), b) Colorado River Lower (Site S01U), c) Big Thompson (site S02), and d) Colorado River Baker (Site S03). A likely future sentinel site on Icy Brook is not shown.

criteria used to locate gradient sites differ from those used to identify sentinel sites. Data from gradient sites are primarily used to characterize stream condition at the extremes of anthropogenic and natural drivers that influence stream ecology. Therefore sites are targeted to streams we expect to be under stress or in pristine condition relative to the complete population of streams in the park.

Site Selection

Gradient sites were located subjectively based on a suite of criteria developed by ROMN staff, collaborators (especially scientists who have been working in ROMO streams for decades) and most importantly ROMO staff. Some criteria were the same as those used to locate sentinel streams (not in any priority order):

1. Allocation of sites across important stream types in ROMO
2. Allocation of sites across geographic classes (elevation, topography, park region)
3. Use of existing stream monitoring locations (especially with established stream gauges)

However, because gradient sites were intended to capture stream condition either under direct anthropogenic disturbance (or alternatively lacking local stressors), two additional criteria were used. No model was used to score potential sites on these criteria other than the author's and our collaborators' expert opinions.

4. Past or ongoing regulatory classification as an impaired stream reach (i.e., on the state's Clean Water Act 303d list, see Table 1)
5. Proximity of stream to relatively localized extant or historic (potential) human disturbances such as roads or visitor facilities.

Target and Sample Populations

The target population for gradient sites is the site. The target population is usually functionally the same as the sample population. This is different than the target/sample population for the survey design and has a series of consequences on analyses and interpretation of gradient site data.

Sample Frame

Because gradient designs do not rely on an algorithm (like GRTS) to select locations, a sample frame is not technically needed. However, GIS data similar (or identical) to SEI survey design sample frames may be used to locate gradient sites. Using the same frame for survey, sentinel and gradient designs is advantageous in linking the design forms.

Revisit Design

There is no intention to use gradient sites to estimate status or detect trend so the gradient revisit design is purely a function of budget and logistical constraints and no power modeling was performed.

ROMO Gradient Sites

Figure 22 and Table 13 show the six gradient sites across the park and select attributes of each site.

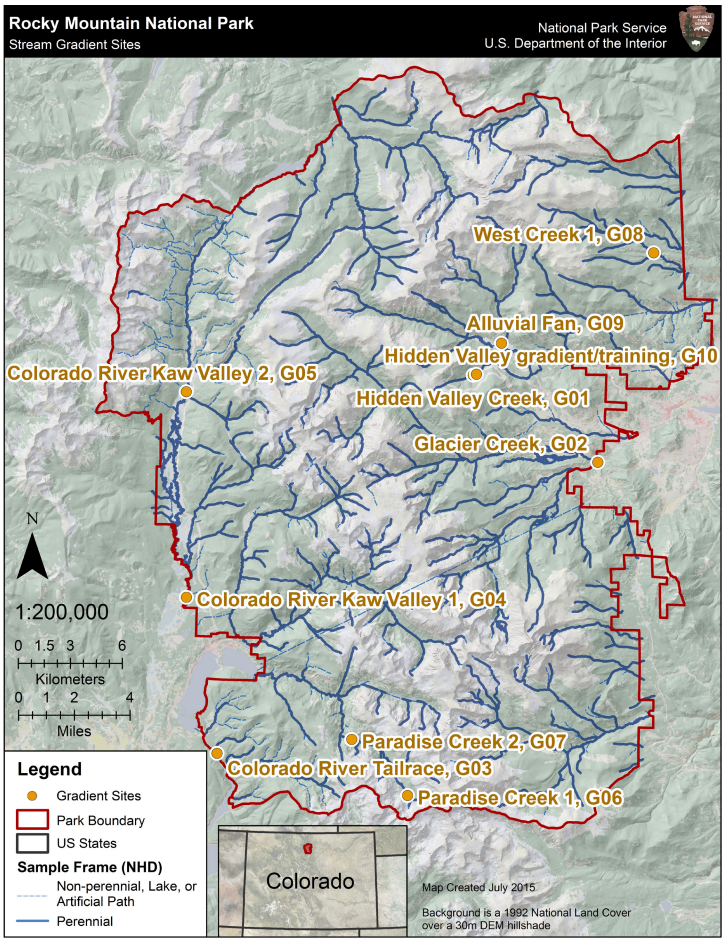


Figure 22. ROMO SEI gradient sites

Table 13. ROMO SEI gradient sites and sample events from 2014 to 2015 (partial sample events are in parentheses).

		Sample Events by Year							
Site ID	Stream Name	2014	2015	Total	Lat.	Lon.	Stream Order	Catch. Area (km^2)	Elev. (m)
SEI-G01	Hidden Valley Creek Upper	1(0)	--	1(0)	40.394	-105.657	1	*tbd*	2883
SEI-G02	Glacier Creek	1(0)	--	1(0)	40.410	-105.638	3	*tbd*	2547
SEI-G03	Colorado River Tailrace	1(0)	--	1(0)	40.349	-105.572	5	*tbd*	2391
SEI-G04	Colorado River Kaw Valley 1	--	2(0)	1(0)	40.277	-105.851	4	*tbd*	2643
SEI-G05	Colorado River Kaw Valley 2	--	2(0)	1(0)	40.384	-105.852	4	*tbd*	2725
SEI-G06	Paradise Creek 1	1(0)	--	1(0)	40.174	-105.699	2	*tbd*	3245
SEI-G07	Paradise Creek 1	1(0)	--	1(0)	40.203	-105.737	3	*tbd*	3137
SEI-G08	West Creek 1	1(0)	--	1(0)	40.458	-105.535	2	*tbd*	2679
SEI-G09	Fall River	1(0)	--	1(0)	40.466	-105.559	2	*tbd*	2948
SEI-G10	Hidden Valley Creek Lower	--	2(0)	2(0)	48.745	-113.432	3	*tbd*	1380

Grant Kohrs Ranch National Historic Site

The Clark Fork River flows through the middle of GRKO and is an important part of the park's ecology and historic context. However, given the limited extent of the river in the park we elected to use only a sentinel design type in GRKO. Between 2008 and 2015 the site was sampled 28 times (seven base flow events with all methods; 21 partial events with a subset of methods).

GRKO Sentinel

The GRKO sentinel design closely mirrors the sentinel design used in other parks. The most important distinguishing features are (1) an expert opinion or judgment-based selection of the site location, (2) multiple samples per year (summarized in the Methods Section below), and (3) no intention to make inference beyond the site or immediate stream reach.

Target and Sample Populations

The target population for sentinel site monitoring is the site (or for some responses a 500-meter supporting stream reach, see the Methods Section below). In sentinel designs, the target population is usually functionally the same as the sample population as there is often no difference in the actual array of sites sampled from what was expected *a priori*. As noted in several places in this protocol this creates a very different inferential context than with a survey design which has a series of consequences on analyses and interpretation of sentinel site data.

Sample Frame

Because sentinel designs do not rely on an algorithm (like GRTS) to select locations, a sample frame is not technically needed. However, GIS data similar (or identical) to SEI survey design sample frames may be used to locate sentinel sites. Using the same frame for both survey and sentinel designs is advantageous in linking the two design forms.

Site Selection

ROMN did not use any sort of model or computer-based algorithm to locate the GRKO sentinel site. Rather, the site was located in consultation with park staff and other collaborators subjectively based on safety and access and because it includes the uppermost reach of the river in the park where surface water first flows into the system. Because the sample site was not selected at random, in a strict sense inference of SEI monitoring data is limited to the site. However, we sample a sizable portion of the river in the park (the total extent of the main stem of the Clark Fork within GRKO is only approximately 5.5 km) and we feel our sample reach is largely representative of this extent. Therefore, we generally interpret results at the scale of the park.

Revisit Design: Modeling Power for Trend Detection and Precision of Status Estimates

The methods we use to estimate power to detect a trend and precision of status estimates at GRKO sentinel sites are the same as those applied to sentinel sites in other parks. They are primarily intended to help understand the implications of the 'affordable' and implemented revisit design and sample size. Methodological details are presented above in the GLAC design sections.

We constructed linear mixed models to two variance components needed for the power models using data from the USGS gauge in Deer Lodge (Table 14). To bracket possible scenarios we used responses that were variable or not. As in other parks the implemented sentinel revisit design at GRKO was simple with four events per year sampled on the limbs of the hydrograph during late spring to early fall. The choice of revisit design to compare to this was limited to monthly year round sampling (N = 12). Schweiger et al. (2014a) gives seasonally and flow adjusted trends for select parameters at GRKO. However, the nonparametric form of these trends and their units of concentration per unit time do not allow direct incorporation as an MDD in our power analyses. Therefore we again use 2% as a default MDD and compare results to a 5% trend. Where possible we qualitatively compare our power results to trends from Schweiger et al. (2014a).

Table 14. Linear mixed models used to derive year variance components for sentinel site power analyses. Year treated as a random effect. Degrees of freedom (df) were constructed following Satterthwaite's method (1946). Coef. Var. = coefficients of variation from untransformed data. A mean of 1.0 is used for log transformed responses by default (Larsen et al. 1995). A Sen slope trend in mg/l/year from published results is shown where available with a slope from a linear fit between year and an increasing or decreasing series at 2% shown for comparison. POR = Period of record, var. comp. = variance component.

Parameter	Descriptive Summary and Model Details	Source	df	Sum of Squares	Mean Squares	p	Variance Component	%
Specific Cond.* (us/cm)	• Log transformed • Mean = 1.0 • Adjusted R^2 = 0.50 • Coef. Var. = 32.13 • Year autocor. = 0.78 • Type III ANOVA	discharge	1	6.48	6.48	0.00		
		year	28	2.33	0.08	0.00	0.004	14.15
		residual	422	9.92	0.02		0.024	85.85
Cadmium (mg/l)**	• Log transformed • Mean = 1.0 • Adjusted R^2 = 0.97 • Coef. Var. = 373.55 • Year autocor. = 0.98 • Type III ANOVA	discharge	1	0.62	0.62	0.00		
		year	25	244.68	9.79	0.00	1.346	96.97
		residual	164	6.89	0.04		0.042	3.03

*Schweiger et al. (2014a): trend mg/l/y = -2.8 (2% MDD ~ -6.69), p = 0.002, POR for trend and var. comp.: 1985-2010 .

**Schweiger et al. (2014a): trend mg/l/y = -0.003 (2% MDD ~ -0.005), p = 0.001, POR for trend and var. comp.: 1985-2010.

Results

We focus our interpretation here on the effect of variation across years in a response, the role of a conservative (2%) and less so (5%) MDD, and the contrast between the implemented revisit design versus a design with monthly samples. In each case, we hold constant all other parameters such that differences are only due to the parameter in question. Our goal is to present the key implications of our sentinel design choice at GRKO so most discussion centers on the implemented revisit design.

Figure 23 presents power for trend and SE for status curves for two responses at GRKO. In general, patterns are similar to those seen in other power models. First, the absolute magnitude of the year variance component matters, with cadmium consistently showing slower accumulation of power and higher SE than specific conductance. Second, revisit design can matter, with monthly samples giving quicker accumulation of power to detect a trend and lower SE for specific conductance and for both MDD. However, with cadmium and its very large year effect, an increase in sample size to 12 per year over the implemented design of four samples per year did not matter. Third, power to detect an MDD of 5% accrues more quickly unless a response has a very large year effect like cadmium.

As discussed in the GLAC sentinel design section, when real trend estimates are available (Schweiger et al. 2014a), we have some sense of how an annualized percent change MDD as used in our power models might compare to an observed trend. A 2% annual decrease in specific conductance is likely about three times less than the Sen slope estimated in Schweiger et al. (2014a). This suggests that power models using 2% as the MDD may be optimistic in the estimated power for detection of the trend in specific conductance as seen at the site from 1985 to 2010. In contrast, we are likely estimating the real trend in cadmium at this location as a 2% MDD is close to the trend reported by Schweiger et al. (2014a) from 1985 to 2010.

As with all SEI monitoring, the details of the implemented GRKO sentinel revisit design were driven largely by operational reality. Nevertheless, the results of our modeling suggest that depending on the response used (and the magnitude of its year variance components), our implemented revisit design at the GRKO sentinel site may be capable of detecting hypothetical MDD (2%) in as soon as six years but in some cases this may take longer than 30 years. Status estimates should be reasonably precise in a relatively short time for parameters with lower yearly variation (but may not be for parameters like cadmium with high levels of yearly variation). In general our results show the negative impacts of a higher year variance component where the only real solution is to extend the monitoring period (i.e., wait for more years to pass).

GRKO Sentinel Site

Figure 24 and Table 15 show the location of the GRKO sentinel site and the 500-meter support reach where subsamples are collected.

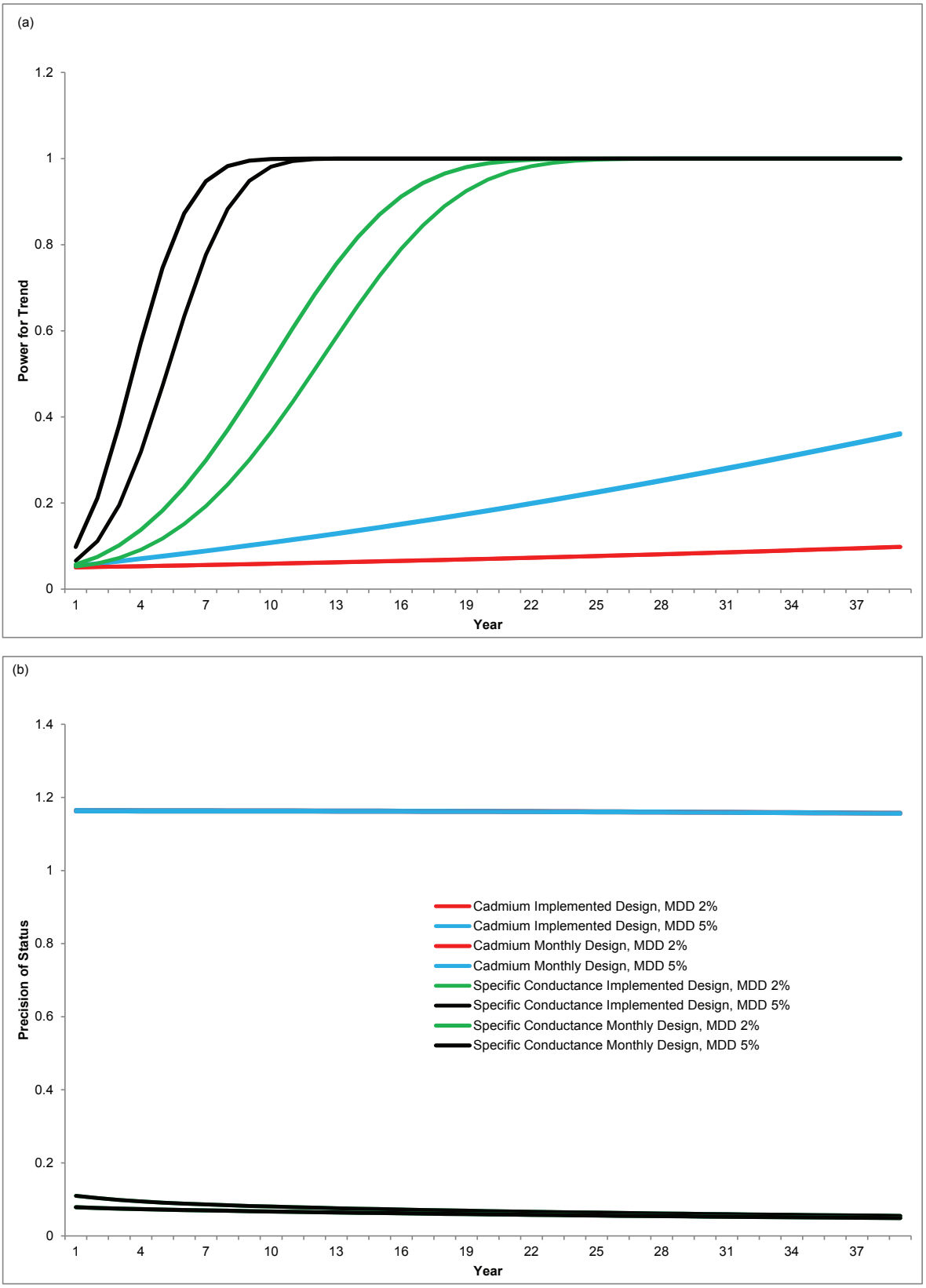


Figure 23. Effect of response measure, revisit design and the minimal detectable difference (MDD; 2% or 5%) on (a) power to detect the trend and (b) the standard error of the mean (status) at the GRKO sentinel site (see Table 14). The "Implemented" design is 4 samples per year (in the spring through fall). The "Monthly" design is 12 samples per year. Note that because MDD has no effect on standard error some curves overlap in panel b and are not visible. Note that the legend for both panels is in (b).

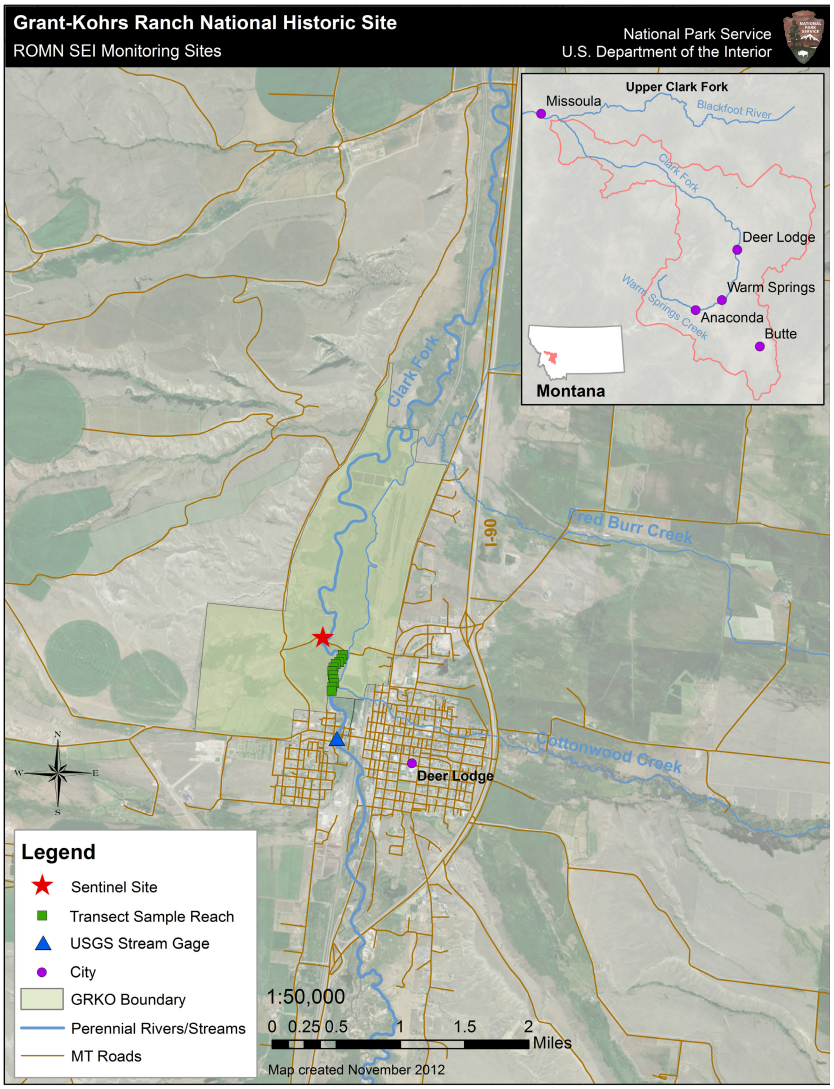


Figure 24. SEI sample site locations at the Grant-Kohrs Ranch National Historic Site. The green squares show transect locations sampled during a full sample event, the red star gives the location of sentinel sample events and the blue triangle shows the USGS gauge. Inset shows the upper Clark Fork River watershed from the Blackfoot River near Missoula.

Table 15. GRKO SEI sentinel site and sample events from 2007 to 2015 (partial sample events are in parentheses).

Site ID	Stream Name	Sample Events by Year										Lat.	Lon.	Stream Order	Catch. Area (km^2)	Elev. (m)
		2007	2008	2009	2010	2011	2012	2013	2014	2015	Total					
SEI-001	Clark Fork River	0(0)	1(0)	1(2)	0(3)	1(3)	1(3)	1(3)	1(3)	1(3)	7(21)	46.409	-112.745	7	2769.9	1370

Little Bighorn Battlefield National Monument

The Little Bighorn River flows through the middle of LIBI and is an important part of the park's ecology and historic context. However, given the limited extent of the river in the park we elected to use only a sentinel design type in LIBI. Between 2007 and 2015 the site was sampled 26 times (seven base flow events with all methods; 19 partial events with a subset of methods).

LIBI Sentinel

The LIBI sentinel design closely mirrors the sentinel design used in other ROMN parks. The most important distinguishing features are (1) an expert opinion or judgment-based selection of the site location, (2) multiple samples per year (summarized in the Methods Section below), and (3) no intention to make inference beyond the site or immediate stream reach.

Target and Sample Populations

The target population for sentinel site monitoring is the stream site (or for some responses a ~1200-meter supporting stream reach, see the Methods Section below). In sentinel designs, the target population is usually functionally the same as the sample population as there is often no difference in the actual array of sites sampled from what was expected *a priori*. As noted in several places in this protocol this creates a very different inferential context than with a survey design which has a series of consequences on analyses and interpretation of sentinel site data.

Sample Frame

Because sentinel designs do not rely on an algorithm (like GRTS) to select locations, a sample frame is not technically needed. However, GIS data similar (or identical) to SEI survey design sample frames may be used to locate sentinel sites. Using the same frame for both survey and sentinel designs is advantageous in linking the two design forms.

Site Selection

ROMN did not use any sort of model or computer-based algorithm to locate the LIBI sentinel site. Rather, the site was located in consultation with park staff and other collaborators subjectively based on safety and access. The reach extends from the last meander bend of the river before it leaves the Custer Unit to near the middle of the Custer Unit. Because the sample site was not selected at random, in a strict sense inference of SEI monitoring data is limited to the site. However, we sample a sizable portion of the river in the park (the total extent of the main stem of the Little Bighorn within LIBI is only approximately 7.2 km) and we feel our sample reach is largely representative of this extent. Therefore, we generally interpret results at the scale of the park.

Revisit Design: Modeling Power for Trend Detection and Precision of Status Estimates

The methods we use to estimate power to detect a trend and precision of status estimates at LIBI sentinel sites are the same as those applied to sentinel sites in other parks. They are primarily intended to help understand the implications of the 'affordable' and implemented revisit design and sample size. Methodological details are presented above in the GLAC design sections.

We constructed linear mixed models to two variance components needed for the power models using data from the USGS gauge in Hardin (Table 16). To bracket possible scenarios we used responses that were variable or not. As in other parks the implemented sentinel revisit design at LIBI was simple with four events per year sampled on the limbs of the hydrograph during late spring to early fall. The choice of revisit design to compare to this was limited to monthly year round sampling (N = 12). Schweiger et al. (2014b) gives seasonally and flow adjusted trends for select parameters at LIBI. However, the nonparametric form of these trends and their units of concentration per unit time do not allow direct incorporation as an MDD in our power analyses. Therefore we again use 2% as a default MDD and compare results to a 5% trend. Where possible we qualitatively compare our power results to trends from Schweiger et al. (2014b).

Table 16. Linear mixed models used to derive year variance components for sentinel site power analyses. Year treated as a random effect. Degrees of freedom (df) were constructed following Satterthwaite's method (1946). Coef. Var. = coefficients of variation from untransformed data. A mean of 1.0 is used for log transformed responses by default (Larsen et al. 1995). A Sen slope trend in mg/l/year from published results is shown where available with slope from a linear fit between year and a increasing or decreasing series at 2% shown for comparison. POR = Period of record, var. comp. = variance component.

Parameter	Descriptive Summary and Model Details	Source	df	Sum of Squares	Mean Squares	p	Variance Component	%
Hardness* (mg/l)	• Log transformed • Mean =306.2 • Adjusted R^2 = 0.33 • Coef. Var. = 19.7 • Year autocor. = 0.79 • Type III ANOVA	discharge	1	1.43	1.43	0.00		
		year	22	2.01	0.09	0.00	0.0073	22.00
		residual	192	4.97	0.03		0.0259	78.00
pH (C)**	• Log transformed • Mean = 8.18 • Adjusted R^2 = 0.x56 • Coef. Var. = 3.64 • Year autocor. = 0.83 • Type III ANOVA	discharge	1	0.01	0.01	0.00		
		year	18	0.14	0.01	0.00	0.0007	54.97
		residual	184	0.11	0.00		0.0006	45.03

*Schweiger et al. (2014 b): trend mg/l/y = 6.2 (2% MDD ~ 9.56), p = 0.02, POR for trend and var. comp.: 1970-1979.

**Schweiger et al. (2014 b): trend mg/l/y = 0.017 (2% MDD ~0.25) , p = 0.002, POR for trend and var. comp.: 1970-2009.

Results

We focus our interpretation here on the effect of variation across years in a response, the role of a conservative (2%) and less so (5%) MDD, and the contrast between the implemented revisit design versus a design with monthly samples. In each case, we hold constant all other parameters such that differences are only due to the parameter in question. Our goal is to present the key implications of our sentinel design choice at LIBI so most discussion centers on the implemented revisit design.

Figure 25 presents power for trend and SE for status curves for two responses at LIBI. In general, patterns are similar to those seen in other power models. First, the absolute magnitude of the year variance component matters, with hardness consistently showing slower accumulation of power and higher SE than pH. Second, revisit design can matter, with monthly samples giving quicker accumulation of power to detect a trend and lower SE for both responses and MDD. However, an increase in sample size to 12 per year over the implemented design of four samples per year mattered less than other variables, especially for parameters like pH with less annual variation and quicker accumulation of power to detect the MDD. Third, power to detect an MDD of 5% accrues more quickly regardless of the response or revisit design.

As discussed in the GLAC sentinel design section, when real trend estimates are available (Schweiger et al. 2014b), we have some sense of how an annualized percent change MDD as used in our power models might compare to an observed trend. At LIBI, a 2% annual decrease in hardness is likely about 30% greater than the Sen slope estimated in Schweiger et al. (2014b). This suggests that power models using 2% as the MDD are likely conservative for detection of trends as seen in hardness at the site from 1970-1979. Likewise for pH the 2% MDD is close to the trend reported by Schweiger et al. (2014b) from 1970 to 2009 and our power modeling likely estimates real capabilities of the implemented revisit design.

As with all SEI monitoring, the details of the implemented LIBI sentinel revisit design were driven largely by operational reality. Nevertheless, the results of our modeling suggest that depending on the response used (and the magnitude of its year variance components), our implemented revisit design may be capable of detecting hypothetical MDD (2%) or even real trends in as soon as a couple of years to around 20 years. Status estimates should be reasonably precise in a relatively short time. In general, our results show the negative impacts of a higher year variance component where the only real solution is to extend the monitoring period (i.e., wait for more years to pass).

LIBI Sentinel Site

Figure 26 and Table 17 show the location of the LIBI sentinel site and the 1200-meter support reach where subsamples are collected.

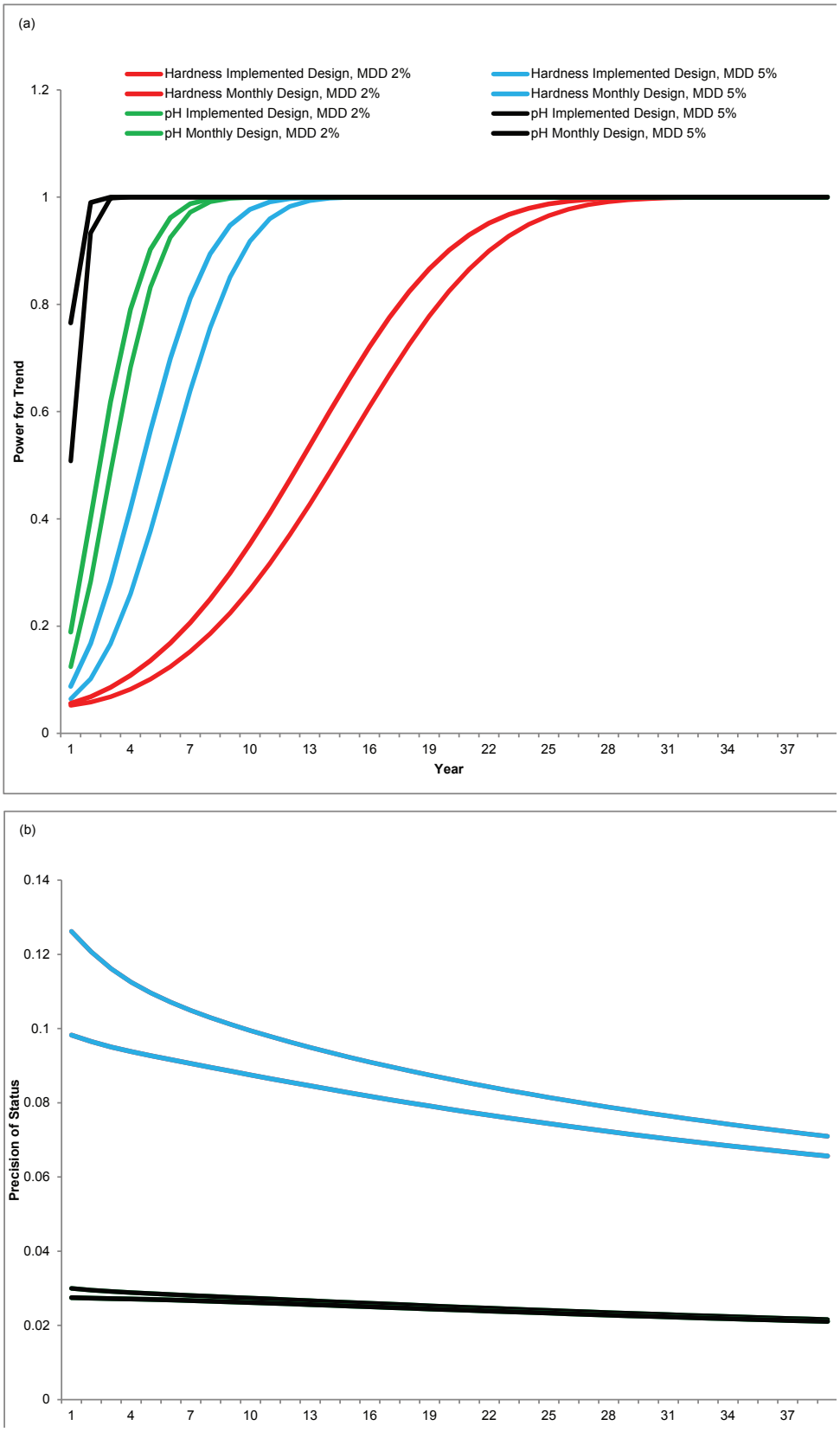


Figure 25. Effect of response measure, revisit design and the minimal detectable difference (MDD; 2% or 5%) on (a) power to detect the trend and (b) the standard error of the mean (status) at LIBI (see Table 16). The "Implemented" design is 4 samples per year (in the spring through fall). The "Monthly" design is 12 samples per year. Note that because MDD has no effect on standard error some curves overlap in panel b and are not visible. Note that the legend for both panels is in (a).

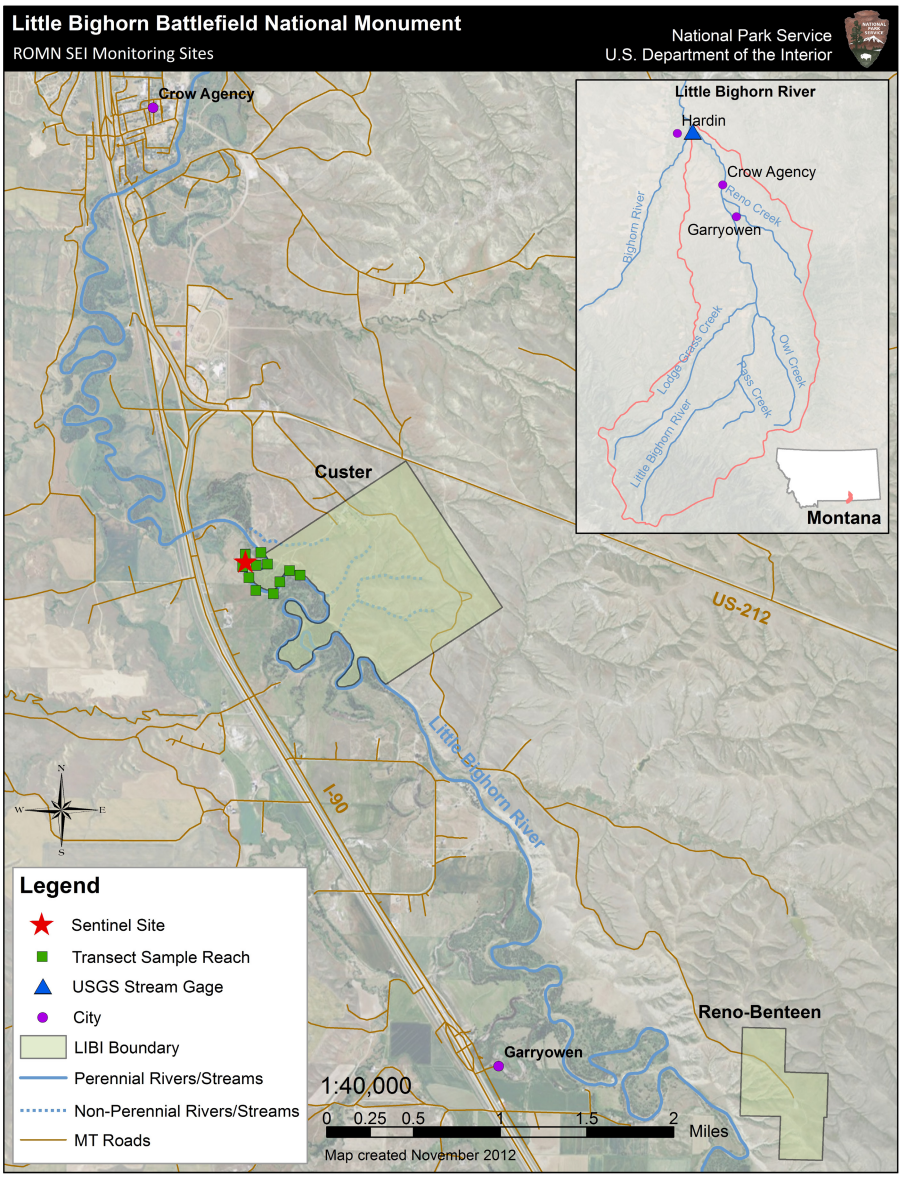


Figure 26. SEI sample site locations at the Little Bighorn Battlefield National Monument. The green squares show each transect location sampled during a full sample event and the red star gives the location of sentinel sample events. Inset shows the Little Bighorn River watershed including the USGS stream gauge (blue triangle) about 22 km river miles north of the Monument.

Table 17. LIBI SEI sentinel site and sample events from 2007 to 2015 (partial sample events are in parentheses).

Site ID	Stream Name	Sample Events by Year										Lat.	Lon.	Stream Order	Catch. Area (km2)	Elev. (m)
		2007	2008	2009	2010	2011	2012	2013	2014	2015	Total					
SEI-001	Little Bighorn River	1(0)	0(0)	1(2)	0(3)	1(3)	1(3)	1(3)	1(2)	1(3)	7(19)	45.566	-107.442	7	3038.5	935

Great Sand Dunes National Park and Preserve

Streams in GRSA are less common than in other large ROMN parks. This is in large part because of the more limited mountainous terrain (that leads to well defined drainages) and the tendency for aquatic resources on the generally flat sandsheet area to be either lentic or wetland. Given this, streams may be less 'on the park's radar.' However, the two primary drainages in the park (Sand Creek, which flows around the northwest side of the dunes, and Medano/Mosca Creeks on the southwest side of the park; Figure 27) are key in maintaining the dune field because they deposit sand on the upwind side of the dune field where it is transported back to the dunes by prevailing winds (Chatman et al. 1997). Therefore, the long-term condition (especially hydrologic) of these systems is important to the founding purpose of GRSA and may warrant monitoring by ROMN. As of publication, we were evaluating sentinel design options to monitor streams in GRSA.

Future updates to this protocol will include the resolution of this choice and all associated supporting materials.



Figure 27. The GRSA main dune field and sandsheet area with Medano Creek in the foreground. Photo NPS.

Field Methods

There are two components to conducting SEI fieldwork: (1) following standard ROMN, park, and NPS procedures for managing a field season, safety, and NPS compliance; and (2) conducting SEI SOPs that detail the methods used to collect and analyze stream data. In the following sections we summarize the resources and methods needed to implement these two types of SOPs. We also include brief justifications for each major class of SEI response measure.

ROMN Shared Standard Operating Procedures

ROMN standard administrative operating procedures describe methods to ensure safety, resource protection, and compliance of ROMN field crews working in all of our parks. In particular, crews and ROMN staff must follow methods to establish permits (ROMN SOP: Permitting) and ensure adequate safety training (ROMN SOP: Safety Preparation and Training) prior to any ROMN activities. End-of-season procedures including maintenance and storage of equipment and data are in ROMN SOP: End of Season. Guidance for hiring and training field crew members, finding housing and park logistics, communications, and use of vehicles can also be found in ROMN SOP: Seasonal Hiring, ROMN SOP: Training, ROMN SOP: Park Logistics, ROMN SOP: Field Communications, and ROMN SOP: GSA Vehicle Leasing, respectively. These administration and equipment operating procedures are maintained and updated by the ROMN staff and are available upon request or via the ROMN website.

Managing the Sample Season

A standard workflow or timeline for a sample season is followed when implementing the SEI protocol in a park (Table 18). More detail is in the standardized ROMN shared SOPs (see box above).

Resource Protection Overview

All efforts aimed at minimizing the impact of crew members on ROMN streams should be taken. Care must be taken that cultural, paleontological, or rare biological resources are not impacted. Details on how to implement each method in a resource-sensitive way are provided in the individual SOPs. Crew members and volunteers will receive training in avoiding sensitive resources. In addition, all appropriate park and I&M staff will be immediately notified of the discovery of any notable resources during sampling.

The following guidelines should be implemented:

- No archeological relicts, paleontological or historical features will be disturbed.
- Any permanent or semi-permanent infrastructure is to be installed with minimal disturbance.
- No flagging or other markers beyond those necessary for the protocol will be left onsite.
- All staff and volunteers will be instructed in appropriate safety and "leave-no-trace" practices for backcountry travel and camping.
- To minimize transfer of organisms

ROMN Shared SOPs

See the ROMN website for current SOPs. Field, data management and analysis SOPs are listed separately.

- ROMN SOP: Safety Preparation and Training
- ROMN SOP: Permitting
- ROMN SOP: Training
- ROMN SOP: Seasonal Hiring
- ROMN SOP: Park Logistics
- ROMN SOP: End of Season
- ROMN SOP: GSA Vehicle Leasing
- ROMN SOP: Specimen Tracking and Vouchering
- ROMN SOP: Using a Digital Camera
- ROMN SOP: Using the Garmin GPS 76csx
- ROMN SOP: Field Communications
- ROMN SOP: SPOT Transponder

Table 18. Key events and timeline in SEI season.

Key Event	Timeline
Initiate field crew hiring	December/January
Review and revise protocols	February/March
Review sample frame, design points, and panel, to determine sites on the annual schedule	February/March
Submit Permit Requests	February/March
Brief the ROMN Technical Committee	March
Determine index period and the field schedule (draft)	March
Make lodging reservations	March
Other logistics	March-May
Vehicle rentals	April-May
Equipment to purchase	April-May
Equipment to ship	May
Coordination with park staff and other personnel	May
Training preparations	May
Final permits acquired (verify)	May
Final equipment inventory	May
Crew training	late May, early June
Fieldwork	May-October*
Season wrap-up	September-October
Data entry, quality assessment, and error corrections	October/November
Finalize database and close-out annual effort (triggers data manager to add annual data to master database files):	December/January

among streams, footwear will be dipped in a bucket with a bleach solution at the end of each day and gear examined for seeds or other propagules.

- Data loggers are installed on stream bottoms in "caves" made from existing substrate and represent no additional impact.
- The protocol allows for adoption of methods with fewer impacts if new technologies become available, such as more precise GPS technology, which could obviate the need for monuments, etc.
- The protocol includes a detailed gear cleaning SOP that specifies how all sampling equipment, field clothing etc. is handled and cleaned to reduce the risk of transmission of invasive species and disease.

Safety

Safety is an overarching concern for the NPS and ROMN (Figure 28). All ROMN streams are or may be cold, fast moving with high bed loads of surprisingly large debris (such as boulders and logs), and vary dramatically in flow. Being swept into a stream could potentially cause hypothermia or death. Therefore, crews conducting field samples need to practice good judgment and decision-making skills when planning for and conducting stream sampling. They also need to have the correct safety equipment and training for stream monitoring work.

The network Safety Plan (NPS-ROMN 2012) provides a general framework and guidance for minimizing safety risks for ROMN staff and partners. It includes safety relative to all aspects of ROMN work including office work, travel, driving, fieldwork etc. The plan includes NPS and ROMN safety policies, SOPs, Job Hazard Analyses (JHAs), and requirements for training. Specific safety issues are dealt with in each SEI SOP as needed and the more general ROMN SOP: Safety Preparation and Training (maintained and updated by ROMN staff and available upon request or via the ROMN website).



Figure 28. ROMN SEI crews wearing proper safety gear cheerfully sampling the Roaring River in ROMO, 2015. Photo by N. Hammond, NPS.

Overview of Stream Sampling Safety Concerns and Procedures

- Job Hazard Analyses (JHAs) for general field sampling and this overview of stream sampling safety concerns must be reviewed by all crew members before sampling.
- Material Safety Data Sheets (MSDS) must be available for all chemicals used in sampling and in the lab.
- Supervisor must be notified of the location and all crew members present for each sample event.
- If administrative access to a closed road is required, the appropriate form must be filled out and signed by the Division Chief and dispatch must be radioed when entering and exiting gates.
- Crews should file a backcountry travel plan, even if the sample site is on the roadside. Stream monitoring can be dangerous regardless of how far the crew is from their vehicle.
- The crew leader has the responsibility to cancel a sampling event (either before leaving for a site or upon reaching a stream) if conditions are unsafe. Sampling should not occur if any crew member feels that the situation is unsafe. Upon reaching a stream, conditions should be assessed and a determination should be made regarding whether or not sampling can take place safely.
- Guidelines and rules to follow for SEI sampling:
  - At least two people must be present on site at each sampling event.
  - Rule of thumb: if there are thoughts or conversation among crew members expressing concern over safety of a given method of sampling, it is probably unsafe and alternatives (including cancelling the sample event) should be assessed.
  - Personal floatation devices (PFDs) must be worn by crew members while sampling in the stream or from shore if appropriate given stream depth and/or velocity. A rule of thumb: if water is expected to be above mid-thigh level, or is unexpectedly swift (i.e. during peak runoff), wear PFDs.

- If water levels are low enough that wading into the stream feels safe, proceed with normal sampling as near as possible to the thalweg (usually the line of fastest flow in the stream).
- At high water, all sampling must be done from the shore or just away from the shore in no more than three feet of water. Do not attempt to get into the thalweg at high water.
- If stream velocity or depth at thalweg creates any feeling of unease, wade only to a comfortable depth for sampling.
- Only one person should be in the water at a time during high water (this usually occurs during May and June sampling events).
- Whenever a crew member is in the water, a second crew member must be close-by (within 15' or within conversational hearing distance). The person on shore should also be wearing a PFD and have a throw rope ready whenever water is fast or above mid-thigh.
- If stream velocity or depth of entire stream creates any feelings of unease, sample from shore (wearing a PFD). A second crew member (wearing a PFD whenever water is fast or above mid-thigh) should be standing by with a throw rope if there is any possibility of a fall into the stream.
- If stream bank is unstable or undercut and no area along the stream bank is safe for sampling, cancel sample event.
- If you must cross a deeper or faster water channel everyone must wear a PFD and do so in groups with linked arms or with one person directly behind the other with your arms on their shoulders. Do not cross upstream of "strainers" (piles of logs and debris) or "sweepers" (fallen trees just above or at the surface of the stream). Use trekking or sample poles for additional stability. Take a route that follows eddies or slack areas of water downstream of boulders. If you must cross a channel with a backpack on, undo the lower waist and chest belts realizing that the pack can shift more easily.
- While sampling or crossing a channel, consider using a trekking pole or the sample staff gauge as a tripod/support.
- Move slowly and deliberately; always have both feet secure on the stream bottom.

- Personal protective equipment (PPE) must be available for all crew members involved with sampling:
  - Waders with cinchable belt (the belt MUST be worn tight at all times.)
  - Wading boots with rubber soles and (optionally) spikes
  - PFD (personal flotation device) worn whenever water is fast or above mid-thigh
  - Neoprene gloves
  - Splash jackets for cold-water sampling (optional)
  - Nitrile gloves (large enough to fit over neoprene gloves)
  - Safety/throw rope (of the type rafters use)
  - Trekking poles or sample staff gauge (for support during sampling)
  - Current and well-stocked first aid kit
  - Bear spray
  - Radio
  - Each crew member must have adequate personal gear for field work in remote areas with variable and often extreme weather.
- Training will be offered for stream safety concerns:
  - First Aid/CPR
  - Backcountry travel and safety
  - Stream safety

Quality Assurance and Quality Control: Field

The ROMN SEI protocol includes various quality assurance and quality control (QAQC) procedures. These are detailed in relevant SEI SOPs and summarized below and in Table 19. Analytical methods focused on developing statistical estimates relevant to QAQC are summarized in the analysis section. At the time of publication, a detailed Quality Assurance Performance Plan (QAPP) for the SEI protocol was under review by the US Environmental Protection Agency (Schweiger, In Review). The ROMN SEI QAPP provides an overview of all measurement and data quality objectives. These objectives assure that the SEI protocol generates data of known and documented quality, resulting in complete, accurate and transferable information.

Data credibility necessary for long-term monitoring of streams in ROMN parks will be achieved when it is consistent over time and among staff members, collected and analyzed using standardized and acceptable techniques, comparable to data collected in other assessments using the same methods and used appropriately to make decisions based on sound statistics. Data quality objectives for measurement data include representativeness, completeness, comparability, measurement sensitivity and detection limits, measurement precision as repeatability (accuracy) and measurement systematic error or bias.

QAQC begins with the development of a protocol, training of field crews (Figure 29), and then consistent measured operational implementation of the methods and QAQC details of the protocol. All field crew personnel participate in a standardized field training session at the beginning of each season. Field trainers are experienced NPS ROMN staff and partners. The training session is one or more days and includes lectures, field demonstrations, and numerous field sam-

Table 19. SEI quality assurance and quality control measures.

QAQC Activity	Description
1. Documentation	Documentation via protocol, SOPs, methodology, etc. are readily accessible.
2. Training	Field crew completes pre-season training.
3. Field datasheets	Datasheets have standardized codes, precision guidelines for measured values, and clearly documented methodology to complete the form.
4. Field oversight	Crew leader / protocol lead provides oversight during the field season and/or periodically during data collection.
5. Field datasheet review	Conduct end of day or end of week quality assurance reviews of field datasheets for completeness, recording errors, and legible handwriting.
6. Data entry quality control	Conduct data entry quality control measures, including electronic data collection devices, to eliminate misspellings, standardize entry, and reduce errors (drop down menus, value range, limited lists, check boxes, and species lists, etc).
7. Quality assurance post-data entry	Quality assurance review completed following SOP DM Quality Assurance and Quality Control. Queries are applied to the data post-data entry to isolate errors. All tests and procedures are documented in the ROMN Quality Assurance Performance Plan (Schweiger, In Review).
8. Quality assurance post-analyses	Quality assurance tests completed for derived data prior to uploading to the database. All tests and procedures are documented in the ROMN Quality Assurance Performance Plan (Schweiger, In Review).
9. Quality assurance queries for data recorded by a digital device	Data collected with electronic equipment must undergo tests using QA software, queries in MS Access, or graphical review in MS Excel for outliers and missing data. Thresholds must be developed for accepting or omitting data. All tests and procedures are documented in the ROMN Quality Assurance Performance Plan (Schweiger, In Review).
10. Lab data quality control	Protocol methodology establishes quality control pertaining to the sample collection. ROMN assumes contract labs maintain a level of quality control that is tractable internally.
11. Lab data quality assurance	Chain of custody forms are crosswalked with lab sample results for completeness. Data results are reviewed by the Protocol lead for outliers and missing data prior to uploading to the database.
12. Species lists	At the end of the field season, the species list, with additions from the current year, are crosswalked and updated with code and names as listed in NPSpecies and ITIS. Database is updated prior to data entry.



Figure 29. Training ROMN SEI crews in Hidden Valley Creek (a small and shallow stream where PFDs are not required by the SEI protocol) in ROMO, 2015. Photo by A. Gohl, NPS

pling exercises. SEI SOPs serve as the basis for the field training program. Field crews often have experienced ROMN staff or collaborators as core members. All collection and measurement procedures are standardized among all field crews. Field crews are offered an opportunity at the end of each year to suggest improvements to the field operations manual and other aspects of field operations.

Field QAQC includes allocating 10% of the total sample effort within a park per year to seasonal revisits at the beginning and end of each season over a one- to three-year period. These sample events are complete replicates (with the exception of re-establishing site transect locations). Each revisited site should be visited a total of four to six times (two times each in two or three successive years). Within a season in a park, another 5 to 10% of total effort is allocated to within-event blind replicate sampling of all field based measures (i.e., habitat) and lab samples (i.e., macroinvertebrates or water chemistry). Selection of sites where QAQC activities will be performed is ideally random (for large surveys this might be the first few sites on the GRTS - generalized random-tessellation stratified spatially balanced design – list), but in many cases site access must be considered. If a non-random selection is required, sites for QAQC should be representative of important or useful stream types and contexts. The Field Coordinator and/or Protocol lead conduct episodic QAQC sample events with the crews to gauge how methods are being implemented and deal with any issues that have arisen during a season.

QAQC of equipment focuses on proper maintenance and error checking/ calibration of all loggers, largely following guidelines of instrument manufacturers and of the NPS Water Resource Division (Penoyer 2003) and USGS (Wagner et al. 2006). Details are provided in SEI SOPs.

QAQC is a key function and responsibility of laboratories that perform analyses of SEI samples. Internal lab QAQC processes include replicates, blind spiked samples, various procedures to ensure proper taxonomic identification, sample tracking via chain of custodies and mutually agreed upon data deliverables. ROMN contracts or agreements are only entered in to with providers that specify acceptable QAQC procedures

including agreed upon reporting and detection limits. QAQC documents from labs used to date in the SEI protocol (US EPA 2012; Kiowa Environmental Chemistry Laboratory 2015; Rhithron Associates Inc. 2014 are available upon request from ROMN.

QAQC continues with data entry and multiple automated procedures within the ROMN SEI database. At least 10% of field forms are randomly selected and all data confirmed. Any systematic errors are evaluated to assess if there is a persistent error and a need for a global correction. Details on automated QAQC procedures implemented within the database are provided in the data management section below and SEI SOPs.

Justification for Core Response Measures

The suite of responses measured within the SEI protocol were derived from the vital sign development process that ROMN followed over two years with a long list of collaborators and partners (Britten et al. 2007). The protocol emphasizes macroinvertebrates and diatoms (two key biological communities in streams) and important drivers like water chemistry, in stream and riparian habitat and hydrology. We do not include any aspects of fish or other aquatic vertebrates for three primary reasons. First, in GLAC and ROMO while fish are a very important element of aquatic systems, diversity tends to be low and this can reduce the sensitivity of community-level approaches (i.e., Griffith et al. 2005). Second, given the importance of specific fish species to these parks, high quality research and monitoring efforts are already in place (i.e., Metcalf et al. 2012; Muhlfeld et al. 2012; Eagles-Smith et al. 2014). Third, monitoring fish assemblages is very expensive and logistically complicated and was outside of ROMN's capacity at the time of publication. Should any of these three considerations change in the future, ROMN will reevaluate the exclusion of fish in SEI monitoring.

The following sections introduce the major classes of SEI response measures and provide brief justification for their inclusion.

Water and Sediment Physiochemistry

Water and sediment physiochemistry have long been used to monitor the condition of streams and rivers. The physiochemistry of the water and sediments in a stream are critical in defining habitat for stream biota. They also influence the human experience of the waters in a park as well as the usability of this resource for park visitors and downstream human populations. The list of included parameters is long – but it could have been much longer. Each was included based on the recommendations of collaborators (external scientists, park staff, etc.), specific constituents on MT DEQ and/or CDPHE lists (for regulatory purposes) and our own professional judgment as to what constitutes a comprehensive approach to monitoring water and sediment chemistry. We also include some parameters in a conservative sense in case at some point in the future an issue arises for which a long-term record would be useful. As we learn more about specific parameters we will adjust the list.

In Situ Parameters

Four core parameters are required by NPS Water Resource Division as part of all NPS I&M aquatic protocols (contributing some measure of consistency and comparability of water quality conditions among multiple NPS monitoring programs). More importantly they can be key indicators of stress in aquatic systems (NPS 2002).

Water Temperature

Water temperature is a critical variable controlling many ecosystem processes, both physical and biological, and it can impact almost all functions within an ecosystem (Allan 2004). Rates of most physical, chemical, and biological processes are strongly influenced by temperature. It is also a critical parameter for tracking climate change response in park ecosystems.

pH

pH (the measure of water hydrogen ion concentration) has many physical and biological effects. Most aquatic species occur within specific habitat envelopes of pH conditions, and changes in pH will likely result in changes in species assemblages. In addition,

the pH determines the solubility of many heavy metals (very important in GRKO, given contaminated sediments).

Specific Conductance

Specific conductance is the ability of a water body to conduct an electric current and is directly correlated with dissolved ion concentrations in water bodies. In essence, the more dilute the water, the lower the concentrations of dissolved salts, and thus, the lower the conductance. Changes in conductance suggest changes in major ions or nutrients, such as potassium, calcium, and other anions and cations.

Dissolved Oxygen

Dissolved oxygen is closely linked to physical and biological processes. For instance, respiration, photosynthesis, and atmospheric exchange (through turbulence in rapids and riffles) are the principle processes that affect or are affected by dissolved oxygen concentrations. In addition to high water temperatures, high microbial activity, which is driven by organic pollution, drives demand for dissolved oxygen resulting in anoxic conditions. High oxygen levels are especially critical for the metabolism of aquatic insects and salmonid eggs.

Nutrients, Major Ions and Trace Elements

Nutrients

Nutrients include the dominant forms of nitrogen and phosphorous (both total and dissolved) as well as organic and total dissolved carbon. Nutrients may be limiting in aquatic ecosystems, controlling productivity, as well as being indicators of eutrophication caused by external stressors (e.g., atmospheric deposition or visitor use activities). Total organic carbon and dissolved organic carbon are essential components of the carbon cycle in streams and their watershed. We include multiple species of N and P given the different potential effects of each, the need to understand nutrient cycles at stream sites and requirements from state regulatory programs.

Major Ions

Major ions include two often dominant anions in streams (sulfate and chloride) and four cations (calcium, sodium, potassium, and magnesium). These six ions, along with carbonates, make up most of the ions in most stream water. They are important indicators of the watershed context of the stream, with different ion concentrations reflecting variation in geology, vegetation, and weathering processes. Sulfate and chloride are also common indicators of pollution (e.g., from mining waste or agricultural runoff). We also include total suspended solids; high concentrations of particulate matter can cause increased sedimentation and siltation in a stream which in turn can impact important habitat areas for aquatic life. Suspended particles also provide attachment places for other pollutants, such as metals and bacteria.

Trace Elements

Trace elements in water include those that typically occur only in minute concentrations, such as metals. Contamination of a stream with trace metals is not always detectable in the water column, however, because they may have precipitated or adsorbed to organic particulates or fine sediments. Therefore, we also sample sediments deposited from the water column to detect trace metal contaminants. Many metal ions are lethal to fish and other aquatic life forms. Metals often are bio-concentrated, leading to increasing concentrations in species higher in the food chain. We include total mercury in the suite of parameters analyzed in the sediment samples. Mercury has no known metabolic purpose and is toxic to living organisms. In humans, mercury adversely affects the central nervous system. Mercury can be converted from an inorganic compound (which is what we measure), to organic forms such as methylmercury, which is easily absorbed by organisms, but harder and more expensive to monitor.

Stream Productivity

We include two measures of general stream productivity (chlorophyll a and ash-free dry mass) as they are general indicators of nutrient load within a stream. These two parameters are derived from periphyton samples, and thus, in contrast with direct measure of nutrients, may incorporate many of the use-

ful aspects of bioassessment. Together these measures complement the species list-based diatom metrics described below.

Physical Habitat

Quantitative characterization of stream physical habitat is an important element of long-term SEI monitoring. Monitoring stream habitat can help describe the context or template for ecosystem function and condition (Frissell et al. 1986; Kaufmann et al. 1999). Habitat is often a driver of stream community composition and can help us understand patterns in aquatic communities by helping predict the presence or absence of organisms. It may also help explain important spatial variation in other aspects of stream community structure. Additionally, habitat is a useful monitoring endpoint itself and can help us understand changes in stressors such as particular land uses outside or inside a park, including possible visitor impacts.

The physical habitat components of the ROMN SEI protocol are based on research conducted by the EPA over the last two decades (Kaufmann et al. 1999; Stoddard et al. 2005). Many of these methods have also been adopted by MT DEQ and CDPHE. Importantly, our approach restricts observations to habitat characteristics themselves versus subjective field evaluation of the quality of habitat (e.g., SEI methods do not include crew members determining in the field if some aspect of stream habitat is in "good condition" or not). Furthermore, SEI data allows derivation of objective habitat quality metrics (Simonson et al. 1994; Meador et al. 1993; Kaufmann et al. 1999). As with several other aspects of the SEI protocol, using these methods also allows us to connect our work to other similar monitoring programs in streams and rivers across Montana and the West.

Macroinvertebrates

Stream macroinvertebrates, also known as benthos, include crustaceans, mollusks, aquatic worms, and most importantly (because of their dominance and ecological function) the immature forms of aquatic insects, such as stonefly and mayfly nymphs. The term "benthic" means "bottom-living," as these organisms usually inhabit stream bottoms for at least part of their life cycle. Macroinvertebrates are among the most widely used organisms for bioassessment because they can be sampled relatively efficiently and effectively (Resh and Jackson 1993); they are widespread in aquatic environments (Merritt et al. 2007); there are a large number of species that have a wide range of responses to environmental impacts (Resh et al. 1995); and since they are relatively sedentary, they can be used to determine the spatial extent of impacts. In addition, since macroinvertebrates are relatively long-lived, community response can integrate the high temporal variability associated with traditional physical and chemical analyses (Rosenberg and Resh 1996).

Periphyton

Periphyton include algae, fungi, bacteria, and protozoa associated with channel substrates. Periphyton can be further grouped into growth forms, either as microalgae (microscopic, appearing as pigmented accumulations or films attached to submerged surfaces, typically single-celled algae), or macroalgae (visible without magnification, typically filamentous). Note that, while all periphyton algae taxa are included in SEI monitoring, diatoms (algae with hard, silica "shells") may be more useful as ecological indicators because they are found in abundance in most stream ecosystems, often have a well understood range in tolerance to stressors (but this may need to be improved at the scale of ROMN parks), and are the focus of other similar monitoring efforts in the west (Spaulding et al. 2010). Periphyton are ubiquitous surface waters of ROMN parks, easy to collect, and represented by large numbers of species.

Periphyton have important functions in aquatic habitats as producers of organic matter and play a vital role in inorganic nutrient retention, transfer, and cycling (Stevenson and Smol 2003). As primary producers, periphyton are more sensitive to certain pollutants, like nutrients and herbicides, than other aquatic organisms. Different species are differentially sensitive to a variety of

pollutants and have been found to be useful indicators of nutrient and clean-sediment impacts. Measures of the structure of algal associations, such as species diversity and dominance, can be sensitive and useful indicators of water-quality impacts and ecological disturbance. Periphyton are useful indicators of environmental condition because they respond rapidly and are sensitive to a number of anthropogenic disturbances, including habitat destruction and contamination by nutrients, metals, herbicides, hydrocarbons, and acidification (e.g., Hill et al. 2003). In streams where flow and substratum characteristics create efficient interactions between water and the benthic periphyton assemblage, benthic algae typically reflect recent water chemistry (Lowe and Pan 1996). Periphyton assemblage composition is also strongly influenced by land-water interactions, and also by stream size and the level of human disturbance.

SEI Standard Operating Procedures: Field Methods

To conduct SEI field monitoring, eleven SOPs were developed and are followed at all sample events. SOPs also detail how data are managed. At the time of publication an SOP for most common and simpler analyses of SEI data was in development. Using detailed and explicit SOPs will help ensure that all data are collected, that data are of the highest quality possible, and that over time (and as personnel change) methods remain consistent to reduce bias and variance (Oakley et al. 2003). Our core field methods and their SOPs are summarized in the following sections.

Stream Ecological Integrity SOPs

These include field based (11), data management (6) and analysis (1) SOPs.

- SEI SOP 1: Pre- and Post-Season Workflow
- SEI SOP 2: Pre- and Post-Sample Event Activities
- SEI SOP 3: Sample Tracking
- SEI SOP 4: Verification of Site Status and Sample Reach Layout
- SEI SOP 5: In Situ Water Physiochemistry
- SEI SOP 6: Water and Sediment Physiochemistry
- SEI SOP 7: Discharge
- SEI SOP 8: Physical Habitat
- SEI SOP 9: Periphyton
- SEI SOP 10: Macroinvertebrates
- SEI SOP 11: Sentinel Sample Events
- SEI SOP 12: Field Sheet Scanning
- SEI SOP 13 Processing SEI Discreet Field and Laboratory Data
- SEI SOP 14: Processing *In Situ* Water Physiochemistry Loggers
- SEI SOP 15: Processing HOBO Water Temperature Logger
- SEI SOP 16: SEI Photo Management
- SEI SOP 17: Data Analysis (in production)
- SEI SOP 18: Revising the Protocol

US EPA Stream Monitoring Protocols

We base the bulk of SEI field methods on protocols developed by the EPA's Office of Research and Development as part of the Environmental Monitoring and Assessment Program (EMAP; Stoddard et al. 2005) and the Office of Water for the National Rivers and Streams Assessment (NRSA; EPA 2007). These methods are peer reviewed, published, well-established and have been shown to generate high quality, repeatable data (Somerville and Pruitt 2004; Roper et al. 2010). They are also used, at least in part, by many ROMN partners like MT DEQ (MT DEQ 2011; MT DEQ 2012a,c) and CDPHE (CDPHE 2005, 2010, 2011, 2012). Using methods employed by other agencies facilitates incorporation of partner data in SEI analyses (see below) and comparisons across sites within ROMN park ecoregions. It is likely that using EMAP or NRSA protocols in their entirety would suffice to accomplish an adequate SEI full sample event (several SEI sample events have been conducted jointly with ROMN and the EPA and its partners at ROMN SEI sites using NRSA methods with the data eventually used in both the ROMN and the NRSA programs).

There are of course other stream monitoring protocols we could have used, notably the USGS National Water-Quality Assessment Program (NAWQA; USGS, variously dated) and the USFS Pacfish Infish Biological Opinion Effectiveness Monitoring Program for Streams and Riparian Areas (PIBO; Heitke et al. 2008). While these and other programs may have worked as the basis for SEI monitoring, a choice was required and based on the experience available within ROMN and our collaborators it was determined that the EPA methods were best suited to our largely survey-based approach and budget. Most importantly, the EPA methods fit SEI objectives well.

Most specific SEI wadeable stream methods are derived from Peck et al. (2006). EMAP developed these methods for the "Western Pilot" conducted in 13 western states from 2000 to 2004 and thus they are well suited to most stream types in ROMN parks. Most non-wadeable or boatable methods are from NRSA (EPA 2007) with some methods also derived from Lazorchak et al. (2000). These methods are also well suited to the non-wadeable rivers in ROMO and LIBI included in SEI monitoring.

We have elected to develop and publish SEI protocols based on similar procedures from EMAP and NRSA in the accompanying ROMN SEI SOPs (Schweiger et al. 2015 a). Other I&M networks (and within our own Alpine protocol: Ashton 2010) instead simply cite published protocols. We decided that our edits of these methods were numerous enough that it was appropriate to include them here and seek independent peer review for them.

Some of the narrative in this document and much of the text, figures etc. in the SEI SOPs are derived from or reproduced with permission from EPA documents and we are grateful for this collaboration from EPA.

Sample Event Types: Full, Sentinel, Wadeable and Non-wadeable

Events at sample sites are of two types. First, full sample events typically include all methods (water/sediment chemistry, habitat, and biology) and are done at base flow, once per year. Second, sentinel or partial sample events include only water/sediment chemistry. They are conducted on key limbs of the hydrograph (rising, falling, etc.). We generally conduct three sentinel events at each sentinel site per year (the main event at base flow also includes water/sediment chemistry).

Full sample events vary based on the 'wadeability' of a site (the ability of crew to safely wade the majority of a sample reach) at the time of the sample while sentinel events are identical regardless of the wadeable nature of a site. Non-wadeable sites require a non-powered raft to sample. Perhaps the biggest functional difference between the methods is that non-wadeable sites must be sampled in one direction (as rarely can the boat be rowed back upstream, especially in white water). This requires a few simplifications in the non-wadeable methods and a few data types are collected remotely (i.e., channel slope and sinuosity come from a GIS) or

taken from auxiliary data sources (discharge is usually from USGS gauges that are often co-located with SEI sites on bigger rivers). However, in the end, data generated from the two types of events is nearly identical and allows nearly the same suite of metrics and types of analyses.

Timing of Sampling: Index Period

The timing of when to sample within a field season (e.g., a given month during a year or a particular hour during a 24-hour period) is a key part of implementing the SEI protocol. The timing of sampling (also known as the index period) must be carefully chosen and justified. Index-period sampling focuses the time of sampling on the most ecologically relevant period(s) for a given response measure. Consequently, the data collected will more likely function as the most useful barometer of a vital sign or of the condition of target populations within a given sampling interval (Landers et al. 1988; Messer et al. 1991; Larsen et al. 1995). Index-period sampling may also reduce inter-annual variability since crews will be sampling at similar phenological or hydrologic times each year, reducing effects of seasonal variation. SEI sample events and their timing are classified as follows (Figure 30):

1. Base or full events with all methods conducted. The calendar dates of the index period for base events can vary depending on the hydrology of a particular stream in a park but are generally in middle to later August.
2. Sentinel events with only a subset of methods implemented. The index period for sentinel events occur on the limbs of the hydrograph (and thus their calendar dates can vary a bit). The first sentinel event of the year is on the rising limb (often in early May), the second at peak flow (usually in mid-June), the third on a falling or base flow (when a full event is done, usually in later August) and the last is a late season winter base flow (usually in early October). Often the rising limb is the most difficult to sample given access issues. The peak flow event may also be challenging given safety issues. The third or base flow event is the main or full sample when all methods are done at most sites, otherwise only water and sediment physiochemistry are sampled during sentinel events.

Overall Work Flow: Full Events

The general sequence of full event field methods is summarized graphically below. It is the same regardless of sampling design (survey, sentinel, or gradient) but does vary

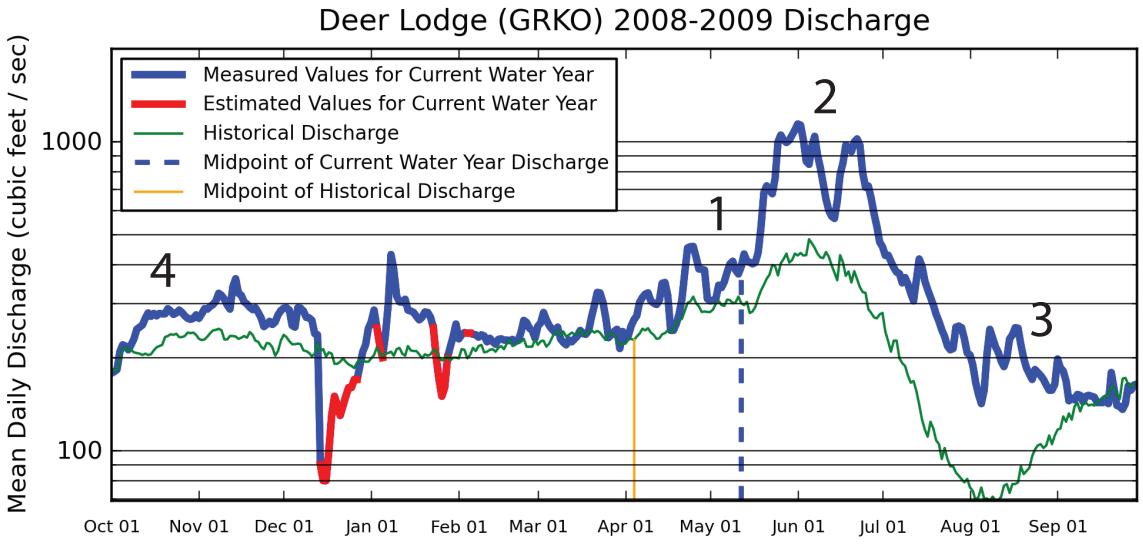


Figure 30. Sentinel sample dates on an example hydrograph (from GRKO, 2008 water year). Numbers indicate the order of the sample events within a calendar year as 1 = rising, 2 = peak (or just off peak and falling due to safety), 3 = base flow and 4 = winter. Note that all SEI methods are conducted with the base flow sample.

by whether a site is wadeable (Figure 31) or non-wadeable (Figure 32). Crews also have some flexibility given the details of a site, especially if there are safety concerns. Sentinel sample events are much simpler and the workflow only involves collecting water and sediment samples as detailed in SEI SOP 11: Sentinel Sample Events.

Field Forms

Thirteen SEI data forms (Table 20) are used for field data collection. Some forms are common to all stream types, sampling designs and event types, while others are only used in a restricted set of circumstances. More specific instructions for completing data forms are provided in the individual SOPs and current forms are available from ROMN upon request.

Determining Site Status and Replacing Sites

Verifying the target population membership and sampleability (together referred to as "status") of a sample site is a key initial step in the implementation of an SEI survey design. Verification of status occurs both in the office and the field. Factors that impact a site's status include its membership in the target population (i.e., it is a perennial stream), accessibility, safety, and resource sensitivity. In some cases, sites will need to be replaced by new site locations selected from the oversample list if they are unsafe, not a stream, or do not meet park compliance needs. It is critical that the fate of sites in the survey design be carefully recorded and tracked. Methods for determining the target status are presented in SEI SOP 4: Verification of Site Status.

Dossiers, which are maps of each site and relevant metadata, such as driving directions and estimated travel time, are prepared for sites prior to the start of fieldwork. All site coordinates will be loaded into crew GPS units for navigation.

Sample Reach and Site Layout

The design of the SEI sample reach (Figure 33) follows the E`MAP site layout (Peck et al. 2006 for wadeable and EPA 2007 for boatable). Eleven cross-section transects, used for physical habitat characterization and biological subsampling, are placed at equal intervals along the reach. Point samples for sediment, benthos, and periphyton collection are set up at middle, left, or right locations on each of these transects or within littoral plots in boatable streams. Twenty-two riparian plots are established on the banks at each transect for collection of vegetation attributes. A thalweg profile is established in the deepest part of the channel along the entire sample reach. Finally, water/sediment physiochemistry and stream discharge are collected at the downstream end of the sample reach.

Sample reaches are 40 times the mean wetted width at time of site establishment (with a 150-m minimum for all sites, a 500-m maximum for wadeable sites and no maximum for non-wadeable sites). This sample reach length captures repeating patterns of local habitat structure and biological variability associated with riffle-pool structure and meander-bend morphology in most streams and rivers. This general site layout (or similar) is

Table 20. Forms needed for ROMN SEI sample events.

Form	Notes
SEI Form #0 All Stream Types Calibration and Error Check	Used for both calibration and error check of water chemistry sondes
SEI Form #1 All Stream Types Stream Verification and Reach Layout	Some parts used only for new or QAQC survey site sample events
SEI Form #3a Event/Logger (front) Water Chem / Discharge (back)	Used for full and sentinel events
SEI Form #4 Discharge	Used infrequently only when discharge is complex
SEI Form #5 Channel/Riparian Cross Section (11 copies)	Used for wadeable full events
SEI Form #6: Thalweg Profile and Woody Debris (11 copies)	Used for wadeable full events
SEI Form #7: Slope and Bearing	Used for wadeable full events; done in GIS for non-wadeable sites
SEI Form #8: Torrent Evidence and Channel Constraint	--
SEI Form #8.5: Dippers	Only in ROMO
SEI Form #9: All Stream Types Periphyton and Benthos	--
PHAB: Channel/Riparian Transect Form – Boatable (Front)	NRSA form used for non-wadeable events
PHAB: Channel/Riparian Transect Form – Boatable (Back)	NRSA form used for non-wadeable events
PHAB: Thalweg Profile Form – Boatable	NRSA form used for non-wadeable events

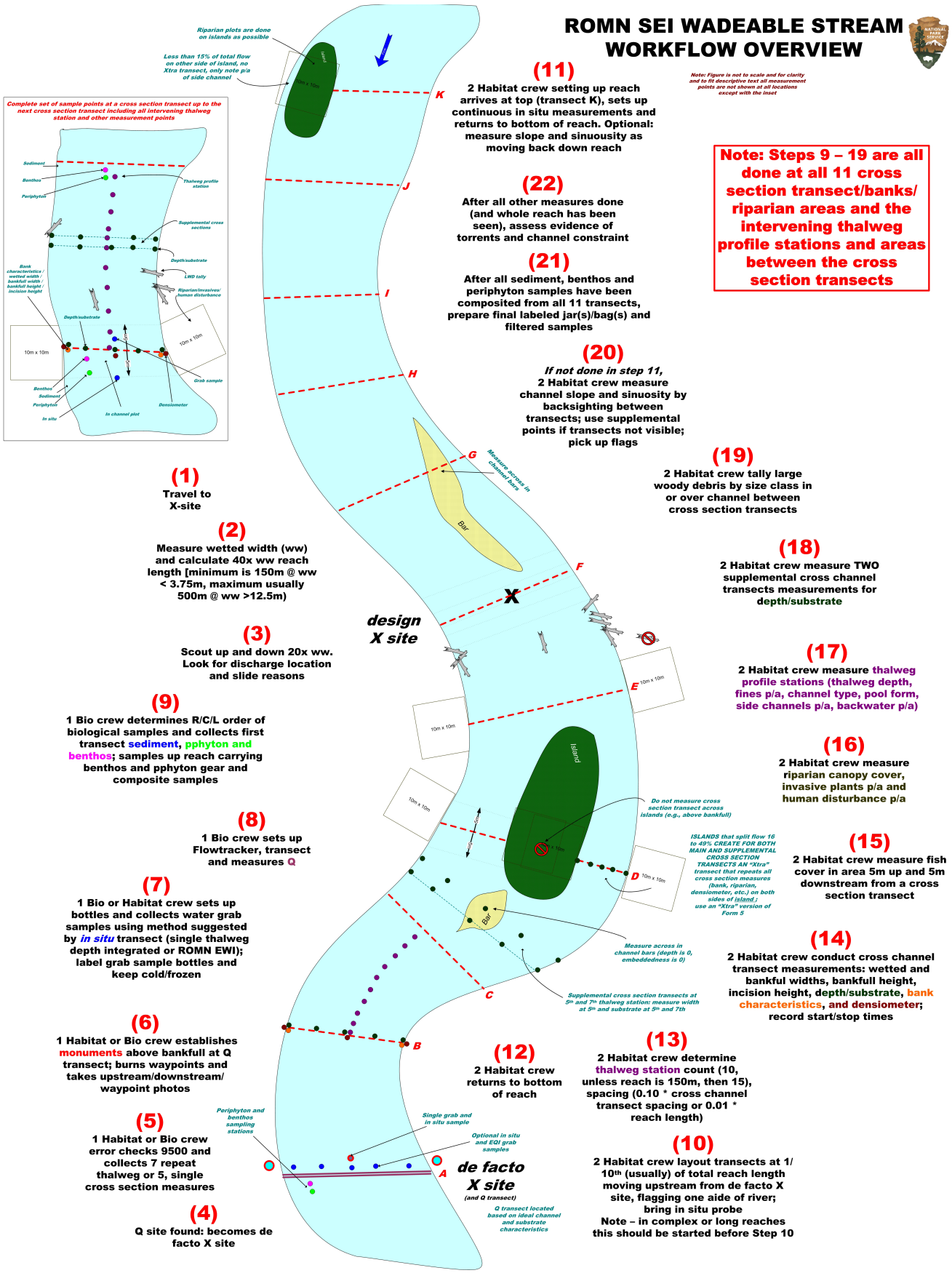


Figure 31. Wadeable workflow overview. Note that steps 9 – 19 (as detailed in the inset) occur at all transects.

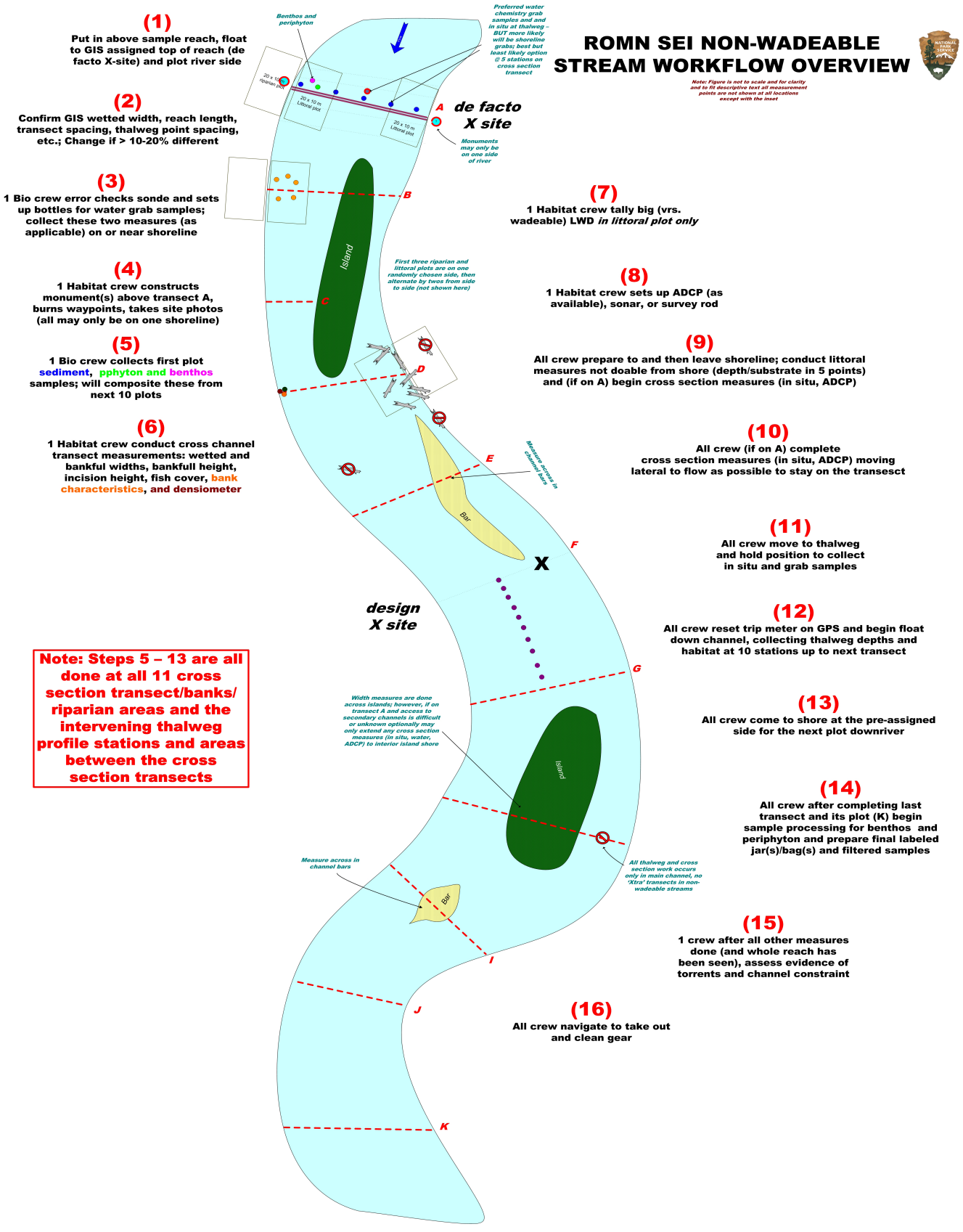
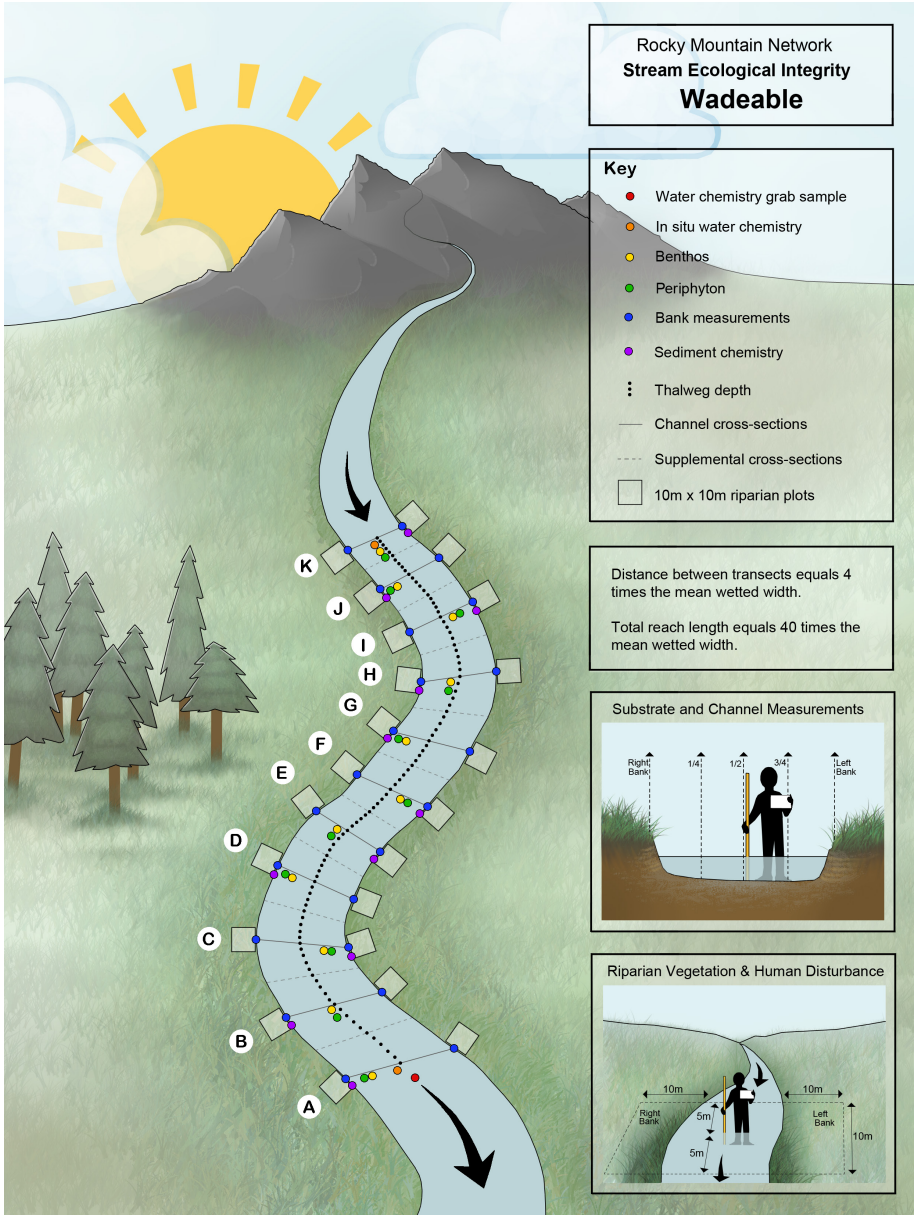


Figure 32. Non-wadeable workflow overview. Note that steps 5 – 13 occur at all transects.



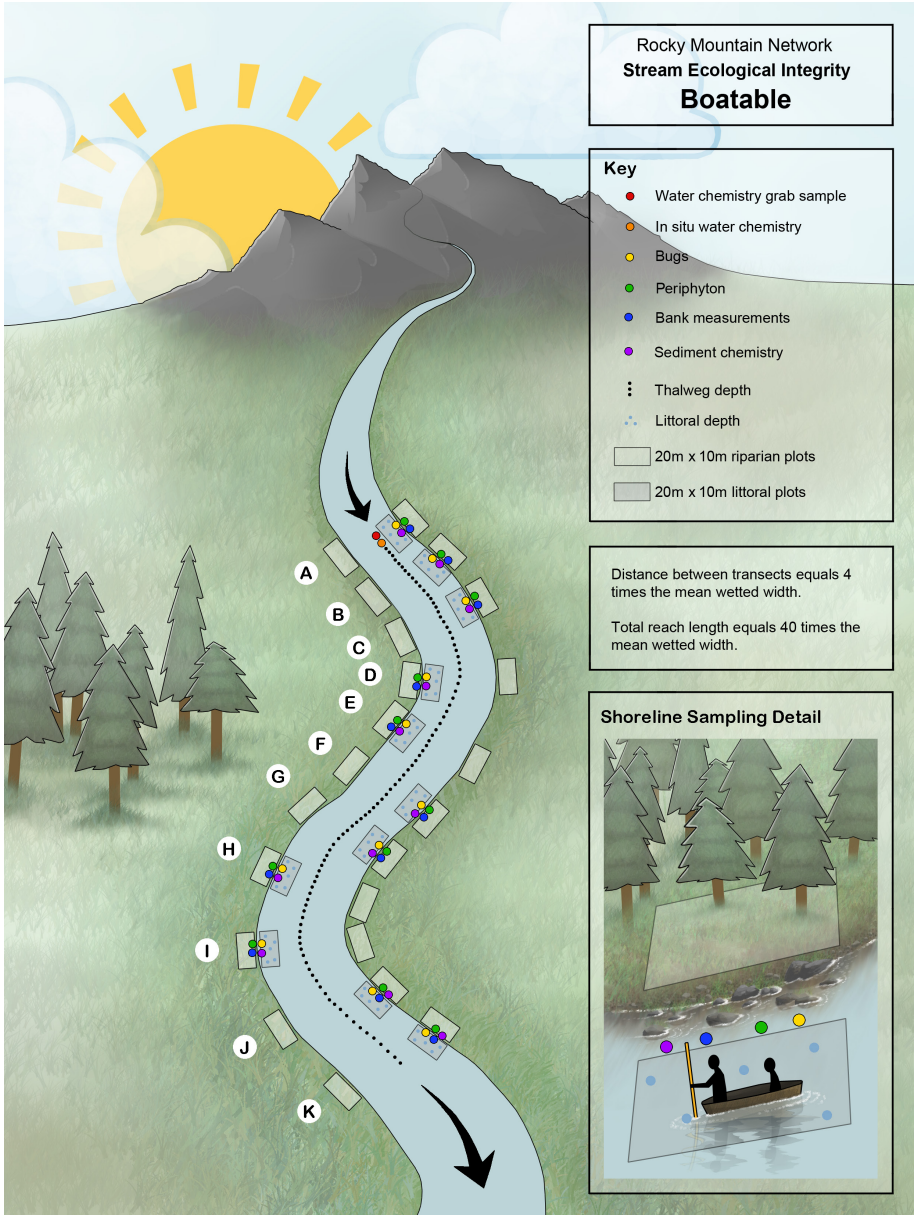


Figure 33. SEI sample reach plot in oblique profile: wadeable (left), boatable (right). Stream flow is from the top to bottom of the figure. Sub-sample locations, riparian plots, and the thalweg profile are all shown. Inset pictures show details for shoreline or in channel sampling.

used by several other long-term monitoring programs (state and federal).

Water and Sediment Physiochemistry

In situ

SEI *in situ* data are collected with a variety of handheld multi-parameter probes (also known as sondes) including the In Situ Smartroll, In Situ Troll 9500, YSI ProPlus, and Hach Hydrolabs. These instruments are compared in the lab before deployment, following WRD guidance, but are not always used congruently in the field due to budget restrictions. Sondes are deployed during a sample event using both instantaneous samples from the thalweg and short-term (1-7 hour) continuous deployments. At a small number of sites, sondes are deployed for two to three months. We also collect continuous data on stream temperature using small HOBO sensors submerged in the channel at select sites. All field methods follow NPS (2002) protocols for quality assurance (i.e., calibration routines and criteria).

Water and Sediment Grab Samples

We measure over 60 parameters from a series of water and sediment samples. Parameters include 11 nutrients, 11 major ions, 12 trace elements (both dissolved and total recoverable metals) in water, and 13 metals in sediment. Water samples are taken using single location, depth-integrated thalweg methods or (rarely) equal width/depth-integrated (EWI/EDI) samples taken at higher flows or in larger rivers that are not well mixed. The decision on when to do thalweg samples or EWI/EDI methods are detailed in SEI SOP 6: Water and Sediment Physiochemistry. Bulk bed sediment samples are composited from eleven individual samples of fine-grained bed sediment collected by scooping material from the surfaces of representative deposits along pool or low-velocity areas at each transect location or during sentinel events at *ad hoc* locations near where water samples were collected. Sediments are not sieved.

Samples are analyzed at several laboratories depending on the sample date and parameter. In 2007 and 2008, all samples went to the Flathead Lake Biological Station (FLBS) lab. From 2009 to 2015 all nutrient samples, major elements, and some trace elements went to the University of Colorado Kiowa lab. All sediment parameters from 2009 on were analyzed by the EPA Region 8 lab. A few trace elements in 2010 were analyzed by the Environmental Testing Corporation lab. Each lab was selected given expertise and operational constraints within the SEI protocol. Each lab followed rigorous internal QAQC that ensured comparability across lab results. Future monitoring will use the Kiowa and EPA labs only as possible.

Stream Productivity

Two indicators of stream productivity are created from composite periphyton samples (see below): chlorophyll a and ash free dry mass (AFDM). Known volumes are filtered from the composite samples in the field and frozen for later analysis. AFDM and chlorophyll a samples are processed using standard methods (APHA 1995). Filters are pre- and post-weighed after combustion in a muffle furnace for AFDM. Chlorophyll a is extracted and analyzed via fluorescence. AFDM and chlorophyll-a concentration per unit area are generated using the area and volume of sample collected and volume of sample filtered.

Physical Habitat

We include five major classes of physical habitat characterization in wadeable (Table 21) and non-wadeable streams (Table 22). The first component (a channel and riparian characterization collected at each of the 11 equally spaced transects and 11 or 22 riparian plots established within the sampling reach) includes measures and visual estimates of channel dimensions, substrate, fish cover, bank characteristics, riparian vegetation structure, nonnative invasive plants, and evidence of human disturbances. Human disturbance measures include in channel, bank side, and indicators of human-caused stress in the nearby floodplain. The second component is a thalweg profile or a longitudinal survey of depth, habitat class, presence of soft/small sediment deposits, and presence of off-channel habitats at 100 equally spaced intervals along the thalweg (deepest part of the channel) between the two ends of the sampling reach. Wetted

Table 21. Categories of ROMN SEI physical habitat measures in a wadeable stream.

Component	Description
Substrate, Channel, and Riparian	Up to 11 cross-section transects (with an additional 20 for substrate size) placed at equal intervals along reach length are used to measure: • Channel cross-section dimensions, bank height, bank undercut distance, bank angle, slope and compass bearing (backsight), and riparian canopy density (densiometer). • Substrate size class and embeddedness; areal cover class and type (e.g., woody trees) of riparian vegetation in canopy, mid layer, and ground cover; areal cover class of fish concealment features, aquatic macrophytes, and filamentous algae. • Presence and proximity of human disturbances, presence of large trees, and presence of target invasive plants.
Thalweg Profile	Measure maximum depth, classify habitat and pool-forming features, presence of backwaters, side channels, and deposits of soft, small sediment at 10-15 equally spaced intervals between each of 11 channel cross-section transects (100 or 150 individual measurements along entire reach). Measure wetted width and evaluate substrate size classes at 11 regular channel cross-section transects and midway between them (for 21 width measurements).
Woody Debris Tally	Between each of the channel cross-sections, tally large woody debris numbers within and above the bankfull channel according to length and diameter classes (10 separate tallies).
Assessment of Channel Constraint, Debris Tor-rents, and Major Floods	After completing thalweg and transect measurements and observations, identify features causing channel constraint, estimate the percentage of constrained channel margin for the whole reach, and estimate the ratio of bankfull/valley width. Check evidence of recent major floods and debris torrent scour or deposition.
Hydrology	Instantaneous measure of discharge with each full sample event. Continuous USGS data on discharge at nearby gauge(s), if present.

Table 22. Categories of ROMN SEI physical habitat measures in a non-wadeable stream.

Component	Description
Channel and Riparian Characterization	At 11 transects at equal intervals along reach length: • Measure/estimate from one chosen bank on 11 transects: ■ Wetted width and mid-channel bar width (laser range finder) ■ Bankfull width (laser) and height (pole and clinometer used as level) ■ Incision height (pole and clinometer used as level) ■ Bank angle (estimate) ■ Riparian canopy cover (densiometer) in four directions from chosen bank ■ Shoreline substrate in the first 1 m above waterline (dominant and subdominant size class) In 20-m-long Littoral Plot extending streamward 10 m from chosen bank: • Littoral depth at 5 locations systematically spaced within plot (sonar or sounding rod) • Dominant and subdominant substrate size class at 5 systematically spaced locations (visual or sounding rod) • Tally large woody debris in littoral plot and in bankfull channel by size and length class • Areal cover class of fish concealment and other features In 20-m-long riparian plot extending 10 m landward starting at bankfull margin on both sides of river: • Estimate areal cover class and type (e.g., woody) of riparian vegetation in canopy, mid-layer, and groundcover layers • Estimate areal cover class and type (e.g., woody) of riparian vegetation in canopy, mid-layer, and groundcover layers • Observe and record human activities and disturbances and their proximity to the channel • Record species of alien (non-native) trees, shrubs, and grasses visible within riparian plot
Thalweg Profile	At 10 equally spaced intervals between each of 11 transects (100 along entire reach): • Classify habitat type, record presence of backwater and off-channel habitats • Determine dominant substrate visually or using sounding rod or sonar
Woody Debris Tally	At 10 equally spaced intervals between each of 11 transects (100 along entire reach): • Record the presence of mid-channel snags • Measure thalweg (maximum) depth using Sonar or rod
Assessment of Channel Constraint debris Torrents, and Major Floods	For the whole sampling reach, after completing thalweg and littoral/riparian measurements: • Classify channel type and degree of constraint, identify features causing constraint, estimate the percentage of constrained channel margin for the whole reach • Estimate the bankfull and valley widths
Hydrology	(Rarely) Instantaneous measure of discharge with each full sample event. Continuous USGS data on discharge at nearby gauge(s) that are more often associated with non-wadeable sites.

width is measured and substrate size evaluated at 21 equally spaced cross-sections (at 11 regular transects, and 10 supplemental cross-sections spaced midway between each of these). In addition, measurements of the stream slope and compass bearing between stations are obtained as possible, providing information necessary for calculating reach gradient, residual pool volume, and channel sinuosity. The third component includes data on woody debris at each of 10 segments located between the 11 regular transects or stream plots adjacent to each riparian plot in boatable streams. The fourth component, assessment of channel constraint, debris torrents, and major floods, is an overall assessment of these characteristics for the whole reach. Finally, the fifth component, stream discharge is measured at the time of each full sample event within the sample reach using a Flowtracker and also taken from USGS gauges where available as a time series of continuous data.

Macroinvertebrates

Quantitative benthos samples are combined to create a single composite sample from eleven 1 ft^2 (0.09 m^2) subsamples taken at each transect along the reach using a D-net or a Stanford-Hauer net with 500 µm mesh net (Figure 34). The choice of gear is clarified in SEI SOP 10: Macroinvertebrates. In summary when the stream is over 3x deeper than the D net and/or most substrates are bigger than cobbles (or around 30cm in diameter), but the stream is still safely wadeable, a Stanford-Hauer net should be used. Results are corrected for any differences in sample area between the two net types. Each subsample was collected over a constant time (30 seconds). Samples are preserved in 95% alcohol (ETOH) for later identification. Samples are spread on a gridded tray or Caton-type splitter and picked from a randomly selected subset of grid cells until 600 organisms are removed (a search for large, rare specimens is also conducted in the whole sample). At least 10x magnification is used to sort invertebrates from debris. All specimens were identified to the lowest practical level or as specified in Kiowa (2015). Voucher specimens, including head capsule mounts for midges, are housed with NPS. Nomenclature follows the Integrated Taxonomic Information System (ITIS). All identifications are crosswalked to Operational Taxonomic Units (OTUs) as developed by MT DEQ (Jessup et al. 2006) or CDPHE (2010) which are used to standardize identifications to a consistent level for some analyses. OTUs may also be linked to NPSpecies nomenclature. At the time of publication we were exploring using the USGS BioData toolset to help manage taxa names (USGS 2015).



Figure 34. Jason Smith (NPS) collecting macroinvertebrates on the Clark Fork River in GRKO, 2010. Photo by B. Schweiger, NPS.

Periphyton

Periphyton samples are combined to create a single composite sample from eleven subsamples taken at each transect along the reach. The specific method used depends on the dominant substrate type present at the chosen microhabitat. For erosional habitat, a piece of cobble within 50 cm of the surface is randomly chosen and a small known area of

the "sunny side" scraped of all benthic algae. For depositional habitat, a small area of organic and mineral fines is vacuumed up with a syringe. A known volume from this composite is preserved with M-fixative (Lugols and dilute formalin) for later identification. The composite field samples are well mixed in the lab, sub-sampled, cleaned with nitric acid digestion, and mounted on four slides using Naphrax. A Palmer-Maloney counting chamber count of 300 soft-bodied algae cells at 400x and a proportional count of 600 diatoμm valves (300 cells) along a scribed line with a random start is then conducted. A 100x scan and count of all valves present on the entire slide for *Didymosphenia geminata* and any novel taxa not in the focal search is also conducted. All specimens are identified to species. Voucher slides are housed with NPS. Nomenclature follows the Montana Diatom Database (Bahls 2004), as there are not well developed taxonomic data in ITIS for algae. Any taxon that is identified in ITIS is crosswalked to the nomenclature used in our analyses. Moreover, all taxa are crosswalked to NPS's NPSpecies nomenclature as possible (although many diatoms and algae are not yet included in NPSpecies). At the time of publication we were exploring using the USGS BioData toolset to help manage taxa names (USGS 2015).

Site Photos

Photographs provide a valuable tool for evaluating ecological change (Mast et al. 1997, Horsted and Grafe 2002). For example, processes such as channel movement or invasion of larger plants into riparian areas are readily visible on photographs (Zier and Baker 2006). Properly framed and documented images are also useful for relocating monitoring sites. The SEI protocol involves collecting four photo points during each sample event at the location where water samples are taken looking upstream, down stream, at the left bank, and at the right bank (Figure 35). Additionally, any site that is revisited within a three-year survey period has a pair of photos at each transect, one taken towards each bank from the center of the channel.



Figure 35. Example of a site photo taken on the Middle Fork of the Flathead in ROMO SEI site. Four photos are taken in an upstream, downstream, left bank, and right bank direction. Photo by B. Schweiger, NPS.

Data Management

Overview

The goal of ROMN information management is to develop high-quality SEI datasets according to standards established in the ROMN Data and Information Management Plan and Standard Operating Procedures (NPS 2007a). The data management system for the SEI protocol is designed to ensure that standardized and reproducible procedures are used to manage all data collected for the SEI protocol effort. Additional details are provided here and in the Data Management SOPs. The SOPs will be updated as needed to reflect minor updates and changes to the protocol over time.

Data Workflow

The same basic lifecycle is used to manage data for all four SEI database systems (Figure 36), which ensures data are accurate, consistent, and comprehensive. This section describes the specific processes involved in planning, collecting, certifying, archiving, and dissimilating data (Figure 37).

Data management is a continuous effort that is implemented during each step of monitoring stream ecological integrity. The annual information lifecycle ensures data are accurate, consistent, and comprehensive.

List of SOPs Used for SEI Data Management:

- SEI SOP 1: Pre- and Post-Season Workflow
- SEI SOP 2: Pre- and Post-Sample Event Activities
- SEI SOP 3: Sample Tracking
- SEI SOP 12: Field Sheet Scanning
- SEI SOP 13: Processing SEI Discreet Field and Laboratory Data (ROMN SEI Database: data entry, validation, and certification).
- SEI SOP 14: Processing *In Situ* Water Physiochemistry Loggers (ROMN Water Quality Database: data entry, validation, and certification)
- SEI SOP 15: Processing HOBO Water Temperature Loggers (ROMN HOBO Logger Database: data entry, validation, and certification)
- SEI SOP 16: SEI Photo Management (ROMN SEI Photo Databases: data entry, validation, and certification)
- ROMN SOP: Folder Structure and File Naming (specifics pertaining to SEI are described below, and are incorporated into the SEI SOPs)
- ROMN SOP: Archive Format Standards for Network Data (specifics pertaining to SEI are described below, and are incorporated into the SEI SOPs)

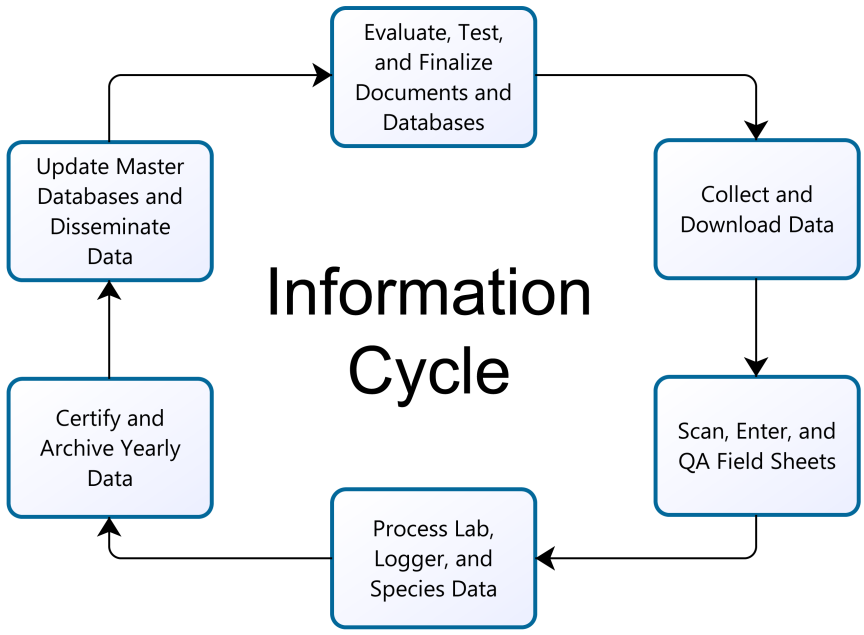


Figure 36. General information lifecycle used for all ROMN monitoring efforts. See text for detailed information about individual SOPs used to manage SEI data.

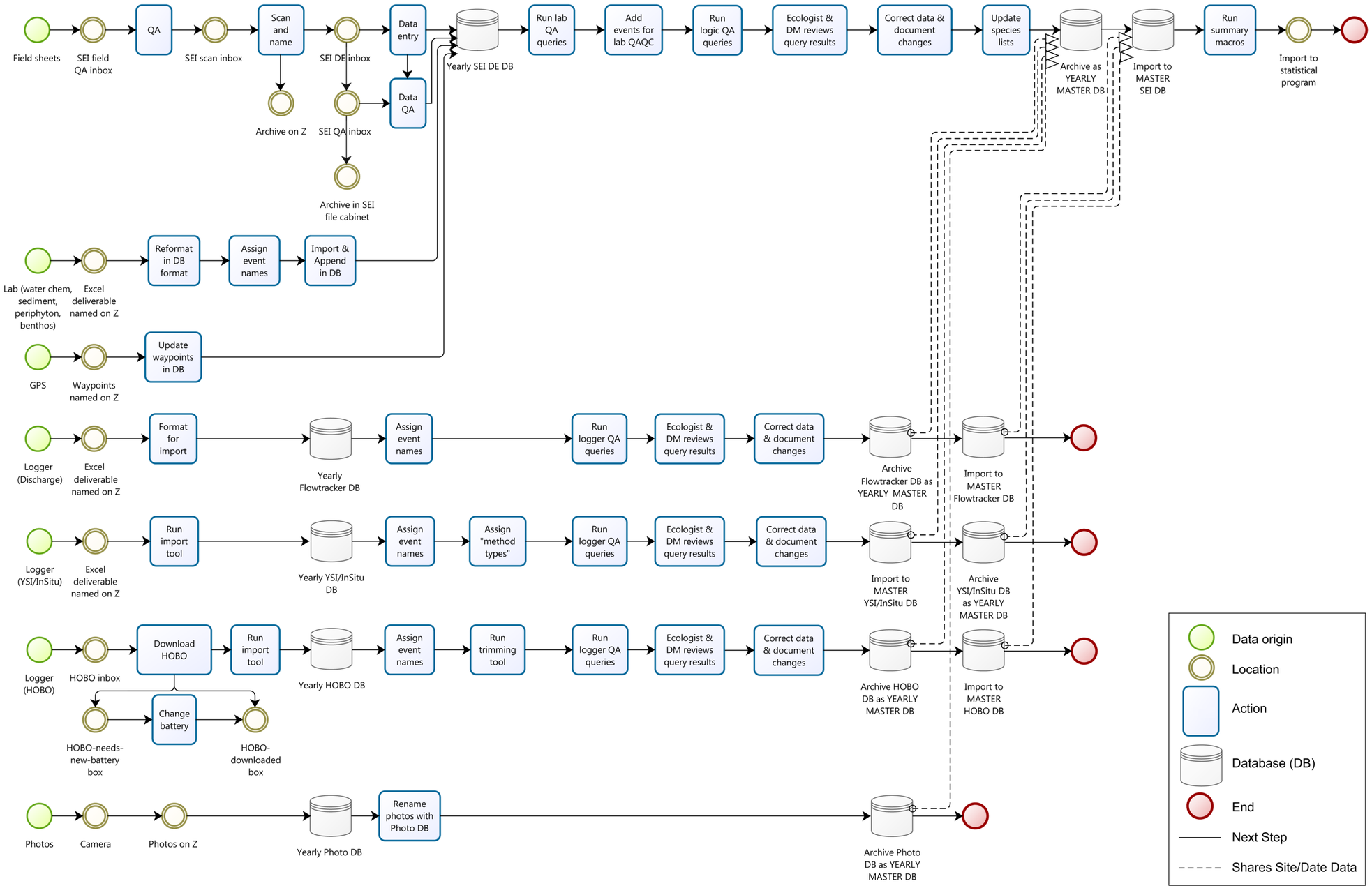


Figure 37. Basic data workflow for SEI monitoring.

In the spring of each year, all amendments to field sheets, database design, and user interfaces are evaluated and tested. Field sheets and maps are printed and the annual databases and GPS units are prepared.

During the field season, the field crew assures the completeness of the collected information and downloads all electronic data. Datasheets are scanned, entered, and archived (SEI SOP 12: Field Sheet Scanning). The data management team assures the quality of the data entered (SEI SOP 13: Processing SEI Discreet Field and Laboratory Data), processes logger data (SEI SOP 14: Processing In Situ Water Physiochemistry Loggers, SEI SOP 15: Processing HOBO Water Temperature Loggers), and processes all photographs taken by SEI field crews (SEI SOP 16: SEI Photo Management).

Lab data consist of water/sediment chemistry and benthos/periphyton analysis. The annual data entry and logger databases are linked and predefined quality control checks are conducted.

Before December, the data are certified and bundled into an annual archive (ROMN SOP: Archive Format Standards for Network Data). The SEI Master Database is updated so that all historical data can be queried, distributed, and reported. The entire information lifecycle is evaluated and adjustments are identified in preparation for the next field season.

Plan

The data manager is responsible for helping prepare field gear and databases as outlined in SEI SOP 1: Pre- and Post-Season Workflow. These tasks are a combination of technical tasks and quality control measures. At the start of the field season, an annual database is prepared for data entry, loggers, and photos.

Collect and Compile

There are five sources of data associated with the SEI protocol: field sheet, logger, GPS, lab, and camera. To accommodate the various formats of data input and quantities of information there are four annual databases and multiple file types maintained in a defined folder structure on a shared drive (Figure 38). The file and folder naming conventions used for all SEI files follow those outlined in ROMN SOP: Folder Structure and File Naming (specifics pertaining to SEI are also incorporated into the individual SEI SOPs).

Field Sheets

At the end of each day, the field crew reviews each data sheet to ensure all data fields are accurately and completely recorded. Upon arriving back in the office, the field sheets are turned in to the SEI Field QA box for additional quality review. Once the sheets have been thoroughly examined, they are turned in to the SEI Scan box. The data management team will scan the field sheets and place them into the SEI Data Entry box (SEI SOP 12: Field Sheet Scanning). The digital files will be named in accordance to ROMN SOP: Folder Structure and File Naming (e.g., *SEI_ROMO_S01L_20120629*) and saved in the Scans folder. One member of the data management team will enter the data from the field sheet into the data entry database and turn the paper field sheet in to the SEI Data QA box. A different member of the data management team will then assure the data were transcribed accurately. Refer to the SEI SOP 13: Processing SEI Discreet Field and Laboratory Data for detailed steps to accomplish the migration of data from the field sheets to the data entry database. After all data from the field sheet have been entered and reviewed, the paper is filed into the SEI filing cabinet. Hard copy documents from the data collected will be stored into perpetuity in areas that have the lowest possible risk as mandated by NPS Director's Order #11D: Records and Electronic Information Management (NPS 2012a), and the Records and Electronic Information Management (REIM) Guide: Preserving the NPS Legacy (NPS 2012b).

Field Instruments

Multi-parameter probes (also called "sondes"), loggers and other field instruments are used to measure *in situ* water physiochemistry and stream discharge and

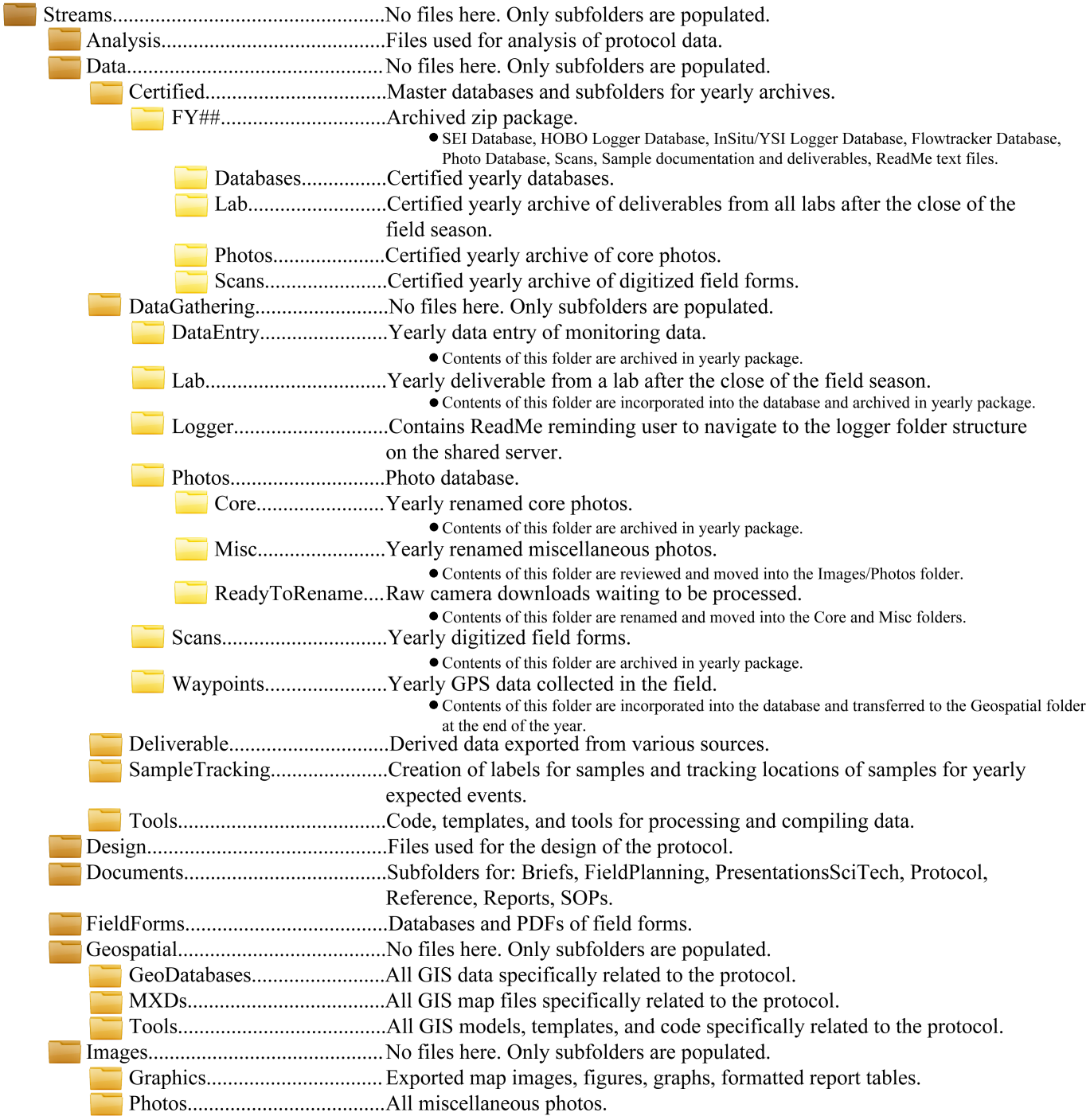


Figure 38. SEI folder structure on the shared drive.

temperature, using sonde stations. Field crews either download files onto a laptop computer in the field or remove and replace loggers from sites. Once the crew is back in the office, the files on the laptop or from loggers are loaded to an external drive and are transferred to the appropriate folder on the shared network drive without being renamed. SEI SOP 14: Processing *In Situ* Water Physiochemistry Logger and SEI SOP 15: Processing HOBO Water Temperature Logger provide detailed instructions on how to prepare the data for input into the annual logger databases. These data are saved on a shared network drive (Figure 39).

Global Positioning System (GPS) Devices

GPS devices are used to navigate to existing sites and document the precise location of

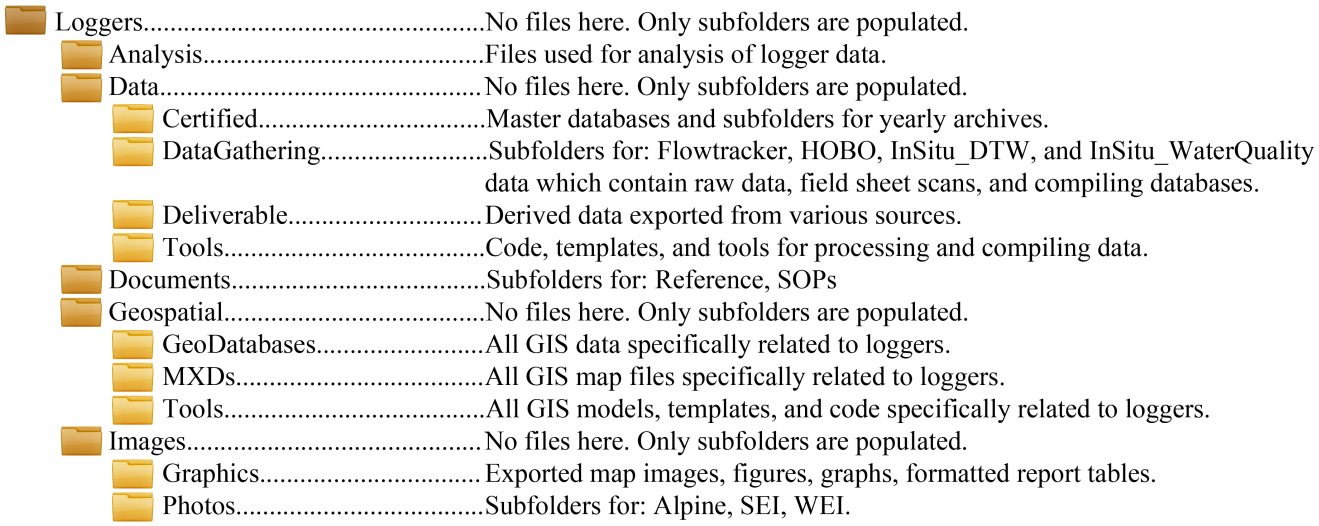


Figure 39. Logger folder structure on the shared drive.

new sites. Waypoints created during a season by field crews are episodically downloaded by data management staff using DNR Garmin and are saved in the Waypoints folder using a standard file naming convention (e.g., *SEI_ROMN_Waypoints_20120726*). At the end of the field season all waypoints are imported into the data entry database and used to update the *Lat_UTM_GPS* and *Lon_UTM_GPS* fields in the *tlu_Sites* table.

Lab Data

Water, sediment, benthos, and periphyton samples collected during monitoring are sent to various labs during or at the close of the field season. Currently, the University of Colorado Kiowa Lab (Boulder, CO) and the EPA Region 8 Lab (Denver, CO) analyze water sediment chemistry and quality samples and Rithron Associates (Missoula, MT) analyze benthos and periphyton samples. After a few months, each lab returns data as MS Excel files. The MS Excel files are formatted using a template in the *Tools* folder. The resulting file is named in accordance with the ROMN file naming standards (e.g., *SEI_ROMN_ProcessedDataKiowa_FY12_20130115*) and saved in the appropriate lab folder. The formatted data are appended to the corresponding "IMPORT" table in the ROMN SEI Database. *Event Names* are manually assigned to each lab record.

Field Photos

Photographs are taken in accordance with the requirements of the field procedures specified in the SEI protocol. When the field crew returns to the office, all photographs are downloaded to the *ReadyToRename* folder. The core photographs are renamed using the methods outlined in the SEI SOP 16: SEI Photo Management. After the files have been renamed, the core monitoring images and miscellaneous photos are separated into two respective folders. This will leave the *ReadyToRename* folder empty. The camera is cleared after the photographs have been downloaded.

Certify and Archive

The objective of SEI records management, data maintenance, and archiving procedures is to ensure that protocol data, analyses, products, and reports are easily accessible, shared, and properly interpreted by a broad range of users in perpetuity (NPS 2008).

After all monitoring data have been digitally compiled, multiple quality assurance tools are used to verify the logical consistency of the data. Each database has been equipped with a user interface to execute appropriate error reports. These reports are designed to identify missing data and data that are outside of conditional ranges of variability. The Protocol Lead and the data management team collaborate to address each data issue.

Event Names are assigned to the lab and logger records. Once all the data are in compliance with our data standards, the benthos and periphyton species lists are updated, and logger data are linked to the data entry database. These connections trigger the process of archiving each Yearly Master database. Each Yearly Master logger database is created with only SEI data and moved into the SEI folder structure.

All digital data acquired and derived are archived annually according to the procedures and standards in NPS National Data Management Plan and ROMN Data Management Plan (NPS 2007a, 2008). Archived data and products are normally stored along with supporting documentation in a format such as ASCII text that is independent of an operating system platform and software to maintain data integrity and accessibility. Refer to the ROMN SOP: Archive Format Standards for Network Data for details on how to package the data for the close of the season.

Disseminate

I&M networks are responsible for developing and deploying a method of data dissemination for each network protocol. The SEI Protocol requires the maintenance of five yearly and master databases: ROMN SEI, ROMN Water Quality, ROMN HOBO Water Temperature, ROMN SEI Photo, and ROMN Flowtracker databases. All lab deliverables associated with the SEI protocol are incorporated into the SEI Database as "IMPORT" tables. The data in each annual database is added to the corresponding master databases.

The outputs from the ROMN SEI Database are exported and used by ROMN ecologists in statistical packages such as R and Statistica. This enables ROMN ecologists to interpret monitoring data and produce documents for other products and park personnel (see the Reporting chapter in this document). The protocol, databases, and reports will be distributed to Integrated Resource Management Applications (IRMA).

ROMN is currently developing additional procedures to manage and disseminate data obtained from on-site continuous water quality, water temperature, and water flow rate stations; using the NPS Aquarius Web Portal and custom online data visualization tools.

Database Design

All ROMN databases are designed to ensure quality control, quality assurance, long-term data integrity, access, reporting, and storage. ROMN monitoring databases share a common object naming convention and relationship hierarchy which is detailed in the ROMN SOP: Database Design. The ROMN SOP: Database Design also outlines quality control standards used for each database. The database structures were designed to accommodate refinements as needed throughout the lifetime of the project. Changes will be documented and reflected in ROMN SOP: Database Design. Software platforms may be upgraded to a more robust database system (e.g., Microsoft SQL Server), as the information management needs of the network develop.

The database design and related procedures for all SEI databases are described below, and in the corresponding SEI SOPs

SEI data is managed using four database systems:

1. ROMN SEI Database – used to manage discrete field and laboratory data
2. ROMN Water Quality Database – used to manage continuous data obtained from *in situ* water physiochemistry logger stations
3. ROMN HOBO Logger Database – used to manage continuous HOBO water temperature logger stations
4. ROMN SEI Photo Databases – annual databases used to manage SEI field photographs and related metadata

ROMN SEI Database

The ROMN SEI Database is based on the standard MS Access NRDS design (NPS 2015c), created by the NPS Inventory & Monitoring Program, and contains all monitoring data spanning back to 2007.

Multiple MS Access versions of the working

SEI Database are maintained by ROMN.

1. The master working SEI Database, containing information for all sampling years, is stored on the local ROMN network drive at : *Z:\MONITORING\Streams\Data\Certified*
2. Separate working copies are maintained for data entry and QAQC. The ROMN SEI Database used for the current field season can always be found at stored at: *Z:\MONITORING\Streams\Data\DataGathering\DataEntry*
3. All versions of the ROMN SEI Database share the same basic schema (Figure 40).
4. More detailed information about da-

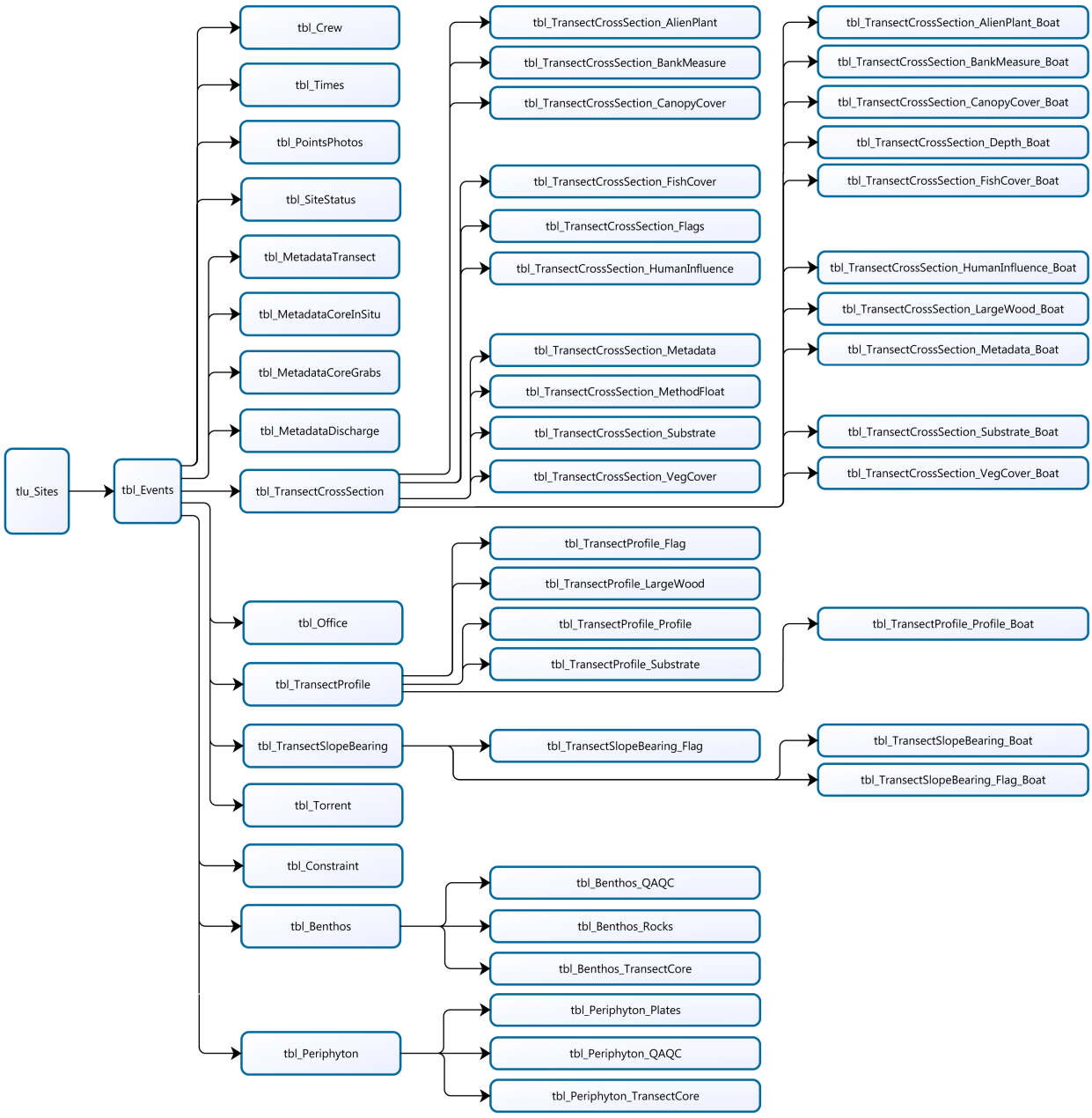


Figure 40. Basic ROMN SEI Database design.

tabase structure, tables, and fields can be found in SEI SOP 13: Processing SEI Discreet Field and Laboratory Data.

ROMN Water Quality Database

The ROMN Water Quality Database is the final destination for all data downloaded from on-site continuous In Situ water physiochemistry Sonde stations.

Multiple MS Access versions of the working ROMN Water Quality Database are maintained by ROMN.

1. The master working ROMN Water Quality MS Access Database, containing information for all sampling years, is stored on the local ROMN network drive at : *Z:\MONITORING\loggers\Data\Certified*
2. Separate working copies are maintained for data entry and QAQC. The ROMN Water Quality Database used for the current field season can always be found at stored at: *Z:\MONITORING\Loggers\Data\DataGathering\In SituYSI_WaterQuality*
3. All versions of the ROMN Water Quality Database share the same basic schema (Figure 41).
4. More detailed information about database structure, tables, and fields can be found in SEI SOP 14: Processing *In Situ* Water Physiochemistry Loggers.

ROMN HOBO Water Temperature Database

The ROMN HOBO Water Temperature Database is the final destination for all data downloaded from on-site continuous water temperature stations.

Multiple MS Access versions of the working ROMN HOBO Water Temperature Database are maintained by ROMN.

1. The master working ROMN HOBO Water Temperature Database, containing information for all sampling years, is stored on the local ROMN network drive at : *Z:\MONITORING\loggers\Data\Certified*
2. Separate working copies are maintained for data entry and QAQC. The ROMN HOBO Water Temperature Database used for the current field season can always be found at stored at: *Z:\MONITORING\Loggers\Data\DataGathering\HOBO*
3. All versions of the ROMN HOBO Water Temperature Database share the same basic schema (Figure 42).

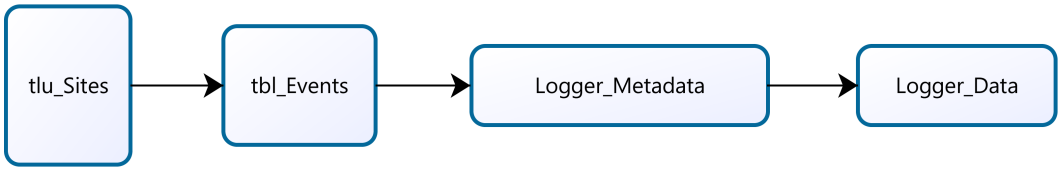


Figure 41. Basic ROMN Water Quality Database design.

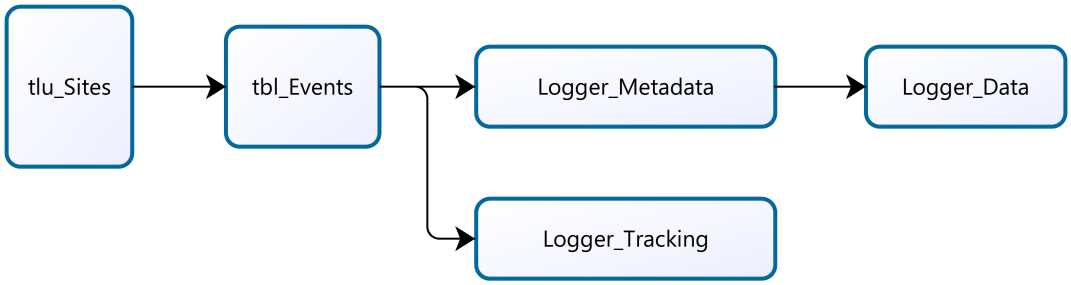


Figure 42. Basic ROMN HOBO Water Temperature Database design.

4. More detailed information about database structure, tables, and fields can be found in SEI SOP 15: Processing HOBO Water Temperature Loggers.

ROMN Flowtracker Database

The ROMN Flowtracker Database is the final destination for all data downloaded from on-site continuous water temperature stations.

Multiple MS Access versions of the working ROMN Flowtracker Database are maintained by ROMN.

1. The master working ROMN Flowtracker Database, containing information for all sampling years, is stored on the local ROMN network drive at : *Z:\MONITORING\loggers\Data\Certified*
2. Separate working copies are maintained for data entry and QAQC. The ROMN HOBO Water Temperature Database used for the current field season can always be found at stored at: *Z:\MONITORING\Loggers\Data\DataGathering\Flowtracker*
3. All versions of the ROMN Flowtracker Database share the same basic schema (Figure 43).
4. More detailed information about database structure, tables, and fields can be found in SEI SOP 19: Processing Flowtracker Loggers.

ROMN SEI Photo Databases

ROMN SEI Photo MS Databases are used to manage digital field photographs, and related metadata, taken by field staff at SEI monitoring locations.

One ROMN SEI Photo Database is maintained for each sampling year.

1. The ROMN SEI Photo Databases for the previous years are stored on the ROMN network drive at: *Z:\MONITORING\SEI\Data\Certified\FY##\Photos*
2. The working SEI Photo Database for the current year is stored at: *Z:\MONITORING\Streams\Data\DataGathering\Photos*
3. All versions of SEI Photo Database share the same basic schema (Figure 44).

More detailed information about database structure, tables, and fields can be found in SEI SOP 15: SEI Photo Database.

Data Standards

We intend to meet the following standards for all data collected and received for SEI monitoring as a basis for scientific credibility (US DOI 2007): 1) qualitative accuracy, 2) completeness, 3) consistency, 4) precision, 5) timeliness, 6) uniqueness, and 7) validity. To facilitate convergence with these standards,

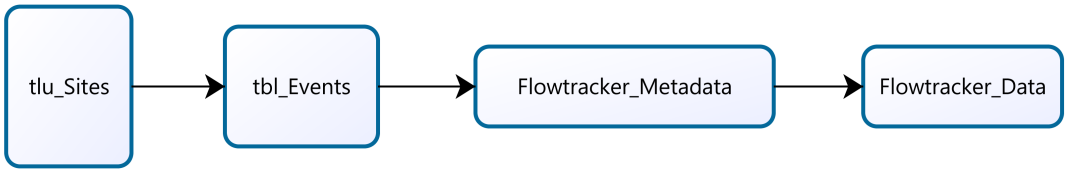


Figure 43. Basic ROMN Flowtracker Database design.

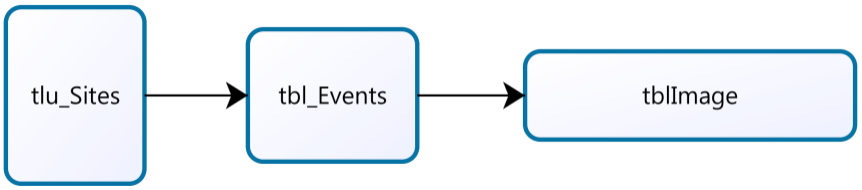


Figure 44. Basic ROMN SEI Photo Database design.

we will use quality control measures and documented quality assurance measures to facilitate the local data management. Data qualifiers will be reported with results to inform readers of important restrictions or limitations to the data.

All data are acquired in or converted to a format compatible with Microsoft Access. As the protocol and program matures, data storage and analyses requirements may be met by migrating to Microsoft SQL Server.

Summarized and derived data are also managed, organized, documented, and distributed as part of the project. These information resources include summary tables in Access, spreadsheets, spatial databases, R scripts, textual outputs from analytical procedures, images, graphics, and reports. Each generated data set or product meets the standards for format, quality, organization, and maintenance as set forth in the applicable NPS data management plans (NPS 2007a, NPS 2008).

Quality Assurance and Quality Control

The data manager and the Protocol Lead coordinate to develop measures of Quality Assurance and Quality Control (QAQC) throughout the lifecycle of the protocol (Figure 45). The ROMN SEI Quality Assurance and Performance Plan (QAPP; SEI SOP 19) details QAQC for laboratory and field data generated by the SEI protocol. Oversight during field data collection and data entry enforce quality, standardization, and completeness of all data collected. The data manager is responsible for ensuring the quality control measures and quality assurance review queries are implemented. Due to the nature of the lab data, the Protocol Lead is responsible for quality assurance of lab data received from a contract lab. Each lab also has internal quality control standards that meet or exceed all standards required by ROMN for sample analyses.

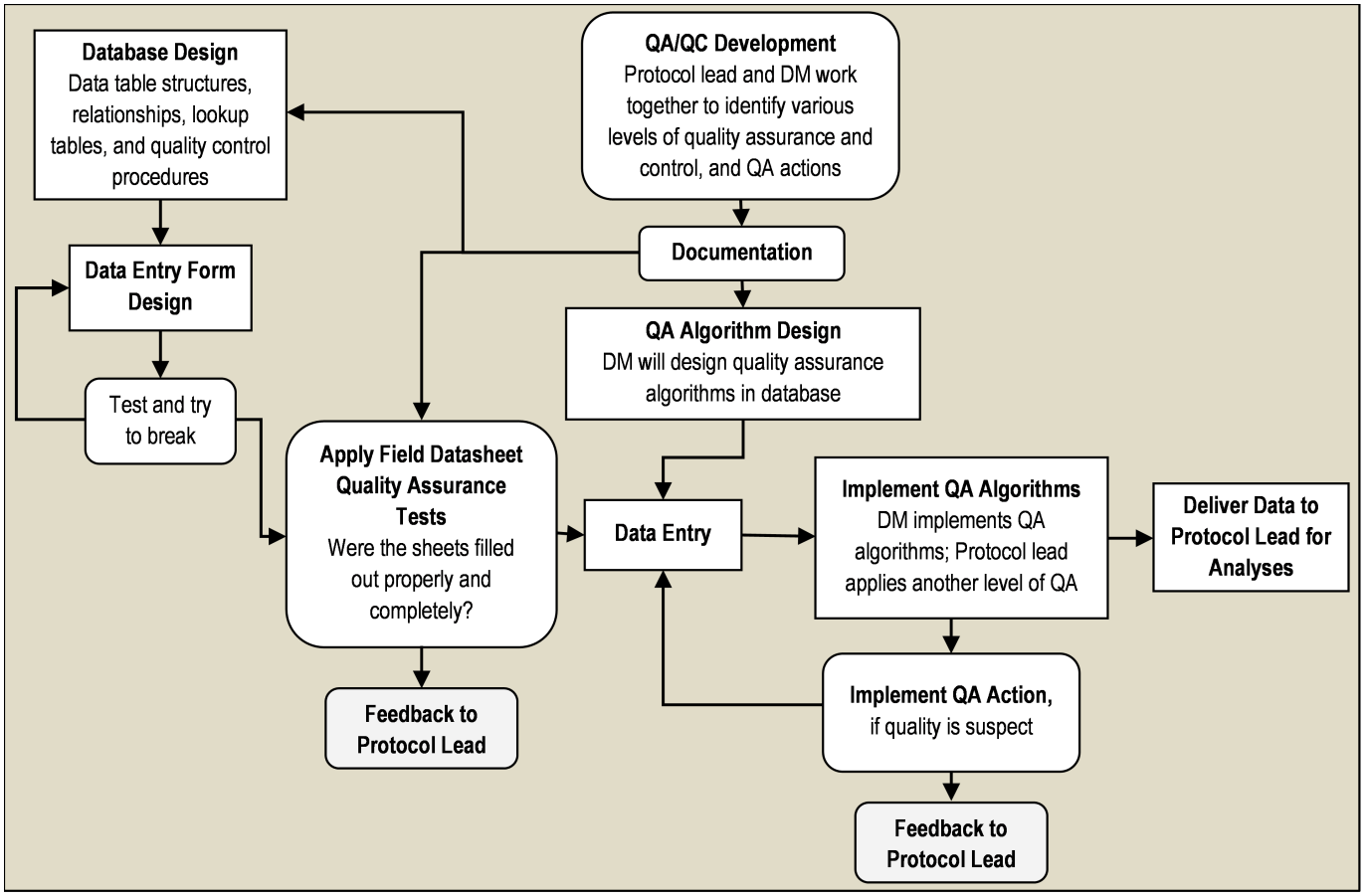


Figure 45. Quality assurance and control workflow.

Sensitive Data Management

National guidance for sensitivity restricts general public accessibility to data determined to be sensitive by park management (NPS 2007a). The SEI protocol follows these guidelines for managing sensitive information and contains measures for identifying and flagging sensitive data. Furthermore, the SEI protocol provides means for collecting data that will not jeopardize sensitive resources. Finally, ROMN staff will consult with ROMN park resource managers before sharing SEI data and information that is potentially sensitive (e.g., regarding rare or sensitive species or potential importance for pending litigation).

Data Storage and Archiving

Data storage and archiving for all SEI digital files follow the ROMN SOP: Folder Structure and File Naming, and ROMN SOP: Archive Format Standards for Network Data. Data storage and archive specifics pertaining to SEI data files are described here and are also incorporated into the SEI SOPs.

All working and archived digital files used by the data management team: databases, scanned field sheets, In Situ logger files, HOBO logger files, and digital photographs; are found on the local network ROMN TeamShare drive at (always mapped as drive: *Z:*\):

inp2300fcvTUMA1\TeamShares\ROMN\

There are two independent backup regimes to help safeguard files stored on the ROMN TeamShare drive:

1. NPS IT specialists at the National Information Services Center backup everything on the network TeamShares environment using the following schedule:
    a. Full backups are performed each Friday at 3 PM, and saved to both disk and tape.
    b. Incremental backups are performed at 3 PM Monday-Thursday, and are also saved to both disk and tape.
    c. A copy of all tape backups for each week are maintained for three years
2. The ROMN data manger manages a separate backup system using two external backup drives, where each week:
    a. One external hard drive containing the backup files from the previous Friday afternoon is kept off site (right now, at the ROMN data manger's home).
    b. One external hard drive is kept in the ROMN offices and is used to perform a nightly mirror backup of the files on the ROMN TeamShare drive.
    c. Each Friday afternoon, the data manager:
        i. Runs a final mirror backup using the external hard drive that has been in the office.
        ii. Switches the external hard drive connected to the office computer with the one that was stored off site during the past week and runs another mirror backup to the new drive.
        iii. Randomly checks a handful of PDF files, image files, and MS Access databases (WEI and HOBO data logger databases) for potential corruption issues on both external hard drives.
        iv. Takes the external hard drive from the current work week home for safekeeping.

SEI Data Management Roles and Responsibilities

Successful data management involves overlapping and shared responsibilities among all project staff over the entire monitoring lifecycle. Network personnel collectively develop, follow, and document standards for information needs, data quality, analytical inputs and outputs, data processing procedures, and reporting requirements to meet the stated objectives of the protocol. Refer to Table 23 for a complete list of the information management tasks and identification of the responsible ROMN staff member.

Table 23. SEI data management roles and responsibilities.

Order	Task	Role
1	Make revisions to field sheets, database structure, and database interfaces	Data Management Protocol Lead
2	Determine what sites will be visited and assign event names	Field Crew Leader Protocol Lead
3	Upload GPS points	Data Management Field Crew Leader
4	Print maps and field sheets	Data Management
5	Print and apply sample labels and organize bottles	Data Management
6	Collect data, QA field sheets, turn in field sheets, upload all electronic data to the shared drive (e.g., GPS, camera, logger)	Field Crew Leader Field Crew
7	Scan, enter, and QA data	Data Management
8	Archive digital and paper data sheets (e.g., follow naming convention for digital files and store in assigned place on shared drive and file papers in SEI cabinet)	Data Management
9	Identify unknown species and archive specimens following the species handling SOPs	Field Crew Leader Protocol Lead
10	Process logger data and import the data into the appropriate yearly logger database	Data Management
11	Update the site lookup table with the most recent GPS data	Data Management
12	Rename photos using the SEI photo database	Data Management
13	Send all samples to the lab and save the lab deliverable on the shared drive	Field Crew Leader Protocol Lead
14	Format all lab data and import into the yearly SEI database	Data Management
15	Assure the quality and completeness of the logger, lab, and field data	Data Management Protocol Lead
16	Certify and archive yearly logger and field data databases and ensure the link between the yearly field database and the logger databases	Data Management
17	Import new data into the master logger and SEI field data databases	Data Management
18	Run summary macros for analytical inputs and conduct analysis	Protocol Lead
19	Determine whether there are sensitive data	Program Manager Protocol Lead in consultation with park resource management staff
20	Write and publish SEI report	Protocol Lead

Analysis

By design, ROMN SEI monitoring is information rich, with many possible analyses. Distilling the large amounts of information from SEI monitoring into meaningful reports is a major challenge. Results must provide an evaluation of the status and trend in stream condition and include timely information useful to park natural resource managers.

In this section we provide an outline of the major types of analyses conducted to meet SEI objectives. Details will be given in SEI SOP 17: Data Analysis in a future update to this protocol.

Overview

The analysis phase of SEI monitoring begins with the delivery of fully quality assured data from ROMN data management (see the Data Management section above) to ROMN ecologists and/or collaborators. The QAQC steps conducted by ROMN data management are largely automated and include checking for data entry errors, logical issues in allowed data values, identifying missing values, and any other problems related to data management procedures and the data-entry process. ROMN ecologists are heavily involved in the QAQC conducted by data management (for example in establishing proper or expected ranges in a measure). Of note, often more subtle issues with data QAQC are not noticeable until analyses are conducted that reveal values that do not make ecological sense.

Once a quality-assured dataset is available, a series of steps including metric estimation, various models, and hypotheses tests follow as discussed below. All analyses, indirectly or directly are structured to address or support SEI monitoring objectives. The ROMN analytical strategy also incorporates feedback with park management and protocol review for purposes of improving efficiency (e.g., modifying sample sizes or response measure selection to lower costs or enhance precision).

The Importance of Sample Design

The form of any analysis, its detail and its inferential capacity follows from the sample design used to collect data. Most importantly, survey design derived data may utilize design-based techniques that allow status estimates to be applied to (all or most depending on the design) non-sampled wetland in a park with known confidence (Olsen et al. 1999). Yet, if treated as a simple random sample, survey data also satisfy many of the assumptions of classic, model-based statistical methods. Moreover, because GRTS samples are spatially balanced, they may also meet the assumptions of geospatial techniques. Sentinel site data analyses are restricted to model-based approaches that generally only allow valid inference to the site or immediate supporting stream reach. However, because sentinel sites will have a much greater sample frequency than surveys, linear model-based trend analyses are possible. Finally, analyses of gradient site data are also restricted to model-based approaches. Given the (usually) single or few sample events at these sites, analyses of gradient data are generally only used in developing bioassessment models.

Measures and Metrics

Multiple types of data are collected with each full SEI sample event. These include both indicators of stream response to disturbance and those that are predictors or drivers of response (although many might arguably fall into both of these groups). SEI data may be grouped in to measures which we define as raw data, used in analyses directly as is from the field (measures also include data generated by lab analyses). Another type of important information created within the SEI protocol is a metric derived from measures using various kinds of models or statistical procedures. Metrics include (as an example) output from bioassessment models that use the occurrence (and sometimes relative abundance) of taxa in a sample, weighted by scores based on autecological attributes (e.g., physiological requirements or tolerances of a taxon to a specific environmental condition, such as change in hydrologic regime, sediment load-

ing, nutrient conditions, trophic status, or more generally, overall condition at a sample site). Ideal metrics describe characteristics that change in predictable ways with wetland condition (usually anthropogenically driven; Barbour 1999). In some cases, the process of generating metrics is involved and will require several years of data and research to complete. Table 24 presents examples of measures and metrics grouped by objective.

Water and Sediment Physiochemistry

SEI physiochemistry data are analyzed and interpreted directly with no metrics planned. However, water chemistry results from laboratories often do include "non-detects" or values below the ability of a given lab's capacity to accurately resolve and we use a regression on order statistics (ROS) imputation method from Helsel (2005) to estimate these values.

Biology

Most SEI biological data are summarized into metrics before analysis. Some of the more important metrics generated by the SEI protocol are derived from bioassessment modeling that include multimetric models (MMI, also known as an Index of Biotic Integrity) and a multivariate approach known as River Invertebrate Prediction and Classification (RIVPACS). For diatoms, we also generate "increaser metrics" that offer a diagnostic bioassessment of specific stressors such as sediment or metals. At the time of this protocol publication, MMI, RIVPACS and increaser metrics developed by the MT DEQ (Jessup et al. 2006; Teply 2010a,b; MT DEQ 2012c) had been applied to data from ROMO, GRKO, and LIBI (Schweiger et al. 2014 a, b; Schweiger et al. In Review).

Multimetric

MMI models combine multiple characteristics of an assemblage that change in predictable ways with human disturbance that alters environmental conditions. MMIs synthesize data from multiple levels of biological organization with the goal of deriving a single index that reflects the overall effects of human disturbance on stream condition. They have a long history of successful use in bioassessment.

In addition to applying existing MMI models developed by a State, at the time of this protocol publication we were also developing specific park-scale MMI models for ROMO using methods developed within the ROMN stream protocol (Schoolmaster et al. 2012, 2013a, b; Grace et al. 2012). These methods generate the optimal number of component metrics within an MMI and correct for correlations among component metrics and with important environmental gradients that might also structure macroinvertebrate communities. The algorithms use information-theoretic principles that result in MMIs that are highly predictive. Most importantly, the models are scaled to the disturbance and environmental gradients specific to a park like ROMO and are thus reflective of conditions relevant to park management.

RIVPACS

RIVPACS models (Hawkins et al. 2000; Van Sickle 2008) use the taxonomic completeness of a sample as an indicator of the ecological condition or quality of a site. Taxonomic completeness is a fundamental aspect of ecological integrity and is defined as the proportion of the taxa that *should* occur in a sample (or the expected; "E") that were *actually sampled* (the observed; "O"). The accuracy and precision of a RIVPACS assessment depends on the quality of the model used to predict the taxa expected (E) to occur in a sample collected from an individual site. These models describe the probability of sampling a given stream taxa across naturally occurring environmental gradients. 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. The model is built such that the taxa occurring in the reference sites are used to predict taxa that are expected to occur in sites with similar environmental characteristics. Sites that are environmentally similar to a reference group are expected to have

Table 24. Example SEI response metrics by objective.

Objective	Measures or Metrics* (Examples)	Units
Determine the status and trend in stream condition using a suite of **macroinvertebrate diatom-based** metrics.*	Species occurrence (frequency, presence /absence) of "key" taxa (i.e., invasives, endemics, etc.)	%, categorical
	Species richness by life history or functional group (total, native taxa, invasive taxa, etc.)	Count
	Taxonomic diversity (multiple types of indices)	Unitless or various
	Evenness (multiple types of indices)	Unitless or various
	Macroinvertebrates, Karr Benthic Index of Biotic Integrity	Unitless
	Macroinvertebrates, Hilsenhoff Biotic Index	Unitless
	Macroinvertebrates, Fine Sediment Biotic Index	Unitless
	Macroinvertebrates, Temperature Index	°C
	Macroinvertebrates, Metal Tolerance Index	Unitless
	Percent Ephemeroptera, Plecoptera, and Trichopetera (EPT)	%
	Macroinvertebrates, Percent Chironomidae	%
	Macroinvertebrates, Percent Crustacea and Mollusca	%
	Macroinvertebrates, Shredder Taxa Richness	Count
	Macroinvertebrates, Percent Predator	%
	Diatoms, Sediment Increasers, Middle Rockies	% or probability
	Diatoms, Nutrient Increasers, Mountains/Foothills	% or probability
	Diatoms, Metal Increasers, Mountains/Foothills	% or probability
	Diatoms, Siltation Index	Unitless
	Diatoms, Pollution Index	Unitless
	Diatoms, Disturbance Index	Unitless
	Multimetric Index (ecoregion, state- or park-scale model)	Unitless
	Observed:Expected and Bray-Curtis Indices from RIVPACS model (ecoregion, state- or park-scale model)	Unitless
Determine the status and trend in stream condition via **water and sediment chemistry.****	Temperature, water	°C
	pH	s.u.
	Dissolved Oxygen	mg/l, %
	Oxygen	mg/L
	Sulfate	mg/L
	Chloride	mg/l
	Ammonia	mg/L
	Nitrite + Nitrate	mg/L
	Nitrite	mg/L
	Phosphorous	mg/l
	Chlorophyll a in periphyton	mg/m^2
	Zinc	µg/L
	Arsenic	µg/L
	Copper	µg/L

* Many other bioassessment metrics are calculated within these and other categories; these are just examples.

**There are about 60 parameters included in the SEI protocol; these are just examples

Table 24. Example SEI response metrics by objective, cont.

Objective	Measures or Metrics (Examples)	Units
Determine the status and trend in stream condition via physical habitat.*	Mean Residual Depth	log
	Coefficient of Thalweg Depth Variation	Unitless
	Volume of Woody Debris per m2 of bankfull channel area	m^3/m^2
	Areal Cover of Woody Debris, Brush, Undercut Banks, Overhanging Vegetation	%
	Areal Cover of Aquatic Macrophytes	%
	Pool density (m of residual pool per m of sampled stream)	m
	Streambed Sand & Finer (<2 mm)	%
	Substrate Embedded by Sand and Fines (wadeable streams only)	%
	Deviation of % Streambed Silt & Finer from expected ("excess Fines")	log
	Relative Bed Stability (mean bed particle diameter/critical (mobile) diameter at bankfull)	log
	Channel Sinuosity	log
	Incision from terrace to bankfull height	m
	Bankfull Width/Depth Ratio	log
	Low flow/annual mean runoff (inverse index of "droughtiness")	log
	Bankfull depth/wetted depth (a morphometric index of "flashiness")	log
	Canopy Density (measured at the bank)	%
	Riparian Canopy+Mid+Ground Layer Vegetation	%
	Riparian & near-Stream Rowcrop Agriculture (prox. weighted index)	Unitless
	Riparian/Near-Stream Walls, Dikes, Revetment (prox. weighted index)	Unitless
	Human Disturbances of All Types (prox. weighted inverse index)	Unitless
	Riparian vegetation alteration (prox. weighted inverse index)	Unitless
	Frequency of individual Invasive Plants	%
	Hydrograph-based metrics for sites with gauges and a long-term record of discharge: Annual total discharge, Annual mean discharge, Highest annual mean, Lowest annual mean, Highest daily mean, Lowest daily mean, Maximum peak flow, Annual seven-day minimum , Annual seven-day maximum, Number of Days to Snowmelt Onset, April, May, June, July discharge as a percent of the total annual discharge, Number of Days from Oct 1 to the Runoff Center of Mass, Monsoon timing	Various (cm, days)

*Many other habitat metrics are calculated; these are just examples.

the taxa that occur in that group to the same degree as their environmental similarity, defined by the probability of class membership. The prediction of expected taxa and observation of those taxa actually occurring in the sample allows calculation of the degree to which a site is attaining its potential in biological diversity. This calculation is observed taxa (O) over expected taxa (E). Values of the ratio, O/E, theoretically can range from zero to one, with values of one implying reference conditions, and values less than one implying biological impairment.

The Bray Curtis (BC) dissimilarity metric may be also generated from RIVPACS models and has some advantages over O:E. MT DEQ (2012c) recommends using both indices. In particular, the BC index facilitates determining if expected reference taxa are being replaced by more tolerant taxa (i.e., indicative of a non-reference state); often O:E may just indicate an increase in taxa diversity. O:E is relatively insensitive to stress-induced shifts in taxonomic composition that have little net effect on the number of reference-site taxa (Hawkins et al. 2000; Davies and Jackson 2006). The BC index is most useful whenever a high (i.e., good) O:E score results from a sample collected from a known stressed stream.

MT DEQ (2012c) develops RIVPACS models for cold water mountain streams macro-

invertebrates. These have been successfully applied to pilot data from ROMO. At the time of this report publication, we had also begun development of novel, park-scaled RIVPACS models focused on climate change driven changes in stream temperature, sediment and other drivers of stream condition within the park. The methods developed for the park-scale ROMO models will also likely have broader applicability in other ROMN parks.

Other Macroinvertebrate Metrics

There are many "classic" metrics used in monitoring by several agencies over the last decade or two. These include other MMI like models, but with different scoring criteria and component metrics.

The Karr Benthic Index of Biotic Integrity (B-IBI) is an MMI developed at a regional scale that has shown a surprising degree of applicability to assessments across a broad variety of stream types (Karr 1998). Karr is considered the seminal author on the MMI approach and the B-IBI model has received much review and use. The theoretical scale of the index is 0 to 100 with higher values indicating more impaired or disturbed communities.

The Hilsenhoff Biotic Index (HBI) is another regionally-scaled metric that has demonstrated a broad degree of applicability in bioassessments. It was originally intended as an assay of low dissolved oxygen caused by organic loading (Hilsenhoff 1987), but it may be sensitive to the effects of impoundment, thermal pollution, and some types of chemical pollution (Hilsenhoff 1998, Hooper 1993). It is similar to many other tolerance indices discussed below in that tolerance values are developed for taxa and then applied as weighted sums based on occurrence within a sample. MT DEQ adjusted HBI tolerance scores for taxa in Montana and the HBI actually appears as a constituent metric in both the current and historic mountain MMI (Bukantis 1998; Jessup et al. 2006) used in ROMO. However, in Montana's montane foothills (where GRKO occurs), the HBI was demonstrated to be significantly associated with conductivity, pH, water temperature, sediment deposition, and the presence of filamentous algae (Bollman 1998). The theoretical scale of the index is 0 to 10 with higher values indicating communities more tolerant of organic pollution. Thresholds in the HBI metric (which increase with organic pollution) are largely derived from professional judgment and have no formal meaning with MT DEQ.

The Fine Sediment Biotic Index (FSBI; Relyea et al. 2000) is based on tolerance scores for macroinvertebrates in Montana. FSBI increases with sediment intolerance (higher scores will contain more taxa that are intolerant to increased sediment or fines), with threshold levels set by professional judgment (Relyea et al. 2000). The theoretical scale of the index is 0 to 10 with higher values indicating communities more tolerant of fine sediment. MT DEQ does not use the FSBI in any formal way. Moreover, assessing differences between natural levels of bed load sediment and anthropogenically increased levels may be difficult given fine scale spatial structure in stream habitat (Relyea et al. 2000). Bollman and Bowman (2007) suggest the index has promise as a screening filter for characterizing site sediment impairment.

The Metal Tolerance Index (MTI) metric quantifies changes in community composition attributable to metals pollution. The format and calculation is similar to the HBI (see above), with tolerance values assigned to each taxon based on sensitivity to metals rather than organics. The theoretical scale of the index is 0 to 10 with higher values indicating communities more tolerant of metals pollution. McGuire (2010) suggests that MTI values for communities dominated by species intolerant of metals are less than 4 while values for communities composed of only the most metals-tolerant species approach 10. Metals tolerance values for most taxa were developed from Ingman and Kerr (1989) and McGuire (1987, 1989).

Diatom Increaser Metrics

We adopt the State of Montana's current approach to bioassessment using stressor-specific increaser diatom taxa, as described in Teply (2010a,b). Briefly, increaser taxa were identified from a large sample of sites across the state of Montana with known impair-

ments. Taxa that, as a group, exist in detectable amounts and demonstrate a meaningful, measurable and significant response to sediment (in the Middle Rockies) or nutrients and sediment (in the Northern Great Plains) were identified on a specific list based on stream groups (derived using the MT DEQ fisheries classification and level III and level IV ecoregions following the same structure as the MT DEQ nutrient assessment methodology). Discriminant analysis was then used to evaluate the ability of the total percent relative abundance (PRA) of taxa on the Increaser Taxa list to discriminate between impaired and non-impaired streams, and to provide a probability of impairment for a given PRA. A single threshold set by MT DEQ at ≥51% suggests the probability of impairment for sediment or nutrients (MT DEQ 2011). Increaser models in Teply and Bahls (2005, 2006) were created using a similar process. Teply and Bahls (2005) develop nutrient increaser models at a fairly coarse scale (mountains and plains). The model has a lower accuracy (~50%) than the current sediment model. We use Teply (2010a) for sediment and Teply and Bahls (2005, 2006) mountain models for metals and nutrient increasers. We are exploring similar models for ROMN parks in Colorado.

Other Diatom Metrics

Bahls (1993) developed a suite of diatom metrics for MT DEQ based on common community-level measures, species autecology or tolerance scores of groups of diatom species. Diatom species tolerances used in these metrics follow Bahls (2004) and are specific to Montana. Metrics included Shannon diversity, a Pollution Index (a composite numeric expression of the pollution tolerances assigned by Lang-Bertalot (1979) to common diatom species), a Siltation Index (sum of the percent abundances of species in the genera *Navicula*, *Nitxschia*, and *Surirella*; predominantly motile taxa that are able to maintain their positions on the substrate surface in depositional environments), and a Disturbance Index (percent abundance of *Achnanthes minutissima*, which resists chemical, physical, and biological disturbances in the form of metals toxicity, substrate scour by high flows and fast currents). The metrics were intended to allow an assessment of the biological integrity of streams within plains and mountain bioregions. Thresholds were derived based on the distribution of metric values measured in least-impaired reference streams (Bahls 1993) and metric values measured in streams that are known to be impaired by various sources and causes of pollution (Bahls 1993).

Structural Equation Modeling: Connecting Bioassessment Metrics to Cause

MMIs and RIVPACS models can provide condensed summaries of condition, but may fail to provide frameworks for interpreting the specific effects of human activities and other stressors on particular ecosystem responses. This is the case despite the fact that both conceptual understanding and adequate data usually exist for developing such frameworks. Without developing frameworks for interpreting the connections between environmental condition and ecosystem response, a capability for suggesting human conservation steps to protect natural resources are not developed. To tackle this problem, as part of the ROMN stream protocol we first developed a next-generation methodology for structural equation modeling (SEM) so we can maximize the extraction of useful interpretations from bioassessment data (Grace et al. 2012). SEM is a methodology designed for representing and evaluating complex causal hypotheses about systems. Its most distinctive strengths relate to an equational form that permits the representation of causal networks of relationships in contrast to conventional statistical models, which are only descriptive. SEM has great potential utility for helping ROMN and our partners learn about the mechanisms controlling stream condition and trend.

As this protocol publication date, we were implementing a new synthesis of SEM that generalizes the equations to permit any form of response (Gaussian or non-Gaussian) and any form or linkage (linear or nonlinear). Further, we increased use of the prediction equations that emerge from SE models for applied purposes. These purposes include both retrospective analyses, such as attribu-

tion of current system properties to previous conditions, as well as prospective analyses that forecast future states, either under constant conditions or under modified conditions.

Physical Habitat

A large number of raw physical habitat measures collected during a full SEI sample event are summarized into synthetic metrics and expressed at the sample reach scale (for select example, see Table 24). SEI habitat sampling within a reach is systematic and this feature lends itself to calculating representative summaries of habitat characteristics. Habitat metrics include simple summaries of raw data, areal cover estimates from cover class data, proximity weighted estimates, and more detailed specific approaches for calculating woody debris abundance, residual pool characteristics, sinuosity, and bed stability. Over 100 habitat responses collected in the field are reduced to dozens of metrics.

Using the Climate Data Summarizer (Walking Shadow Ecology 2012) or custom R code, we create hydrographs by water year with data from USGS gauges associated with SEI sentinel sites. These figures include discharge during the water year, the median discharge over the historic period of record, and the midpoint of the annual discharge for these two time intervals. We also develop a suite of hydrology metrics for sites with associated USGS gauges including total discharge across each water year, maximum flow, the date of maximum flow, annual median flow, etc. (see Table 24)

Human Disturbance Index

We estimate gradients in anthropogenic disturbances to streams in GLAC and ROMO using a Human Disturbance Index (HDI) that combines multiple measures of anthropogenic disturbance potentially impacting condition at a site. Table 25 presents the variables used in estimating the ROMO HDI. Most variables are also used by MT DEQ, CDPHE or EPA in similar composite disturbance indices. We recognize that some may only be marginally relevant to ROMO (i.e., Toxic Release Inventory or Point Discharge Site Densities). We include them for comparability to other programs and for the future possibility that anthropogenic disturbances in or near the park change (i.e., mining in the North Fork of the Flathead). The index is constructed by scoring each SEI site for each variable and then averaging across these scores. Scores are the percent deviation from a reference value threshold for each variable scaled such that the deviation decreases with increasing condition or less disturbance at the site (the HDI ranges from ~0 to ~1, with anthropogenic disturbance increasing as values approach 1). Note that our approach differs from some other programs that have an all-or-nothing approach where a site that is non-reference for any variable is classified as a whole to be non-reference (MT DEQ calls this the "Anna Karenina principle").

Biological response at SEI sites is not used in estimating the HDI to avoid circularity or any preconceived notions about the expected structure and composition of biotic assemblages in a reference or disturbed state (Bailey et al. 2004). Following Stoddard et al. (2006), the overall goal of this method is to define and describe a gradient in disturbance, especially where there is minimal human disturbance (e.g., low HDI scores). This gradient in disturbance can be used as a continuum or it can be used to classify sites in the park into discrete classes (reference and non-reference).

Analyses for Status

We define status as a "snap shot" evaluation of a SEI response at single point or well-defined and concise range in time (Britten et al. 2007). SEI status-based objectives have been defined for all ROMN SEI parks. Status may be estimated for the target population scale using survey data and design-based analyses (see below) or with sentinel site data (in which case the results apply only to the target population of the sentinel site in lieu of complex models or assumptions). Status can be estimated using either measures or metrics and a variety of statistics (e.g., means or proportions) and statistical methods. Note that if trend is present in a response, it may need to be controlled for in status estimates. Status will almost always have a measure of precision (e.g., a confidence interval, stan-

Table 25. Example disturbance variables and their thresholds used for developing a composite Human Disturbance Index in GLAC.

Measures	Threshold	Units	Relation to Increased Human Disturbance	Notes	Source
Total Phosphorous	<0.01	In water, mg/l	Increases	Site/event scale	Stoddard et al. (2005)
Total Nitrogen	<0.125	In water, mg/l	Increases	Site/event scale	Stoddard et al. (2005)
Chloride	<7.1	In water, mg/l	Increases	Site/event scale	Stoddard et al. (2005, 2006)
Sulfate	<9.6	In water, mg/l	Increases	Site/event scale	Stoddard et al. (2005, 2006)
pH	<9	In water, su	Varies	Site/event scale	Stoddard et al. (2005)
Specific Conductance	<500	In water, us/cm	Increases	Site/event scale	Stoddard et al. (2006)
Total Metals in Water**	[MTDEQ criteria]	µg/l	Increases	Site/event scale	MT DEQ (2010)
Riparian Disturbance***	>0.74	Riparian, Index	Decreases	Site/event/meso-scale	Stoddard et al. (2005)
Relative Bed Stability****	F*: >-1.1; A*: <-0.4	Channel bedform, Index	Varies	Site/event scale	Stoddard et al. (2005)
Percent Fines	<15%	Channel bedform, %	Increases	Site/event scale	Bryce et al. (2010), Stoddard et al. (2005), MT DEQ (2005)
Natural Fish Cover	>34%	In-channel cover,%	Decreases	Site/event scale	Stoddard et al. (2005)
Stream Canopy Density	>50%	Riparian,%	Decreases	Site/event scale	Stoddard et al. (2005)
Embeddedness	<25%	Channel bedform,%	Increases	Site/event scale	MT DEQ (2005)
Agricultural Land Use	<29%	% of catchment	Increases	Catchment; NLCD/VegMap Attila	Wang et al. (1997), MT DEQ (2005)*
Urban Land Use	<4%	% of catchment	Increases	Catchment; NLCD/VegMap Attila	Wang et al. (1997)
Percent Natural Vegetation	>36%	% of catchment	Decreases	Catchment; NLCD/VegMap Attila	Wang et al. (1997)
Road-Stream Crossing	<0.6	Number per unit area in catchment	Increases	Catchment; NHD/TIGER Attila	Wang et al. (1997)
Road Density	<0.6	Number per unit area in catchment	Increases	Catchment; TIGER Attila	Wang et al. (1997), MT DEQ (2005)*
Phosphorous Load	<25	kg/km^2/year in catchment	Increases	Catchment; NLCD/VegMap Attila	Wang et al. (1997)
Nitrogen Load	<2.7	kg/km^2/year in catchment	Increases	Catchment; Attila/Baron Models	Baron (2006), Aldous (2002)
Human Population Density	<50	Number per km^2 catchment	Increases	Catchment; Census	Wang et al. (1997)
Percent Impervious Surfaces	<10	% of catchment	Increases	Catchment; NLCD/VegMap Attila	Wang et al. (1997)
Abandoned Mine Density	<0.01	Number per 10k km^2 catchment	Increases	Catchment; EPA/MT DEQ	Wang et al. (1997), MT DEQ (2005)*
Active Mine Density	<0.01	Number per 10k km^2 catchment	Increases	Catchment; EPA/MT DEQ	Wang et al. (1997), MT DEQ (2005)*
Active Dam Density	<17.5	Number per 10k km^2 catchment	Increases	Catchment; EPA/MT DEQ	Wang et al. (1997), MT DEQ (2005)*
Toxic Release Inventory Site Density	<10	Number per 10k km^2 catchment	Increases	Catchment; EPA	Wang et al. (1997), MT DEQ (2005)*
Point Discharge Site Density	<10	Number per 100k km^2 catchment	Increases	Catchment; EPA	Wang et al. (1997), MT DEQ (2005)*

* MT DEQ only provides a narrative or qualitative treatment of these variables; Wang et al. (1997) is a more regional perspective but provides numeric thresholds so it is preferred.
** Only used qualitatively given number of non-detects in SEI data
*** Stoddard et al. (2005) threshold is for a slightly different variable (w1Hall with a threshold of ≤0.35) and we use a variant of this metric more relevant to ROMO and a corresponding threshold
****Thresholds from Stoddard et al. (2005), the first value is the threshold for the reference state and the second the threshold for a most-disturbed state with the direction of the inequality indicating the direction of relationship.

dard error, variance, etc.). The precision of a status estimate determines the "quality" of the measure and how it might perform in statistical analysis (e.g., in a comparison of two status estimates). Finally, status can be assessed relative to an assessment point either qualitatively or with statistical hypotheses tests.

Exploratory Data Analyses, Visualizations, and Summary Statistics

All status (and trend) analyses begin with exploratory data analyses (EDA) and modification of data as needed to deal with outliers, missing data, and transformation of data to meet test assumptions (some of these procedures overlap or are similar to various QAQC procedures conducted by ROMN data management). Most status-based objectives require summary statistics (e.g., means and variances) and associated graphical treatments to illustrate spatial and temporal patterns in SEI response and to visualize relationships with spatial (i.e., elevation) or temporal (i.e., climate) covariates. Typical visualizations include box plots and scatter plots of two or more variables (that have a meaningful or likely relationship). Cumulative summary techniques are more sophisticated, but still largely graphical tools that can be used to look for change in a response measure based on the measured pattern of responses and systematic deviations from this pattern (Barnard 1959, Page 1996). Graphical analysis will be particularly important in the early years of SEI monitoring in a park to identify a workable set of variables or metrics that best explain the status of streams among the vast possible sets, to aid in the refinement of existing hypotheses, and to generate new hypotheses about pattern and process.

Multivariate Models

More involved exploratory analyses include various multivariate classification and ordination techniques that examine relationships between vegetation composition patterns and the underlying environmental gradients which might be influencing these patterns. Typically, we first conduct a cluster analysis to group macroinvertebrate or diatom samples followed by ordination with samples coded by cluster results (or other categorical variables of interest) that map select environmental gradients or indicator species into multivariate space. These allow interpretation of how these communities are structured relative to environmental gradients or anthropogenic disturbance. There are numerous ordination methods to choose from representing both indirect gradient and direct gradient analyses. Indirect gradient analysis utilizes only a species by sample matrix. Interpretation of environmental attributes occurs after indirect gradient analysis. Direct gradient analysis utilizes external environmental data in addition to the species data, providing information about the relationship between species composition and measured environmental attributes, similar to regression.

More involved exploratory analyses include various multivariate classification and ordination techniques that examine relationships between macroinvertebrate and/or diatom community composition patterns and the underlying environmental gradients which might be influencing these patterns. However, because there is no statistical inference conducted using the results of multivariate models we often also use sentinel and gradient sites (with the caveat that results may not be representative of an extensive target population). In many cases, the reference or non-reference conditions sampled by targeted gradient (and some sentinel) sites are very useful in positioning the vectors of environmental gradients in ordination plots. While most ordinations are an analysis of status with no explicit incorporation of time, future work will include ordinations that incorporate temporal data, especially using sentinel data from complexes with larger numbers of individual sites. Note that the MMI, RIVPACS and SEM modeling discussed above all heavily use multivariate techniques.

Design-based Estimation of Status

To generate proper inference of population or park-scale status, we use a design-based approach fundamentally different than more traditional model-based approaches. In design-based analysis, 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). Design-based analyses are well documented; (Cordy 1993; Diaz-Ramos et al. 1996; Stevens 1997) and are the foundation of long-established analyses used in fields such as socioeconomics and medicine. The approach may be used to generate statistics such as a mean, total, proportion, etc. of any raw SEI response measure (e.g., canopy density) or derived metric (e.g., O:E). The algorithms used are beyond the scope of this report (see Diaz-Ramos et al. 1996). In summary, they resemble traditional formulae for a statistic, but incorporate sample weights (or the inclusion probability) for each sample used in the analysis.

In contrast to model-based results, design-based results apply *to the entire target population of all sampleable streams in a* ROMN park. We use tables and a graphical presentation of the cumulative distribution function of values (CDF; see Figure 46 for an example). CDFs describe the probability that a real-valued random variable (an SEI response measure) with a given probability distribution will be found at a value less than x. Generally speaking it is an "area so far" function of the probability distribution. Graphical presentations of CDFs are very useful as they completely visualize the probability distribution of a response and readily facilitate interpreting thresholds placed within the distribution by locating the proportion and/or real unit-based percentage of the response that is above or below the threshold. Statistics including means, totals and percentiles are estimated using a suite of

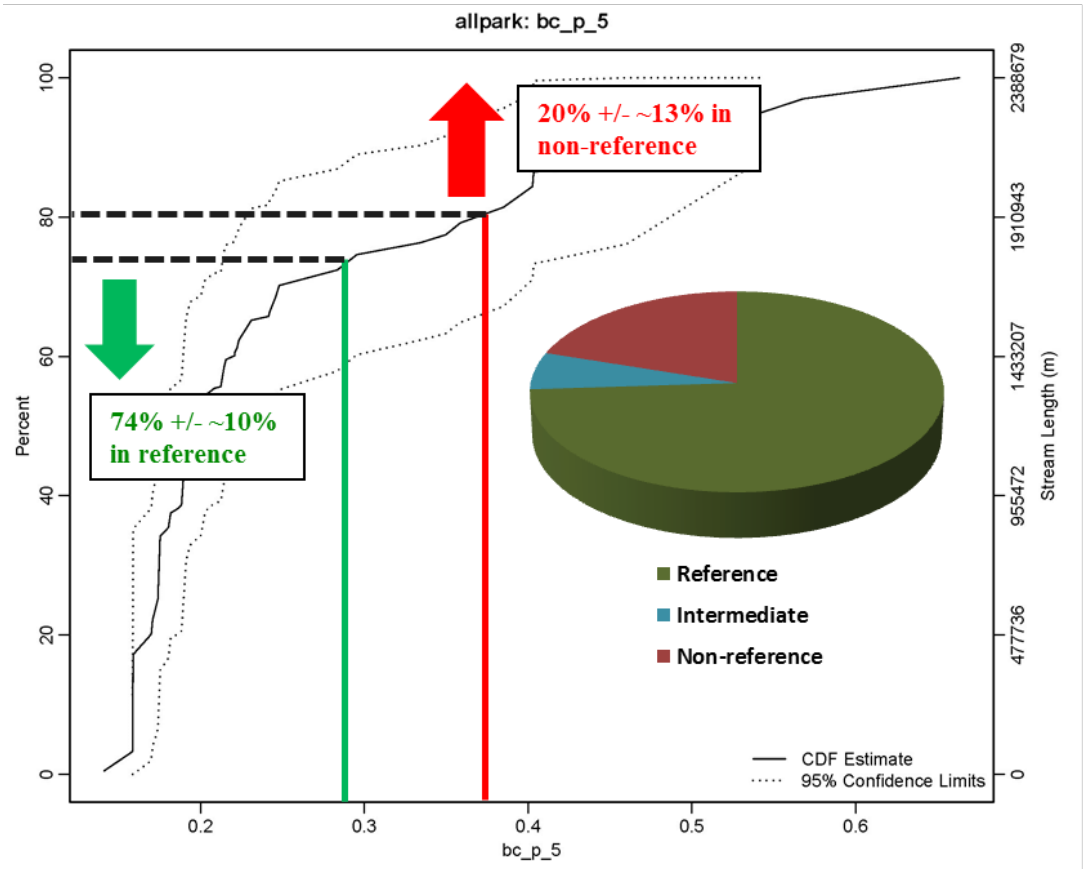


Figure 46. Example Cumulative Distribution Function (CDF) and associated pie chart of a Bray-Curtis dissimilarity index of the Observed to Expected ratio using the MT DEQ RIVPACS model applied to GLAC 2007-2009 SEI data. Confidence intervals (95%) around the estimate are included (faint dotted lines). Red and green vertical lines show the location of non-reference and reference (respectively) threshold values DERIVED from state and federal reference sites in the ecoregions surrounding GLAC (W. Schweiger, unpublished data). Horizontal dashed lines show location of corresponding proportion of the stream population at these thresholds. These break points are also reflected in the pie chart.

algorithms such as Horvitz and Thompson (1952) and its analogs (the details of which are beyond our scope here). In summary, the methods resemble traditional formulae for a statistic, but incorporate sample weights for each site to account for the selection probabilities in the sample design. This is done by utilizing the weights associated with each SEI site. The weights represent length of stream to which data from an SEI site are inferred. The sum of the weights equals the total length of stream in a park. Cochran (1987) gives the equations for estimating the mean and Diaz-Ramos et al. (1996) give the equations for estimating the cumulative distribution.

Because a GRTS design was used we can generate more precise variance estimates around design-based estimates of status using a proprietary technique developed by Stevens and Olsen (2003, 2004). Known as local neighborhood variance, it is derived from smoothed or averaged contrasts among values in the local neighborhood of a sampled point. It provides estimates 20% to 60% smaller (i.e., more precise) than similar traditional survey-design variance estimators. The local neighborhood variance is used to generate confidence intervals around means and the cumulative distribution (and these are placed on all CDFs). Confidence intervals are calculated assuming the estimates are from a normal distribution for the mean and cumulative distribution. Percentile confidence limits are interpolated from the cumulative distribution confidence limits. Plots of the CDF present the entire range for the estimate but only the confidence limits for the percent of stream length between 5% and 95%.

Analyses for Trend

Estimating the magnitude and direction of changes in vital signs through time is perhaps the foremost objective of the SEI protocol. We define trend as a non-cyclic, directional change in a response measure that can be with or without pattern (Urquhart et al. 1998). Some SEI response measures may have a temporal pattern that is not a trend, and vice versa. For example, an ascending line has trend but no pattern, while a sine curve has pattern but no trend. Trend may be site specific (e.g., at sentinel sites) or apply to an entire target population as the average (or net) trend. Furthermore, if trend is present, linear trend will be present (Urquhart and Kincaid 1999). Most SEI analyses therefore, use a conservative approach for detecting trend by seeking only linear trend without asserting that a detected trend is linear (i.e., the underlying linear component will be different than zero when a trend is present).

Several methods of estimating trend are available. Parametric approaches allow greater flexibility (Piepho and Ogutu 2002), but require more rigorous assumptions. Nonparametric approaches, such as the seasonal Kendall test discussed below, provide a useful check for parametric tests and are especially suited for non-normally distributed data, censored data, data containing outliers, and non-linear trends (Hirsch and Slack 1984).

Population-scale

Our primary method for estimating trend is parametric; the general linear mixed model as described by Urquhart et al. (1998) and Urquhart and Kincaid (1999). We use a variation on this type of model in the power analyses presented above. This model can simultaneously estimate trend, variance components, and the effects of covariates (Larsen 1997). Important sources of variance in the model include site or stream (population variance), year, year-by-stream (interaction effects), and in some cases, within-stream and seasonal variation. The trend of interest is estimated from the slope coefficient of the year effect in this linear model. Importantly, the approach can be applied to single sentinel sites through time (Larsen et al. 1995) or to populations of survey sites (although, as of yet the methods for including design attributes do not exist, so we must assume our surveys are simple random samples; the results will be conservative (Urquhart et al. 1998). We will estimate trend at sentinel sites on an annual basis and for entire populations after surveys are completed.

Site-scale

We use the Estimate Trend (ESTREND; Schertz et al. 1991; Slack and Lorenz 2003) model to estimate long-term trend in select water physiochemistry parameters for a single (usually sentinel) site. ESTREND computes a trend slope, which represents the median rate of change in concentration or discharge for the selected period of record. Trends are considered statistically significant at a 0.01 probability level. The model uses nonparametric seasonal Kendall tests or a parametric Tobit model to account for variation across time due to season. The specific number of "seasons" for a parameter is determined by pattern in and the density of data (typically there are 4 to 6 seasons in most water chemistry parameters). The models may also use daily mean discharge to adjust for flow-related variability if the concentration-discharge relationship is significant (at the 0.10 probability level and if less than five percent of the data were censored). A model selection procedure was used to select the specific form of the flow adjustment model used. Incorporating flow in ESTREND not only improves the power of the statistical test, but decreases the possibility that an observed trend is an artifact of discharge (Hirsch et al. 1982; Schertz et al. 1991).

Hypothesis Tests

The final type of analysis we introduce are comparisons of the status or trend in a ROMN vital sign to assessment points with formal hypothesis tests. We use this method in the SEI protocol in select situations to test whether or not statistical conclusions can be drawn about the relationship between a parameter estimate or model prediction and an assessment point. However, the focus of much SEI assessment and interpretation will be on estimating parameters that have long-term management relevance and ensuring that biological and statistical significance are appropriately distinguished, following Yoccoz (1991).

Hypotheses tests are used when data constraints (sample size, etc.) allow statistical comparisons. They may be most appropriate when a status or trend estimate is to be tested against a formal legal criteria, whether or not certain Congressional mandates have been met, or whether or not performance targets have been achieved. Many analyses to be used in the SEI protocol are suitable for hypothesis testing. For example, population-scale, design-based results can use non-parametric tests such as the Wald statistic and chi-squared statistics suggested by Rao and Scott (1981). Both of these models incorporate GRTS design attributes.

Analyses to Assess the Quality of Measures and Metrics

SEI data will be analyzed using various methods that help understand the utility, quality and efficiency of a particular measure or metric. These include (1) coefficients of variation, 2) differences among within sample event replicated measures, and (2) signal to noise (S:N) analyses. The S:N method is briefly summarized below.

Signal to Noise

A key statistic used to investigate the value of SEI measures and metrics is the ratio of the signal to noise (S:N) in a response measure (Kaufmann et al. 1999). This is the ratio of variance between multiple sites (signal) and the variance of repeated visits to the same site (noise). As such it requires larger sample sizes, with a subset of sites revisited and is best suited to GLAC and ROMO survey data. Noise includes measurement variation, the combined effects of within-season habitat variation, differences in estimates obtained by separate field crews, uncertainty in the precise relocation of plots and variation between years. A low S:N value indicates that a metric has nearly as much variability within a site (over time) as it does across different sites, and thus indicates a measure that does not distinguish well between sites. Responses with high S:N values are more likely to show consistent responses to stressors than are metrics with low S:N values. A response that is perfectly correlated with a hypothetical stressor and that has no sampling variability will have an R^2=1.0 with that stressor. As S:N decreases, the maximum possible R^2 value of the regression decreases because the sampling variability of the metric increases. There is no fixed threshold below which

we consider a response poor based on S:N. However, we do use a general rule of thumb from Stoddard et al. (2008) of S:N<1.0. A S:N below 1.0 indicates that visiting a single site twice would yield as much response variability as visiting two different sites.

Auxiliary Data

Analyses of SEI data often require data not generated by the SEI protocol itself. These data are episodically pulled from readily available NPS or partner sources and built into the SEI database. Brief descriptions of these data and how they are used in conjunction with or in support of SEI analyses follow.

Water Physiochemistry and Streamflow

SEI sentinel sites are often co-located with USGS gauge stations. Given the breadth of high-quality, long-term monitoring by the USGS at these sites, we acquire, analyze, and assess data for select long-term trends in water physiochemistry and streamflow where it provides additional context or insight. Nutrient, trace element, major ions, *in situ* (especially temperature), and streamflow data are retrieved from the National Water Information System database over variable periods of record from gauges closely associated with ROMN sentinel sites. Only data publically available and thus passing all USGS QAQC checks are collected. However, following (Mast 2007), we do use trace elements prior to 1992, even though it is documented that dissolved concentrations in these samples may have been contaminated during sample collection and processing (USGS Office of Water Quality Technical Memorandum 91.10 ; USGS 2013b).

Biology, Habitat, and Water Physiochemistry

We collect data for a subset of biological, habitat, and water physiochemistry responses from partner monitoring sites located in ecoregions (or in Colorado "bioregions") around each ROMN park (see Figure 47 for an example for ROMO). ROMN partners with comparable auxiliary data include MT DEQ, CDPHE, EPA, and USGS with most sites part of long-term monitoring conducted by these agencies (Hawkins et al. 2003; Stoddard et al. 2005; Suplee et al. 2005; Bollman 2006). In several cases, auxiliary data may have been sampled during different

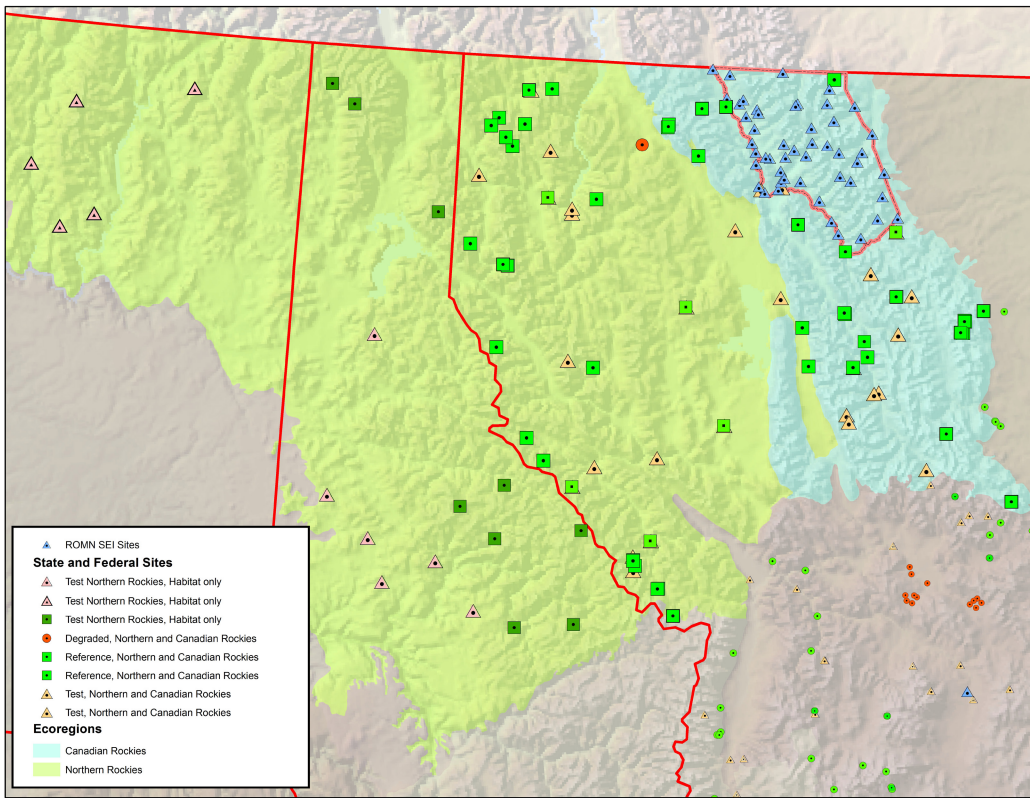


Figure 47. Example auxiliary data monitoring sites in the Northern and Canadian Rockies ecoregions used in comparison with select ROMN SEI habitat and biological metrics in ROMO. Sites are classified into reference, non-reference ("degraded"), or intermediate ("test") status by each program that established the sites. Note that only sites in Montana were used for comparison to biological metrics given MT DEQ thresholds specific to the state.

years than SEI data collection, and this is an important caveat on models that use these data. The EPA National Rivers and Stream Assessment (NRSA; EPA 2007) will be an important future source for additional and more recent data as field and analytical methods for these programs are largely comparable to the SEI protocol.

For macroinvertebrates, auxiliary data should have appropriate QAQC, a multi-habitat sampling method (i.e., not just riffles), a minimum 300 organism lab count, and identical or comparable OTU-level identification of macroinvertebrates (including Chironomids). Even within these constraints, some data we use come from protocols that differ from the SEI protocol. Jessup et al. (2006) show that, for at least MMI and RIVPACS metrics, bioassessment using data collected with MT DEQ or EPA (on which the SEI protocol is based) methods generate similar interpretation. We restrict sites from which we pull macroinvertebrate data to the state of Montana and the state of Colorado given our use of thresholds from MT DEQ or CDPHE developed from data only from within each state's boundaries.

At the time of this protocol publication we had yet to acquire auxiliary periphyton data. When we do it will have appropriate QAQC, a multi-habitat sampling method (i.e., depositional and erosional habitats), a Palmer-Maloney or similar counting chamber count of 300 soft-bodied algae cells and a proportional count of 600 diatom valves (300 cells). Most importantly, specimens will be identified to species as often as possible. Nomenclature will follow the Montana Diatom Database (Bahls 2004) as there is not well developed taxonomic data in ITIS or NPSpecies for algae. We may restrict sites from which we pull periphyton data to the state of Montana or Colorado given probable use of thresholds from these states.

For water physiochemistry, auxiliary data should have appropriate QAQC, a depth-integrated thalweg sampling method and published reporting and/or detection limits that are sufficiently precise for the often dilute waters in ROMN parks.

For habitat, we restrict auxiliary data to sites sampled as part of the EPA EMAP Western Pilot Project (Stoddard et al. 2005), the Colorado Regional EMAP project or (in the future) from NRSA given near identical field and analytical methods with the SEI protocol and rigorous QAQC. We do not restrict habitat data to the state of Montana or Colorado because there are no thresholds from these states for habitat responses and we either develop our own thresholds or use existing values created for entire ecoregions.

Disturbance, Landscape and Climate

Many analyses of SEI data use covariates as ways to help understand patterns and lend insight into the factors controlling status and trend in a response. These variables can also be used as part of the filtering process for selection of reference sites within a ROMN

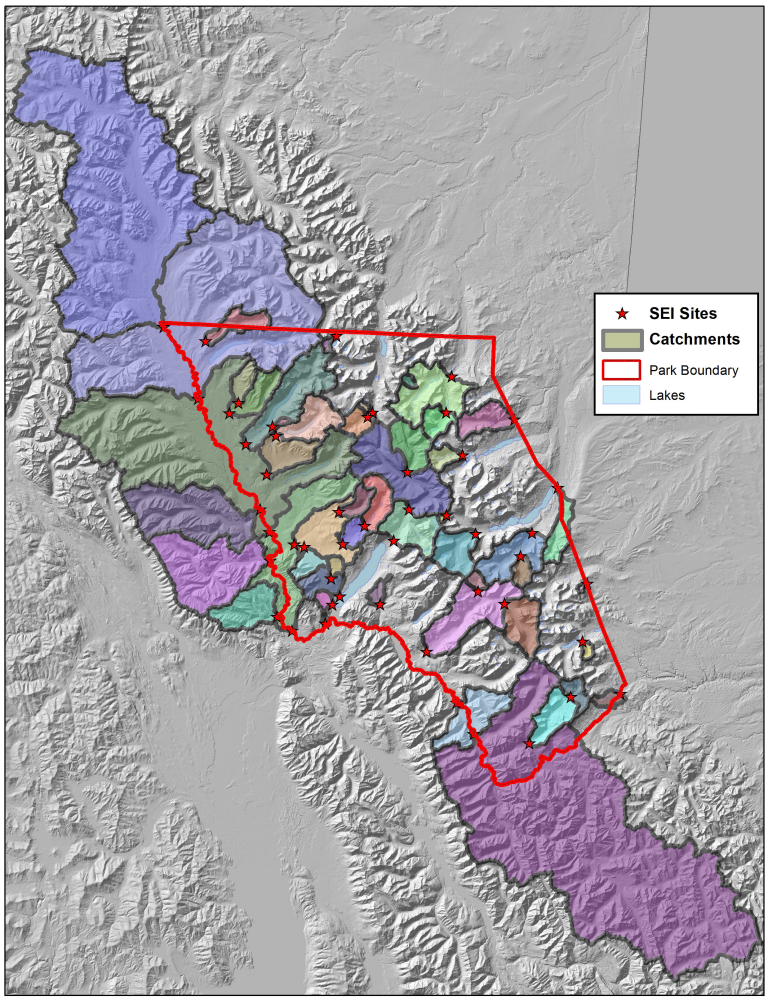


Figure 48. Example of catchments for SEI sites in GLAC.

park. We focus on simple measures that have well-established relationships with stream response as suggested by conceptual modeling or other research. However we also recognize that there is value in exploring statistical relationships among a suite of predictors and stream responses that may suggest interesting and useful ecological relationships. Covariates may come from GIS models, from output borrowed from other ROMN protocols, or from ROMN collaborator research projects. They can occur at multiple scales including within catchments (upstream watersheds; Figure 48). Table 26 lists several examples of important covariates in SEI analysis.

Table 26. Example context, landscape composition, and climate auxiliary data for analyzing SEI data. PRISM = Parameter Elevation Regression on Independent Slopes Model; DEM = Digitial Elevation Model; NHD = National Hydrogrpahy Database; TIGER = Topologically Integrated Geographic Encoding and Referencing; NLCD = National Land Cover Database; VegMap = a park's vegetation map.

Parameter	Units	Source
Reach Slope	Degrees	DEM
Site Elevation	m	DEM
Strahler Stream Order	Index	NHD
Catchment Size	m^2	GIS
Mean Precipitation, (30-year normal)	cm	PRISM
Mean Precipitation (sampled year)	cm	PRISM
Min/Max/Mean USGS Modeled Stream Water Temperature in Catchment, 2008	C	Jones et al. (2013)
Min/Max/Mean Ambient Air Temperature in Catchment	C	PRISM
Road Density	Length per unit area in catchment	TIGER (US CENSUS Bureau)
Road-Stream Crossing	Number per unit area in catchment	TIGER (US CENSUS Bureau)
Agricultural Land Use	% of catchment	NLCD/VegMap
Urban Land Use	% of catchment	NLCD/VegMap
Percent Natural Vegetation	% of catchment	NLCD/VegMap
Nitrogen Load	kg/ha/yr	Baron et al 2011, Beam et al 2010
Human Population Density	Number residents per unit area	US CENSUS Bureau
Percent Impervious Surfaces	%	NLCD/VegMap
Accessibility	Time	ROMN Cost Model
Percent as glacier	%	NHD
Distance to Upstream Lake Outlet	Km	NHD
Watershed Membership	Categorical	US EPA
Percent of Watershed Burned over last 5 and last 25 yrs	%	GIS

Reporting

The goal of the SEI protocol is to produce scientifically sound, consistent, and comparable monitoring information that can be used to support park management and decision making. The production of reports and effective communication of scientific results serves as a key link in transforming data into information.

General ROMN reporting plans are outlined in Chapter 7 of the Vital Signs Monitoring Plan (Britten et al. 2007). The plan guides the goals and concepts for reporting and communicating all ROMN data and information, including monitoring results. The network is also preparing a detailed Communications Plan, which will identify audiences, best formats and media, and delivery systems for all ROMN results. Our specific *internal* audiences include (1) ROMN park managers, (2) ROMN park resource professionals and other park staff, (3) the ROMN Technical Committee, and (4) general NPS entities, such as the Intermountain Region, the I&M Program, and Resource Stewardship Programs. Our *external* audiences include (5) the academic community, (6) other government agencies, (7) non-profit/non-governmental organizations, and (8) the public.

We anticipate providing quality-assured ROMN data and information including (non-sensitive) data, reports including annual reports, synthesis reports, and other products (such as project summaries or briefs). ROMN will also publish select SEI data and associated research in peer-reviewed journals. All ROMN publications are peer reviewed and revised for improvements. In general, ROMN is committed to regular reporting of SEI information to internal and external audiences to maximize the usefulness of our data.

Three types of SEI reports will be produced (1) relatively simple data summary reports for each park where SEI monitoring is conducted produced every two years, (2) comprehensive extensive status (and eventually trend) reports, produced as soon as possible after the initial implementation of the GLAC or ROMO survey and thereafter every ten years, and (3) comprehensive trend reports for sentinel sites in all ROMN parks with SEI monitoring, produced every five years (the frequency of these reports may vary based on temporal patterns in the data). The timing of report production is staggered by park to accommodate limitations in ROMN staff time. All reports will be published after review and data clearance through the NPS Natural Resource Stewardship and Science (NRSS) Natural Resource Report Series and available on the NPS Washington Support Office (WASO) data and information management and delivery systems (IRMA) the ROMN website. More details on the content of SEI reports will be provided in SEI SOP 17: Data Analysis.

Data Summary Reports

The routine preparation on a predictable and recurring basis of biannual data summaries and basic interpretation can (1) foster program support by establishing a client base, (2) motivate continued progress in program components, and (3) serve as the foundation for the more comprehensive reports. Data Summary Reports will include all sample events for a given two-year period and may combine ROMN parks into a single report. They typically focus on sentinel site results and are therefore usually focused on specific streams within a park.

Data Summary Reports will:

- List project personnel and their roles.
- List sites sampled during preceding year(s).
- Provide a summary history of the number of sites, park unit, and stream type during each year of the project.
- Identify any data quality concerns and deviations from the protocol that affect data quality and interpretability.
- Include information on any rare native species, invasive species detected, or other information that could be of immediate interest to park managers.

- Evaluate and identify suggested or required changes to the protocol.
- Provide maps of sampled sites.
- Provide tables of status summaries of measured variables (focused on biological metrics, water/sediment physiochemistry, and habitat) summarized by stream type and park unit.
- Eventually include simple trend results for select sentinel sites.
- Discuss results and management implications.
- As directed by park management, include a summary condition table (see below).

Additionally, every two years ROMN will provide non-sensitive and non-proprietary monitoring data and information to IRMA. We will provide this information as bundled snapshot summaries, including two years of data along with supporting protocols, reports, and any other documentation. These reports and the associated databases will be available to the NPS, Department of the Interior, other land managers, Congress, and the Executive Branch.

Comprehensive Reports

Comprehensive Reports include detailed summaries of extensive status in stream condition (and eventually trend) for GLAC and ROMO and detailed trend reports for sentinel sites in all ROMN parks. The inferential scale of the results in these reports varies with sample design. Comprehensive reports will focus on a single park. In general, the reports will present status and trend (reliable trend estimates will take some time to develop, see the Sample Design sections) in individual response measures and bioassessment metrics and interactions among drivers and stressors. Extensive survey design-based status reports will include more detailed modeling of patterns across sites in macroinvertebrate and diatom community structure and relationships with management relevant needs. Trend reports for sentinel sites will include more detailed analyses of patterns in surface water hydrology. Reliable trend estimates for sentinel sites will be possible sooner for sentinel sites than for extensive populations of streams in GLAC and ROMO.

The frequency of these reports will allow meaningful assessment of the status and change in important responses like species richness, presence of exotic species, loss of rare species, changes in dominant life forms, and changes in hydrologic regime. Changes in macroinvertebrate and diatom community structure over time or differences among sites should be examined in relation to three primary stressors—water chemistry, hydrology and climate. Climate effects can be inferred from hydrographs and modeled from climate data. Where evidence of resource degradation exists, mitigation measures will be developed with the park.

Comprehensive Reports will:

- Include all relevant results from Data Summary Reports (see above).
- Present park-scale status from survey sites and (eventually) present park-scale trend results.
- Present detailed trend results from sentinel sites.
- Provide an overview of the protocol status and major accomplishments.
- Give recommendations for future improvements.
- Discuss in detail the results and implications to park management of streams.
- Identify any changes in spatial patterns of streams.
- Include a summary condition table (see below).

Summary Condition

As discussed in the Assessment section above, ROMN SEI results are summarized in "summary condition" tables. These will appear in Data Summary Reports as directed by ROMN park staff and (always) in Comprehensive Reports. They include a brief description of a vital sign or class of vital signs, example measures and/or metrics, and summaries of the status and/or trend in the condition of the vital sign(s) and our confi-

dence in the result (accompanied by simple graphic symbols; see Figure 49 for a draft legend for a summary condition table). These are important treatments for rapid integration into park resource management but they are a considerable simplification of details presented in even Data Summary Reports and should be used with caution.

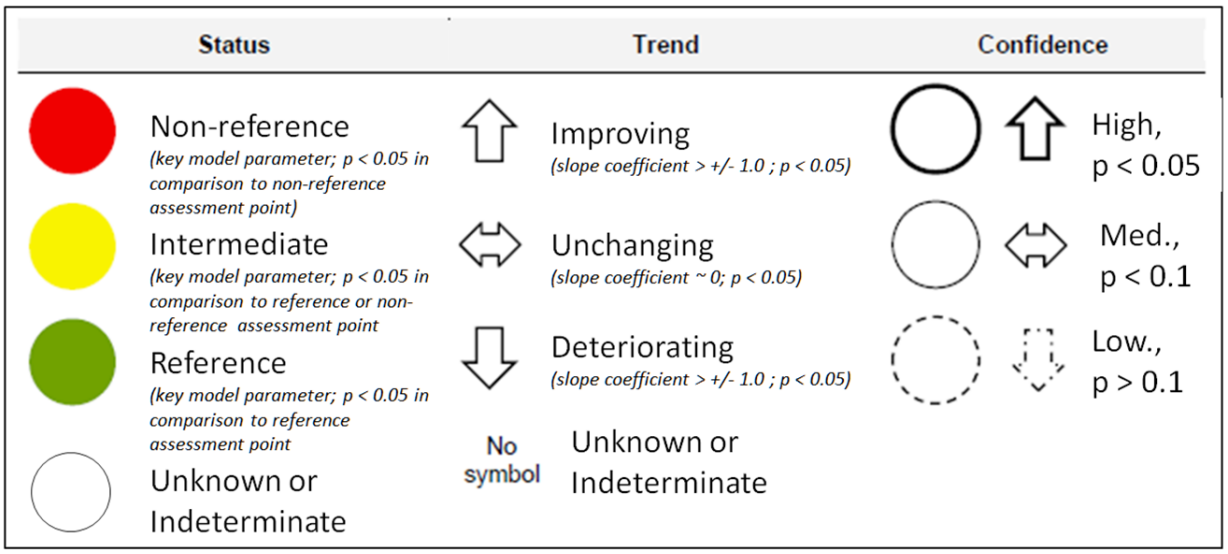


Figure 49. Draft symbology and terminology for summary conditions. Model and statistical details are included when possible. For example, if the statement is for a single measure or metric and it is statistically compared to an assessment point or analyzed with a trend model these supporting details can be included. owever, in other cases a summary condition statement is largely qualitative and no test is performed. Confidence is ideally a function of p-values or some other statistical parameter (e.g., Signal:Noise), the quality of the sampled design, the appropriateness of any inference made, etc. Statements about the temporal and spatial scale (site or extensive) are required.

Administration and Operations

Introduction

In this chapter we describe the administration and operation of the SEI protocol. We include SEI protocol development and pilot monitoring efforts, outline roles and responsibilities for SEI monitoring, provide a schedule for periodic park-wide surveys in GLAC and ROMO and annual sentinel site monitoring in all ROMN parks with perennial streams, describe the preferred staffing model for field crews, describe sample analysis arrangements with laboratories (past and future), and provide a budget for SEI monitoring.

SEI Protocol Development and Pilot Monitoring Efforts

The ROMN long-term ecological monitoring program developed over several years (2003-2007) and was a collaborative effort among many ROMN parks and external partners. The final ROMN Vital Signs Monitoring Plan was approved by the ROMN Board of Directors and the NPS I&M Division Chief and published in 2007 (Britten et al. 2007). The plan covers all aspects of the ROMN monitoring program including vital sign selection, conceptual models, sample design, sampling protocols, data management, analysis and reporting, administration and implementation, schedule, and overall budget. It guides the overall implementation of ROMN monitoring and provides guidance on program implementation and management, roles and responsibilities, partnerships, and budget.

The ROMN began SEI protocol development in 2006 and pilot monitoring efforts in 2007. We have conducted pilot monitoring in four ROMN parks through 2015. Major projects and events in SEI protocol development and associated costs are presented in Table 27.

Roles and responsibilities

The SEI protocol requires fieldwork and coordination for cost-effective and safe data collection; data management support to effectively manage and deliver abundant and complex SEI data; ecological and statistical expertise for design, analysis and interpretation of SEI data; administrative support to manage all aspects of the SEI monitoring program and resource management involvement in the application of monitoring results. Network staff have the primary responsibility for implementation, but SEI monitoring is much more effective with the involvement of park staff and outside scientists and technical experts. Table 28 presents the roles and responsibilities of everyone involved in ROMN SEI monitoring.

Partnerships

External Partnerships

ROMN worked with many NPS and external partners to develop the ROMN Vital Signs Monitoring Plan and the SEI Protocol. Specifically, we worked cooperatively with several external partners to develop this stream ecological integrity monitoring protocol; conduct pilot monitoring in GLAC; and analyze and interpret our stream monitoring data. This work has been done primarily through cooperative agreements with partner universities, but also through the USGS National Parks Status and Trends Program.

This approach has been very beneficial for the ROMN parks and the stream monitoring protocol because it has provided us linkages to several well-known and respected stream ecologists including Ric Hauer at University of Montana Flathead Lake Biological Station, David Clow and Alisa Mast of the USGS Colorado Water Science Center, Clint Muhlfeld of the USGS Northern Rocky Mountain Science Center, Mark Williams of University of Colorado at Boulder, and Tony Olsen, John Stoddard, Phil Kaufmann, Phil Larsen, and Dave Peck of the EPA Office of Research and Development.

Park Partnerships

Development of the Vital Signs Monitoring Plan and this SEI Protocol involved a great deal of ROMN park staff participation and input. Park resource managers and their

Table 27. ROMN Stream Ecological Integrity monitoring protocol development projects and events, timeline, and costs; 2003-2015.

Year	Event, Agreement or Contract Title	Amount	Funding source	Principal Investigators	Institution(s)	Notes
2003	Task Agreement - SEI protocol development and pilot monitoring	$79,925	NPS: Vital Signs Monitoring ($55,000) and Biological Inventories ($24,925)	Ric Hauer	UM, Flathead Lake Biostation	Funds obligated in this task agreement in FY 04 funded fieldwork for the SEI pilot survey in ROMO in 2007 and 2008.
2004	Water Quality Workgroup (2004-06)	n/a	Funding was contributed salaries for Workgroup participants (not tracked during the protocol development process or reported here)	n/a	NPS	ROMN established a WQ workgroup from 2004-06 to advise the network in developing plans for water quality monitoring in ROMN parks.
2004	Interagency Agreement - water quality data mining/management project for ROMN parks - phase I	$73,800	NPS: Water Quality Monitoring ($59,780) and Vital Signs Monitoring ($14,020)	Alisa Mast	USGS-Colorado Water Science Center	Phase I of a project to develop the ROMN historic water quality database (and report).
2004	Inter-network collaboration - water quality planning assistance	$2,395	NPS: Vital Signs Monitoring	Susan O'Ney	Greater Yellowstone Network	ROMN enlisted the assistance of the Greater Yellowstone Network in water quality monitoring planning.
2004	Task Agreement - SEI protocol development and pilot monitoring	$246,000	NPS: Vital Signs Monitoring ($215,000) and Biological Inventories ($31,000)	Ric Hauer	UM, Flathead Lake Biostation	Funds obligated in this task agreement in FY 04 funded fieldwork for the SEI pilot survey in ROMO in 2007 and 2008.
2005	Interagency Agreement - water quality data mining/management project for ROMN parks - phase II	$62,000	NPS: Water Quality Monitoring ($59,530) and Vital Signs Monitoring ($2,470)	Alisa Mast	USGS-Colorado Water Science Center	Phase II of a project to develop the ROMN historic water quality database (and report).
2007	Stream protocol development workshop	$3,593	NPS: Water Quality Monitoring	n/a	Various, including NPS ROMN and ROMN parks, UC-Boulder (Mark Williams), UM (Ric Hauer and Erin Sexton), Utah State (Chuck Hawkins), and the USGS Colorado Water Science Center (Don Campbell, Dave Clow, Alisa Mast)	ROMN hosted a Stream Protocol development workshop in Lakewood, CO on February 20th and 21st. Thirty nine representatives from Federal, State, and local agencies and other stakeholders participated. ROMN paid travel costs for ROMN park and invited participants. The meeting successfully introduced key components of the ROMN stream protocol, solicited input on sentinel stream monitoring locations and assisted ROMN staff in continued development of this important long-term monitoring effort.
2007	Interagency Agreement - Developing Baseline conditions on N. Fork of the Flathead River. in GLAC	$300,000	USGS Water Quality Partnership funds	David Clow and Alisa Mast	USGS and Rocky Mountain Network	Research to analyze historic data and collect novel data on water chemistry and hydrology of the North Fork and its tributaries to understand baseline condition and historic trend in the face of possible coal mining and other resource extraction in Canada.
2008	Pilot SEI monitoring survey of GLAC	n/a	NPS	Billy Schweiger	Rocky Mountain Network	Fieldwork was funded by ROMN Vital Signs and Water Quality monitoring funds obligated in 2003 and 2004
2008	Pilot SEI sentinel site monitoring in GRKO	n/a	NPS	Billy Schweiger	Rocky Mountain Network	First (limited) SEI sampling in GRKO
2009	Pilot SEI monitoring survey of GLAC	n/a	NPS and EPA	Billy Schweiger	Rocky Mountain Network	Fieldwork was funded by ROMN Vital Signs and Water Quality monitoring funds obligated in 2003 and 2004; some sites sampled in collaboration with EPA and MT DEQ as part of National Rivers and Streams Assessment program

Table 27. ROMN Stream Ecological Integrity monitoring protocol development projects and events, timeline, and costs; 2003-2015, cont.

Year	Event, Agreement or Contract Title	Amount	Funding source	Principal Investigators	Institution(s)	Notes
2009	Pilot SEI sentinel site monitoring in LIBI	n/a	NPS and EPA	Billy Schweiger	Rocky Mountain Network	First SEI sampling in LIBI; sampled in collaboration with EPA and MT DEQ as part of National Rivers and STreams Assessment program.
2010	Pilot SEI sentinel site monitoring at two Colorado River locations in ROMO	n/a	NPS	Billy Schweiger and Pete Penoyer	Rocky Mountain Network and NPS-Water Resources Division	First SEI sampling in ROMO; initiated in collaboration w/WRD and ROMO to capture "baseline" stream data prior to Grand Ditch restoration project.
2010	Task Agreement - water chemistry sample analysis and reporting	$4,630	NPS Vital Signs Monitoring	Mark Williams and Chris Siebold	UC, Kiowa Laboratory	
2011	Contract - biological sample (macroinvertebrate and periphyton and AFDM and Chlor-A) analysis and reporting	$21,120	NPS Vital Signs Monitoring	Wease Bollman	Rhithron Associates	
2013	Task Agreement - water chemistry sample analysis and reporting	$25,547	ROMN Vital Signs Monitoring	Mark Williams and Chris Siebold	UC, Kiowa Laboratory	The ROMN obligated an estimated $25,547 towards a task agreement to analyze SEI water chemistry samples from 2013-2015.
2013	Contract - biological sample (macroinvertebrate and periphyton and AFDM and Chlor-A) analysis and reporting	$61,160	ROMN Vital Signs Monitoring	Wease Bollman	Rhithron Associates	The ROMN obligated an estimated $61,160 towards a contract to analyze SEI biological samples from 2013-2015.
2010-present	Annual sentinel site monitoring in ROMO, GRKO, LIBI and ROMO (limited in ROMO)	n/a	NPS	Billy Schweiger	Rocky Mountain Network	Annual sentinel site monitoring
2013-2016	Integrated Bioassessment of Imperiled Alpine Aquatic Ecosystems using NPS Vital Signs and USGS Research Data: Implications for Conservation under a Warming Climate	$282,540	USGS I&M funds	Clint Muhlfeld and Billy Schweiger	USGS and Rocky Mountain Network	Integration of ROMN and USGS data in ROMO and development of bioassessment models, including aspects of climate change
2014-2016	ROMO SEI survey planned (likely this will involve multiple agreements and contracts through this period)	$166,333	NPS Vital Signs Monitoring	Billy Schweiger	Rocky Mountain Network and ROMO	Large Probability survey and sentinel site monitoring of all flowing waters in ROMO
2003-2016	Grand Total SEI protocol development funding	$1,329,043				

Table 28. Personnel and roles and responsibilities for Stream Ecological Integrity monitoring.

Role	Responsibilities
Protocol Lead	Coordinate all protocol activities: advise Field Coordinator of annual field season monitoring targets and needs; validate and analyze data; write data summary and comprehensive monitoring reports; manage protocol budget; work with ROMN Program Manager and Data Manager to meet reporting requirements, help manage SEI database, and revise protocol as needed.
Data Manager	Maintain SEI database; provide technical support for database management, data quality assurance/quality control (QAQC), data queries, data storage, certification, archiving and dissemination, and data analysis procedures; provide GIS technical support.
Program Manager	Coordinate with Protocol Lead and Field Coordinator and Data Manager to meet I&M Program requirements (e.g., budget, data management, reporting, education/outreach, safety, and others); integrate streams monitoring with the rest of the ROMN Vital Signs Program.
Park natural resource staff	Assist with oversight, training, and support of field crew(s) in respective park. Provide guidance and technical assistance as needed; recommend cross-country hiking routes, permitting, Wilderness Minimum Requirements Analysis, and other tasks. Participate as members of field crews.
Field Coordinator	Lead field implementation of SEI monitoring. Hire, supervise, direct, and manage field technicians/crews. Assign a Crew Lead for each monitoring event or series of events. Provide field training for crew members including SEI monitoring, safety, backcountry, and park communication. Ensure crews have proper field monitoring equipment and supplies. Schedule field monitoring for SEI (and all) monitoring protocols. Manage the collection and transfer of field data, specimens, and samples from the field to ROMN offices and labs and to museums. Report accidents or near accidents and safety concerns to the Program Manager as soon as possible. Report any monitoring issues to Program Manager.
Crew Leader (assigned by the Field Coordinator, the Crew Leader may be the Field Coordinator or Ecologist or a seasonal ROMN technician)	Organize and manage all aspects of individual monitoring trips including scheduling, communication with park staff, filing backcountry travel plans, preparing equipment and sampling supplies, and other tasks. Make decisions during the trip regarding routes to sample locations. Work with field crew members to assess risks and make appropriate decisions relative to crew safety during sampling trips. Ensure all data, specimens, and samples are delivered to ROMN offices and labs. Ensure that equipment and vehicles are cared for and returned in good working condition and ready for the next use. Report accidents or near accidents and safety concerns to Field Coordinator as soon as possible. Report any monitoring issues to Field Coordinator soon after the monitoring trip.
Crew Members	Prepare for field sampling and wilderness travel; carefully and accurately collect vegetation and hydrologic data following SEI SOPs; fully document procedural anomalies; enter field data into database; perform end-of-season procedures; fully participate in safety/risk assessments and decision making before, during, and after monitoring trips. Notify Crew Leader of safety issues and concerns as they occur. Immediately report accidents or near accidents to the Crew Leader.
Outside subject-matter experts	Sample identification (e.g., macroinvertebrates, diatoms). Consult with ROMN staff on analysis and interpretation of SEI data.
Park staff and local area experts	Provide guidance and technical assistance as needed; recommend cross-country hiking routes, permitting, Wilderness Minimum Requirements Analysis, and other tasks. Participate as members of field crews.
Park resource manager(s)	Incorporate and apply SEI monitoring results to resource management decisions as appropriate. Assist in interpreting monitoring data and help ROMN staff develop management relevant reference conditions and thresholds for SEI data. Assist ROMN to obtain resources needed for monitoring (especially park-wide SEI survey efforts). Application of SEI monitoring results to park management will be done at the park scale and possibly, through the ROMN Technical Committee and Board of Directors, at broader scales (e.g., multi-park and network-wide).

staff were key contributors in developing the monitoring questions and objectives in the SEI protocol. They were instrumental in developing our field SOPs, especially for safety, communication, backcountry travel and access, and training. Park expertise in wetland function, plant species, location, and access contributed to the success of our initial SEI pilot projects. Finally, park superintendents and resource managers are the primary authorities and partners in developing appropriate and useful reference conditions for SEI data since the ultimate goal of our monitoring is to provide information to allow them to effectively protect and manage park stream resources.

Based on this experience to date, we see many advantages to increasing park participation in ROMN SEI monitoring. SEI monitoring costs are significant, especially if the network has to hire and train dedicated SEI crews for park SEI surveys. While we have been able to hire generally well-qualified crews, it takes time for them to gain the knowledge and expertise for SEI monitoring, especially park-specific knowledge. Many of our sampling needs are for partial sample events that take only one day (or less). If we can train and utilize park staff to conduct partial sample events (e.g., data logger downloads) and/or assist in full sample events as a crew member, there will be substantial savings to ROMN in crew costs and travel. The savings can be applied to other park monitoring needs.

An additional benefit of park participation in SEI monitoring (especially participation by Technical Committee members and natural resource professional staff) is that they see and better understand our field methods and the uses (and limitations) of SEI data and information and ROMN staff better understand park SEI issues and information needs.

As ROMN SEI monitoring continues, we will continue to partner with outside scientists and experts whenever appropriate and possible to help make our monitoring more effective and useful. Specifically, we will consider improving connections with EPA, the Colorado Department of Public Health and Environment and Montana Department of Environmental Quality. We will also continue to partner with park staff so that monitoring implementation is as cost-effective and safe as possible and data analysis and interpretation is appropriate and useful for park resource management.

Field Implementation

Field sampling for SEI monitoring is accomplished by field crews of two to five or more temporary Biological Science Technicians (hired by ROMN or by ROMN parks). All field efforts are led by the ROMN Field Coordinator.

Field Crews for Annual Sentinel Site Monitoring

We have accomplished field monitoring at SEI sentinel sites in the Montana parks by using a combination of the ROMN Ecologist and staff from the parks. In ROMO, the ROMN ecologist leads the field monitoring assisted by other core ROMN staff (all ROMN staff except seasonally employed technicians) and park staff (a few cases) and volunteers. We will continue our current approach in Montana parks and consider options for annual sentinel site monitoring in Colorado parks. Likely we will continue to use the ROMN Ecologist and/or Field Coordinator and ROMN seasonal Biological Science Technicians. We will continue to solicit assistance from park staff and qualified volunteers for annual stream monitoring.

Field Crews for Large Park Stream Surveys

For large park surveys, we will hire a crew of three to four seasonal Biological Science Technicians. We will also seek park support for fieldwork such as park-based field technicians, interns and possibly volunteers, and we will seek to partner with outside scientific and technical partners (e.g., USGS, EPA and universities) as appropriate. Other ROMN staff will supplement field sampling efforts as appropriate and time allows. We will also evaluate ROMN Vital Signs and Water Quality monitoring budgets, and especially other funding opportunities, to determine if we

should conduct park-wide surveys with partners through a cooperative or interagency agreement.

Field Crew Training

ROMN field crew members all receive training in backcountry safety, travel and communication with parks including Wilderness First Aid (24 hour course) or standard first aid (8 hour course); defensive driving; and for work in GLAC, Bear Safety. They also receive administrative training in subjects such as Federal Information System Security Awareness, time and attendance, and travel procedures. SEI field crew members are provided time to read and understand the SEI protocol and standard operating procedures and receive a half-day office training that covers challenging concepts and methods for measuring more nuanced parameters and one or more days of SEI monitoring field training. They also receive a half day of data management training so they can better understand how the data they collect are entered and managed. Early in the field season, SEI crews are provided on-the-job field training by the Field Coordinator and/or Protocol Lead as sampling occurs. All told, SEI crew members will receive at least one full week of training in various subjects at the start of the field season with additional on-the-job training as needed throughout the field season. As discussed in the Field Methods QAQC section, the Field Coordinator and/or Protocol Lead conduct episodic QAQC sample events with the crews to gauge how methods are being implemented and deal with any issues that have arisen during a season.

Table 29. Number of Stream Ecological Integrity monitoring sites and sample events by ROMN park per year.

Park	# sites	# sample events/year	notes
GLAC	4	16	
GRKO	1	4	
LIBI	1	4	
ROMO	5	25	# sites may be decreased
GRSA	?	?	# sites to be determined
Totals	13	57	

SEI Monitoring Schedule

ROMN began SEI protocol development in 2006 and pilot monitoring efforts in 2007. As discussed in the Sample Design section we have conducted pilot monitoring in four ROMN parks through 2015. Based on these efforts and power modeling, we have estimated the annual SEI monitoring sampling effort and schedule for annual SEI sentinel site monitoring (Table 29) and periodic (~ every 10 years) SEI surveys in GLAC and ROMO (Table 30; for more detail see Table 6). These schedules are subject to change based on network funding and updated power models and whether or not we can focus our monitoring efforts to be more cost effective at estimating the ecological integrity of streams (i.e., by adjusting or improving the indicators we use).

Budget

Funds for SEI monitoring come from Water Resource Division Water Quality Monitoring funds ($55,700 in FY 2015) and ROMN Vital Signs Monitoring funds ($677,000 in FY 2015). ROMN Vital Signs Monitoring funds are used for monitoring all high priority ROMN vital signs including streams. We do not anticipate increases in funding for Water Quality or Vital Signs monitoring in the near future.

However, GRSA has expanded since the ROMN I&M network was funded and we have requested (August, 2015) additional funding (~$55,000) from the Inventory and Monitoring Division to cover the additional effort needed to sample the expanded area of GRSA. If we get additional funds for monitoring for GRSA, we will consider expanding GRSA SEI monitoring to include additional high elevation sentinel sites and possibly conducting a GRSA Preserve SEI survey.

Current ROMN SEI monitoring consists of annual sentinel site monitoring in GLAC (4 sites), GRKO (1 site), LIBI (1 site), ROMO (5 sites) and surveys every 10 years in GLAC and ROMO. We estimate costs for annual SEI monitoring including costs for core network staff plus costs for seasonal field

Table 30. Stream Ecological Integrity sampling schedule for GLAC and ROMO surveys.

2007	X	
2008	X	
2009	X	
2010		
2011		
2012		
2013		
2014		X
2015		X
2016		X*
2017	X	
2018	X	
2019	X	
2020		
2021		
2022		
2023		
2024		X
2025		X
2026		X*
2027	X	
2028	X	
2029	X	

*some additional survey sampling conducted by ROMN core staff.

technicians to conduct annual sentinel site field monitoring plus the costs for laboratory analysis.

Annual SEI Monitoring Costs for ROMN Staff (Not Including Field Crews)

ROMN core staff have primary responsibility for all aspects (except for field monitoring and most laboratory sample analysis) of implementing long-term SEI monitoring as described above under Roles and Responsibilities. The total cost is approximately $111,979 (based on FY 2015 costs). The time (and cost in terms of salary and benefits) each staff member must dedicate to SEI monitoring is presented in Table 31. This cost estimate for ROMN staff includes both annual sentinel site monitoring and periodic surveys. This will be more in some years (e.g., when we are conducting a stream survey in a large park) and less in other years.

Annual SEI Sentinel Site Monitoring Field Crew Costs

We estimate the annual cost (in FY 2015) for field crews to conduct SEI sentinel site monitoring is $15,956. This includes salary, benefits and travel (Table 32). For this estimate, we assume a salary (and benefits) cost for two GS-6, step 1 Biological Science Technicians to conduct each water chemistry sampling event and the main sample event at each sentinel site and include an estimate for the travel cost (based on actual 2015 travel

Table 31. Time (by pay period) and FY 2015 cost for ROMN core staff (all staff except seasonally employed technicians) for annual SEI monitoring.

Staff person	# pay periods (PP - 14 days)	FY 2015 cost/ PP	Total FY 2015 cost
Program Manager	1	$5,292	$5,292
Protocol Lead	14	$4,926	$68,964
Field Coordinator	3	$2,979	$8,937
Data Manager	4	$3,876	$15,504
Asst. Data Manager	4	$1,869	$7,476
Admin. Asst.	1.5	$2,176	$3,264
Data Entry Tech.	2	$1,271	$2,542
Total annual cost			$111,979

Table 32. Estimated annual sentinel site monitoring field crew salary and benefits and travel costs, 2015.

Park	# sample sites	# chemistry only sample events	# full sample events	# paid tech. days	Cost
GLAC	4	12	4	32	$5,046
GRKO	1	3	1	0	$0
LIBI	1	3	1	0	$0
ROMO	5	15	5	40	$6,307
GRSA	2	6	2	16	$2,523
Total field crew salary (and benefits) cost					$13,876
Travel for field crews					$2,080
Total field crew and travel cost					$15,956

costs for SEI sentinel site monitoring). Park staff at GRKO and LIBI conduct the water chemistry sampling and assist the ROMN Ecologist with the main sample event in August at no cost to the network.

Annual ROMN SEI Sentinel Site Monitoring Sample Analysis Costs

ROMN collaborates with several laboratories to analyze water chemistry and quality samples and stream biota samples (aquatic macroinvertebrates, periphyton, and chlorophyll a and ash free dry mass). For pilot monitoring in 2007-2009, we worked cooperatively with the University of Montana Flathead Lake Biostation for water chemistry/quality analysis through the Rocky Mountains Cooperative Ecosystem Studies Unit cooperative agreement. Since then, we have worked with the University of Colorado Boulder's Kiowa Laboratory for water chemistry/quality analyses through the same agreement. For pilot monitoring in 2007 - 2009, we worked with the Flathead Biostation and Dr. Loren Bahls to identify and analyze stream biota samples. Since then we have worked with Rhithron Associates (Missoula, MT) for stream biota sample analysis through a contract. Finally, we obtain some sample analyses for metals from the EPA Region 8 Laboratory in Denver CO pro bono, starting in 2010 through 2015. If and when EPA can no longer provide free sample analysis assistance, ROMN will consider options including discontinuing metal sample analyses.

Costs (based on the most current Task Agreement with Kiowa Lab and contract with Rhithron Associates) for water chemistry/quality and biota sample analyses are detailed in Table 33. Water chemistry sample analysis costs $184 per sample and stream biota costs $655 per sample. We will collect 57 water chemistry samples per year; total cost for analysis is $10,488 per year. We collect 13 biota samples per year for a total annual sample analysis cost of $8,515. The total annual sentinel site sample analysis cost is $19,003.

Annual ROMN SEI Sentinel Site Monitoring Equipment, Equipment Maintenance, Supplies, Travel and GSA Vehicle Costs

In 2015 ROMN spent ~$10,000 on SEI monitoring equipment, equipment maintenance, calibration standards, waders, and miscellaneous supplies and $3,500 to lease, fuel, and maintain a GSA vehicle for stream monitoring.

Table 33. Annual SEI monitoring sample analysis costs.

Park	# sample sites	# sample events	Costs
Water chemistry ($184 per sample)			
GLAC	4	16	$2,944
GRKO	1	4	$736
LIBI	1	4	$736
ROMO	5	25	$4,600
GRSA	2	8	$1,472
Total water chemistry sample cost			$10,488
Stream biota ($655 per sample)			
GLAC	4	4	$2,620
GRKO	1	1	$655
LIBI	1	1	$655
ROMO	5	5	$3,275
GRSA	2	2	$1,310
Total stream biota sample cost			$8,515
Total annual sample analysis cost			$19,003

Total Annual ROMN SEI Monitoring Costs

The current (FY 2015) total annual cost for SEI sentinel site monitoring in the ROMN is $160,438 and includes the cost (salaries and benefits) for ROMN office staff (excludes field crews) to manage the protocol, coordinate field activities, manage SEI data, and analyze and report on results ($111,979); personnel cost for field sampling (salaries and benefits and travel for field crews - $15,956); cost for sample analysis ($19,003), and cost for equipment, equipment maintenance, supplies, travel and GSA vehicle costs ($13,500). Assuming inflation is 2.1%/year, total annual SEI monitoring will cost $178,006 in 2020, $197,499 in 2025, and $219,126 in 2030.

Cost for ROMN SEI surveys in GLAC and ROMO

ROMN is completing the fieldwork for a pilot survey of ROMO SEI in 2014-2016 with ~$86,714 of Vital Signs funding. This includes ~$42,814 for a field crew of three Biological Science Technicians and ~$43,900 for sample analysis. This doesn't include an estimate of the cost for ROMN office staff to administer, coordinate, manage data, and analyze and report on the survey. We estimate those costs above.

ROMN did a pilot survey of GLAC SEI in 2007-2009 in cooperation with the Flathead Lake Biostation (FLBS) of the University of Montana. The ROMN Ecologist was the protocol lead and did the bulk of the field coordination work using field crews from the Biostation through the Rocky Mountains Cooperative Ecosystem Studies Unit cooperative agreement using ROMN Vital Signs monitoring funds ($325,925). Sample analysis (conducted by FLBS) was also paid with these funds through the same agreement. Since some of this funding was for assistance in protocol development and because this was our first large SEI survey, the cost for the next GLAC SEI survey should be much lower, perhaps ~$150,000.

Publishing and Revising the Protocol

The SEI protocol is an original ROMN publication (e.g., it does not consist of material largely published elsewhere). Therefore the network has the responsibility to update the document.

Methodological details of the SEI protocol will be re-evaluated as needed after each season of data collection. A major evaluation will be conducted with the completion of a monitoring cycle (every six to ten years). The purpose of the reviews is to evaluate the procedures and determine where procedures fall short of stated objectives. These reviews may include suggested modifications to field methods, data analysis, and reporting based on either scientific considerations or budgetary constraints. An official programmatic review of the SEI approach, including the objectives, designs, methods, and results as well as the ability of the network to sustain these protocols, will be conducted after at least two parks complete sample and resample events (approximately every two to five years). If changes to the protocol are made, these will be included as a new revision and made available in the manner described above.

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