



# Rocky Mountain Network Wetland Ecological Integrity Monitoring Protocol

## *Narrative, Version 1.0*

Natural Resource Report NPS/ROMN/NRR—2015/991





#### ON THIS PAGE

Establishing a wetland monitoring site at the Great Sand Dunes National Park and Preserve, 2010  
Photograph by NPS, B. Schweiger

#### ON THE COVER

Monitoring an alpine wetland sentinel site in Rocky Mountain National Park, 2008  
Photograph by NPS, M. Britten.

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### Authors

E. William Schweiger<sup>1</sup>, Ed Gage<sup>2</sup>, Katharine M. Haynes<sup>3</sup>, David Cooper<sup>2</sup>, Laura O’Gan<sup>1</sup>, and Mike Britten<sup>1</sup>

*With contributions from* Isabel Ashton<sup>1</sup>, Erin Borgman<sup>1</sup>, Donna Shorrock<sup>4</sup>, Laura Atkinson<sup>1</sup>, Kristin Long<sup>1</sup>

<sup>1</sup>National Park Service  
Rocky Mountain Network  
1201 Oakridge Drive  
Suite 200  
Fort Collins, Colorado 80525

<sup>2</sup>Colorado State University  
Department of Forest, Rangeland and Watershed Stewardship  
1472 Campus Delivery  
Fort Collins, Colorado 80523-1472

<sup>3</sup>Medicine Bow – Routt National Forests and Thunder Basin National Grassland  
Forest Supervisor’s Office  
2468 Jackson Street  
Laramie, Wyoming 82070-6535

<sup>4</sup>National Park Service  
12795 West Alameda Parkway  
Lakewood, CO 80228-2838

### Editor

Nina Chambers

Northern Rockies Conservation Cooperative  
P.O. Box 2705  
Jackson, WY 83001

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# List of Standard Operating Procedures (SOPs)

This report is linked to the following Standard Operating Procedures (SOPs), which can be found in Schweiger et al. (2015).

WEI SOP 1: Pre- and Post-Season Workflow

WEI SOP 2: Pre- and Post-Sample Event Workflow

WEI SOP 3: Use of Electronic Data Recorders

WEI SOP 4: Verification of Site Status

WEI SOP 5: Plot Layout and Site Photos

WEI SOP 6: Groundwater Monitoring Well Installation

WEI SOP 7: Manual Reading of Water Table Height

WEI SOP 8: Installing and Reading Continuous Depth-to-Groundwater Data Loggers

WEI SOP 9: In Situ Water Physiochemistry

WEI SOP 10: General Soil Characterization and Chemistry

WEI SOP 11: Vegetation Composition and Cover

WEI SOP 12: Woody Structure and Herbivory

WEI SOP 13: Meso-scale Landscape Context, Site-scale Disturbance, and Site-scale Characterization

WEI SOP 14: Large-scale Landscape Context, Disturbance, and Characterization

WEI SOP 15: Field Sheet Scanning

WEI SOP 16: Data Entry

WEI SOP 17: In-Situ Groundwater Depth Logger Processing

WEI SOP 18: In-Situ Water Physiochemistry Logger Processing

WEI SOP 19: Data Analysis

WEI SOP 20: Revising the Protocol

In addition, the following ROMN shared data management, administrative, and equipment SOPs apply:

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

ROMN SOP: Archive Format Standards for Network Data

ROMN SOP: Folder Structure and File Naming

ROMN SOP: Scanning

ROMN SOP: YSI Logger

ROMN SOP: HOBO Logger

ROMN SOP: Photo Management

ROMN SOP: Database Design

ROMN SOP: Quality Control and Quality Assurance

# Change History

| Previous Version Number | Date | Author | Change Description | Reason | New Version Number |
|-------------------------|------|--------|--------------------|--------|--------------------|
|                         |      |        |                    |        |                    |
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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 of the protocol. The creation of the protocol began in 2007. Major changes and their reasoning in these early internal drafts 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 (<http://science.nature.nps.gov/im/units/romn/>).



# Executive Summary

The Rocky Mountain Inventory & Monitoring Network (ROMN) of the National Park Service (NPS) includes a wide range of environments ranging from mountain peaks to deciduous forests to Western grasslands. The six units of the network include Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), Little Bighorn Battlefield National Monument (LIBI), Florissant Fossil Beds National Monument (FLFO), Great Sand Dunes National Park and Preserve (GRSA), and Rocky Mountain National Park (ROMO).

Here, we present a protocol to monitor wetland ecological integrity (WEI) within four units of the network (GLAC, GRSA, ROMO, and FLFO). The protocol comprises 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 part, in a separate document, consists of specific standard operating procedures (SOPs) that provide instructions for executing field, analytical, and select administrative components of the protocol.

The general goals for long-term ecological monitoring of ROMN wetlands focus on documenting the status and trend in wetland condition, understanding the causes of change in wetland condition, and assisting in the application of WEI results and relevant auxiliary information to park wetland management. Under budget scenarios and management needs as of 2015, we expect to conduct and report on park-scale surveys only in ROMO and in GRSA every 10 years. We report on objectives specific to data derived from annual sample efforts in ROMO, GRSA, FLFO, and GLAC every fifth year, staggered by park. Continuously logged hydrologic data will be reported on more frequently. The ROMN will consider altering this schedule with changes in budget, resource condition and management needs. Generalized WEI objectives include the following:

1. Determine the status in wetland areal extent using survey site extent data and park-scale map or imagery data.
2. Determine status in a suite of response measures:
  - a. Vegetation composition, including bioassessment modeling
  - b. Groundwater hydrology (more detailed and continuously logged at most sentinel sites)
  - c. Soil chemistry (more detailed at sentinel sites)
  - d. In situ water chemistry
  - e. Anthropogenic and natural disturbances
3. Determine the long-term trend in the condition of select wetland responses.
4. Assess status of select responses through:
  - a. Comparisons to existing and published assessment points, including any regulatory criteria (rare for wetlands), ecological thresholds or ecoregion assessment points that are relevant to ROMN park wetlands and their management
  - b. Comparisons to ecoregion assessment points derived from distributions of reference site data from within the park or surrounding ecoregion(s)
  - c. Comparisons to baselines derived from partner or auxiliary data
5. Relate any spatial or temporal patterns (including trend when possible) in select wetland responses to important ecological and anthropogenic drivers.

To meet the WEI monitoring objectives we have designed a multi-faceted, integrated approach. We have three sample design forms that each 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 WEI monitoring in most years is restricted to annually sampled sentinel sites. A focus on sentinel sites is both more realistic given our budget and at a temporal scale more likely to elucidate the role of hydrology and soil chemistry in controlling wetland condition as measured by vegetation. We emphasize response measures of community-level floristic composition and vegetation structure, hydrology, and qualitative or categorical indicators of condition and stress (including both anthropogenic and natural). We develop park-specific integrative bioassessment models using vegetation as the response and the suite of stressor or driver covariates collected at all wetland sites. WEI methods are documented in this protocol and are largely derived from well-established and existing protocols developed by ROMN partners. The application of standardized protocols facilitates comparison of wetlands within an ecoregion and across ROMN and other NPS units.

A key step in the reporting of WEI data is interpreting the meaning behind a given result or set of results. In broad stroke, our approach is to compare WEI results to established or novel numeric assessment points and evaluate each indicator based on these comparisons. Where relevant thresholds do not exist, we attempt to estimate these using a variety of methods. We interpret patterns in these comparisons using

ecological literature and theory, NPS I&M 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 criteria and thresholds. A vital sign/indicator can be in a *reference* state, that is, based on WEI or partners’ data estimating a vital sign, within a range of values considered functional, intact, or loosely speaking, “good condition” from an ecological or other perspective (e.g., human health). The status may also be *non-reference* or degraded, dysfunctional or in a “bad” condition; or it may be in a state that is intermediate between reference and non-reference. To avoid confusion with a strictly regulatory approach we do not apply terms like “impaired” or “meets designated uses.”

This effort has been, and will continue to be, a cooperative undertaking between ROMN staff, wetland scientists (especially from Colorado State University), the U.S. Geological Survey (USGS), the U.S. Environmental Protection Agency (EPA), Colorado and Montana Natural Heritage Programs, and most importantly, park management and staff. The WEI protocol represents the efforts of many dedicated scientists and resource managers. WEI monitoring will assist in managing important wetland systems within ROMN parks over the long term.

# Acknowledgments

The Rocky Mountain Network (ROMN) Wetland Ecological Integrity Monitoring Protocol was prepared by ROMN and Colorado State University (CSU) 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, Mark Biel, Ben Bobowski, Fred Bunch, Tara Carolin, Jeff Connor, Ken Czarnowski, Chris Ford, 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.

Thanks to the many park staff members who shared their experience and knowledge of wetlands and other park resources in vital signs scoping meetings, conceptual models workshops, and informal park visits, and via phone calls and e-mail. These include (but are not limited to): Jeff Wolin (FLFO); Jen Asebrook, Dennis Divoky, Steve Gniadek, Sallie Hejl, Jennifer Hintz, Dawn LaFleur, Joyce Lapp, Richard Menicke, Bill Michels, and John Waller (GLAC); Andrew Valdez (GRSA); and Karl Cordova, Therese Johnson, Ron Thomas, Mary Kay Watry, and Nate Williamson (ROMO).

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The Network worked closely with statisticians and ecologists at CSU (S. Urquhart), the EPA (T. Olsen) and from several other I&M Networks (notably, S. Garman at Northern Colorado Plateau Network) to develop our sample designs. We are grateful for the significant amount of (often gratis) advice and help these individuals have offered.

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# 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.

5. 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 units: Glacier National Park (GLAC), Grant-Kohrs Ranch National Historic Site (GRKO), and Little Bighorn Battlefield National Monument (LIBI), Montana; and Florissant Fossil Beds National Monument (FLFO), Great Sand Dunes National Park and Preserve (GRSA), and Rocky Mountain National Park (ROMO), Colorado (Figure 1). Through a comprehensive three-year scoping process, the 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; wetland 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 parks across the network, the 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 Wetland Ecological Integrity (WEI) Protocol presented here directly addresses four of ROMN's 12 high-priority vital

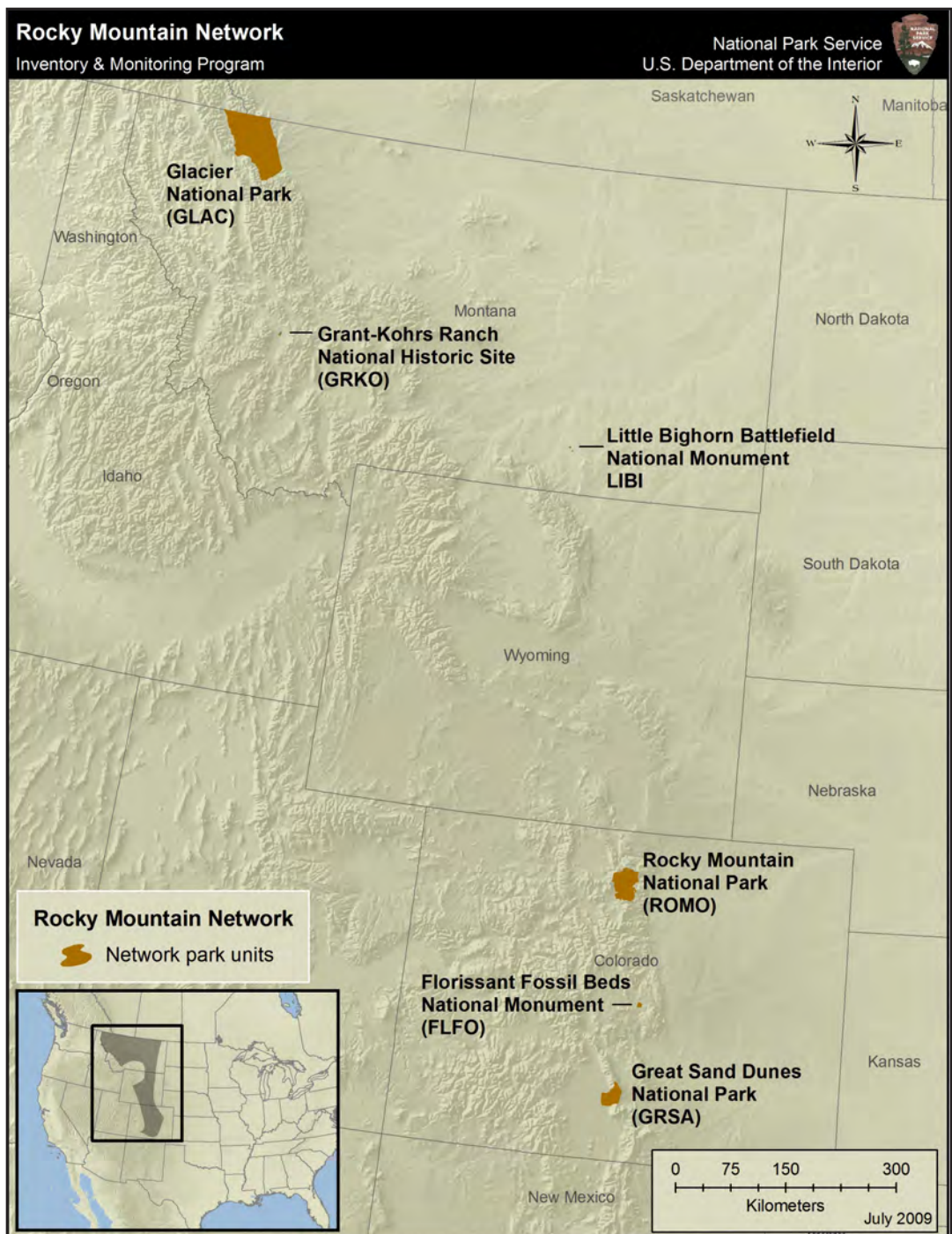


**Figure 1.** National park units in the Rocky Mountain Inventory and Monitoring Network. The wetland ecological integrity protocol will be implemented in four units: Glacier National Park, Rocky Mountain National Park, Florissant Fossil Beds National Monument, and Great Sand Dunes National Park and Preserve.

signs: wetland communities, groundwater dynamics, invasive/exotic plants, and focal species (beaver and elk). Three other high-priority vital signs are indirectly linked with the WEI protocol, including: landscape dynamics, wet and dry deposition, and weather and climate. WEI monitoring will be conducted in four ROMN parks: ROMO, GRSA, GLAC, and FLFO. 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 wetlands 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 procedures (SOPs) which provide instructions for executing field, analytical, and select administrative components of the protocol.

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

## Wetland Definition

There is no universal definition of “wetland.” Rather, multiple regulatory and scientific definitions have been developed for wetland ecosystems because of their high ecological diversity; special legal status under certain federal, state, and local laws; and unique place at the intersection of several scientific disciplines. For example, the definition used by the U.S. Army Corps of Engineers (USACE) to administer section 404 of the Clean Water Act aims to provide consistent and uniform criteria for field delineation (USACE 2008), while the Cowardin definition was developed for national inventory and mapping efforts (Cowardin et al. 1979).

All definitions recognize, to some degree, the key role of hydrologic processes in wetland formation and the resulting suite of soil and vegetation characteristics that result. The definition used by the National Research Council (NRC 2001) is broad in scope, emphasizing the unique suite of hydrological, chemical, and biological characteristics which differentiate wetlands from uplands. The definition used by the National Wetlands Inventory (NWI) program contains elements found in both the USACE and NRC definitions (Cowardin et al. 1979).

The ROMN definition of wetland follows Cowardin (1979), and specifies that wetlands must have one or more of the following three attributes:

1. vegetation dominated, at least periodically, by hydrophytes;
2. predominantly un-drained hydric soils; and
3. saturated with water or covered by shallow water at some time during the growing season of each year.

The definition of wetland (and its partitioning into distinct types, see below) plays a critical role in the WEI protocol. As the target population or resource for WEI monitoring, it is one of the key elements of the sample design we use to select monitoring sites and to which monitoring results are extrapolated.

## Wetland Conceptual Diagram

To help visualize and understand the major components, ecosystem functions, and drivers and stressors of wetlands, we developed a general wetland characterization diagram (“model”; Figure 2). The figure provides a simple framework for understanding the relationship between wetlands and surrounding park lands, as well as current and anticipated issues potentially impacting wetlands in ROMN parks. We define three major components to wetlands: hydrology, soil, and flora, with hydrology the primary driver of both soil and vegetation response (with many complex interactions among them). Key large-scale drivers of wetlands include geology, climate, disturbance regimes, and landscape context, with climate perhaps the most important external variable. Key local- to meso-scale anthropogenic stressors that impact wetlands include hydrologic alteration (ditching, dams, and other diversions), nutrient loading, erosion and sedimentation, and biological alteration such as increases in invasive flora or shifts in wetland usage by species such as beaver and elk. Wetland condition is also closely connected to aquatic and upland systems through hydrologic gradients, wildlife use and movement, and overlapping cover and

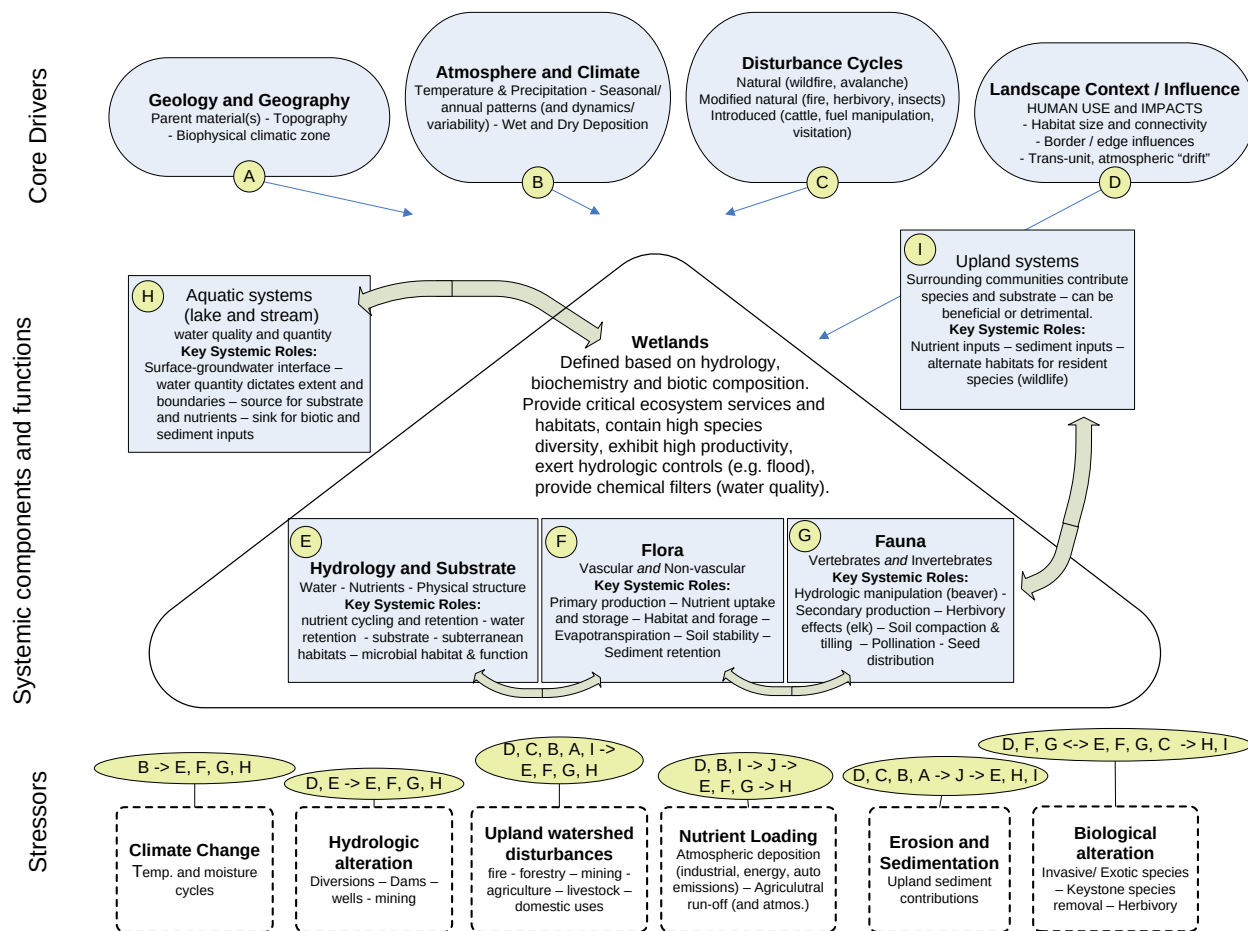


**Figure 2.** ROMN wetland ecosystem characterization model.

NOTE: The model identifies core drivers of pattern and process (ovals at the top of the figure), major components of wetlands (rectangles in the center of the figure), and known or anticipated stressors that drive changes in the processes and patterns that define wetlands (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 this is not a state-transition or energy-material flow model; it does not explain the details of component-driver interactions, rather it conceptualizes the system at a level critical for scoping and design. This model depicts the major components and drivers of wetlands, and connects 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).

distribution of some plant species. These stressors and drivers may be imposed from outside the system resulting in a new set of determining conditions, or they may be a natural part of the system, but currently realized at an excessive (or deficient) level.

### Rationale and Justification for Wetland Monitoring

There are several reasons behind the choice to conduct long-term wetland monitoring in ROMN parks. In general, wetlands are

fundamental components of the ecological and cultural context of ROMN parks. They are often what visitors come to see, what they remember when they leave, or in the case of our cultural parks, form an important backdrop to the historical or cultural events preserved by the park. Perhaps most importantly, the NPS recognizes that aquatic and wetland 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 the ROMN is to provide long-term ecological monitoring data and information for a suite of wetland “vital signs” to park managers to assist them in preserving park wetlands unimpaired for the enjoyment of current and future generations. The ROMN has implemented WEI monitoring to monitor several important wetland vital signs including vegetation community structure and condition, ground water dynamics, invasive/exotic vegetation and water chemistry (Britten et al. 2007). Understanding and managing wetlands is best accomplished by treating them as complete hydrologic or ecological systems where the natural processes that deliver ground water, sediment, and support vegetation communities are maintained and human disturbances are minimized. *While regulatory considerations (summarized below) provide an important context for WEI monitoring, the emphasis of long-term ecological monitoring within the protocol is a key distinction from wetland monitoring conducted by States or other federal agencies like the EPA.*

Although typically comprising only a small portion of total area in western landscapes, wetlands are widely recognized for the numerous important ecological functions they provide (Mitsch and Gosselink 2007, Naiman et al. 1993, Cooper and Sanderson 1997, Stohlgren et al. 1997, Cooper et al. 2002, Heidel and Laursen 2003). Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs. Wetlands are local and regional centers of biodiversity, and support many rare or endemic species, especially in montane and alpine landscapes. Wetlands support a disproportionate amount of each ROMN park’s biodiversity, relative to their area (Niering 1988, D. Cooper, pers. comm. September 2011). Wetlands provide surface and subsurface water storage, which maintains natural groundwater flows via aquifer recharge/discharge in wilderness areas; and in populated areas, wetlands can help prevent flooding by temporarily storing water, allowing soil infiltration or evaporation. Wetlands improve water quality by cycling nutrients, removing pesticides

and other pollutants through absorption and chemical processes within the wetland. This can enhance the decomposition of organic matter, cycling nutrients back into the food chain. Wetlands also have a long list of values or characteristics that are beneficial for the public in national parks and society in general. Some examples of these types of wetland values include reduced damage from flooding; providing fish, waterfowl, and other wildlife habitat for hunting, fishing, and trapping; boating; photography; outdoor classrooms or environmental education; and the wilderness experience. Finally, the ecological diversity and high productivity of wetlands make them one of the most scenic features in ROMN parks such as ROMO, GLAC, and GRSA.

## **Ecological Integrity**

We focus on the ecological integrity of wetlands. 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 floristic composition and vegetation structure, hydrology, and soils. Our primary focus is on multi-metric and multivariate indices of wetland ecological integrity from wetland vegetation data (EPA 2002, Jones 2004, Faber-Langendoen et al. 2006, Rocchio 2007, Lemly and Rocchio 2009). We use qualitative or categorical indicators of condition and stress (including both anthropogenic and natural) to help understand patterns in these responses and develop bioassessment models of wetland condition.

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”). The ROMN will work with parks to develop approaches that are

specific to each park and the key issues impacting wetland condition in a given system, integrating the broader, longer-term concepts within ecological integrity with more case-specific needs.

### Wetland Sensitivity

Wetlands are relatively uncommon in ROMN parks due to continental climatic conditions, including low precipitation and low atmospheric humidity, high solar radiation, and seasonally dry periods. Steep topographic gradients result in excessive drainage and most wetlands occur in confined topographic positions where bedrock and landforms allow groundwater to concentrate (Windell et al. 1986, Patterson and Cooper 2007). Therefore, ROMN wetlands typically have small water-storage capacity, high surface and groundwater flow rates, and water levels that respond rapidly to changes in groundwater inflows or precipitation amounts. These conditions result in a habitat type that is sensitive to perturbation.

### Threats to Wetlands

Wetlands are among the most significantly altered ecosystems in North America. Classically, this is due to stress on wetland hydrology from (among other things) flow regulation, ditching, installation of drain tiles, pumping, fill placement, overgrazing by domestic and native ungulates, atmospheric deposition, ski and housing developments, and exotic species invasion (see Figure 2; Patten 1998, Bedford et al. 1999, Zedler and Kercher 2005). Recently, however, the increasing role of climate change in altering wetland functions and values has been recognized (Baron et al. 2000, Field et al. 2007). While the more proximate, classic stressors impact ROMN wetlands, climate change in our wilderness parks is likely to be the most important direct and indirect stressor over the long term. The maintenance of wetlands depends on particular hydrologic regimes. For example, Poff et al. (2002) predicts that inflows to groundwater-fed wetlands could be severely affected by future climate changes. Reduced groundwater flow due to lower snowpack, earlier melt dates, or reduced summer precipitation could result in lower water tables in wetlands dependent

on groundwater inputs for perennial soil saturation. Wetlands may also be affected by changes in the timing, duration, or amount of summer seasonal precipitation, which historically has come from mid-July through August, at the height of the growing season. Climate change may affect types of wetlands differently and insight into variations in hydrologic regime, soil, and vegetation will aid in identifying climate-driven changes as they occur in wetlands.

Current projections suggest that climate change will likely reduce the number and extent of wetlands and cause declines in the condition of associated flora and fauna and critical functions, such as carbon and water storage (OTA 1993, Field et al. 2007). Protected landscapes such as ROMN parks—even large wilderness systems like ROMO, GLAC, and GRSA—do not insulate wetlands from the pervasive direct and indirect impacts of a changing climate regime. Expected shifts in climate that will impact the hydrologic regimes supporting ROMN wetlands include a loss of glaciers, less snow, earlier peak flows, less stream flow, warmer water temperatures, more frequent droughts, and more intense storms (Barnett et al. 2008). Streamflows have shifted toward earlier peak runoff, and this has been attributed to more precipitation falling as rain rather than snow and earlier snowmelt (Knowles et al. 2006), especially in the northern (e.g., GLAC) and central Rocky Mountains (e.g., ROMO) compared to the south. Warmer wintertime and spring temperatures have accelerated snowmelt and caused an overall decline in spring snowpack, particularly at lower elevations, despite increases in winter precipitation in many places (Mote et al. 2005, Field et al. 2007, Ray et al. 2008). For example, high end estimates of a 4°C temperature increase in the Loch Vale Watershed in ROMO may result in a 50% reduction in snowpack and 4-5 week earlier increases in soil moisture and run-off compared to mean onset of spring conditions from 1984 to 1998 (Baron et al. 2000). The loss of winter snowpack will greatly reduce a major source of groundwater recharge and summer runoff, resulting in a potentially significant lowering of water levels in streams, rivers, lakes, and wetlands during the growing season. Lower summer base flows will cause

a reduction in groundwater tables, which are important for sustaining riparian tree communities (Stromberg 1998, Scott et al. 1999). Reduced water depths may also increase the vulnerability of sensitive species such as amphibians (Kiesecker et al. 2001) and wetland-obligate vegetation. Despite this recognition, there is a paucity of studies in ROMN parks or the Rocky Mountains in general that document climate-driven declines in wetland function or extent (McMenamin et al. 2008).

### ***Regulatory Considerations***

Wetlands are a highly regulated natural resource and multiple federal and state programs must be implemented by NPS and its partners to protect wetlands and their many ecologic and hydrologic functions. In general, the National Park Service is required to manage all park units in accordance with the Organic Act and other laws so as not to be in derogation of the values and purposes for which these various areas have been established (NPS 1970). Under the General Authorities Act, all resources, including wetlands, 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 Wetlands**

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 park wetlands and the ecological processes that support and maintain them. NPS policies direct park managers to work with the appropriate partners (e.g., Montana Department of Environmental Quality [MT DEQ], the Colorado Department of Public Health and Environment [CDPHE], the U.S. Army Corps of Engineers [USACOE], the EPA or Tribal Nations) to obtain the highest-possible standards for park wetlands and to maintain or restore wetland water quality and condition.

The NPS Wetlands Program within the Water Resources Division (WRD) is responsible for developing the NPS wetland

protection policies and procedures found in Director's Order #77-1: Wetland Protection (NPS 2012) and NPS Management Policies (NPS 2006). These establish a "no-net-loss of wetlands" policy for the NPS, which requires avoiding, minimizing, and compensating for adverse impacts on wetlands. If a proposed action will have such impacts, then compliance with these policies and procedures must be recorded in a Wetland Statement of Findings.

### **Clean Water Act**

The federal Clean Water Act (CWA), first promulgated in 1972, is designed to maintain and restore the chemical, physical, and biological integrity of the Nation's waters. Within the CWA, there are a number of sections that specifically address protection or regulation of wetlands. For example, Section 303 addresses water quality standards; Section 401 addresses certification of condition permits; Section 402 addresses the National Pollutant Discharge Elimination System; and Section 404 includes the dredge and fill permitting program. Regulation of wetland impacts is primarily the jurisdiction of the USACOE, under Section 404 of the CWA. USACOE works in conjunction with EPA and numerous state agencies to process Section 404 permit applications.

The inclusion of wetlands as part of the "Nation's waters" was complicated by Supreme Court decisions in 2001 and 2006. The U.S. Environmental Protection Agency and U.S. Army Corps of Engineers jointly released a proposed rule to clarify protection under the Clean Water Act for (streams and) wetlands (Federal Register 2014). The proposed rule attempts to re-establish most natural wetlands adjacent to navigable streams or rivers and those with a "significant nexus" to such streams and rivers as subject to the CWA. Significant nexus means that a water, including wetlands, either alone or in combination with other similarly situated waters in the region (i.e., the watershed that drains to the nearest navigable water) significantly affects the chemical, physical, or biological integrity of a navigable water (Federal Register 2014). It was unclear as of 2014 what the final resolution of this would be and how it might impact treatment of

wetlands by ROMN states. Therefore the following may change if/when this issue is resolved.

In Colorado, wetlands are included as part of the state waters and CWA based monitoring and regulatory actions are applied (CDPHE 2012). CDPHE takes an exclusively regulatory approach to wetlands protection, administering the state's water quality certification program and 402 discharge permit program. Water quality standards for wetlands were developed by the CDPHE Water Quality Control Commission in 1993 (WQCC Regulation 31.27 and 5 CCR 1002-31) and are usually set by baseline ambient quality, if known, or the standards of the surface water segment into which the wetland falls. Biological criteria have not been developed or applied to wetlands in Colorado. Designated uses for wetlands are the same as those applied to surface waters that a wetland is associated with. The state's Antidegradation Policy for wetlands is consistent with all other waters in the state. Other regulatory wetland activities in the state are conducted by the Colorado Department of Transportation (CDOT), the Division of Mined Land Reclamation within the Department of Natural Resources (DNR), and the Colorado Department of Parks and Wildlife (CDPW) (most non-regulatory wetlands programs). Additionally, local governments are encouraged to define and regulate areas of state interest. The goals of no net loss of wetlands and net gain of wetlands are largely implicit in all of the state's programs. Finally, inventory, monitoring, and assessment of wetlands has largely been led by the Colorado Natural Heritage Program (CNHP) under guidance from the state of Colorado and EPA. By design, the ROMN WEI protocol shares many elements with CNHP's approach.

In Montana the state does not explicitly include wetland as part of the waters of the state but has a growing program (MT DEQ 2013), including a strategic five-year plan to prioritize and direct collective efforts on wetland conservation including mapping, monitoring and assessment, restoration, and management. The primary form of wetland regulation at the state level is water quality certification under the CWA 401 program

administered by MT DEQ. Montana does not have regulations, policies, or legislation that guide wetland mitigation. Enforcement actions under the state's water quality laws apply but are not specific to wetlands. In 2008-2012, MT DEQ investigated wetland water quality standards and did a nationwide permit review, but as of 2014 no actions have been formalized. The state does have a no-net-loss policy addressed through regulatory actions by USACOE and the EPA. As with streams and rivers, Montana is a leader in developing inventory, assessment and monitoring for wetlands. The state has landscape-level and rapid assessments and has explored the development of a bioassessment focused on vegetation, birds, amphibians and diatoms. Many of these approaches are compatible with the ROMN WEI protocol.

Section 313 of the CWA requires that all federal agencies comply with the requirements of state law for water quality management, regardless of other jurisdictional status or landownership. In Colorado it is clear that the NPS must also include wetlands as waters of the state and thus subject to anti-degradation policies of the CWA within ROMO, GRSA and FLFO. In Montana, the state program is less explicit but, given the themes and precedent set by the Organic Act and NPS Management Policies, we recommend that wetlands in Montana parks should be treated by NPS similarly to those in Colorado.

#### The Interpretation of WEI Data in a Regulatory Context

As emphasized in several places in this document, the primary motivation for WEI monitoring is to understand and document the long-term ecological condition of wetlands in ROMN parks in order to better protect and manage them. The NPS does not have CWA regulatory authority over wetlands in a park; any CWA motivated regulatory action is the responsibility of a State, Tribe, the USACOE, or the EPA. However, as noted above, the CWA, the Organic Act and various NPS Management Policies do require park management to maintain, rehabilitate, and perpetuate the inherent integrity of wetlands and NPS

will work with appropriate State and other Federal partners to do so.

## **Wetland Classification**

Although often regarded as a single resource, wetland ecosystems vary widely in their functional and structural characteristics (Mitsch and Gosselink 2000). Various classification schemes have been applied to wetlands in an attempt to better understand this variability. Criteria or attributes and their relative importance within these classifications differ. Common examples include dominant vegetation, hydrologic characteristics, geomorphic setting, and water chemistry. The most common classifications include Ecological Systems (Comer et al. 2003, Salas et al. 2005, Cowardin et al. 1979), and the Hydrogeomorphic (HGM) Approach (Brinson 1993, Cooper 1998). While the WEI protocol emphasizes a more specialized (and relevant for ROMN parks) classification system and wetland types as discussed below (Cooper 1998, Gage and Cooper 2013), these are readily crosswalked to the existing approaches.

Any classification is an artificial description of the functioning of complex systems. In some cases, determination of a type may be difficult. For example, Cooper (1998) identifies problems in defining the boundaries of certain HGM classes in Colorado with detailed assessments necessary to completely describe the HGM characteristics of a particular wetland (see also Brinson 1993). Terminology can be ambiguous, with different classifications variably lumping different ecosystem types together.

### **Cooper Types**

The Cooper approach builds upon other (see below) systems, but is specialized for wetlands in ROMN parks. The Cooper system evolved from HGM and emphasizes both hydrology and soils, but uses more intuitive and simpler wetland names that are specific to the landscapes in and around ROMN parks. In this protocol, we describe five Cooper wetland types: fens, marshes, wet meadows, salt flats, and riparian (a dichotomous key to these is included in WEI SOP 4: Verification of Site Status). Each type

differs in basic hydrologic regime and soil characteristics, in turn driving differences in floristic composition, vegetation structure, and biogeochemical functioning. Cooper types are not a priori mapped wetlands in any of the existing landcover maps available; we develop maps for these as needed and crosswalks to the existing classification systems in all ROMN parks as part of the WEI protocol. Depending on the park, one to all of these wetland types are the target populations for WEI monitoring.

### **Ecological Systems**

Ecological Systems (Comer et al. 2003) are defined as groups of plant community types that tend to co-occur within landscapes and that have similar ecological processes, substrates, and/or environmental gradients. For wetland Ecological Systems, these processes are typically hydrologic. A given wetland Ecological System will manifest itself in a landscape at intermediate geographic scales of tens to thousands of hectares and will persist for 50 or more years. This temporal scale allows typical wetland successional dynamics to be integrated into the concept of each unit. More specific diagnostic classifiers can be used to define each classification unit. For wetland Ecological System types, these include soil organic matter, vegetation structure, landscape position, and hydrology.

### **Cowardin**

The Cowardin or National Wetland Classification System (NWCS) has been in place for three decades (Cowardin et al. 1979). It is used in several programs such as the U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) and is the formal or legal system recognized by the NPS. It provides a useful base for understanding the distribution of wetlands as a whole across broad regions. The Cowardin system emphasizes water body types (marine, riverine, palustrine), substrate materials, vegetation life forms, hydrology, water chemistry, and certain impacts (e.g., partly drained, excavated, impounded, and farmed). These properties are important for describing wetlands and separating them into groups for inventory and mapping purposes and for natural resource

management. They do not, however, include several abiotic properties important for evaluating wetland functions (Brinson 1993). The Cowardin system is of limited utility for discriminating functional wetland types and long-term monitoring within ROMN parks. Most wetlands are classified in the palustrine system, and depending upon their vegetation, may be placed in the moss-lichen, forested, emergent, or scrub-shrub class. Various hydrologic regime and chemistry modifiers can also be added, although in practice, these data are rarely available and little field testing has been done on their utility. Given the ubiquity and legal context of Cowardin types, however, we include them in the WEI protocol.

### Hydrogeomorphic

Finally, wetlands are also commonly classified using the Hydrogeomorphic (HGM) Approach (Brinson 1993, Cooper 1998), which emphasizes physical variables such as geomorphic setting and hydrologic regime in classification. The approach is useful for evaluating the ecological functions of individual wetlands because of its emphasis on physical variables in classification. The HGM system emphasizes the location of a wetland in a watershed (its geomorphic setting), its sources of water, and its hydrodynamics. The system was designed for evaluating similar wetlands in a given geographic area and for developing a set of quantifiable characteristics for “reference wetlands” (Smith et al. 1995). A series of geographically focused models or “function profiles” for various wetland types have been created and are in development for use in functional assessment (e.g.,

Brinson et al. 1995). A suite of indicators are used to describe each of these properties and then develop profiles that describe the functions the wetland is likely to perform. While of great utility for its intended purpose, the HGM approach is not designed to be sensitive to the species composition of vegetation.

### ROMN Wetland Types

ROMN parks have five Cooper wetland types: fens, wet meadows, riparian wetland, marshes and salt flats. We summarize the major characteristics of each of these types in the following sections. For additional discussion, see Gage and Cooper (2013).

#### Fen

Fens have two consistent features (1) stable groundwater-driven hydrologic regimes with high water tables that retard organic matter decomposition, and (2) peat accumulation. Fens form in a variety of landscape settings and differ widely floristically (Figure 3; Bedford and Godwin 2003, Cooper 1996). ROMN fens are ecologically diverse and like all wetlands, support a disproportionate share of a park’s biodiversity and numerous rare or endemic species (Cooper and Andrus 1994, Cooper and Sanderson 1997, Chadde et al. 1998, Hiedel and Laursen 2003). ROMN fens may be less diverse floristically than other wetland types due to nutrient-poor conditions caused by certain types of bedrock geology (especially in ROMO and other parks with granitic bedrock).

Fen vegetation is commonly dominated by species of *Carex*, *Juncus*, *Eleocharis*, *Salix*,

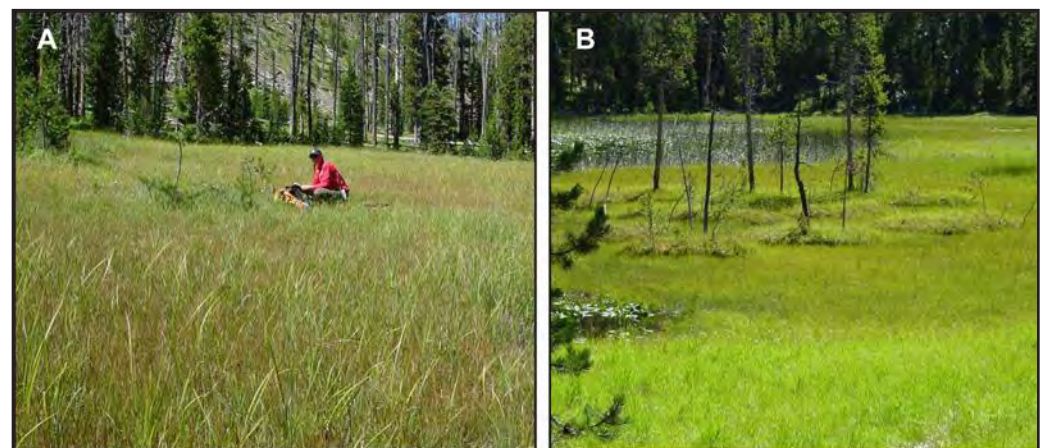


**Figure 3.** ROMO fens (A) on a slope and (B) in a basin. The fen in B supports a floating mat.

and *Calamagrostis*. Cover of herbaceous dicots is often low. Clonal sedges such as *Carex utriculata* and *C. aquatilis* and spike-rush sedge, *Eleocharis quinquefora*, are among the most common dominants and often grow in dense, lawn-like stands, although a wide variety of other sedges also occur. Grasses are less common and are found sparsely on fen margins and hummocks, with the exception of *Calamagrostis canadensis*, which may be abundant. Rushes are infrequent and most prevalent along fen margins, particularly where fens abut riparian areas. Semi-aquatic dicots such as *Menyanthes trifoliata* and *Nuphar lutea* are found in ponds and seasonally flooded fens. Fens may also have shrub-dominated communities, sometimes referred to as “carrs.” Shrubs such as *Salix planifolia*, *S. wolfii*, *S. candida*, and *Betula nana* are common, may co-dominate with herbaceous, forested, or moss communities, and often form characteristic hummock patterning. Forested fens (“treed fens”) also occur in some ROMN parks. The canopy of forested fens is comprised of common, upland trees such as *Picea engelmannii* and *Pinus contorta*, although individual trees often take on a noticeably “spindly” appearance. Finally, fens often support extensive bryophyte communities. Communities dominated by *Sphagnum* mosses are largely restricted to acidic peatland types such as iron fens, but can be found in microenvironments, such as hummock tops, and in less-acidic, nutrient-poor peatlands. More commonly in ROMN parks, bryophyte communities are dominated by brown moss species in the genera *Drepanocladus*, *Aulacomnium*, *Warnstorfia*, and *Tomenthypnum*. The distribution of mosses commonly follows a strong pattern of vertical zonation along water table gradients and microtopographic features, such as hummocks.

Fens have stable water supplies with water tables at or close to the ground surface for most of the growing season (Windell et al. 1986, Winter et al. 2001, Chimner and Cooper 2003a). Unlike riparian wetlands, fens do not experience high velocity surface flows or sediment deposition from fluvial processes, and unlike marshes, fens do not experience deep inundation, although microsites (e.g., water tracks and

spring-fed ponds) can have over 20 cm of standing water (Cooper 1990). Hydrologic regimes within individual fens can be variable, and differences in the amplitude and timing of water table fluctuations can occur among sites such as fen margins, spring discharge zones, or on floating mats. While hydrologic processes vary widely among fens as a function of factors such as geologic and geomorphic setting, overall hydrologic regimes are relatively similar across floristic and geographic gradients. Because fens receive inputs of groundwater, geological factors such as the mineralogy of watersheds can influence water chemistry, affecting biotic composition in fens (Cooper and Andrus 1994, Cooper 1996) and ecological processes, such as productivity and decomposition (Verhoeven and Arts 1992, Szumigalski 1995, Chapin et al. 2004). Areas with bedrock dominated by granitic (e.g., ROMO) and metamorphic rocks often support fens with neutral or slightly acidic pH, while watersheds composed of limestone, dolomite, or shale produce circumneutral to basic pH and higher concentrations of mineral ions. Past glaciation strongly influences contemporary patterns of fen occurrence. For example, fens have formed in kettles, depressions filled with impounded water formed by the melting of stagnant ice blocks that were buried in outwash or moraines as glaciers retreated (Menzies 2002). Fens can also be found in drainages partially impounded by lateral or terminal moraines. While the dominant water source for fens is groundwater, all fens receive some water via direct precipitation, although much of this may be lost through evapotranspiration (Gorham and Hofstetter 1971). Accumulated snowpack overlying some fens may also be an important source of water, especially in the subalpine fens of ROMO, GLAC, and GRSA (Windell et al. 1986). Surface water inputs to fens can occur as sheet flow or channelized flow; however, sheet flow rates are typically low with widely dispersed tracks, while channelized streams flow slowly in sinuous and braided patterns, otherwise high-velocity flows would erode the peat. Sheet flow from seasonal snowmelt may contribute a significant amount of water to fens, and in larger fens, flows may coalesce to form water tracks around the

margins of peat bodies (Heinselman 1970, Crum and Crum 1988).

Anthropogenic and natural disturbances are rare in ROMN fens compared to other wetland types. Fire and grazing may both affect fens, although there are few historical data. Direct fire effects include plant mortality and peat combustion; indirect effects may be caused by changes in hydrologic or chemical characteristics of surrounding burned watersheds. Fire can maintain open conditions in some ROMN fens by selectively killing woody species (Jacobson et al. 1991) and favoring early successional plant communities. Increases in water and sediment yield may affect fen function by creating a flush of nutrients, such as nitrogen following fire (Anderson and Menges 1997, Dikici and Yilmaz 2006). Typically, wet and dry atmospheric deposition and the mineralization of organic matter are the main inputs of N to fens (Bayley et al. 2005), while processes of nitrate reduction, nitrogen (N<sub>2</sub>) fixation, and denitrification control nitrogen flux (Williams and Wheatley 1988, Beltman et al. 1996, Oien 2004). Atmospheric deposition of N and other minerals in ROMN parks (especially ROMO) are elevated relative to historical conditions as a result of increased mineral inputs to the atmosphere from industrial and agricultural sources (Vitousek et al. 1997, Baron et al. 2000, Kittel et al. 2002, Fenn et al. 2003). ROMN fens may be sensitive to and easily disturbed by shifts in climate due to their reliance on high water tables for peat accumulation. Although fen water tables are high in the spring and early summer due to snowmelt runoff, they may require precipitation in the late summer to avoid major water table drops.

### **Wet Meadow**

Wet meadows are the most abundant wetland type in the western U.S., and occur from the alpine zone to the plains. Wet meadows typically exhibit seasonally saturated soils, but lack the perennial high water tables of fens or the large seasonal and inter-annual water table fluctuations characteristic of marshes. Unlike fens, wet meadow soils are mineral, but have significantly more organic matter than soils in the surrounding upland. Mineral soils often have lower water-holding

capacity than peat and mineral substrates, and may drain and dry more readily. The lack of perennial saturation results in aerobic organic matter decomposition during dry periods which, along with mineral soil throughout the plant root zone, provides higher levels of nutrient availability to wet meadow vegetation (Venterink et al. 2002).

The vegetation of ROMN wet meadows is variable, but some community types are very common. For example, wet meadows dominated by *Juncus arcticus* ssp. *ater* occur throughout all ROMN parks from low to middle elevations. *Muhlenbergia asperifolia* and *Scirpus microcarpus* communities are common at low elevations adjacent to ponds, lakes, or low-gradient streams, while *Iris missouriensis* is commonly found in mesic meadows on the plains and may be more abundant in heavily grazed areas. Wet meadows dominated by *Carex nebrascensis*, *Eleocharis macrostachya*, and *C. praeegracilis* occur throughout most ROMN parks at middle elevations of 1,000 to 2,800 m above sea level. In alpine and subalpine areas (Figure 4), wet meadows may be dominated by *Carex scopulorum*, *C. nigricans*, *C. illota*, and *Deschampsia cespitosa*. Shrubs (commonly *Salix*) and trees may be present, but canopy cover is usually low. Conditions such as moist, unsaturated, mineral soils, and high levels of nutrient availability in wet meadows, often support high cover and diversity of exotic species (Stohlgren et al. 1999). Introduced perennial sod-forming grasses such as *Agrostis stolonifera* and *A. gigantea* are common dominants, particularly at lower elevations and in wet meadows adjacent to riparian areas. Pasture grasses *Poa pratensis* and *Phleum pratense* are also present in meadows impacted by livestock and historical homesteading.

In ROMN parks, wet meadows frequently occur in stream valleys as part of larger wetland complexes, although unlike riparian wetlands, wet meadows are not subject to high-velocity surface flows or sediment deposition from fluvial processes. Wet meadows typically occur in sites where soils are seasonally saturated; however, unlike fens or marshes, perennially high water tables or seasonal flooding does not typically occur. High, early-summer water levels are common, but water tables in wet meadows



**Figure 4.** Sampling an alpine wet meadow in ROMO.

may drop to a meter or more below the soil surface in July and August, while in fens they typically remain within ~20–40 cm of the soil surface (Cooper 1990, Chimner and Cooper 2003b). Precipitation and groundwater flows are likely the most important contributors to hydrologic regimes of wet meadows in ROMN parks. Local and regional aquifers contribute groundwater by creating shallow water tables along aquifer flow paths or discharging directly to the soil surface. This is especially true during spring snowmelt when aquifers are swollen, and spring melt water may be the primary source of seasonal inundation for wet meadows in dry areas. Direct surface water inputs to wet meadows are generally limited to rainfall and sheet flow following extreme precipitation or snowmelt events and, similar to fens, may have a greater impact in middle to late summer when groundwater flows are diminished. The frequency of flooding in wet meadows is low, but in settings such as wide, low gradient alluvial valleys flooding may be episodic due to the activities of beaver in surrounding riparian areas.

Relative to riparian areas or marshes, anthropogenic and natural disturbances such as floods are less important in ROMN wet meadows, while biotic disturbances from animals are of greater significance. Beavers are a significant geomorphic driver of meadow formation and landscape

dynamics in many ROMN parks. In low gradient glacial valleys, beaver dams may cause channel avulsions, flooding surrounding wet meadows (Cooper et al. 2006), and lead to either wet meadow or marsh development depending on resulting water table levels. At landscape scales, beaver can create a complex heterogeneous pattern of wetland type including wet meadows, marshes, and riparian wetlands, increasing landscape patterns of species richness (Wright et al. 2002, Westbrook et al. 2006). Native ungulates such as deer, elk, and bison, as well as domestic livestock such as sheep and cattle can have important effects on the abiotic and biotic environment in wet meadows (Dull 1999, Binkley et al. 2003). Meadows may provide the most significant resource of graminoid vegetation in conifer dominated montane areas. Herbivore effects include plant mortality from herbivory or trampling and altered soil chemistry and nutrient availability through urine and feces deposition (Hobbs 1996, Frank and Evans 1997). Finally, small mammals can have a significant influence on wet meadows through their burrowing and foraging (Huntly and Inouye 1988, Sherrod and Seastedt 2001).

### ***Riparian Wetland***

Riparian wetlands are diverse in terms of ecological functioning, hydrology, and

vegetation composition. Because of the linear and interconnected nature of riparian environments, gradients in important environmental variables (water table depth, elevation, soil characteristics, and flood disturbance) and resulting vegetation patterns vary both laterally and longitudinally (Friedman et al. 2006). Channel migration and episodic floods along meandering rivers with broad floodplains results in pulses of woody plant establishment, creating patches of different age cohorts (Shafroth et al. 1998, Cooper et al. 2003). The principal characteristic unifying riparian wetlands is the presence of unidirectional moving water and a connection, at least part of the time, to lotic or lentic surficial hydrology (Figure 5). Surface flows within riparian wetlands are important as they have the potential to erode and transport sediment, with the potential energy contained in flowing water a key variable influencing ecosystem structure and function. The frequency, magnitude, and energy of floods, which vary widely due to differences in basin size, topography, and climatic regime, affect all ecological processes in riparian wetlands from nutrient cycling to plant establishment (NRC 2002, Karrenberg et al. 2002, Cooper et al. 2003, Adair et al. 2004). Note that simple adjacency to a lotic or lentic feature does not automatically result in a riparian wetland; one or more of the three general requirements for wetland must also be met.

The vegetation of ROMN riparian wetlands is highly variable, but some community types and dominant species are notable. In high-elevation headwater areas, vegetation is often dominated by herbaceous plants, such as *Senecio triangularis*, *Mertensia ciliata*, and *Cardamine cordifolia*. Low-stature shrubs, such as *Salix planifolia* and *S. glauca*, may also be common, particularly where shallow groundwater and snowmelt are the principal water sources. Moving downstream, the stature, composition, and diversity of shrub dominants typically increases. Tall willows, *Salix monticola*, *S. geyeriana*, and *S. boothii* are dominant in broad, open basins and low-gradient streams. Along higher-gradient streambanks *Alnus incana* ssp. *tenuifolia* and *Betula fontinalis* are abundant, while *Salix drummondiana* is commonly found rooted in fast flowing water. Along larger mid-elevation montane streams, and lower in the foothill valleys, riparian wetland is dominated by *Populus angustifolia*, *Abies concolor*, and *Picea pungens* with shrubs such as *Cornus sericea* and *Salix exigua* and diverse herbaceous canopies.

Surface water and floods are critical to the healthy functioning of riparian areas. Important variables include flood magnitude, frequency, duration, timing, rate of change (Poff et al. 1997). Water tables along intermittent and ephemeral streams often drop well below stream channels,



**Figure 5.** Riparian wetland in Paradise Park, ROMO. The complex also contains wet meadow and small inclusions of fen.

limiting the distribution of hydrophytes, except deep-rooted phreatophytes like cottonwoods, tamarisk, or upland species tolerant of low soil moisture (Goodwin et al. 1997). Many headwater streams receive perennial groundwater inputs from side slopes, maintaining high base flows. Stream and riparian wetlands in GRSA are functionally unique among ROMN parks owing to the high porosity of underlying sand (Wurster et al. 2003).

Anthropogenic and natural disturbances are common in ROMN riparian wetlands relative to other ROMN wetland types. Natural physical disturbance agents include floods, fire, landslides, avalanche, and channel migration. As in upland systems, these perturbations and the ecosystem response to the changed conditions are important to ROMN park managers as well as ecologists because many anthropogenic impacts are manifest through changes to disturbance regimes (Brinson and Brinson 1981, Patten 1998, Shafroth et al. 2002). Floods are the most important disturbance type in many riparian ecosystems. Because floods have such a broad range in magnitude, it is useful to reserve the term “flood disturbance” for those flows that directly or indirectly cause plant mortality. The effect of floods on riparian vegetation includes direct plant mortality, as well as indirect effects on vegetation through altered environmental conditions and resource availability. Ice flow within flood events can also be a factor influencing patterns of mortality among riparian species. Research suggests that in montane and subalpine settings, fire frequency in riparian areas is often lower than in adjacent upland cover types, although differences may be minor in drier habitats like ponderosa pine forests and grasslands (Dwire and Kauffman 2003). Because fire regimes vary so widely among upland cover types, generalizations are difficult to make for riparian areas; however, the broad gradients in fire frequency documented for uplands, with high-elevation ecosystems rarely experiencing fire and low elevation shrublands and grasslands experiencing relatively frequent fires, likely apply to riparian systems (Pyne et al. 1996).

Beaver can profoundly alter the age and size structure of woody riparian communities

through foraging and dam building (Johnston and Naiman 1990, Baker et al. 2005, Breck et al. 2003). Dam-building activities strongly modify local hydrology, thereby influencing a wide range of biotic and abiotic processes (Butler and Malanson 1995, Gurnell 1998, Wohl 2000). Widely recognized as a keystone species, beaver are an important factor influencing local and regional biodiversity patterns and geomorphic change (Johnston and Naiman 1987, Naiman et al. 1994, Dickens 2003). Beaver are an explicit ROMN focal species vital sign as well as a critical element of the WEI protocol in parks like ROMO.

Riparian wetlands are often subject to a greater degree of anthropogenic disturbance than other ROMN wetland types. Much of this is simply due to the landscape position of riparian wetland along streams. Park visitors are often attracted to stream corridors and many roads and trails parallel streams and intersect riparian wetland. Finally, many of the climate change stressors discussed for other wetland types are relevant to riparian wetlands.

### **Marsh**

Marshes are depressional wetlands characterized by inundation on a relatively frequent basis, often with deep standing water (Figure 6). ROMN marshes include such diverse systems as prairie potholes, playas, lacustrine fringe wetlands, kettle ponds, and abandoned oxbow lakes on river floodplains. Hydrologic variability, water depth, and salinity are key factors determining the species composition of marshes, both spatially within and among marsh complexes, and temporally from wet to dry years (Seabloom et al. 1998, Smith and Haukos 2002, van der Valk 1994). Seed banks play a particularly important role in marsh vegetation dynamics (Smith and Kadlec 1983, van der Valk et al. 1994, Wilson et al. 1993), with large fluctuations in species composition commonly occurring over relatively short time scales. Strong water depth gradients also generate distinct vegetation zonation patterns in many marshes (Johnson et al. 1987, Lenssen et al. 1999). Marshes are not common in ROMN parks and we only include them as

**Figure 6.** Marsh in the upper North Fork of the Flathead Valley, GLAC. Note presence of deeper standing water and macrophytes.



target types for sentinel sites in GRSA and potentially GLAC.

The vegetation of marshes is often limited to species that are capable of rooting in mucky, saturated soil and can tolerate submersion and occasional dry periods. These include monotypic freshwater communities dominated by hydrophytes such as *Typha latifolia* and *Schoenoplectus pungens*, and in saline playa environments halophytes such as *Amphiscirpus nevadensis* and *Distichlis spicata*. Playas are infrequent in ROMN parks and these highly specialized environments support some rare and uncommon species such as *Salicornia europaea* ssp. *rubra* and *Cleome multicaulis*. In GLAC, where marshes are more common, aquatic *Myriophyllum sibiricum* and semi-aquatics *Stuckenia pectinata* and *Sparganium angustifolium* live floating at the surface or directly under nearly constant standing water. Other typical marsh species include *Potamogeton* spp., *Hippuris vulgaris*, *Carex vesicaria*, and *Sagittaria latifolia*.

Marsh hydrology can be extremely variable and frequently includes both prolonged periods of inundation as well as extended dry periods, particularly during dry years (Winter and Rosenberry 1998, Winter et al. 2001). The water tables of marshes are thought to be supported primarily by precipitation and surface water runoff

(Weller and Weller 1994) in contrast to groundwater-supported ecosystems like fens. Temperature and precipitation are among the main determinants of marsh hydrology, creating moisture surplus or moisture deficit, thereby influencing marsh distribution and hydrologic function (Kantrud et al. 1989). Most ROMN marshes are freshwater; however, terminal basins at GRSA and GLAC where water is lost primarily through evapotranspiration may be highly saline, affecting species composition, litter decomposition, and productivity (Thormann et al. 1999).

Anthropogenic and natural disturbances are relatively common in marshes relative to other ROMN wetland types. For example, sediment flux into marshes is often high, and many marshes provide ideal settling environments for fine-grained sediments. Sediment accumulation in beaver ponds, which often support marsh communities, can lead to accumulation of significant bodies of fine-textured sediments (Butler and Malanson 1995, Gurnell 1998). Finally, many of the climate change stressors discussed above are relevant to ROMN marshes.

### **Salt Flat**

Salt flats are a widespread wetland type at low elevations within intermountain basins



through the western U.S., yet in the ROMN they only occur in GRSA (Figure 7). They form in closed basins in areas to the west of the main dune field with heavy-textured soils or where evaporation from a high water table promotes the accumulation of salts. WEI monitoring includes this type as a target for survey-based monitoring in GRSA.

High salt concentrations create a difficult environment for most plants; consequently, plant cover and productivity is generally low, and species composition is limited to salt-tolerant species (Dodd and Coupland 1966, Ungar 1974). Characteristic species may include *Allenrolfea occidentalis*, *Leymus cinereus*, *Distichlis spicata*, *Sarcobatus vermiculatus*, and *Atriplex canescens*.

As with all wetlands, hydrologic regime is a key variable controlling the structure and function of salt flats; however, because it is the presence of high salt concentrations that most clearly distinguishes salt flats from other ecosystem types, there is considerable variability in hydrologic characteristics among salt flats. For example, some salt flats have hydrologic regimes similar to marshes and water levels fluctuate widely both seasonally and among years, with extended periods of deep inundation alternating with periods where surface water may be completely absent (Cooper and Severn 1992). Salt flats may also be influenced by the groundwater, either through direct discharge in discrete springs or through capillary movement of water from seasonally high water tables (Joeckel and Clement 2005, Riley 2001). High-velocity surface

flows resulting from precipitation runoff may affect salt flats, but are less important to geomorphic and ecological processes than in riparian ecosystems. In many wetlands, spatial and temporal patterns of salt accumulation in near-surface groundwater and surface water are dynamic, and closely linked with discrete recharge events (Arndt and Richardson 1993).

The role of disturbance in salt flat dynamics is largely unstudied in the region, although disturbance is likely a major environmental gradient affecting salt flat vegetation (Walker and Wehrhahn 1971). Ironically, because salt flats are so marginal in terms of forage production or suitability for crops, they may have been spared many of the anthropogenic impacts affecting the other wetland types. Disturbance in salt flats may include high water periods, which can drown plants, as well as multi-year droughts, also leading to high plant mortality. As wetlands dry out, salt concentrations can increase due to evaporation, eventually exceeding plant tolerances. Disturbances from animals may be locally important to salt flats. Livestock and native ungulates can trample salt flat plants, causing plant mortality. Salt flat soils with high clay contents can shrink and swell, forming large crack networks (Hovorka 1995). Salt flats also have salt efflorescence and precipitation features, which can create complex microtopography.

Soil deformation and crust formation may kill seedlings, but can also serve as sites for the entrapment of seeds (Goodall et al. 2000). Finally, many of the climate change

**Figure 7.** Salt flat wetland on playa lake fringe (above left), Baca National Wildlife Refuge, near GRSA; salt flat wetland west of main dune field (above right; white substrate is salt, not snow).

stressors discussed above are relevant to ROMN salt flats.

## ROMN Wetland Extent

Tables 1 through 4 give various estimates of the extent of wetland within each ROMN park based on both NWI and NPS Vegetation Maps (VegMap) source data (of varying quality and date; FLFO: Owens et al. 2004, ROMO: Salas et al. 2005, GRSA: Salas et al. 2011, and GLAC: Hop et al. 2007). These extent estimates were done prior to any implementation of the WEI protocol in ROMN parks where a survey design was used to estimate wetland extent or changes in wetland area through time, as possible. For an example of wetland extent estimation using design-based methods, see the ROMO Pilot Report (Schweiger, unpublished data). Unfortunately, while NPS Vegetation Maps are the best and most current data available for these mapping exercises, they are not necessarily consistent in the way wetlands are classified or mapped among parks. Where possible, we use crosswalks from the map units used in a vegetation map to NWI and Ecological Systems to deal with this issue as best we can.

Fens in ROMN parks are not well mapped using the native NWI (Cowardin) or Ecological System classification systems. In ROMO, where the vegetation map has been more thoroughly analyzed, around 13% of total wetland area in the park appears to be fen. In GLAC, however, less than 1% of the park's wetland is mapped as fen in the vegetation map. In GRSA, fen is not even a map unit or an Ecological System class. These are almost certainly errors, reflecting issues with the classification and mapping approaches. Wet meadows in ROMN parks are typically the most common type of wetland. For example, using the Ecological System classification they account for about 44% of total wetland area in ROMO and around 52% in GLAC. Riparian wetlands in ROMN parks are also typically more common, with about 32% of the wetland area in ROMO. Vegetation Maps may overestimate riparian wetland distribution, however, by describing most vegetation adjacent to water features as "riparian"—while much of this is not functional wetland. Marsh extent in ROMN accounts for less

than 1-2% of total wetland area in ROMO and GLAC, but 16% in GRSA. Marshes are abundant in the San Luis Valley and are a more important wetland type in GRSA. Finally, salt flats in ROMN parks are restricted to GRSA, where they account for 63% of the park wetland.

## Prior Research and Historical Wetland Monitoring

Vegetation maps, experimental work, and surveys have been conducted in the wetlands of many ROMN parks (see Appendix A for a bibliography of published work and investigator annual reports relating to wetlands in ROMN parks). Vegetation maps were recently completed (FLFO: Owens et al. 2004, ROMO: Salas et al. 2005, GRSA: Salas et al. 2011, and GLAC: Hop et al. 2007). The maps include descriptions of vegetation communities throughout the park, including wetland.

Driven in large part by the central role wetlands play in the interaction between hydrology, large ungulates and beaver, and the regulatory issues surrounding their treatment under the Clean Water Act, there have been considerable efforts to research and monitor wetlands in ROMN parks, particularly at ROMO. Much of the emphasis has been on wetland area, although more recently, function has become more important in regulatory contexts. Approaches like the USFWS Status and Trends reports (e.g., Dahl and Dahl 2000), are broad in scope and may have limited direct utility in ROMN parks (although they provide useful regional context and perhaps reference conditions). The EPA National Wetland Survey will likely provide useful context and reference data and several WEI sites will likely be co-sampled by the ROMN and EPA.

Of the ROMN parks, wetlands are best described and studied in ROMO. Most of these studies were established for purposes such as evaluating elk herbivory impacts (Peinetti et al. 2002, Gage and Cooper 2005, Cooper and Wolf 2006), ecological effects of beaver (Baker et al. 2005, Westbrook et al. 2006), stream diversion impacts (Woods 2001, Woods and Cooper 2005, Woods et al. 2006), or fen restoration (Cooper

**Table 1. ROMO wetland extent by data source and wetland type. Total park area for ROMO: 107,940 ha.**

A: From 1970s NWI data using 1:80k imagery hand digitized with Cowardin types.

| Wetland Type (Generalized NWI)     | Count | Mean Patch Size (ha) | Total Area (ha) | Percent of Park Wetland | Percent of Park Area |
|------------------------------------|-------|----------------------|-----------------|-------------------------|----------------------|
| Lacustrine Littoral                | 4     | 1.73                 | 6.94            | 0.18                    | 0.0064               |
| Palustrine Emergent                | 65    | 6.37                 | 413.82          | 10.89                   | 0.3834               |
| Palustrine Forested                | 19    | 6.35                 | 120.59          | 3.17                    | 0.1117               |
| Palustrine Scrub Shrub Emergent    | 732   | 4.45                 | 3,259.44        | 85.75                   | 3.0197               |
| Palustrine Semipermanently Flooded | 2     | 0.21                 | 0.42            | 0.01                    | 0.0004               |
| <b>Total.NWI</b>                   |       |                      | <b>3,801.20</b> |                         | <b>3.52</b>          |

B: From 2001 VegMap data using 1:12k 2001 imagery hand digitized with park-specific map unit names that were cross walked to both Ecological Systems and Cowardin. The cross-walk process was based on plot-level floristics.

| Wetland Type (VegMap MapUnit)                     | Wetland Type (Ecological System)                             | Wetland Type (Generalized NWI)                                         | Count | Mean Patch Size (ha) | Total Area (ha)  | Percent of Park Wetland | Percent of Park Area |
|---------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------------|-------|----------------------|------------------|-------------------------|----------------------|
| Herbaceous Wetland SubAlpine/Alpine-Alpine Meadow | Rocky Mountain Alpine-Montane Wet Meadow                     | Palustrine Emergent                                                    | 1,056 | 6.75                 | 7,123.91         | 44.36                   | 6.5999               |
| Herbaceous Wetland Cross Zone-Wetland             | Rocky Mountain Subalpine-Montane Fen                         | Palustrine Emergent                                                    | 1,495 | 1.45                 | 2,162.66         | 13.47                   | 2.0036               |
| Herbaceous Wetland Cross Zone-Marsh               | North American Arid West Emergent Marsh                      | Palustrine Emergent/<br>Lacustrine Littoral/<br>Palustrine Aquatic Bed | 26    | 0.58                 | 15.11            | 0.09                    | 0.0140               |
| Riparian Lower Montane Mixed Conifer <8,500 ft    | Rocky Mountain Lower Montane Riparian Woodland and Shrubland | Palustrine Forested                                                    | 41    | 1.91                 | 78.38            | 0.49                    | 0.0726               |
| Riparian Upper Montane Mixed Conifer >8,500 ft    | Rocky Mountain Subalpine-Montane Riparian Woodland           | Palustrine Forested                                                    | 536   | 5.02                 | 2,692.34         | 16.77                   | 2.4943               |
| Shrub Riparian Cross Zone <9,600 ft               | Rocky Mountain Subalpine-Montane Riparian Shrubland          | Palustrine Scrub Shrub Emergent                                        | 290   | 3.31                 | 960.73           | 5.98                    | 0.8901               |
| Shrub Riparian Cross Zone >9,600 ft               | Rocky Mountain Subalpine-Montane Riparian Shrubland          | Palustrine Scrub Shrub Emergent                                        | 401   | 3.49                 | 1,400.08         | 8.72                    | 1.2971               |
| Shrub Upland Alpine                               | Rocky Mountain Subalpine-Montane Riparian Shrubland          | Palustrine Scrub Shrub Emergent                                        | 641   | 2.54                 | 1625.72          | 10.12                   | 1.5061               |
| <b>Total.VegMap</b>                               |                                                              |                                                                        |       |                      | <b>16,058.92</b> |                         | <b>14.88</b>         |

**Table 2. GRSA wetland extent by data source and wetland type.**

A: From 1983 to 1985 NWI data using 1:24 or 1:62k imagery hand digitized with Cowardin types. Total park area for GRSA NWI calculations: 48,551 ha (NWI is missing from the NE 1,007 ha corner of the park).

| Wetland Type (Generalized NWI)   | Count | Mean Patch Size (ha) | Total Area (ha) | Percent of Park Wetland | Percent of Park Area |
|----------------------------------|-------|----------------------|-----------------|-------------------------|----------------------|
| Palustrine Aquatic Bed           | 49    | 0.36                 | 17.67           | 0.71                    | 0.0364               |
| Palustrine Emergent              | 517   | 4.08                 | 2,110.71        | 84.58                   | 4.3474               |
| Palustrine Scrub Shrub           | 8     | 0.65                 | 5.17            | 0.21                    | 0.0106               |
| Palustrine Unconsolidated Bottom | 16    | 0.09                 | 1.50            | 0.06                    | 0.0031               |
| Riverine Intermittent Stream Bed | 30    | 11.06                | 331.83          | 13.30                   | 0.6835               |
| Riverine Unconsolidated Shore    | 8     | 3.59                 | 28.73           | 1.15                    | 0.0592               |
| <b>Total.NWI</b>                 |       |                      | <b>2,495.60</b> |                         | <b>5.14</b>          |

B: From 2006 or 2007 VegMap data using 1:12k imagery hand and auto digitized with park-specific map unit names that were (draft) cross walked to Ecological Systems. Total park area for VegMap: 49,560 ha (includes the missing piece from NWI layer).

| Wetland Type (VegMap Map Units)                             | Wetland Type (Ecological System)                                      | Count | Mean Patch Size (ha) | Total Area (ha) | Percent of Park Wetland | Percent of Park Area |
|-------------------------------------------------------------|-----------------------------------------------------------------------|-------|----------------------|-----------------|-------------------------|----------------------|
| Alpine-Upper Subalpine Herbaceous Wetland Alliances         | Rocky Mountain Alpine-Montane Wet Meadow                              | 26    | 3.77                 | 98.13           | 3.77                    | 0.1980               |
| Coyote Willow Temporarily Flooded Shrubland Alliances       | Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland | 10    | 1.58                 | 15.82           | 0.61                    | 0.0319               |
| Emergent Marsh Alliances                                    | North American Arid West Emergent Marsh                               | 43    | 9.42                 | 405.14          | 15.56                   | 0.8175               |
| Montane Riparian Shrubland Alliances                        | Rocky Mountain Subalpine-Montane Riparian Shrubland                   | 5     | 7.72                 | 38.62           | 1.48                    | 0.0779               |
| Montane-Lower Subalpine Wetland Alliances                   | Rocky Mountain Alpine-Montane Wet Meadow                              | 14    | 1.01                 | 14.14           | 0.54                    | 0.0285               |
| Narrowleaf Cottonwood Temporarily Flooded Woodland Alliance | Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland | 57    | 5.38                 | 306.51          | 11.77                   | 0.6185               |
| San Luis Valley Mesic Meadow Alliances                      | Inter-Mountain Basins Alkaline Closed Depression                      | 162   | 10.13                | 1,640.78        | 63.03                   | 3.3107               |
| Subalpine-Alpine Riparian Shrubland Alliances               | Rocky Mountain Subalpine-Montane Riparian Shrubland                   | 18    | 4.68                 | 84.17           | 3.23                    | 0.1698               |
| <b>Total.VegMap</b>                                         |                                                                       |       |                      | <b>2,603.32</b> |                         | <b>5.25</b>          |

**Table 3. GLAC wetland extent by data source and wetland type. Total park area for calculations was 408,056 ha.**

A: From 1970s NWI data using 1:80k imagery hand digitized with Cowardin types.

| Wetland Type (Generalized NWI)   | Count | Mean Patch Size (ha) | Total Area (ha) | Percent of Park Wetland | Percent of Park Area |
|----------------------------------|-------|----------------------|-----------------|-------------------------|----------------------|
| Lacustrine Littoral              | 60    | 6.15                 | 368.73          | 8.58                    | 0.0904               |
| Palustrine Aquatic Bed           | 1075  | 0.28                 | 298.89          | 6.95                    | 0.0732               |
| Palustrine Emergent              | 1243  | 0.69                 | 857.09          | 19.94                   | 0.2100               |
| Palustrine Forested              | 52    | 1.95                 | 101.38          | 2.36                    | 0.0248               |
| Palustrine Scrub Shrub           | 1297  | 1.49                 | 1,935.43        | 45.02                   | 0.4743               |
| Palustrine Unconsolidated Bottom | 81    | 0.22                 | 18.22           | 0.42                    | 0.0045               |
| Riverine Intermittent            | 20    | 1.34                 | 26.80           | 0.62                    | 0.0066               |
| Riverine Unconsolidated Shore    | 941   | 0.74                 | 692.75          | 16.11                   | 0.1698               |
| <b>Total.NWI</b>                 |       |                      | <b>4,299.30</b> |                         | <b>1.05</b>          |

B: From 1999 VegMap data using 1:16k imagery hand digitized with park specific map unit names that were cross walked to Ecological Systems.

| Wetland Type (VegMap MapUnit)                                  | Wetland Type (Ecological System)                                         | Count | Mean Patch Size (ha) | Total Area (ha)  | Percent of Park Wetland | Percent of Park Area |
|----------------------------------------------------------------|--------------------------------------------------------------------------|-------|----------------------|------------------|-------------------------|----------------------|
| Dwarf-shrub/Herbaceous Complex: Mesic-Wet                      | Rocky Mountain Alpine Dwarf-Shrubland                                    | 4413  | 1.84                 | 8,102.48         | 48.64                   | 1.9856               |
| Cedar-Hemlock Forest (wet phase)                               | Northern Rocky Mountain Conifer Swamp                                    | 57    | 3.74                 | 213.12           | 1.28                    | 0.0522               |
| Black Cottonwood Forest                                        | Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland    | 635   | 1.14                 | 722.81           | 4.34                    | 0.1771               |
| Lodgepole Pine Wet Forest                                      | Northern Rocky Mountain Conifer Swamp                                    | 7     | 1.80                 | 12.62            | 0.08                    | 0.0031               |
| Engelmann Spruce-Wet Shrub Forest                              | Rocky Mountain Subalpine-Montane Riparian Woodland                       | 980   | 2.11                 | 2,068.37         | 12.42                   | 0.5069               |
| Mixed Conifer-Deciduous Wet Forest                             | Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland    | 893   | 2.26                 | 2,017.13         | 12.11                   | 0.4943               |
| Exposed Shoreline Herbaceous: Pioneering Vegetation            | Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland    | 442   | 0.64                 | 282.62           | 1.70                    | 0.0693               |
| Permanently Flooded Herbaceous                                 | North American Arid West Emergent Marsh                                  | 22    | 1.40                 | 30.75            | 0.18                    | 0.0075               |
| Semi-permanently Flooded Herbaceous                            | Rocky Mountain Subalpine-Montane Fen                                     | 31    | 0.93                 | 28.72            | 0.17                    | 0.0070               |
| Wet Meadow Herbaceous                                          | Rocky Mountain Alpine-Montane Wet Meadow                                 | 924   | 0.80                 | 734.82           | 4.41                    | 0.1801               |
| Deciduous Wet Shrubland                                        | Rocky Mountain Subalpine-Montane Riparian Shrubland                      | 1706  | 1.23                 | 2,095.67         | 12.58                   | 0.5136               |
| Exposed Shoreline Sparse Vegetation (wet riparian/basin phase) | NoEcoSyst_Exposed Shoreline Sparse Vegetation (wet riparian/basin phase) | 560   | 0.62                 | 347.28           | 2.08                    | 0.0851               |
| <b>Total.VegMap</b>                                            |                                                                          |       |                      | <b>16,656.39</b> |                         | <b>4.08</b>          |

**Table 4. FLFO wetland extent by data source and wetland type. Total park area for calculations was 2423 ha.**

A: From 1970s NWI data using 1:80k imagery hand digitized with Cowardin types.

| Wetland Type (Generalized NWI)   | Count | Mean Patch Size (ha) | Total Area (ha) | Percent of Park Wetland | Percent of Park Area |
|----------------------------------|-------|----------------------|-----------------|-------------------------|----------------------|
| Palustrine Emergent              | 215   | 0.44                 | 94.42           | 84.45                   | 3.90                 |
| Palustrine Scrub Shrub           | 41    | 0.17                 | 6.86            | 6.14                    | 0.28                 |
| Riverine Intermittent Stream Bed | 96    | 0.11                 | 10.52           | 9.41                    | 0.43                 |
| <b>Total.NWI</b>                 |       |                      | <b>111.80</b>   |                         | <b>4.61</b>          |

B: From 1996 VegMap data using 1:15k imagery hand digitized with park-specific map unit names.

| Wetland Type (VegMap MapUnit)                                   | Count | Mean Patch Size (ha) | Total Area (ha) | Percent of Park Wetland | Percent of Park Area |
|-----------------------------------------------------------------|-------|----------------------|-----------------|-------------------------|----------------------|
| Aquatic Sedge-Beaked Sedge-Baltic Rush<br>Herbaceous Vegetation | 44    | 2.06                 | 90.84           | 91.98                   | 3.75                 |
| Mountain Willow Shrubland                                       | 16    | 0.46                 | 7.41            | 7.5                     | 0.31                 |
| Sandbar Willow Temporarily Flooded<br>Shrubland                 | 2     | 0.20                 | 0.40            | 0.4                     | 0.02                 |
| Shortfruit Willow Shrubland                                     | 1     | 0.12                 | 0.12            | 0.12                    | 0.0049               |
| <b>Total.VegMap</b>                                             |       |                      | <b>98.76</b>    |                         | <b>4.07</b>          |

1990, Cooper et al. 1998). In addition to providing some historical data sets, in many cases these sites have functional monitoring wells still present. In ROMO, these sites will be utilized as sentinel sites. There are few parallel opportunities in other ROMN units, but where such sites exist, they should be evaluated for inclusion in future monitoring.

Compared to ROMO, wetlands in the other parks in ROMN are poorly studied. There has been a small but diverse set of research programs on wetlands in GLAC, including efforts to understand the ecology of the Nyack floodplain (Mouw and Alaback 2003), the threats to amphibian populations (Hossack and Corn 2007), and the sensitivity of rare alpine plants to climate change (Lesica and McCune 2004). At GRSA, there has been research on the wetlands in the San Luis Valley (Cooper and Severn 1992) and on the causes for their disappearance (Wurster et al. 2003). Relatively little work has been conducted in FLFO on wetlands beyond mapping their aerial extent as part of the Vegetation Map (Owens et al. 2004).

In summary, while wetlands have been mapped within the ROMN parks, and there is a good deal of information on wetlands in ROMO, relatively few studies have explicitly monitored wetlands. The WEI protocol should help address this shortcoming by providing standardized methods for long-term monitoring of wetlands within FLFO, GLAC, GRSA, and ROMO.

## **Monitoring Objectives**

The general goals for long-term ecological monitoring of ROMN park wetlands focus on documenting the status and trend in condition, helping to understand the causes of change in condition, and assisting in the application of WEI results and relevant auxiliary information to park wetland management. Specific objectives vary somewhat with park and wetland type. In some cases analyses and models are also park and wetland type specific. Importantly, under budget scenarios and management needs as of 2015, we expect to conduct park-scale surveys over the long term only in ROMO and in part of GRSA. The 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 WEI design type is a probabilistic or “random” survey of wetland in ROMO and GRSA (but only in the large sandsheet portion of the park). Survey designs are the default design recommended within the I&M Program (Fancy et al. 2009). The 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 the 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 (Schreuder et al. 2004, Olsen et al. 1999). 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 provide 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 wetland 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 wetland 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 amongst vegetation, hydrology, soils, and environmental or disturbance gradients.

While our episodic large surveys are essential for meeting several of our objectives, most WEI monitoring in most years is conducted at sites selected with the second WEI design form, a targeted or hand-picked “sentinel” approach. We conduct sentinel site monitoring in all ROMN parks where we do or will monitor wetlands. The 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—this is generally not the case for most wetlands), 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 both more realistic given our budget and the long-term time-series generated at sentinel sites, which support trend modeling and a detailed perspective of the “ecology of place” (Billick and Price 2010) at select wetlands. “Status” at sentinel sites is estimated using multiple types of statistics, such as the 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. In lieu of more complex modeling or often untestable assumptions, sentinel status may not be inferred to wetland beyond the sentinel site or complex (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 located at the tails of distributions of anthropogenic disturbance or interesting environmental gradients (i.e., elevation) that can strongly affect wetland 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 ROMO and GRSA, although in many ways, sentinel sites (in all parks) can also be used to meet objectives linked to gradient sites.

### ***Survey Objectives (ROMO and GRSA)***

We address and report on objectives specific to data derived from survey designs in ROMO and GRSA following large survey efforts conducted approximately every 10 years. The most important use of survey data is to estimate episodic park-scale status. There is great value in such status estimates, associated modeling, and its interpretation. Most status estimates from survey data are generated using design-based inference to the extensive population of all sampleable wetland in a park (or wetland in a large subset of a park). In select cases, model-based or geographic information systems (GIS) driven analyses are also used to estimate park-scale status. Statistically rigorous estimates of population scale trend from survey site data, while also important, are difficult until several cycles of data collection have been completed (with each cycle being 10 years). However, simpler estimates of change are conducted after the first two survey cycles.

Status and trend estimates in ROMO are for three wetland types—fens, wet meadows, and riparian—and are for each of these types across the complete sampleable target population within the park. Estimates in GRSA are for two wetland types—wet meadows and salt flats—but restricted to the sampleable target population within the sandsheet zone of the park. In each park we combine data across wetland type to estimate some responses. Specific survey objectives for ROMO and GRSA are to

1. Determine the status in wetland areal extent using survey site extent data and/or park-scale imagery data.
2. Determine status in a suite of response measures:
  - a. Vegetation

- i. Abundance of important species or key indicator groups (i.e., bryophytes)
    - ii. Woody species stand composition and woody stem condition.
    - iii. Simple vegetation metrics such as percent hydrophyte, percent invasive, and species richness.
    - iv. More complex metrics such as mean wetland indicator score, mean Coefficient of Conservatism, or a Floristic Quality Index.
    - v. Composite bioassessment metrics such as a Multimetric Index (MMI) of Biotic Integrity or a multivariate comparison of Observed to Expected vegetation species composition. These may include metrics from existing ecoregional-scale models and/or novel park-specific models.
  - b. Groundwater hydrology
    - i. Peak growing season depth to groundwater (from hand instantaneous measures).
  - c. Soil chemistry
    - i. Percent organic matter and peat depth.
  - d. In situ water chemistry
    - i. pH, specific conductance and temperature.
  - e. Anthropogenic and natural disturbances
    - i. Composite indices such as a Human Disturbance or Natural Disturbance Index (note that in many cases these indices are also used to assess and model vegetation or hydrologic response, see objective 6).
3. Determine the percent change in the condition of select wetland responses detailed in objectives 1 and 2a-e after each cycle of a survey.
  4. Determine the long-term trend in the condition of select wetland responses detailed in objectives 1 and 2a-e after the fifth and each subsequent cycle of the survey.
  5. Assess status of select responses detailed in objectives 1 and 2a-e 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 (rare for wetlands), ecological thresholds or ecoregion assessment points that are relevant to ROMN park wetlands 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 WEI responses based on data availability and quality and the relevance of the response to wetland management.
    - c. Compare to baselines derived from partner or auxiliary data or (preferably) WEI survey data. Baselines are developed for a subset of WEI responses based on data availability and quality and the relevance of the response to wetland management.
  6. Relate spatial or temporal patterns (including trend when possible) in select wetland responses detailed in objectives 1 and 2a-e to important ecological and anthropogenic drivers. These models depend on scale-appropriate covariate WEI and auxiliary data with clear (and often causal) connections to WEI responses and are therefore done on an as possible basis and left unspecified here.

#### ***Sentinel Objectives (ROMO, GRSA, FLFO)***

We address and report on objectives specific to data derived from annual sample efforts at sentinel sites in ROMO, GRSA, and FLFO. As of publication, all WEI objectives for GLAC were still under development and are only included here in draft format. Similarly,

a set of additional park-specific objectives for GLAC and GRSA were also under development and are presented here in draft format following core objectives.

The most important use of sentinel data is to estimate long-term trend at select wetlands in a park. Statistically rigorous estimates of site or complex level trend from sentinel site data are generally possible after five to ten years of data collection. 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 WEI survey results (and/or results from auxiliary data in our around a park).

Reporting cycles are approximately every fifth year, staggered by park. Continuously logged hydrologic data at select sentinel sites will be reported more frequently (at the time of publication, this strategy was under development). The wetland types of sentinel sites in each park vary and in some cases wetland complexes are a mosaic of types (i.e., wet meadow and fen). Therefore, estimates of status and trend at sentinel sites are for the wetland type(s) in a given complex or, for some responses, a more general combined wetland type. Specific sentinel site monitoring objectives for ROMO, GRSA, and FLFO are to

1. Determine the change (after the second year of sampling) and long-term trend (after ten to fifteen years of sampling) in the condition of select wetland responses:
  - a. Vegetation
    - i. Abundance of important species or key indicator groups (i.e., bryophytes).
    - ii. Woody species stand composition and woody stem condition.
    - iii. Simple vegetation metrics such as percent hydrophyte, percent invasive, and species richness.
    - iv. More complex metrics such as mean wetland indicator score,

mean Coefficient of Conservatism, or a Floristic Quality Index.

v. Composite bioassessment metrics such as a Multimetric Index of Biotic Integrity or a multivariate comparison of Observed to Expected vegetation species composition. These may include metrics from existing ecoregional-scale models and/or novel park-specific models.

b. Groundwater hydrology

i. Peak growing season depth to groundwater (from hand instantaneous measures).

ii. Dates of spring thaw and fall freeze (from continuous loggers).

iii. Duration of continuous saturation (from continuous loggers, especially important for fens and some wet meadows).

iv. Dates and duration of monsoon (from continuous loggers, especially important for wet meadows and some fens).

v. Monthly and annual summaries of select hydrologic parameters after the first two to four water years of sampling.

vi. If the density and location of wells with loggers in a sentinel complex allows, determine the dominant hydraulic gradients and physical boundaries of the shallow ground water table.

c. Soil chemistry

i. Percent organic matter and peat depth.

ii. Nutrients (N, P and C), major ions, cation exchange capacity, and percent slit/clay (texture).

d. In situ water chemistry

i. pH, specific conductance and temperature.

- e. Anthropogenic and natural disturbances

- i. Composite indices such as a Human Disturbance or Natural Disturbance Index (note that in many cases these indices are also used to assess and model vegetation or hydrologic response, see objective 4).

- 2. Determine the status at a sentinel site or complex in the responses listed in objectives 1a-e.

- 3. Assess the status of select responses detailed in objectives 1a-e 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 (rare for wetlands), ecological thresholds or ecoregion assessment points that are relevant to ROMN park wetlands and their management.

- b. Compare to novel 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 WEI responses based on data availability and quality and the relevance of the response to wetland management.

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

- 4. Relate spatial or temporal patterns (including trend when possible) in select wetland responses detailed in objectives 1a-e to important ecological and anthropogenic drivers. These models depend on scale-appropriate covariate WEI and auxiliary data with clear (and often causal) connections to WEI responses and are therefore done on an as possible basis and left unspecified here.

#### Glacier National Park and Great Sand Dunes National Park Secondary Sentinel Site Objectives (Draft)

At the time of publication, additional or secondary long-term wetland monitoring objectives were under development for Glacier and the Great Sand Dunes. These objectives are distinct from those described above and were motivated by ecological and management challenges in these two parks. These require a pseudo-experimental sample design (i.e., sites in specific hydrologic contexts) or unique analyses (i.e., survey data analyzed across independent variables such as presence/absence of bison). Reporting on these objectives is coupled with core sentinel reports (see above) and is done approximately every fifth year, staggered by park. However in some cases, data will be analyzed and presented separately if required for a report, plan or interpretive product that GRSA or GLAC needs on a different schedule.

*Great Sand Dunes Wetlands and the Ungulate Management Plan*—Wetlands in GRSA, especially on the sandsheet, are important habitat for bison and elk (Figure 8). Management of these two species attempts to balance population size and distribution with the condition of habitat they use. ROMN wetland monitoring may assist in adaptive management and monitoring relative to impacts on sandsheet wet meadows and salt flats. Importantly, ROMN WEI monitoring in GRSA is designed to complement adaptive management and monitoring efforts by the park and other partners, such as USGS. We use the same WEI sample sites and site level methods as for the objectives detailed above. We include data collected at sites maintained by the park and others as possible in select analyses. As of publication, the following objectives were in development. They are more focused on analyses intended to describe potential wetland responses to differing levels of ungulate habitat use. Subsequent revisions to the WEI protocol will develop objectives more “classically monitoring in nature.” Specific objectives for secondary sentinel site monitoring at GRSA are to

- 1. Model wetland vegetation composition data and vegetation metrics using

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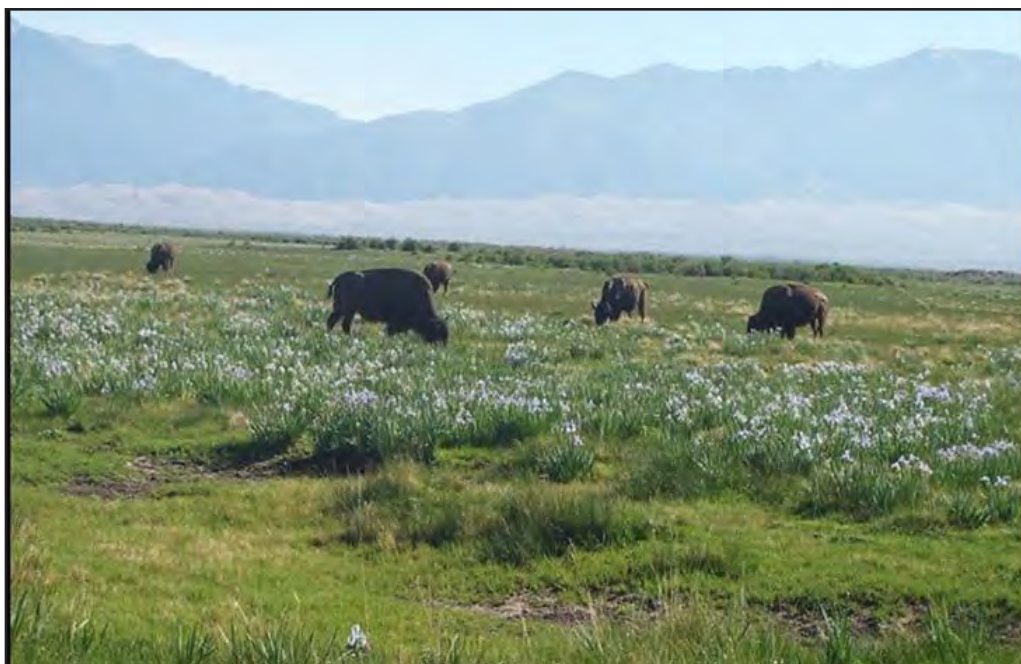


**Figure 8.** Bison graze a ROMN WEI site on the GRSA sandsheet, 2010. Wallows and hoof punches are visible in the foreground of the image.

NPS/BILLY SCHWEIGER



**Figure 9.** An enclosure on Sand Creek at GRSA in 2010. The interior of the enclosure is on the left of the image. The structure had been in place for five years at the time this image was taken.

multimetric and multivariate approaches to determine vegetation metrics that alone or in combination best estimate potential impacts of ungulates.

- a. The most sophisticated models will use ungulate or human disturbance

as the primary stressor gradient and control for the confounding effects of alternate stressors (i.e., ungulate disturbance gradient driven models will control for a human disturbance gradient) and natural gradients like precipitation, ground water hydrology and soil chemistry.

2. Using the modeling output from objective 1 (both MMIs and component metrics) and additional woody stand composition data (i.e., stem heights), compare wetland vegetation response using USGS and NPS data across sites in and outside of permanent paired enclosures on the sand sheet (Figure 9). Models will attempt to control for the type of ungulate grazing occurring, wetland type and year.

- a. Enclosures are likely an artificial context for future management at GRSA (there will always be at least some elk impacts) and significant additional covariate data are needed to better isolate drivers.

**Glacier Alpine Wetlands and Climate Change**—In GLAC, alpine riparian wetland in the park is ecologically important and highly sensitive to local and large scale disturbances (Hauer et al. 1997). Alpine wetland occupies a relatively

small percentage of the landscape in the park, but provides important ecosystem services, including wildlife habitat, stream temperature moderation, and protection of water quality (Dosskey et al. 2010, Burt and Panay 2005, NRC 2002, Vought et al. 1994, Gray and Eddinton 1969). Riparian wetland is primarily structured by hydrologic regime which, in turn, responds to climate drivers. Warming in the mid- to high-latitudes is occurring at two to three times the rate of the global average (Hansen et al. 2005, Pederson et al. 2010), and in mountainous regions like GLAC, particularly at higher-elevations, recent data show increased magnitude and rate of warming with extensive loss of glaciers and snowpack (Hall and Fagre 2003, Rauscher et al. 2008; Figure 10). In high-elevation watersheds, glacier meltwater exerts substantial influence on hydrogeomorphic processes such as floods, landslides, and debris flows (Stahl and Moore 2006, Fountain and Tangborn 1985). These drivers in turn have direct and indirect impacts on wetland distribution, extent and the condition of vegetation communities. ROMN wetland monitoring may assist the park in understanding and interpreting these dynamics. Future updates to this protocol may include a sentinel sample design specific to the unique context and

(to be developed) monitoring objectives for Glacier's alpine wetlands. Specific objectives for sentinel site monitoring at GLAC are to

1. Determine the status in select wetland responses:
  - a. Vegetation
    - i. Cover by important species or key indicator groups (i.e., bryophytes).
    - ii. Simpler vegetation metrics such as percent hydrophyte, percent invasive, and species richness.
    - iii. More complex metrics such as mean wetland indicator score, mean Coefficient of Conservatism, or a Floristic Quality Index.
  - b. Channel geomorphology
    - i. Channel shape, bankfull width, depth, channel slope, and wetted perimeter.
    - ii. Substrate size and embeddedness.
    - iii. Shear stress and stream power.
  - c. Water physiochemistry

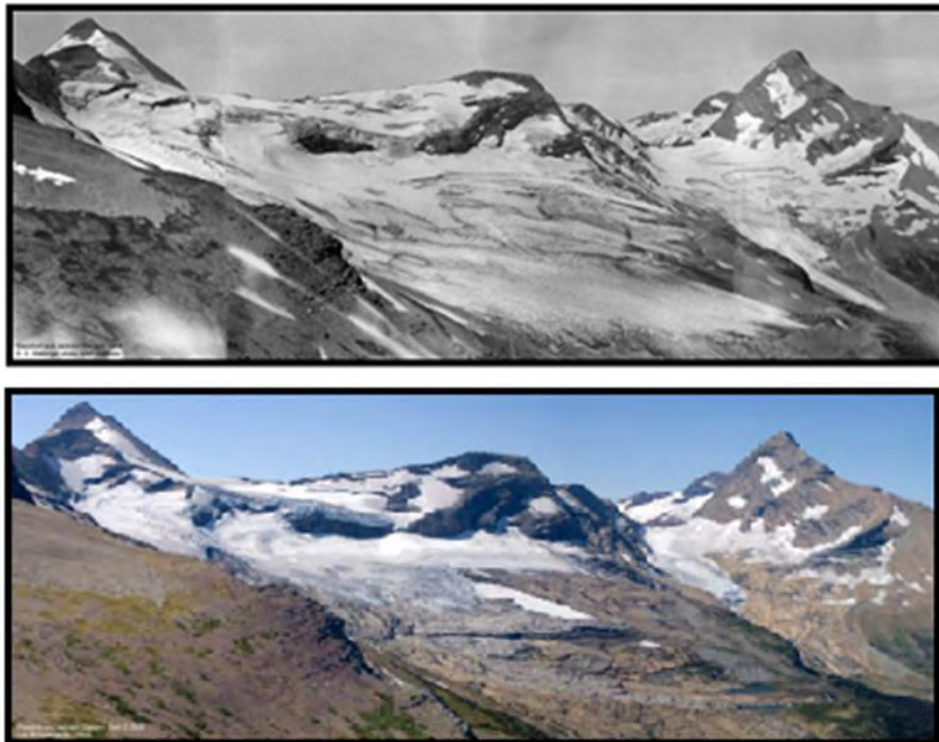


**Figure 10.** The retreat of Blackfoot and Jackson glaciers in GLAC from 1914 to 2009. As of 2013, seven AWEI sites had been established near the receding edge of this glacier. Top: Blackfoot and Jackson glaciers 1914, GLAC Archives. Bottom: Blackfoot and Jackson glaciers 2009, GLAC Archives.

- i. pH, specific conductance and temperature (as a proxy for stream persistence).
2. Compare the status in responses listed in objectives 1a-c across three hydrologic contexts (glacier meltwater, permanent snow/ice fields, and springs).
3. Estimate and compare across hydrologic regime the annual change (after the second year of sampling) and long-term trend (after ten to fifteen years of sampling) in the responses listed in objectives 1a-c.
4. Relate spatial or temporal patterns in the responses detailed in objectives 1a-c to important ecological and anthropogenic drivers, especially climate driven shifts in hydrologic regime as mediated by changes in the prominence of glaciers in a basin, stream water temperature, and sediment and nutrient concentrations. These models depend on scale-appropriate covariate data, with clear (and often causal) connections to measured AWEI responses.

## Assessment

A key element of the WEI protocol is interpreting the meaning of WEI 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 and something the ROMN stresses. We do not want to merely collect data and report numbers, rather we seek to, in concert with ROMN park staff and other partners, include management relevant interpretation in the reporting of our WEI 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). These methods have become established in other federal monitoring programs, they are used in part by the states of Montana (Suplee et al. 2005) and Colorado (CO DPHE 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 WEI data from their parks. The following section provides an overview of the key elements of WEI assessment. More details are provided in Schweiger et al. (in prep).

## Overview

In broad stroke, 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 a WEI 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 catchall for a variety of thresholds or boundaries used in monitoring and assessment. Table 5 presents brief summaries of the types of assessment points used in the WEI protocol. More details are provided in Schweiger et al. (in prep) including detailed references behind each type of assessment point.

**Table 5. Assessment points used by the ROMN to interpret WEI data. Assessment points are listed in the order they are considered by the ROMN when multiple possibilities exist for a given WEI measure or metric.**

| Assessment Point                    | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Management assessment point         | Assessment point(s) along a WEI 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 and 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 WEI 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 wetlands within ROMN parks under the Clean Water Act, 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 wetlands and their ecological processes and NPS will work with appropriate state and other federal partners to do so. Currently uncommon in the WEI protocol. States and EPA are developing more criteria for wetland monitoring and assessment. |
| Ecological threshold                | Assessment points that define a boundary at which a small change in external factors causes 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 WEI 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 WEI reference condition distributions include other monitoring programs such as the National Wetlands Condition Assessment. See text for more details. Currently uncommon in the WEI 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 a WEI result does not fall within a baseline it may or may not suggest the WEI data are in reference condition. Currently uncommon in the WEI protocol.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

### 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, Karr and Chu 1999; Hughes 1995, Jackson and Davis 1995, Davies and Jackson 2006; Stoddard et al. 2006). More complex scenarios include intermediate assessment points that bound one to many condition range(s) 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, Grace, Schweiger, Guntensbergen et al. (2013).

The ROMN has elected to use two variants of the reference condition in the WEI protocol, depending on which park is being evaluated. First, for wilderness parks (GLAC, GRSA, ROMO), we use a *minimally disturbed condition* (MDC). Second, for FLFO, 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 wetlands in the absence of significant human disturbance and is the best approximation or estimate of true ecological integrity. However, if a MDC is estimated empirically from reference sites, there are few if any wetlands 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 a MDC (e.g., atmospheric contaminants at levels below known effects). Similarly, several authors (i.e., Dufour and Piegay 2009) 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 wetlands 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 (Bailey et al. 2004, Hughes et al. 1986, Hughes 1995). These rules vary from region to region, given 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 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. Methods and the actual values are presented in select data summary and all comprehensive WEI reports.

# Sample Designs

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). WEI 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 and may take several sampling cycles to adequately estimate). Therefore, we employ a suite of three sample designs that compromise among these competing objectives.

Our three designs forms include (1) “random” probabilistic surveys implemented in ROMO and part of GRSA, (2) targeted or hand-picked sentinel designs implemented in all ROMN parks where we do or will monitor wetlands, and (3) targeted or model-based gradient designs used in ROMO and part of GRSA. Table 6 and the following sections summarize these designs and present the WEI sample sites in each park. Note that we include additional background and detail for ROMO designs simply because we present this park’s designs first. At the time of publication, models to assess the power to detect trend were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; McDonald 2003). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

## Rocky Mountain National Park

ROMO has extensive wetland that, along with the alpine, is the park’s most important ecological resource. We use all three design types in ROMO to monitor wetlands. Between 2007 and 2013 there were 154 sites established in the park and sampled 362 times; 96 survey sites with 127 full sample events, 28 sentinel sites with 186 full sample events, and 32 gradient sites with 49 full sample events. Most sites also had many

partial events over the years (not included in the numbers given here).

### *ROMO Survey*

A distinguishing feature of the WEI protocol in ROMO is a survey design approach to establishing most wetland monitoring locations. This random selection allows valid statistical inference to the population of wetlands in the park, with known confidence, from a relatively small sample. Given the challenges of monitoring wetlands in ROMO within a survey context, we used a complex survey design that included three stages of randomization as summarized in the following sections.

#### Target Population

A target population explicitly identifies the resource of interest and includes criteria for determining whether a resource unit is in or out of the target population. It is the resource for which quantitative estimates are needed. For ROMO, this included three types of wetland as defined by the Cooper classification system: fen, wet meadow, and riparian wetland. We describe each of these wetland types in detail in the classification section above—these attributes define the target populations for each type in ROMO. We did not constrain this spatially within the park—in other words, all of the wetland of these three types in the park was defined as our target population.

#### Sample Population

In general, a 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., incorrectly mapped wetland), damaged or lost samples, or incorrectly collected data. Quality control and proper training can deal with some of these issues and a GRTS design aids in maintaining valid samples; however, some

**Table 6. Summary of sample designs used in ROMN WEI monitoring. GRTS=generalized random-tessellation stratified spatially balanced design. Event counts are for complete sample events (additional partial visits not included here) and are through 2013, except where noted.**

| Park | Survey                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Sentinel                                                                                                                                                                                                                                                                                                                                  | Gradient                                                                                                                                                                                                                                                         |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ROMO | Three wetland types across complete park with a total sample size of 96, mostly sampled once every 10 years (a subset of sites was revisited within each survey's implementation). Design is a three-stage GRTS sample stratified by watershed type (1st stage), with unequal probability sampling across accessibility weighted wetland types (2nd stage) and an areal sample (3rd stage) of locations within selected wetland complexes treated as strata. Optionally, sites selected in panels are available for sampling in intervening years between main efforts, should budget allow. From 2007 to 2009 there were 127 events at the 96 sites.                                                                                                  | Four sentinel complexes with a mix of three wetland types and 6-10 sites per complex, sampled biannually once or twice per season. As of 2013, there were 27 sites, sampled 183 times (from 2007 to 2013).                                                                                                                                | Thirty-two sites within three wetland types sampled once or twice every 10 years. As of 2013, there were 32 sites, sampled 49 times (from 2007 to 2013)                                                                                                          |
| GRSA | Two wetland types across the sandsheet zone of the park with a total sample size of 49, mostly sampled once every 10 years (a subset of sites was revisited within each survey's implementation). Design is a two-stage GRTS with unequal probability discrete sampling across accessibility weighted wetland types (1st stage) and an areal sample (2nd stage) of locations within selected wetland complexes treated as strata. Optionally, sites selected in panels available for sampling in intervening years between main efforts should budget allow. In the 2010 survey, there were 56 events at the 49 sites.<br><br>Note that GRSA survey data are also used to address additional objectives linked to the park's Ungulate Management Plan. | Five sentinel complexes with a mix of four wetland types and 3-5 sites per complex, sampled biannually once or twice per season. As of 2013, there were 21 sites, sampled 83 times (from 2010 to 2013).<br><br>Note that GRSA sentinel data are also used to address additional objectives linked to the park's Ungulate Management Plan. | Fourteen sites within two wetland types sampled once or twice every 10 years. As of 2013, sampled 15 times (from 2010 to 2013)<br><br>Note that GRSA gradient data are also used to address additional objectives linked to the park's Ungulate Management Plan. |
| GLAC | None as of publication.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | As of publication, GLAC sentinel designs were unresolved.                                                                                                                                                                                                                                                                                 | None as of publication, although sentinel sites may serve similar function.                                                                                                                                                                                      |
| FLFO | None as of publication.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Three sentinel complexes with a mix of three wetland types and 3-4 sites per complex, sampled biannually once or twice per season. As of 2013, there were 10 sites, sampled 34 times (from 2010 to 2013).                                                                                                                                 | None as of publication, although sentinel sites may serve similar function.                                                                                                                                                                                      |

errors that reduce the sample population from the target are unavoidable or even included intentionally.

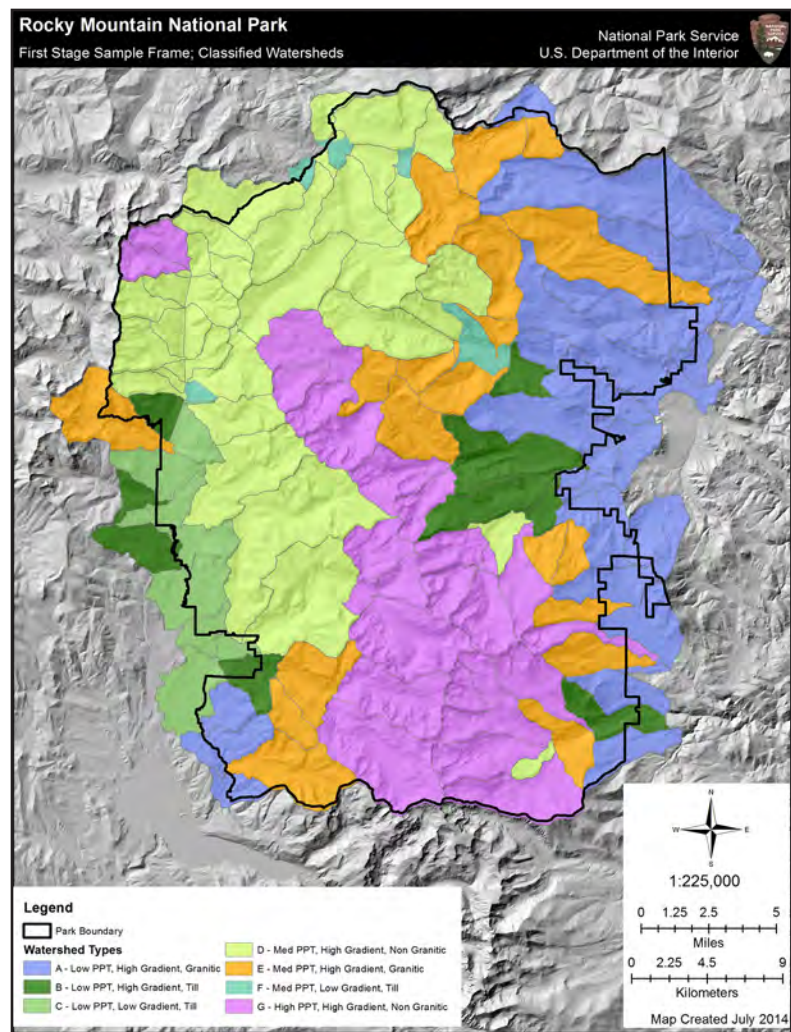
We constrained selection of sites from all the wetland in the park largely based on accessibility (see below). We did not restrict the size of an individual wetland complex within the target population although the sampled population could only include wetland patches large enough to fit at least 80% of our response design. Finally, the ROMO sampled population was restricted to later summer when wetland vegetation is at its peak phenology but also likely most stressed from water drawdown, grazing, and reproduction. Taking all these constraints into consideration, the sample population for ROMO WEI survey design based monitoring is all safely accessible and in compliance Cooper-type wet meadow, fen or riparian wetland greater than 80 m<sup>2</sup> in size with peak summer vegetation phenology during a survey's implementation (i.e., 2007-2009, 2017-2019, etc.).

### 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., wetland types, hydrologic gradients, or management units). Sample frames incorporate all boundaries and all attributes used within the design (e.g., accessibility class). For the ROMO survey design, two frames were required: watersheds within the park (used in the first stage of the design, see below) and wetland complexes within watersheds (used in the second and third stages).

#### First Stage

The ROMO first stage sampling frame was created from watersheds within the park. We first classified each using an agglomerative cluster analysis (McCune and Grace 2002, McCune and Mefford 2006) of large-scale drivers of wetland occurrence and type (annual precipitation, bedrock geology, landform and stream gradient; Winters et al. 2005, Wohl et al. 2007; Figure 11).



The cluster model partitioned the ROMO watersheds into seven strata used as discrete strata in the first stage selection.

#### Second and Third Stage

The ROMO second and third stage frames were created from wetland polygons digitized as described below in the subset of watersheds selected by the first stage of the design. The second stage frame consisted of the wetland complex centroids and the third stage was the polygons themselves.

Novel digitizing of wetland polygons was required as existing wetland maps in the park used different (not Cooper type) wetland classification systems and were generally poor representations of true wetland boundaries. This was a labor intensive step, and reducing the number of watersheds in which it was conducted was the main reason for the complex multistage survey design used in ROMO. Polygons were

**Figure 11.** ROMO first stage watersheds characterized by a cluster analysis of annual precipitation, bedrock geology, and landform and stream gradient (attributes that drive wetland formation). PPT=precipitation from 30-year normal PRISM data (PRISM Climate Group 2015).

created using heads-up stereoscope analysis at a fine scale (i.e., 1:12k) with a background of imagery and a digital elevation model. Auxiliary geospatial data sets were also used to assist the digitization process. In ROMO, the Vegetation Map (Salas et al. 2005) and National Wetlands Inventory (NWI) map (Cowardin et al. 1979) provided useful guides for delineation. The delineation process also included assigning an expected Cooper wetland type to each polygon (the final type was not known until a site was visited). Assignment of type was based on best professional judgment and location, color, texture, and the classification of the auxiliary layers in and around the target polygon (Figure 12, Table 7). A series of known Cooper-type wetlands were also used as a library to guide delineation. Finally, field-based ground checks were conducted in 2006 on at least 10% of the delineated polygons with correction rule

sets developed and applied to the entire dataset. To accommodate transitional habitat along edges or errors in wetland boundary delineation, each WEI second stage frame polygon was buffered within a GIS using a flood model (Figure 13). A one meter deep flood was used to expand a wetland into the local topography but was limited to be no more than 20 meters in a horizontal plane (to deal with flat topography).

#### Cost Model

Sampling in the remote wilderness settings of large ROMN parks like ROMO is often difficult. We incorporated accessibility or cost into the ROMO survey design via a cost surface derived from a GIS model (Frakes et al. 2007, Theobald et al. 2010) that generated a grid of the estimated time required to access any point in the park (Figure 14). The central algorithm of the model predicted traveling speed from the

**Figure 12.** Example of novel digitizing for second stage wetland frame. (A) wetland polygon from the ROMO Vegetation Map (Salas et al. 2005); (B) polygon redrawn after stereoscope analysis to include tree islands and boundaries that were more likely treed fen (this is a well-known site in ROMO called Spring Fen that includes woody vegetation). Polygons are shown prior to any buffering (see text and Figure 13).

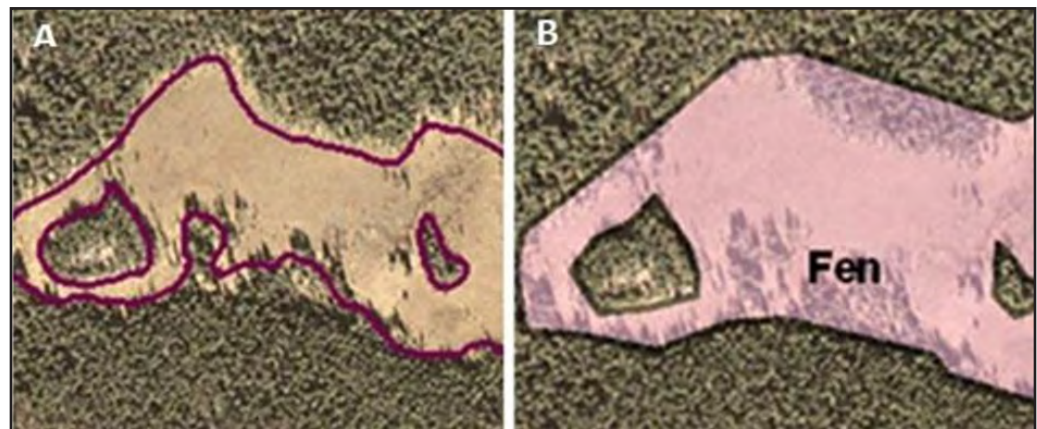


**Table 7. Diagnostic characteristics of different wetland types in ROMO used to differentiate types from one another in aerial photographs and in the field.**

|                                             | Wet Meadow                                                                        | Fen                                                                                                                                      | Riparian                                                                                                                                     |
|---------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Geomorphic context (typically in the field) | Moderate slopes, valley bottoms, saddles                                          | Glacial lake basins, potholes, slopes associated with springs, toeslope settings                                                         | High gradient bedrock or colluvial-dominated, low to moderate gradient alluvial                                                              |
| Imagery characteristics                     | Difference in tonal characteristics from dry meadows and fens, landscape position | Difference in tonal characteristics from other wetland types; presence of hummocks, strings and larks or other microtopographic features | Presence of stream channel, fluvial landforms such as point bars, oxbows, beaver dams, distinct cohorts of woody species, landscape position |

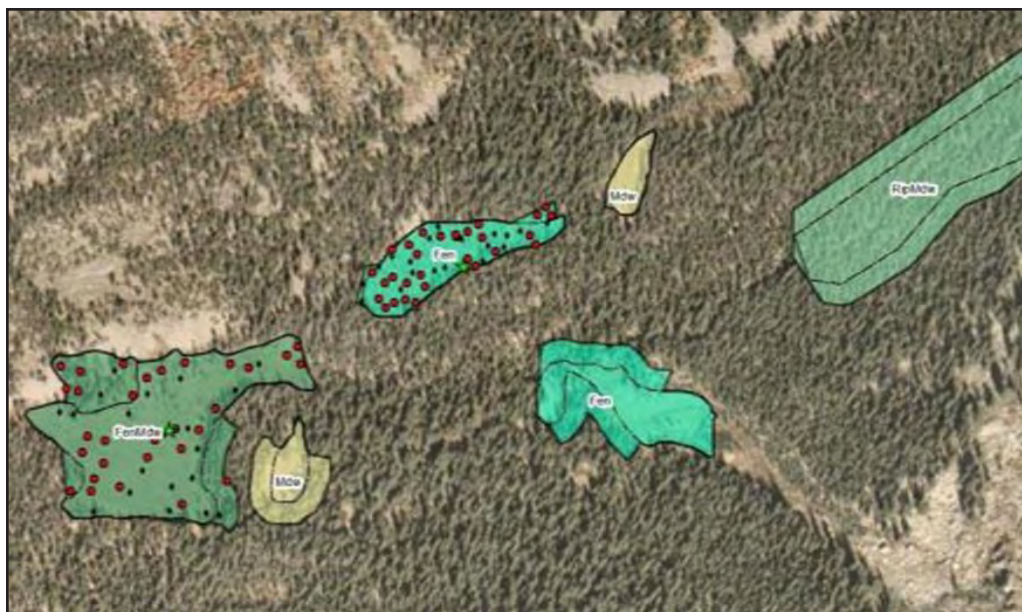


**Figure 13.** Example of second stage wetland complexes in ROMO. Third-stage sample points are shown with large red dots for base points and small black dots for oversample sites. Green stars are actual sample locations chosen from the ordered list of third stage points. Polygons with no third stage points were not selected by the second stage of the design. The dashed inner lines in some polygons are the non-flood buffered original extent of the polygon.

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 (e.g., a backcountry campsite), and landcover type (with weights applied for differential permeability through these landcover types). Impassable barriers such as streams (over a certain size), lakes, and slopes greater than 35 degrees were also included in the model as impermeable. GRTS designs can adjust 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. The final cost values were averaged across each second stage WEI polygon, classified into 10 classes using quantile breaks, attached to the wetland type(s) for each polygon (i.e., Fen\_High, FenMdw\_Med, etc.) and used in the second stage of the design as presented below.

### Site Selection

The following sections give summaries of how sites were selected at each stage of the design, including how target sample size was estimated.

We used a generalized random-tessellation stratified (GRTS) spatially-balanced algorithm to select sample units from each of the frames described above (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

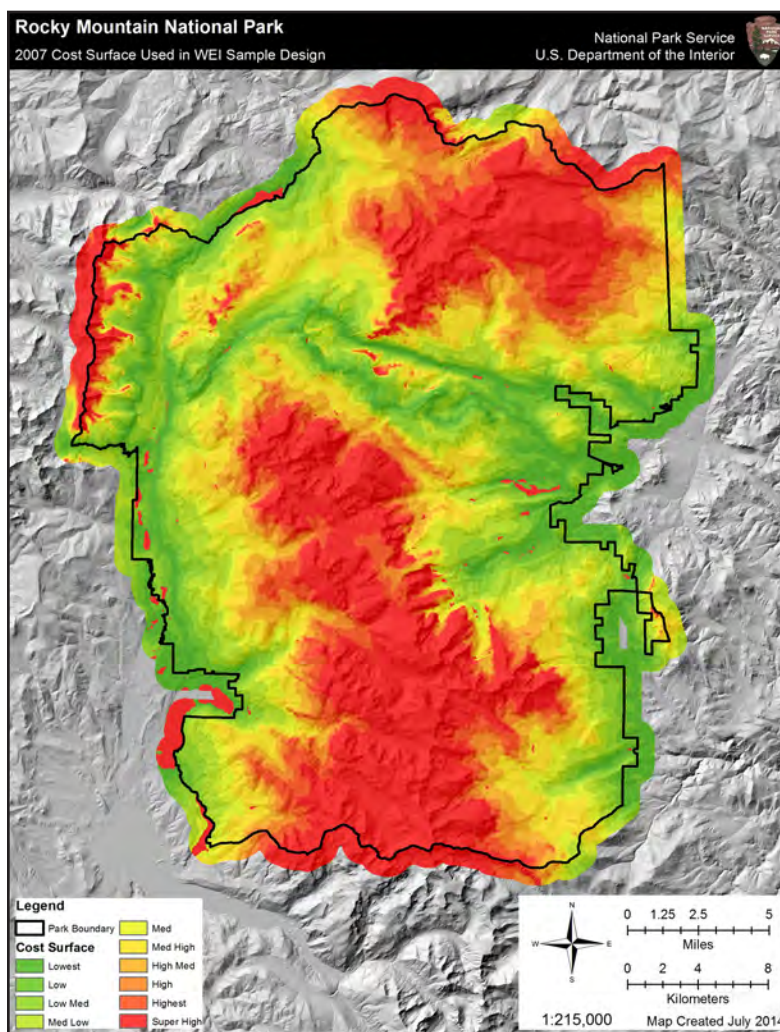


**Figure 14.** Example of a cost surface as used in the ROMO WEI survey design. Cost is symbolized using nine classes created using quantiles. Redder colors within the park represent higher cost.

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 wetland) or sites not sampleable due to safety or compliance issues, it maintains spatial balance, and, through a novel variance estimator, increases precision of status estimates (Stevens and Olsen 2003). These attributes help ensure that WEI GRTS survey designs are representative of the target population of interest, may be efficiently implemented, and allow unbiased inference from sampled sites to un-sampled elements of the target population with known confidence (Hansen et al. 1983).

**First Stage**

For the first stage, watersheds were selected by GRTS from within each strata (see Figure 11) with an equal probability using watershed centroids as a discrete or list frame. Total target sample size was arbitrarily set to 20, with the sample size within each strata determined by its relative frequency across the park (Table 8). Because there was no interest in making estimates to specific strata (watershed type), the relatively small strata samples sizes were acceptable, especially with the small range in sample weights among strata (S. Urquhart pers. comm., March 2007). We ordered the complete list of watersheds in each strata such that units beyond the target sample size could be used as oversamples. When implementing the design we learned that the park did not want us monitoring wetlands in Research Natural Areas (see Figure 15) due to compliance issues, and therefore, two entire watersheds

had to be replaced following GRTS rules (slightly adjusting the initial weights).

**Second Stage**

Wetland complex centroids were selected by GRTS using a discrete design with unequal probability of selection among wetland type(s)-accessibility classes (see below for details on how cost was treated in the design). To derive target sample size for each wetland type we used methods given in Cochran (1987) in which sample size calculations are based on a proportion as the statistic used to estimate status, the target or required precision, and the confidence at which the estimate is to be made (Equation 1). This

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

**Equation 1.** Formula for estimating sample size (n) based on a proportion (p) and desired precision (Cochran 1987). Z=1.645 at a confidence of 90% or 2 for 95%.

method is very useful because sample size estimation does not require pilot data. The most conservative estimate of precision is obtained at a proportion of 0.5, at which variance is maximized.

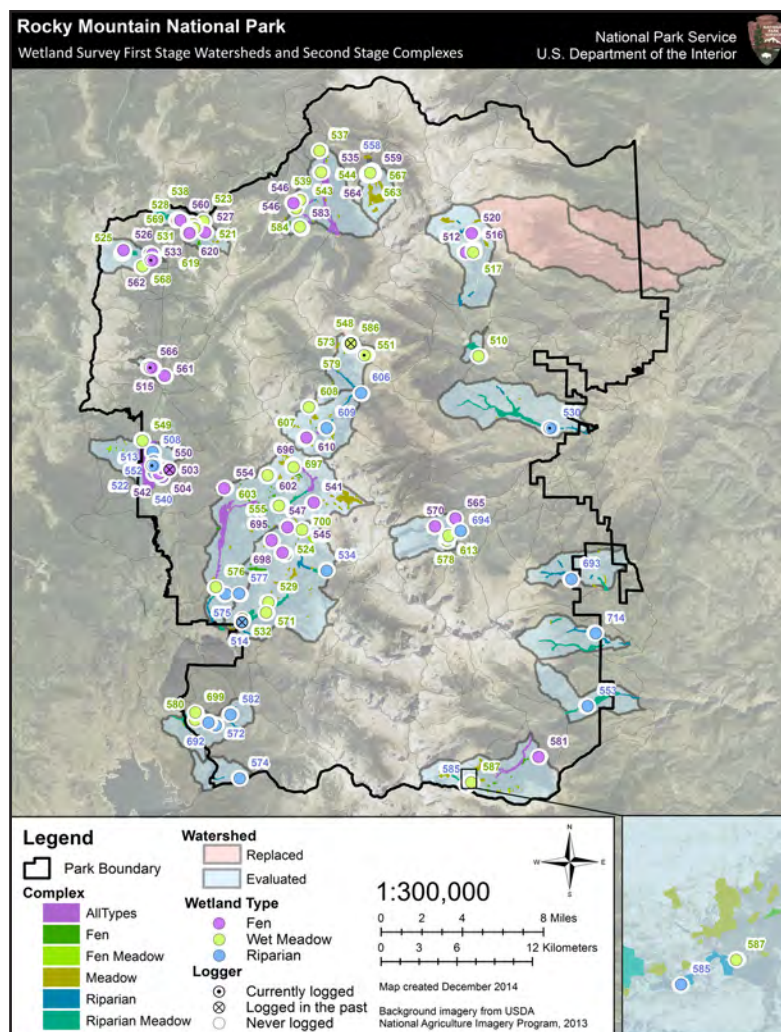
Applying this method, a sample size of 30 per wetland type gives a precision of ±15% with 90% confidence. This sample size (a total of 90 with three wetland types) was affordable within the ROMN budget but resulted in larger confidence intervals than we would have liked. However, estimating proportions is difficult, statistically speaking, so a sample size based on a proportion will

| Table 8. Basin frequency by type and first stage sample size. Sample weights are adjusted for replacement of two watersheds due to non-compliance. |               |          |            |                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------|------------|-----------------|
| Basin Type                                                                                                                                         | Total in Park | Target N | Oversample | Adjusted Weight |
| A                                                                                                                                                  | 26            | 4        | 22         | 5.2             |
| B                                                                                                                                                  | 9             | 1        | 8          | 9               |
| C                                                                                                                                                  | 8             | 1        | 7          | 8               |
| D                                                                                                                                                  | 36            | 6        | 30         | 6               |
| E                                                                                                                                                  | 20            | 3        | 17         | 5               |
| F                                                                                                                                                  | 7             | 1        | 6          | 7               |
| G                                                                                                                                                  | 27            | 4        | 23         | 6.75            |

likely be conservative for other statistics, like a mean. This method also assumed the design was a simple random sample and GRTS based estimates of variance are smaller (Stevens and Olsen 2003). These two factors should reduce the precision around a proportion of 0.5 from a sample size of 30 to  $\pm 10$ -12% (from  $\pm 15$ %, T. Olsen, pers. comm. September 2010). With this, a target sample size of 30 was deemed acceptable and within our budget.

Because wetland type was not exclusive to a complex (i.e., fen and meadow could appear as a mosaic in one wetland), and the second stage of the design selected complex centroids, allocating these 30 samples was somewhat involved. In summary, to determine how many complexes should be included in the second stage sample to reach our target sample sizes, we calculated the frequencies of the six existing combinations of wetland types across all complexes in the ROMO frame and then through trial and error derived coefficients that when applied to the sum of the frequency of each of the six wetland type combinations generated final expected sample sizes for each wetland type (Table 9). Given the way wetland type was arrayed among complexes, the final integer sample sizes turned out to not be exactly 30. Note that because the second stage sample was discrete, the actual area of each wetland complex was not a factor in the design (e.g., very large wet meadows were selected with the same probability as very small ones).

We had no interest in making estimates for wetland type and cost class combined, therefore we ignored cost modifiers when (1) determining the number of complexes



needed to reach our target sample sizes (S. Urquhart, pers. comm. March 2007), (2) replacing non-target or otherwise non-sampleable sites encountered in the field, and (3) in constructing the final estimates for a wetland type (deconvoluting cost from wetland type; T. Olsen, pers. comm. October 2010). Additionally, while

**Figure 15.** ROMO WEI survey sites sampled in 2007-2009. Both the first stage watersheds and second stage wetland complexes are shown (the two pink shaded watersheds were replaced, see text). The inset shows an example of the wetland sample frame and sampled sites on the south central edge of the park. See Figure 13 for an example of the third-stage points evaluated to locate the actual sample locations in a complex.

**Table 9.** Expected sample sizes per wetland type(s).

| Class                           | Number of complexes per wetland type(s) in frame | Target Sample Sizes |           |        |
|---------------------------------|--------------------------------------------------|---------------------|-----------|--------|
|                                 |                                                  | Fen                 | Riparian  | Meadow |
| Fen                             | 15                                               | 15                  | -         | -      |
| Riparian                        | 27                                               | -                   | 27        | -      |
| Meadow                          | 15                                               | -                   | -         | 15     |
| Fen+Meadow                      | 14                                               | 14                  | -         | 14     |
| Riparian+Meadow                 | 1                                                | -                   | 1         | 1      |
| AllTypes                        | 2                                                | 2                   | 2         | 2      |
| <b>Total target sample size</b> | <b>31</b>                                        | <b>30</b>           | <b>32</b> |        |

much effort was expended in determining a priori wetland type(s) in each complex, this was fundamentally not knowable until a site had been visited, or even until vegetation composition or soil chemistry had been analyzed. Therefore, wetland type, central to WEI monitoring in ROMO, was not really knowable until after the design had been implemented. This had strong impacts on our final sample sizes as shown below.

The target number of samples per wetland type (see Table 9) were allocated across cost classes within type(s) using an iterative and somewhat ad hoc approach that eventually reduced the range in initial sample weights below a recommended maximum of around 30x (Table 10; T. Olsen, pers. comm. October 2010). This was done largely by restricting the number of samples allocated to higher wetland type-cost classes. In some cases we eliminated type(s)-cost classes entirely (perhaps the most important way the target population differed from the sampled one). In most cases, if a wetland-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 depend on the frequency of a wetland type(s)-cost class, as we iterated possible combinations of sample size allocation, higher/lower cost or more common or more rare classes 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 wetland type (ignoring cost) and no type was 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 wilderness wetland in WEI monitoring as possible.

### *Third Stage*

Finally, the third stage of the design placed a dense set of points in each of the selected complexes using an extensive GRTS design (see Figure 13). Each wetland complex was treated as an explicit stratum to allow an exact sample size of 30 base and 20

oversample points within each complex. No third stage design attributes (weights or strata) were used in estimation; rather, only the first two stages are included as part of design based inference. The points selected by the third stage were the actual candidate locations where plots were established. Candidate third stage sites were evaluated in the field within each second stage selected wetland following specific rules and in the order specified by GRTS. The lowest ranked sampleable site(s) in the polygon was designated the final location for establishing a WEI plot. The details of implementing the third stage of the design are in WEI SOP 4: Verification of Site Status.

### *Realized 2007-2009 Sample Size*

The total realized sample size for each wetland type was 33 in fens, 41 in meadows and 22 in riparian wetland (96 across all types). The discrepancies from the target sample sizes of 30-32 per type were largely due to the rate at which meadows were encountered in association with fens (the design required establishing sample sites at each type found in a selected wetland complex and meadows were often found in association with fens) and errors in the a priori classification of riparian wetland (several sampled sites that were expected to be riparian were instead meadow). As the design was implemented we reached our maximum total sample size before we could establish the target number of riparian sites. These changes did increase the range in adjusted sample weights to less than ideal (see Table 10). Future surveys will attempt to rectify this by adding riparian sites and sampling fewer meadows following the order set by the GRTS design.

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

At the time of publication, models to assess the power to detect trend using ROMO survey sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 11). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

**Table 10. Allocation of target sample size across wetland type(s)-cost classes. Frequency is the total count of wetlands in each type(s)-cost class. Mean cost is the average travel time in seconds across all wetlands in each type(s)-cost class. Cost rank is ordered from highest cost (1) to lowest (43) to access a site type, on average.**

| Wetland Type(s) | Cost Class | Frequency | Mean Cost | Cost Rank | Target N | Initial Weight | Realized N | Adjusted Weight |
|-----------------|------------|-----------|-----------|-----------|----------|----------------|------------|-----------------|
| AllTypes        | High       | 2         | 12464.05  | 6         | 0        | 0              | 0          | 0               |
| AllTypes        | HighMed    | 1         | 7603.30   | 15        | 0        | 0              | 0          | 0               |
| AllTypes        | MedHigh    | 3         | 5366.66   | 19        | 0        | 0              | 0          | 0               |
| AllTypes        | Med        | 1         | 4099.40   | 22        | 1        | 1.00           | 0          | 0               |
| AllTypes        | MedLow     | 1         | 1273.20   | 33        | 1        | 1.00           | 0          | 0               |
| Fen             | Highest    | 5         | 22658.72  | 2         | 1        | 5.00           | 1          | 20.00           |
| Fen             | High       | 11        | 12617.49  | 5         | 1        | 11.00          | 1          | 33.00           |
| Fen             | HighMed    | 17        | 8932.95   | 11        | 1        | 17.00          | 0          | 0               |
| Fen             | MedHigh    | 16        | 5641.80   | 16        | 1        | 16.00          | 2          | 32.00           |
| Fen             | Med        | 6         | 3344.79   | 26        | 1        | 3.00           | 1          | 4.50            |
| Fen             | MedLow     | 9         | 1545.73   | 32        | 1        | 4.50           | 5          | 5.86            |
| Fen             | LowMed     | 7         | 464.95    | 38        | 1        | 2.33           | 2          | 3.40            |
| Fen             | Lowest     | 5         | 151.16    | 40        | 1        | 1.25           | 3          | 1.75            |
| FenMdw          | Highest    | 5         | 28266.82  | 1         | 2        | 5.00           | 6          | 6.25            |
| FenMdw          | High       | 6         | 11613.75  | 8         | 2        | 3.00           | 6          | 3.60            |
| FenMdw          | HighMed    | 7         | 8480.14   | 13        | 2        | 2.33           | 11         | 2.43            |
| FenMdw          | MedHigh    | 2         | 5627.85   | 17        | 2        | 1.00           | 2          | 1.00            |
| FenMdw          | Med        | 1         | 3334.50   | 27        | 0        | 0              | 0          | 0               |
| FenMdw          | MedLow     | 2         | 2044.45   | 28        | 2        | 0.50           | 2          | 0.50            |
| FenMdw          | LowMed     | 1         | 1018.00   | 34        | 0        | 0              | 0          | 0               |
| FenMdw          | Lowest     | 2         | 90.69     | 43        | 2        | 1.00           | 2          | 2.00            |
| Mdw             | Highest    | 26        | 22387.78  | 3         | 2        | 26.00          | 2          | 39.00           |
| Mdw             | High       | 72        | 12102.33  | 7         | 0        | 0              | 0          | 0               |
| Mdw             | HighMed    | 42        | 8689.31   | 12        | 0        | 0              | 0          | 0               |
| Mdw             | MedHigh    | 30        | 5442.36   | 18        | 3        | 30.00          | 0          | 0               |
| Mdw             | Med        | 25        | 3345.20   | 25        | 3        | 12.50          | 5          | 20.00           |
| Mdw             | MedLow     | 20        | 1776.75   | 30        | 4        | 10.00          | 5          | 10.00           |
| Mdw             | LowMed     | 19        | 496.57    | 37        | 3        | 4.75           | 5          | 12.67           |
| Mdw             | Lowest     | 26        | 103.16    | 41        | 2        | 5.20           | 11         | 6.12            |
| Rip             | High       | 6         | 11471.00  | 9         | 4        | 3.00           | 2          | 6.00            |
| Rip             | HighMed    | 5         | 7859.64   | 14        | 4        | 1.67           | 3          | 3.00            |
| Rip             | MedHigh    | 8         | 5166.31   | 21        | 5        | 2.00           | 2          | 8.00            |
| Rip             | Med        | 4         | 3791.85   | 23        | 4        | 1.00           | 2          | 2.00            |
| Rip             | MedLow     | 6         | 1914.54   | 29        | 5        | 1.50           | 3          | 3.00            |
| Rip             | LowMed     | 9         | 501.93    | 36        | 4        | 1.80           | 5          | 2.13            |
| Rip             | Lowest     | 11        | 153.07    | 39        | 4        | 2.20           | 2          | 4.17            |
| RipMdw          | Highest    | 1         | 16866.50  | 4         | 0        | 0              | 0          | 0               |
| RipMdw          | HighMed    | 2         | 9061.29   | 10        | 0        | 0              | 0          | 0               |
| RipMdw          | MedHigh    | 1         | 5235.80   | 20        | 0        | 0              | 0          | 0               |
| RipMdw          | Med        | 5         | 3555.98   | 24        | 0        | 0              | 0          | 0               |
| RipMdw          | MedLow     | 3         | 1766.78   | 31        | 5        | 3.00           | 5          | 3.00            |
| RipMdw          | LowMed     | 4         | 576.71    | 35        | 0        | 0              | 0          | 0               |
| RipMdw          | Lowest     | 4         | 90.96     | 42        | 0        | 0              | 0          | 0               |

Table 11. Final ROMO survey design revisit structure. Values in cells are sample sizes. Within season and across year revisits are of the same sites (i.e., Site 506 was 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 (primarily in 2007-2009) were different than shown here. Future years will adjust sample effort to the values shown here. The design repeats indefinitely through time.

[illegible]

### ROMO Survey Sites

Table 12 and Figure 15 present the 96 WEI survey sites in ROMO as sampled in the 2007-2009 survey. Five sites selected by the survey and analyzed using design-based methods later became sentinel sites (see below).

### **ROMO Sentinel**

The ROMO sentinel design uses a very different approach than the survey design. The most important distinguishing features are (1) an expert opinion or judgment based selection of wetland complexes, (2) an annual or biannual sample frequency, and (3) no intention to make inference beyond the site or sentinel wetland complex scale.

### Target and Sample Populations

The target population for sentinel site monitoring is the site. When a complex has sufficient sites (around 10 in larger more heterogeneous complexes) the target population can also be the wetland complex that a set of sites is located in. 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 for 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 WEI survey design sample frames may be used to locate sentinel sites and to assist in delineation of the wetland complex in which specific sites are located. Using the same frame for both survey and sentinel designs is advantageous in linking the two design forms.

### Site Selection

The ROMN did not use any sort of model or computer-based algorithm to locate ROMO sentinel wetland complexes. Rather, sentinel complexes were located subjectively based

on a suite of criteria developed by ROMN staff, collaborators (especially scientists who have been working in ROMO wetlands for decades), and most importantly, ROMO staff. Key criteria used to select complexes include the following (not in any priority order):

1. Allocation of complexes across three important wetland types in ROMO: fens, riparian wetland and wet meadows.
2. Allocation of complexes across geographic classes (elevation, topography, park region).
3. Representativeness of a complex for wetland type(s) and/or geographic context. For example, is a particular alpine wet meadow typical in its hydrology, vegetation, etc.?
4. Uniqueness (somewhat in contrast to criteria three) of a complex. For example, is a particular wetland ecologically important or interesting in a way that will help the long term monitoring and management of wetlands in ROMO in general?
5. Use of existing wetland monitoring locations (especially established groundwater wells).
6. Management importance or utility of a wetland for the park (i.e., as a restoration site, usefulness for visitor interpretation, etc.).

Within a selected complex the specific locations of plots are also subjectively selected. Note the terms site and plot are used interchangeably, but “plot” is generally preferred when talking about locations in a sentinel complex. Criteria for these usually field-based decisions include the following (not in any priority order):

1. Use of existing plot locations, especially if a well has been in place for several years at the site.
2. Allocation of plots across wetland types, if more than one, within a complex.

**Table 12. ROMO WEI survey sites (96) with type complex and catchment area and the number of full sample events from 2007 to 2009. Sites are ordered by Site ID within wetland type. \*Four sites became auxiliary or 'satellite sentinel' sites after initial survey implementation. \*\*Site was selected by the survey design and then treated as a sentinel site with additional plots placed in the complex. See text for further explanation.**

| Site ID | Site Name                      | Wetland Type | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Latitude | Longitude | Number Full Visits (2007-2009) |
|---------|--------------------------------|--------------|-------------------|-----------------------------------|----------|-----------|--------------------------------|
| 503     | Poor Revisit Fen               | Fen          | 0.759             | 0.57                              | 40.341   | -105.848  | 5                              |
| 504     | Service Road 2 Fen             | Fen          | 1.409             | 1.21                              | 40.337   | -105.853  | 1                              |
| 512     | Lawn Lake Ridge 2 Fen          | Fen          | 0.874             | 0.72                              | 40.459   | -105.637  | 1                              |
| 515     | Red Mountain Fen *             | Fen          | 0.150             | 0.46                              | 40.396   | -105.861  | 6                              |
| 516     | Lawn Lake Ridge 1 Fen          | Fen          | 2.441             | 1.00                              | 40.460   | -105.631  | 1                              |
| 520     | Lawn Lake Head Fen             | Fen          | 0.680             | 5.26                              | 40.469   | -105.633  | 1                              |
| 526     | Skeleton Gulch 1 Fen           | Fen          | 3.502             | 2.96                              | 40.460   | -105.881  | 1                              |
| 527     | Poudre Pass Lake Fen           | Fen          | 0.425             | 1.17                              | 40.470   | -105.823  | 1                              |
| 533     | Grand Ditch Fen *              | Fen          | 0.719             | 5.27                              | 40.455   | -105.860  | 6                              |
| 535     | Hazeline Lake 1 Fen            | Fen          | 0.533             | 0.08                              | 40.502   | -105.705  | 1                              |
| 541     | Murphy Lake Fen                | Fen          | 0.416             | 2.08                              | 40.323   | -105.746  | 1                              |
| 542     | Service Road Fen               | Fen          | 0.312             | 0.61                              | 40.339   | -105.856  | 1                              |
| 545     | Tonahutu Ridge Fen             | Fen          | 0.744             | 0.14                              | 40.309   | -105.764  | 1                              |
| 546     | Willow Creek Fen               | Fen          | 0.648             | 0.11                              | 40.486   | -105.760  | 1                              |
| 547     | Tonahutu Creek 1 Fen           | Fen          | 2.481             | 0.21                              | 40.321   | -105.768  | 1                              |
| 550     | Grassy Kook Fen                | Fen          | 0.205             | 0.06                              | 40.341   | -105.853  | 1                              |
| 554     | Onahu Creek Fen                | Fen          | 0.183             | 0.20                              | 40.331   | -105.809  | 1                              |
| 559     | Corral Creek Fen               | Fen          | 0.716             | 4.45                              | 40.502   | -105.703  | 1                              |
| 560     | Slope Fen                      | Fen          | 0.230             | 1.62                              | 40.476   | -105.840  | 1                              |
| 561     | Hell's Upper Fen               | Fen          | 1.215             | 0.22                              | 40.392   | -105.852  | 1                              |
| 562     | Forest Meadow Fen              | Fen          | 0.101             | 5.09                              | 40.458   | -105.861  | 1                              |
| 564     | Hazeline Lake 3 Fen            | Fen          | 0.848             | 0.08                              | 40.501   | -105.707  | 1                              |
| 565     | Bear Lake Parking Lot Fen      | Fen          | 0.045             | 0.73                              | 40.314   | -105.645  | 1                              |
| 566     | Beaver Creek Fen               | Fen          | 0.193             | 0.34                              | 40.397   | -105.863  | 1                              |
| 570     | Dream Lake Fen                 | Fen          | 0.217             | 2.15                              | 40.310   | -105.659  | 1                              |
| 581     | Finch Lake Fen                 | Fen          | 0.352             | 3.87                              | 40.184   | -105.585  | 1                              |
| 583     | Poudre River Fen               | Fen          | 2.523             | 0.00                              | 40.472   | -105.755  | 1                              |
| 602     | Nakai Peak Fen                 | Fen          | 0.653             | 0.43                              | 40.337   | -105.778  | 1                              |
| 610     | Hayden Tarn Fen                | Fen          | 0.583             | 0.20                              | 40.358   | -105.751  | 1                              |
| 620     | Ditch Fen                      | Fen          | 1.713             | 2.85                              | 40.469   | -105.834  | 1                              |
| 695     | Kettle Fen                     | Fen          | 2.953             | 0.11                              | 40.302   | -105.776  | 1                              |
| 696     | Haynach Lake Fen               | Fen          | 7.864             | 1.61                              | 40.343   | -105.760  | 1                              |
| 698     | Rock Hike Fen                  | Fen          | 3.004             | 2.14                              | 40.296   | -105.768  | 1                              |
| 510     | Sheep Lake Mdw                 | Mdw          | 0.661             | 0.46                              | 40.403   | -105.628  | 1                              |
| 517     | Lawn Lake Ridge 3 Mdw          | Mdw          | 2.441             | 1.02                              | 40.459   | -105.632  | 1                              |
| 521     | Poudre Pass Ranger Station Mdw | Mdw          | 1.250             | 2.58                              | 40.474   | -105.828  | 1                              |
| 523     | Poudre Pass Gauge Mdw          | Mdw          | 1.541             | 2.70                              | 40.476   | -105.824  | 1                              |

**Table 12. ROMO WEI survey sites (96) with type complex and catchment area and the number of full sample events from 2007 to 2009. Sites are ordered by Site ID within wetland type. \*Four sites became auxiliary or 'satellite sentinel' sites after initial survey implementation. \*\*Site was selected by the survey design and then treated as a sentinel site with additional plots placed in the complex. See text for further explanation (continued).**

| Site ID | Site Name                     | Wetland Type | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Latitude | Longitude | Number Full Visits (2007-2009) |
|---------|-------------------------------|--------------|-------------------|-----------------------------------|----------|-----------|--------------------------------|
| 524     | Rock Hike Mdw                 | Mdw          | 3.004             | 2.50                              | 40.295   | -105.765  | 1                              |
| 525     | Skeleton Gulch 2 Mdw          | Mdw          | 3.502             | 2.95                              | 40.459   | -105.882  | 1                              |
| 528     | Bennett Creek Mdw             | Mdw          | 0.128             | 1.52                              | 40.476   | -105.843  | 1                              |
| 529     | Summerland Park Ridge Mdw     | Mdw          | 0.148             | 1.41                              | 40.269   | -105.778  | 1                              |
| 531     | Lulu Creek Grand Ditch Mdw    | Mdw          | 0.577             | 5.07                              | 40.458   | -105.862  | 1                              |
| 532     | Summerland Park Mid Mdw       | Mdw          | 96.496            | 0.15                              | 40.260   | -105.796  | 1                              |
| 536     | Willow Creek Saddle 1 Mdw     | Mdw          | 0.851             | 0.15                              | 40.483   | -105.758  | 1                              |
| 537     | Cache La Poudre Boundary Mdw  | Mdw          | 0.143             | 50.94                             | 40.514   | -105.741  | 1                              |
| 538     | Park Cabin Mdw                | Mdw          | 1.102             | 0.26                              | 40.474   | -105.831  | 1                              |
| 539     | Willow Creek Saddle 2 Mdw     | Mdw          | 0.076             | 0.06                              | 40.487   | -105.755  | 1                              |
| 543     | Cache La Poudre Edge Mdw      | Mdw          | 0.406             | 0.45                              | 40.503   | -105.740  | 1                              |
| 544     | Hazeline Lake 2 Mdw           | Mdw          | 0.848             | 0.06                              | 40.502   | -105.707  | 1                              |
| 548     | Alpine Headwaters Revisit Mdw | Mdw          | 0.222             | 0.17                              | 40.409   | -105.719  | 5                              |
| 549     | Bower Baker Mdw               | Mdw          | 1.523             | 18.65                             | 40.356   | -105.867  | 1                              |
| 551     | Alpine Sentinel 1 Mdw **      | Mdw          | 1.437             | 0.31                              | 40.403   | -105.708  | 4                              |
| 555     | Tonahutu Creek 2 Mdw          | Mdw          | 2.481             | 0.20                              | 40.321   | -105.770  | 1                              |
| 563     | Hazeline Lake 5 Mdw           | Mdw          | 0.716             | 4.35                              | 40.501   | -105.704  | 1                              |
| 567     | Hazeline Lake 4 Mdw           | Mdw          | 0.533             | 0.08                              | 40.502   | -105.705  | 1                              |
| 568     | Little Dutch Creek Upper Mdw  | Mdw          | 0.418             | 0.02                              | 40.452   | -105.864  | 1                              |
| 569     | Ditch Road Monday Mdw         | Mdw          | 0.178             | 2.94                              | 40.472   | -105.830  | 1                              |
| 571     | Avalanche Mdw                 | Mdw          | 0.086             | 68.39                             | 40.263   | -105.779  | 1                              |
| 573     | Alpine Elk Mdw                | Mdw          | 0.170             | 0.21                              | 40.408   | -105.718  | 1                              |
| 576     | Tonahutu Creek Lower Mdw      | Mdw          | 8.464             | 37.66                             | 40.277   | -105.815  | 1                              |
| 578     | Alberta Falls Mdw             | Mdw          | 1.183             | 0.55                              | 40.302   | -105.651  | 1                              |
| 579     | Alpine Pool Mdw               | Mdw          | 0.079             | 0.05                              | 40.408   | -105.719  | 1                              |
| 580     | Shadow Mountain Dam Mdw       | Mdw          | 0.579             | 0.32                              | 40.205   | -105.830  | 1                              |
| 584     | Poudre River Mdw              | Mdw          | 2.523             | 0.01                              | 40.473   | -105.755  | 1                              |
| 586     | Alpine Mdw                    | Mdw          | 0.222             | 0.17                              | 40.409   | -105.719  | 1                              |
| 587     | Lake Hutch Mdw                | Mdw          | 0.132             | 3.71                              | 40.171   | -105.633  | 1                              |
| 603     | Nakai Peak Mdw                | Mdw          | 0.653             | 0.43                              | 40.338   | -105.778  | 1                              |
| 607     | Hayden Tarn Mdw               | Mdw          | 0.583             | 0.26                              | 40.358   | -105.751  | 1                              |
| 608     | Terra Tomah Chute Mdw         | Mdw          | 2.754             | 0.03                              | 40.375   | -105.749  | 1                              |
| 613     | Labor Day Mdw                 | Mdw          | 1.120             | 0.66                              | 40.305   | -105.649  | 1                              |
| 619     | Ditch Meadow Mdw              | Mdw          | 1.713             | 2.85                              | 40.471   | -105.835  | 1                              |
| 697     | Haynach Mdw                   | Mdw          | 7.864             | 1.63                              | 40.342   | -105.760  | 1                              |
| 699     | Green Ridge 1 Mdw             | Mdw          | 1.722             | 0.03                              | 40.209   | -105.830  | 1                              |

**Table 12. ROMO WEI survey sites (96) with type complex and catchment area and the number of full sample events from 2007 to 2009. Sites are ordered by Site ID within wetland type. \*Four sites became auxiliary or 'satellite sentinel' sites after initial survey implementation. \*\*Site was selected by the survey design and then treated as a sentinel site with additional plots placed in the complex. See text for further explanation (continued).**

| Site ID | Site Name                      | Wetland Type | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Latitude | Longitude | Number Full Visits (2007-2009) |
|---------|--------------------------------|--------------|-------------------|-----------------------------------|----------|-----------|--------------------------------|
| 700     | Alpine Meadow Big Pool Mdw     | Mdw          | 13.356            | 0.21                              | 40.308   | -105.754  | 1                              |
| 508     | Coyote Creek 1 Rip             | Rip          | 0.458             | 107.64                            | 40.344   | -105.859  | 1                              |
| 513     | Baker Lower Rip                | Rip          | 0.292             | 106.82                            | 40.350   | -105.860  | 1                              |
| 514     | North Inlet Rip                | Rip          | 96.496            | 72.84                             | 40.258   | -105.796  | 1                              |
| 522     | Rainy Riparian Rip *           | Rip          | 0.248             | 107.71                            | 40.343   | -105.859  | 6                              |
| 530     | Beaver Meadows Creek Rip *     | Rip          | 4.868             | 15.18                             | 40.363   | -105.576  | 6                              |
| 534     | Bench Lake Rip                 | Rip          | 2.843             | 42.90                             | 40.286   | -105.736  | 1                              |
| 540     | Cloudy Day Rip                 | Rip          | 0.398             | 109.32                            | 40.339   | -105.859  | 1                              |
| 552     | Coyote Creek 2 Rip             | Rip          | 0.129             | 107.53                            | 40.345   | -105.860  | 1                              |
| 553     | Wild Basin Rip                 | Rip          | 50.633            | 82.46                             | 40.212   | -105.550  | 1                              |
| 558     | Corral Creek River Rip         | Rip          | 1.134             | 4.60                              | 40.503   | -105.704  | 1                              |
| 572     | Lower Pole Creek Rip           | Rip          | 1.506             | 3.18                              | 40.202   | -105.815  | 1                              |
| 574     | Endless Drain Rip              | Rip          | 0.940             | 0.14                              | 40.173   | -105.798  | 1                              |
| 575     | Beaver Mdws Utility Area Rip   | Rip          | 8.464             | 16.12                             | 40.273   | -105.808  | 1                              |
| 577     | Tanahutu Little Creek Rip      | Rip          | 3.260             | 1.00                              | 40.274   | -105.799  | 1                              |
| 582     | Pole Creek Upper Rip           | Rip          | 0.210             | 0.63                              | 40.208   | -105.805  | 1                              |
| 585     | Alpine T-storm Rip             | Rip          | 0.436             | 3.57                              | 40.169   | -105.637  | 1                              |
| 606     | Forest Canyon Big Thompson Rip | Rip          | 19.784            | 42.92                             | 40.383   | -105.712  | 1                              |
| 609     | Hayden Spice Rip               | Rip          | 4.928             | 6.83                              | 40.363   | -105.736  | 1                              |
| 692     | Hump Day Drain Rip             | Rip          | 1.563             | 3.54                              | 40.203   | -105.821  | 1                              |
| 693     | Longs Riparian Rip             | Rip          | 16.104            | 3.03                              | 40.282   | -105.562  | 1                              |
| 694     | Beaver Marsh Rip               | Rip          | 1.008             | 1.38                              | 40.307   | -105.641  | 1                              |
| 714     | Rockwood Rip                   | Rip          | 14.968            | 3.40                              | 40.252   | -105.545  | 1                              |

3. Allocation of plots across general vegetation community types (within wetland type), if more than one. that have or will be restored or areas heavily used by park visitors).
4. Allocation of plots to extant general hydrologic types (i.e., drier or wetter areas of the complex), if more than one. Ideally, this includes siting plots along transects paralleling dominant hydrologic gradients in a complex. Revisit Design: Power for Trend Detection and Precision of Status Estimates  
At the time of publication, models to assess the power to detect trend using ROMO sentinel sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 13). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.
5. Placing plots on both edges and interior locations of the complex.
6. Placing plots in locations useful for park management (i.e., areas of a wetland

Table 13. Final ROMO sentinel design revisit structure. Values in cells are sample sizes. As detailed in the text, the realized sample sizes from 2007 to 2013 were different than shown here. Future years will adjust sample effort to the values shown here. The design repeats indefinitely through time.

[illegible]

### ROMO Sentinel Sites

Sentinel complexes in ROMO (Figure 16) include (a small portion of) the Kawuneechee Valley, lower Big Meadows, the northeast section of Moraine Park, and a small alpine meadow complex near the top of Trail Ridge Road. Table 14 gives select attributes of each plot in these complexes (as of 2013) and summarizes the key criteria behind the selection of the complex as a sentinel monitoring location.

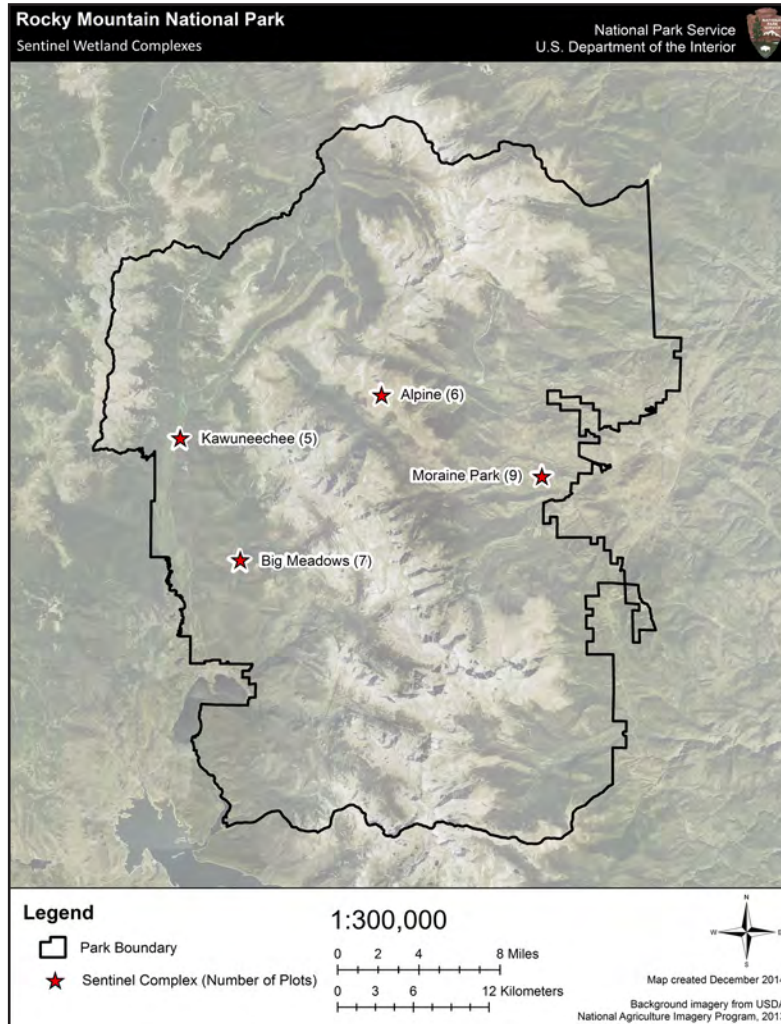


**Figure 16.** ROMO WEI sentinel complexes. As of 2013, each complex had from 6 to 9 individual plots (see Figure 17 and Table 14).

As shown in Table 12, after the initial implementation of the survey in 2007-2009, 5 sites (originally sentinel or gradient in design) were selected for continued episodic sampling (satellite sentinel sites). These sites are typically in smaller wetlands with unique characteristics important to the park. They are generally located near one of the four main sentinel complexes and the logistics

of sampling them are relatively efficient. The ROMN will sample these sites on an ad hoc basis into the future, with data from them contributing to meeting sentinel site objectives.

### **ROMO Gradient**

The ROMO gradient design is similar to the sentinel design in some aspects including (1) an expert opinion or judgment based selection of wetland complexes, and (2) no intention to make inference beyond the sites or the sentinel wetland 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 wetland condition at the extremes of anthropogenic and natural drivers that influence wetland ecology. Therefore sites are targeted to wetlands we expect to be under stress or in pristine condition.

### 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 wetlands for decades), and most importantly, ROMO staff. Some criteria were the same as those used to locate sentinel wetland complexes and included (not in any priority order):

1. Allocation of complexes across three important wetland types in ROMO: fens, riparian wetland and wet meadows.
2. Allocation of complexes across geographic classes (elevation, topography, park region).
3. Use of existing wetland monitoring locations (especially established groundwater wells).

However, because gradient sites were intended to capture wetland condition either under direct anthropogenic or important natural disturbances, or completely lacking any local stressors, three additional criteria were used. A long list of candidate sites were scored within three disturbance gradients by

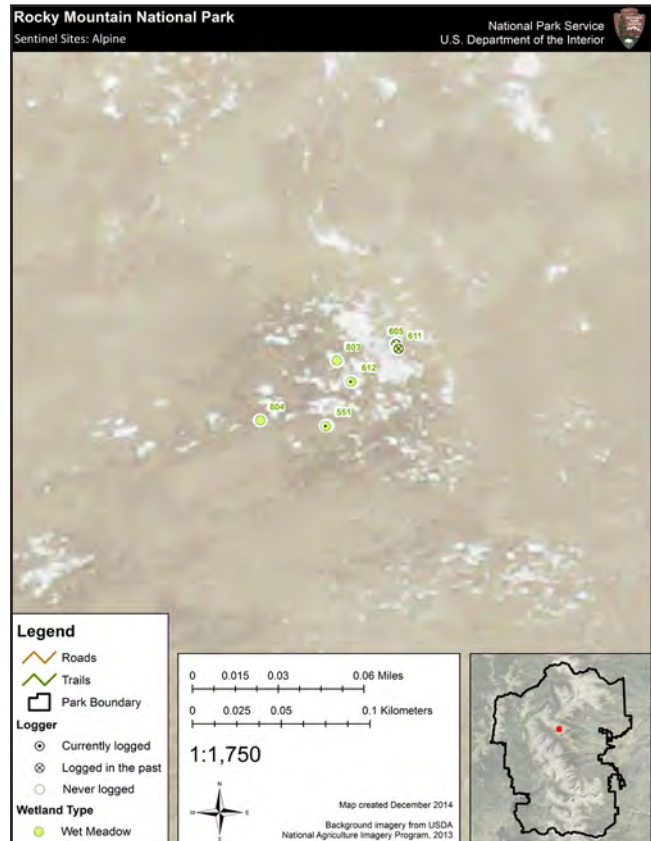
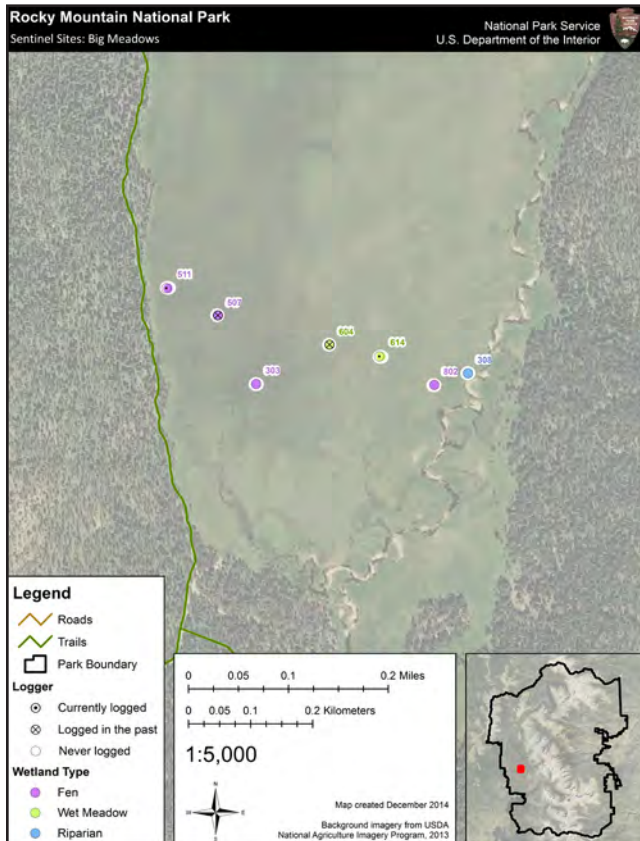
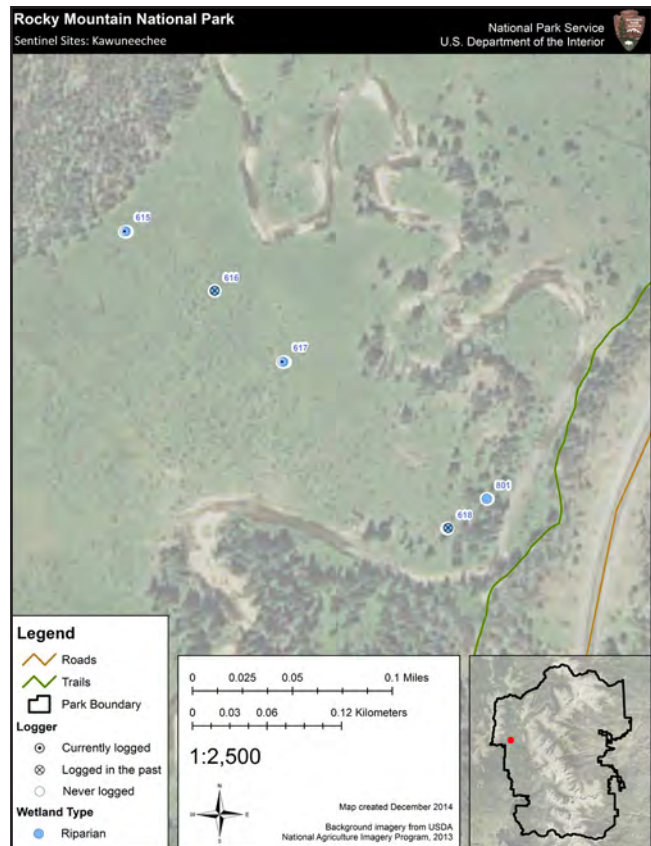
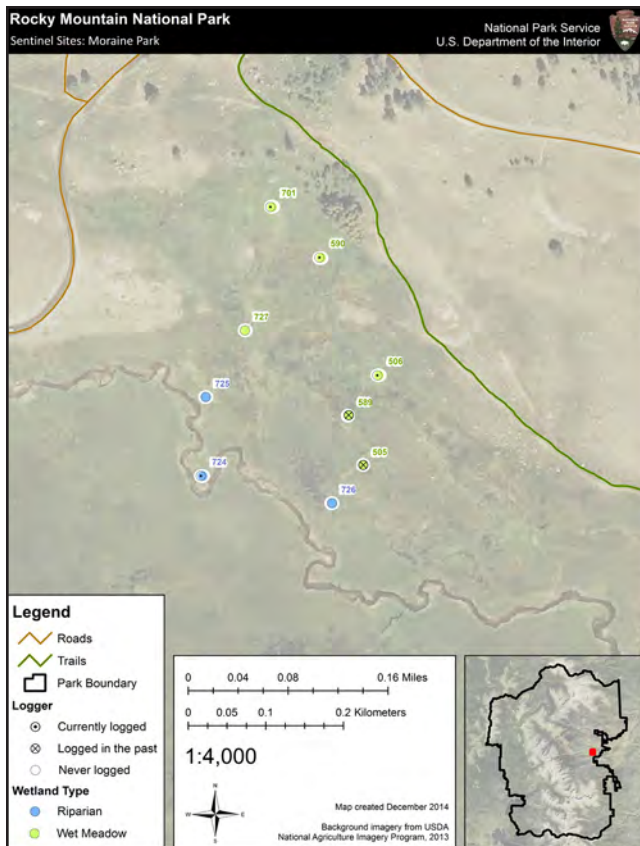


**Figure 17.** ROMO Sentinel sites in (clockwise from top left) Moraine Park, Kawuneechee Valley, Alpine, and Big Meadows.

**Table 14. ROMO WEI sentinel sites (28) with site selection criteria and full sample events from 2007 to 2013. The final revisit design structure as shown above is to be implemented 2015 and/or 2016. Sites are ordered by Site ID. \*\*Plot originally selected by the survey design (all other plots in the sentinel complex located subjectively using the criteria given in text).**

| Complex Size                            | Elevation Zone   | General Topography                                                                                         | Park Region              | Disturbance Regime(s)                                                                                              | Historical Monitoring                                  | Resource Management Issues                                                           | Site ID | Type   | Latitude | Longitude | # Full Events |
|-----------------------------------------|------------------|------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------------------------------|---------|--------|----------|-----------|---------------|
| Moraine Park (9 sites as of 2014)       |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      |         |        |          |           |               |
| Medium to Large (16.9 ha)               | Low (2,450 m)    | Flat alluvial valley bottom; meandering multithread stream; no active beaver or remnant habitat            | East side, front country | Human: heavy historical (visitor recreation) and current (medium visitor use); Natural: heavy elk use              | Extensive, groundwater, vegetation and elk             | Active vegetation and hydrologic restoration, elk management, visitor interpretation | 505     | Mdw    | 40.355   | -105.594  | 7             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 506     | Mdw    | 40.356   | -105.594  | 16            |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 589     | Mdw    | 40.356   | -105.594  | 6             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 590     | Mdw    | 40.357   | -105.594  | 7             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 701     | Mdw    | 40.358   | -105.595  | 5             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 724     | Mdw    | 40.356   | -105.595  | 3             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 725     | Rip    | 40.355   | -105.596  | 4             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 726     | Rip    | 40.356   | -105.596  | 4             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        | 727                                                                                  | Rip     | 40.355 | -105.594 | 4         |               |
| Kawuneechee Valley (6 sites as of 2014) |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      |         |        |          |           |               |
| Medium to Large (41.3 ha)               | Low (2,700 m)    | Flat alluvial valley bottom; mostly single thread stream; remnant and a few active areas of beaver habitat | West side, front country | Human: heavy historical (grazing and agriculture) and current (mild visitor use); Natural: heavy elk and moose use | Extensive, ground-water, vegetation, elk/ moose/beaver | Active vegetation restoration, elk and moose management, visitor interpretation      | 294     | Rip    | 40.383   | -105.852  | 3             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 615     | Rip    | 40.384   | -105.853  | 16            |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 616     | Rip    | 40.383   | -105.852  | 6             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 617     | Rip    | 40.383   | -105.852  | 7             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 618     | Rip    | 40.382   | -105.851  | 6             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 801     | Rip    | 40.382   | -105.850  | 3             |
| Big Meadows (7 sites as of 2014)        |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      |         |        |          |           |               |
| Large (116.3 ha)                        | Medium (2,875 m) | Flat meadow; single thread stream; few remnant beaver habitat, no active beaver                            | West side, back country  | Human: medium historical (grazing) but light current (little visitor use); Natural: sporadic elk use               | Extensive, ground-water and vegetation                 | Historical vegetation and hydrologic restoration                                     | 303     | Fen    | 40.313   | -105.811  | 3             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 308     | Rip    | 40.313   | -105.808  | 2             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 507     | Fen    | 40.314   | -105.812  | 7             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 511     | Fen    | 40.314   | -105.812  | 16            |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 604     | Mdw    | 40.314   | -105.810  | 6             |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 614     | Mdw    | 40.313   | -105.809  | 21            |
|                                         |                  |                                                                                                            |                          |                                                                                                                    |                                                        |                                                                                      | 802     | Rip    | 40.313   | -105.808  | 3             |

**Table 14. ROMO WEI sentinel sites (28) with site selection criteria and full sample events from 2007 to 2013. The final revisit design structure as shown above is to be implemented 2015 and/or 2016. Sites are ordered by Site ID. \*\*Plot originally selected by the survey design (all other plots in the sentinel complex located subjectively using the criteria given in text), continued.**

| Complex Size                       | Elevation Zone    | General Topography                                            | Park Region                                  | Disturbance Regime(s)                                                                                  | Historical Monitoring | Resource Management Issues                      | Site ID | Type | Latitude | Longitude | # Full Events |
|------------------------------------|-------------------|---------------------------------------------------------------|----------------------------------------------|--------------------------------------------------------------------------------------------------------|-----------------------|-------------------------------------------------|---------|------|----------|-----------|---------------|
| <b>Alpine (6 sites as of 2014)</b> |                   |                                                               |                                              |                                                                                                        |                       |                                                 |         |      |          |           |               |
| Small<br>(4.13 ha)                 | High<br>(3,600 m) | Small flat/<br>sloped alpine<br>meadow, not<br>beaver habitat | West side,<br>front (but<br>high)<br>country | Human: little<br>historic but<br>medium<br>current (mild<br>visitor use);<br>Natural: heavy<br>elk use | Little                | Elk<br>management,<br>visitor<br>interpretation | 551**   | Mdw  | 40.403   | -105.708  | 9             |
|                                    |                   |                                                               |                                              |                                                                                                        |                       |                                                 | 605     | Mdw  | 40.403   | -105.708  | 5             |
|                                    |                   |                                                               |                                              |                                                                                                        |                       |                                                 | 611     | Mdw  | 40.403   | -105.708  | 5             |
|                                    |                   |                                                               |                                              |                                                                                                        |                       |                                                 | 612     | Mdw  | 40.403   | -105.708  | 8             |
|                                    |                   |                                                               |                                              |                                                                                                        |                       |                                                 | 803     | Mdw  | 40.403   | -105.708  | 2             |
|                                    |                   |                                                               |                                              |                                                                                                        |                       |                                                 | 804     | Mdw  | 40.403   | -105.708  | 2             |

**Table 15. Final ROMO gradient design revisit structure. Values in cells are sample sizes. As detailed in the text, the realized sample sizes in the first implementation of the gradient design (in 2007-2009) were slightly different than shown here. Future years will adjust sample effort to the values shown here. The design repeats indefinitely through time.**

|                               | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Gradient Panel 1, mixed types | 10   |      |      |      |      |      |      |      |      |      | 10   |      |      |      |      |
| Gradient Panel 2, mixed types |      | 10   |      |      |      |      |      |      |      |      |      | 10   |      |      |      |
| Gradient Panel 3, mixed types |      |      | 10   |      |      |      |      |      |      |      |      |      | 10   |      |      |
| Samples per year              | 10   | 10   | 10   |      |      |      |      |      |      |      | 10   | 10   | 10   |      |      |
| Cumulative unique sites       | 10   | 20   | 30   |      |      |      |      |      |      |      |      |      |      |      |      |

ROMO and ROMN staff, with the final sites selected from extremes of these values:

4. Invasive vegetation cover (known populations in the park).
5. Ungulate disturbance (elk and moose density and habitat use).
6. Hydrologic alteration (largely loss of beaver and direct alteration (i.e., ditches) in a wetland complex or its watershed).

Sites were scored on a scale of 1 to 5, with lower scores given to less disturbed conditions (Table 16). A final overall score was taken as a simple average (with no weights or priority given to one class over the others). For the hydrologic alteration class, sites that were in viable beaver habitat or expected to have beaver (all riparian sites, most meadows) were scored lower if they had current or recent beaver sign (or they were less disturbed). In contrast, anthropogenic modification of natural hydrology (i.e., extensive ditching) scored

higher (or more disturbed) and in some cases lack of beaver and anthropogenic modifications of hydrology had synergistic effects on sites.

### 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 for 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 WEI 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 ROMN WEI design forms.

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

At the time of publication, models to assess the power to detect trend using ROMO gradient sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 15). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

### ROMO Gradient Sites

Figure 18 shows the 32 gradient sites across the park and Table 16 shows select attributes of each site. As shown in Table 12 and Table 14, after the initial implementation of the survey in 2007-2009, eight sites (originally sentinel or gradient in design) were selected for continued episodic sampling as satellite sentinel sites. These sites are typically in smaller wetlands with unique characteristics important to the park. They are generally located near one of the four main sentinel complexes and the logistics of sampling them are relatively efficient. The ROMN will sample these sites on an ad hoc basis into the future, with data from them contributing to meeting sentinel site objectives.

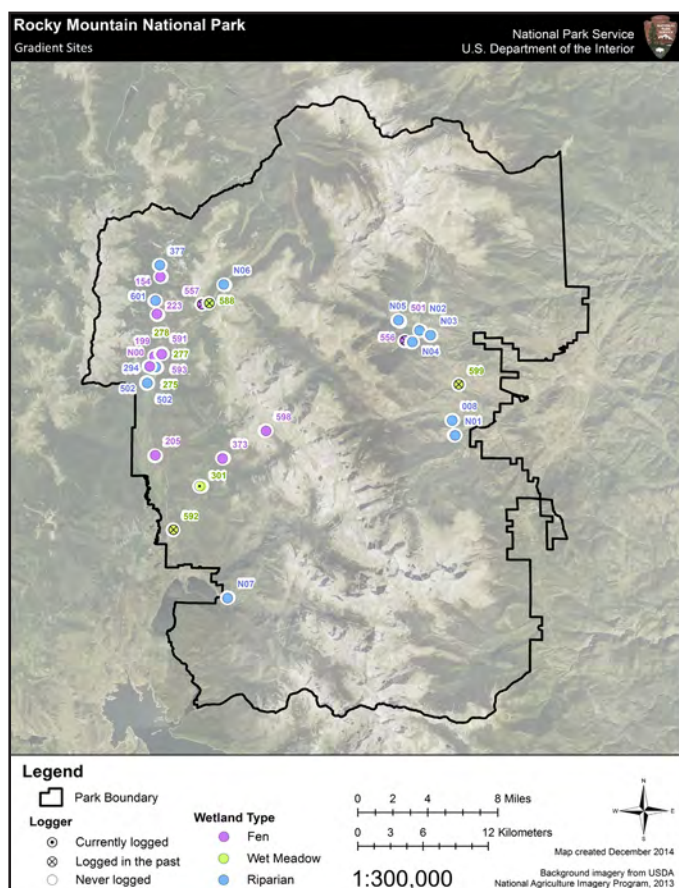


Figure 18. ROMO WEI Gradient sites.

**Table 16. ROMO gradient sites (32) with key site selection criteria and full sample events from 2007 to 2013 (most gradient visits were in 2007-2009). Sites are given in rank order from most disturbed to least. \*Four sites became auxiliary or satellite sentinel sites after initial gradient design implementation. For the disturbance measures (Invasive Veg, Ungulate Disturbance, Hydrologic Alteration, Mean Disturbance Score), a lower number means less disturbance.**

| Site ID | Site Name                          | Wetland Type | Invasive Veg | Ungulate Disturbance | Hydrologic Alteration | Mean Disturbance Score | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Lat    | Lon      | Number Full Visits (2007-2013) |
|---------|------------------------------------|--------------|--------------|----------------------|-----------------------|------------------------|-------------------|-----------------------------------|--------|----------|--------------------------------|
| 8       | Moraine Park Upper Rip             | Rip          | 4            | 5                    | 5                     | 4.67                   | 1.479             | 95.451                            | 40.350 | -105.607 | 2                              |
| N07     | East Inlet Riparian Rip            | Rip          | 4            | 4                    | 5                     | 4.33                   | 6.735             | 71.135                            | 40.237 | -105.793 | 1                              |
| N02     | Endo Valley Alluvial Fan Rip       | Rip          | 3            | 4                    | 5                     | 4.00                   | 22.080            | 65.987                            | 40.406 | -105.634 | 1                              |
| 592     | Harbison Mdw                       | Mdw          | 4            | 4                    | 3                     | 3.67                   | 1.840             | 2.877                             | 40.281 | -105.837 | 1                              |
| 377     | Colorado River Ditch Breach Rip    | Rip          | 3            | 3                    | 5                     | 3.67                   | 24.722            | 25.293                            | 40.448 | -105.849 | 1                              |
| 502     | Kawuneechee Old 1 Rip              | Rip          | 3            | 5                    | 3                     | 3.67                   | 41.306            | 97.379                            | 40.373 | -105.859 | 1                              |
| 509     | Kawuneechee Old 2 Rip              | Rip          | 3            | 5                    | 3                     | 3.67                   | 41.306            | 97.455                            | 40.373 | -105.859 | 1                              |
| N03     | Horseshoe Park Rip                 | Rip          | 3            | 4                    | 4                     | 3.67                   | 3.352             | 18.601                            | 40.403 | -105.625 | 1                              |
| 278     | Kawuneechee Satellite 2 Mdw *      | Mdw          | 3            | 5                    | 2                     | 3.33                   | 41.306            | 0.254                             | 40.384 | -105.854 | 3                              |
| 294     | Kawuneechee Sentinel 1 Rip *       | Rip          | 3            | 5                    | 2                     | 3.33                   | 41.306            | 82.316                            | 40.383 | -105.852 | 3                              |
| 277     | Circle Fen                         | Fen          | 2            | 3                    | 4                     | 3.00                   | 41.306            | 0.249                             | 40.383 | -105.855 | 3                              |
| N01     | Hallowell Park Butter and Eggs Rip | Rip          | 4            | 3                    | 2                     | 3.00                   | 13.060            | 13.461                            | 40.340 | -105.605 | 1                              |
| N04     | Hidden Valley Restoration Site Rip | Rip          | 2            | 3                    | 4                     | 3.00                   | 3.514             | 8.639                             | 40.399 | -105.640 | 1                              |
| N06     | Dr Coopers Walk Rip                | Rip          | 3            | 3                    | 3                     | 3.00                   | 26.684            | 4.885                             | 40.435 | -105.796 | 1                              |
| 556     | Hidden Valley Fen                  | Fen          | 2            | 4                    | 2                     | 2.67                   | 4.213             | 7.486                             | 40.400 | -105.646 | 1                              |
| 599     | Beaver Meadows Heliport Mdw        | Mdw          | 3            | 3                    | 2                     | 2.67                   | 70.710            | 3.236                             | 40.372 | -105.602 | 2                              |
| 601     | Shy Moose Rip                      | Rip          | 2            | 3                    | 3                     | 2.67                   | 9.264             | 43.966                            | 40.425 | -105.852 | 1                              |
| N00     | Alder Fen                          | Rip          | 2            | 3                    | 3                     | 2.67                   | 4.239             | 0.175                             | 40.384 | -105.857 | 1                              |
| 205     | Moose Fen                          | Fen          | 2            | 3                    | 2                     | 2.33                   | 1.137             | 111.533                           | 40.328 | -105.852 | 1                              |
| 501     | Fall River Endo Valley Fen         | Fen          | 2            | 2                    | 2                     | 2.00                   | 3.344             | 32.651                            | 40.412 | -105.649 | 2                              |
| 591     | Sphagnum Fen *                     | Fen          | 1            | 3                    | 2                     | 2.00                   | 53.991            | 75.914                            | 40.392 | -105.847 | 3                              |
| 593     | Kawuneechee Satellite 3 Fen        | Fen          | 1            | 3                    | 2                     | 2.00                   | 53.991            | 75.914                            | 40.391 | -105.847 | 2                              |

**Table 16. ROMO gradient sites (32) with key site selection criteria and full sample events from 2007 to 2013 (most gradient visits were in 2007-2009). Sites are given in rank order from most disturbed to least. \*Four sites became auxiliary or satellite sentinel sites after initial gradient design implementation. (continued)**

| Site ID | Site Name                    | Wetland Type | Invasive Veg | Ungulate Disturbance | Hydrologic Alteration | Mean Disturbance Score | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Lat    | Lon      | Number Full Visits (2007-2013) |
|---------|------------------------------|--------------|--------------|----------------------|-----------------------|------------------------|-------------------|-----------------------------------|--------|----------|--------------------------------|
| 275     | Kawuneechee Satellite 1 Mdw  | Mdw          | 1            | 3                    | 2                     | 2.00                   | 1.559             | 0.255                             | 40.383 | -105.854 | 3                              |
| 588     | Mills Pass Mdw               | Mdw          | 1            | 3                    | 2                     | 2.00                   | 3.626             | 0.899                             | 40.424 | -105.808 | 1                              |
| N05     | Endo Valley Beaver Ponds Rip | Rip          | 2            | 2                    | 2                     | 2.00                   | 25.690            | 1.724                             | 40.413 | -105.651 | 1                              |
| 223     | Lost Creek Fen               | Fen          | 1            | 2                    | 2                     | 1.67                   | 0.742             | 0.377                             | 40.417 | -105.851 | 1                              |
| 154     | Lulu City Slope Fen          | Fen          | 1            | 1                    | 2                     | 1.33                   | 24.722            | 0.458                             | 40.440 | -105.848 | 1                              |
| 199     | Hell's Fen                   | Fen          | 1            | 2                    | 1                     | 1.33                   | 2.299             | 0.088                             | 40.390 | -105.853 | 1                              |
| 301     | Green Mountain Pond Fen *    | Fen          | 1            | 1                    | 2                     | 1.33                   | 0.881             | 0.050                             | 40.308 | -105.814 | 4                              |
| 373     | Spring Fen                   | Fen          | 1            | 2                    | 1                     | 1.33                   | 11.086            | 0.340                             | 40.325 | -105.797 | 1                              |
| 557     | Specimen Mtn Fen             | Fen          | 1            | 1                    | 1                     | 1.00                   | 1.355             | 0.076                             | 40.423 | -105.814 | 1                              |
| 598     | Haynach Fen                  | Fen          | 1            | 1                    | 1                     | 1.00                   | 7.864             | 1.614                             | 40.343 | -105.761 | 1                              |

## Great Sand Dunes National Park and Preserve

GRSA has extensive wetland, especially on the sandsheet region. Wetlands are, after the main dune field, the park's most important ecological resource. We use all three design types in GRSA to monitor wetlands. Between 2010 and 2013 there were 83 sites established in the park and sampled 154 times, 48 survey sites with 55 full sample events (all in 2010), 21 sentinel sites with 83 full sample events, and 14 gradient sites with 16 full sample events. Most sites also had many partial events over the years (not included in the numbers given here).

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

*As of publication, the possible designs behind draft park-specific objectives focused on the possible long-term effects of ungulates for GRSA were under development and are not presented here.*

### GRSA Survey

Like at ROMO, monitoring wetlands in GRSA within a survey context is challenging and expensive. GRSA has a diverse suite of wetland types including fens, wet meadows, marshes, riparian wetland, and salt flats. In consultation with park management, ROMN staff and ROMN collaborators elected to restrict the implemented component of the survey at GRSA to a subset of the park and wetland types. However, survey sites were selected for all wetland across the entire park. We also used a fairly complex survey design that included two stages of randomization, as summarized below.

### Target and Sample Populations

The implemented target population at GRSA was all Cooper-type wet meadow and salt flat on the sandsheet portion of the park during peak summer vegetation phenology. We treated these two wetland types as a gradient and sampled them together largely because final classification of type strongly depended on site scale soil and vegetation data and the park manages these two types largely together. Should future objectives

include treating these two types separately, post hoc design weights may be created (but more sample sites will likely need to be added). After implementation of the design, the sample population was all safely accessible and in compliance sandsheet wet meadow/salt flat wetland greater than 80 m<sup>2</sup> in size with peak summer vegetation phenology during a survey's implementation (i.e., 2010, 2020, etc.).

### Sample Frame

The sample frame at GRSA consisted of GIS coverages of all wetland at GRSA, with the implemented portion of the survey restricted to wet meadow and salt flat wetland complexes on the sandsheet. These data were used in the first and second stages of the GRSA design.

As at ROMO, novel digitizing of wetland polygons was required as existing wetland maps in the park used different (not Cooper type) wetland classification systems and were generally poor representations of true wetland boundaries. This was a labor intensive step but because of the smaller size of GRSA an initial watershed selection was not required. The same methods employed at ROMO were used with the Vegetation (Salas et al. 2011) and NWI maps (Cowardin et al. 1979), providing important guidance. Each wetland polygon was buffered within a GIS using the same flood model as in ROMO. While access in the mountainous portion of GRSA is similar to ROMO (hard), because we restricted the implemented portion of the survey to the sandsheet where access is more straightforward, we elected to not complicate the GRSA sample frame and design with a cost component.

### Site Selection

We again used a GRTS spatially balanced algorithm to select sample units (Stevens and Olsen 2004) with two stages of selection.

#### First Stage

For the first stage, we first stratified the park into sandsheet and mountainous zones using a well-defined elevation boundary (which generally corresponds to the upper limit of Pinyon-Juniper) on the toe slope of the Sangre de Cristo Mountains (see Figure 19). We then used an unequal probability

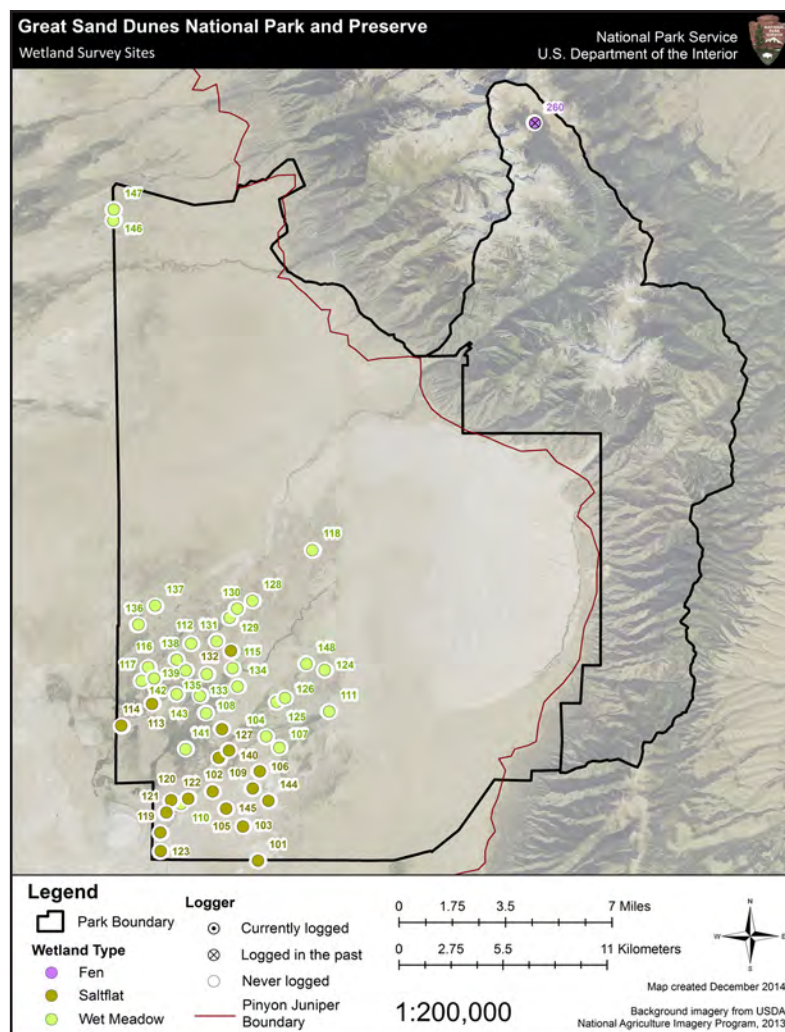


**Figure 19.** GRSA WEI survey sites sampled in 2010. The first stage wetland complexes are not shown (see Figure 13 and Figure 15 for similar examples from ROMO).

selection of wetland polygon centroids in each strata as follows. For wetland in the mountain strata (not currently sampled or analyzed within a survey context), we set the target sample size to the total number of complexes in the frame (9 fens, 45 riparian

wetlands, and 44 wet meadows). This creates a GRTS ordering of all wetlands in the sample frame for this part of the park. Should monitoring high elevation wetlands at GRSA with a survey design approach ever be added, the design will be in place to do so. For wetland in the sandsheet strata, we also assigned a GRTS order to all complexes in the frame but set a total target base sample size of 89 for the three types that occurred on the sandsheet, allocated across expected type as shown in Table 17. Of these types, we expected only to sample a sufficient number of sites to make inference to wet meadows/salt flats (with a base or expected sample size of 51).

### Second Stage

The second stage of the design placed a dense set of points in each complex using an extensive GRTS design. Each wetland complex was treated as an explicit stratum to allow an exact sample size of 30 base and 20 oversample points within each complex. No second stage design attributes (weights or strata) were used in status (and eventually trend) estimation; rather, only the first stage is included as part of design based inference. The points selected by the second stage were the actual candidate locations where plots were established. Candidate second stage sites were evaluated in the field within each second stage selected wetland following specific rules and in the order specified by GRTS as discussed above. The target sample size of 50 was derived using the same methods discussed above for ROMO (Cochran 1987; Equation 1). A sample size of 50 gives a precision of  $\pm 12\%$  with 90%

**Table 17. Expected first stage sample size per sandsheet wetland type(s).**

| Expected Wetland Type  | Base/Oversample                   | Sample Size |
|------------------------|-----------------------------------|-------------|
| Marsh                  | Base                              | 10          |
|                        | Over                              | 24          |
|                        | <b>Marsh Total</b>                | <b>34</b>   |
| Riparian               | Base                              | 29          |
|                        | Over                              | 78          |
|                        | <b>Riparian Total</b>             | <b>107</b>  |
| Wet Meadow, Salt Flat  | Base                              | 50          |
|                        | Over                              | 147         |
|                        | <b>Wet Meadow/Salt Flat Total</b> | <b>197</b>  |
| <b>All Types Total</b> |                                   | <b>338</b>  |

confidence around a proportion of 50%. As noted above, given the properties of GRTS, precision for the GRSA design was expected to improve (likely reducing the 90% confidence interval around a proportion of 50% to about  $\pm 9\%$ ; T. Olsen, pers. comm. September 2010).

Because all wetland polygons in the sample frame were ordered by GRTS with each receiving 50 total second stage points, all wetland in the park that is represented in the sample frame is available for survey design based monitoring. As noted below, many sentinel and gradient sites were located by using the sites selected by the survey. However, because these sites were not necessarily selected using the complete requirements of GRTS (i.e., they do not follow the ordering required by the design), they cannot be used in design-based inference as is.

#### ***Realized Sample Size***

The total realized sample size for the wet meadow/salt flat wetland type on the sandsheet in the 2010 survey was 48. The small discrepancy from the target sample size of 50 was due to two sites expected to be wet meadows instead turning out to be marshes, based on post sample season evaluation of field derived vegetation, soils and hydrology data. Logistical constraints prohibited us from sampling additional sites to increase the realized sample size. The initial sample weight for wet meadow/salt flats changed marginally with this shift in sample size (from 10.257 to 10.260). Note that several survey sites on the sand sheet and in the mountains were sampled opportunistically (but out of GRTS order) or were not wet meadow/salt flat and are thus treated as sentinel or gradient sites (see below).

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

At the time of publication, models to assess the power to detect trend using ROMO survey sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 18). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

#### **GRSA Survey Sites**

Figure 19 and Table 19 present the 48 WEI survey sites on the GRSA sandsheet as sampled in the 2010 survey and analyzed as part of the survey design. Twenty sites selected by the survey but not included in design-based inference are treated as sentinel or gradient sites (but may be included in a design-based context in the future). These sites were within the mountain strata or riparian wetland or marshes on the sandsheet and are presented with the sentinel or gradient designs below.

#### ***GRSA Sentinel***

The GRSA sentinel design is quite different than the survey approach and closely mirrors the sentinel design used in ROMO. The most important distinguishing features are (1) an expert opinion or judgment based selection of wetland complexes, (2) an annual or biannual sample frequency, and (3) no intention to make inference beyond the sites or the sentinel wetland complex.

#### **Target and Sample Populations**

The target population for sentinel site monitoring is the site. When a complex has sufficient sites (around 10 in larger more heterogeneous complexes), the target population can also be the wetland complex that a set of sites is located in. 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 for 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 WEI survey design sample frames may be used to locate sentinel sites and to assist in delineation of the wetland complex in which specific sites are located. Using the same frame for both survey and sentinel designs

[illegible][illegible]

**Table 19. GRSA WEI survey sites (48) on the sandsheet with type, complex, and catchment area, and the number of full sample events in 2010. Two fen, 7 wet meadow and 11 marsh sites selected by the survey but treated as sentinel or gradient sites are given in Table 21 and Table 23. Sites are ordered by Site ID. See text for further explanation.**

| Site ID | Site Name                             | Wetland Type | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Latitude | Longitude | Number Full Visits (2010) |
|---------|---------------------------------------|--------------|-------------------|-----------------------------------|----------|-----------|---------------------------|
| 101     | Southern Medano Ranch                 | Slt          | 3.375             | 4.370                             | 37.663   | -105.660  | 1                         |
| 102     | Medano Ranch                          | Slt          | 31.607            | 0.160                             | 37.689   | -105.682  | 2                         |
| 103     | Medano Ranch Near Closed Basin Well   | Slt          | 3.555             | 1.216                             | 37.676   | -105.667  | 1                         |
| 104     | Medano Ranch                          | Mdw          | 7.426             | 12.928                            | 37.710   | -105.656  | 2                         |
| 105     | Lower Medano Ranch                    | Slt          | 4.349             | 0.943                             | 37.683   | -105.675  | 1                         |
| 106     | Medano Ranch                          | Slt          | 17.354            | 12.502                            | 37.697   | -105.659  | 1                         |
| 107     | Medano Ranch                          | Mdw          | 48.428            | 135.455                           | 37.706   | -105.650  | 1                         |
| 108     | Medano Ranch Rd                       | Mdw          | 4.034             | 83.086                            | 37.719   | -105.685  | 2                         |
| 109     | Medano Ranch                          | Slt          | 4.993             | 137.266                           | 37.702   | -105.679  | 1                         |
| 110     | North Of Twin Lakes                   | Mdw          | 4.450             | 46.518                            | 37.685   | -105.697  | 1                         |
| 111     | Upper Big Spring Crk Interdunal Swale | Mdw          | 0.296             | 0.945                             | 37.719   | -105.626  | 2                         |
| 112     | Middle Sand Crk                       | Mdw          | 0.466             | 0.863                             | 37.745   | -105.692  | 2                         |
| 113     | Medano Ranch                          | Slt          | 5.653             | 2.338                             | 37.722   | -105.710  | 1                         |
| 114     | Medano Ranch                          | Slt          | 0.280             | 118.839                           | 37.714   | -105.725  | 1                         |
| 115     | Big Spring Crk Below Main Culvert     | Mdw          | 4.887             | 81.237                            | 37.736   | -105.672  | 1                         |
| 116     | Middle Sand Crk                       | Mdw          | 0.327             | 0.671                             | 37.736   | -105.712  | 1                         |
| 117     | Middle Sand Crk                       | Mdw          | 4.220             | 1.123                             | 37.731   | -105.715  | 1                         |
| 118     | Elks Springs                          | Mdw          | 0.819             | 51.298                            | 37.780   | -105.634  | 2                         |
| 119     | Medano Ranch                          | Slt          | 1.735             | 0.706                             | 37.674   | -105.706  | 1                         |
| 120     | West Of Twin Lakes                    | Slt          | 0.081             | 0.055                             | 37.686   | -105.701  | 1                         |
| 121     | Twin Lakes                            | Slt          | 0.284             | 0.132                             | 37.681   | -105.704  | 1                         |
| 122     | North Of Twin Lakes                   | Slt          | 1.147             | 46.292                            | 37.687   | -105.693  | 1                         |
| 123     | South Of Twin Lakes                   | Slt          | 2.023             | 69.949                            | 37.667   | -105.706  | 1                         |
| 124     | North Of Little Spring Creek          | Mdw          | 2.711             | 0.159                             | 37.735   | -105.628  | 1                         |
| 125     | North Of Spring Crk Ranch Rd          | Mdw          | 0.691             | 9.990                             | 37.723   | -105.651  | 1                         |
| 126     | North Of Spring Crk Ranch Rd          | Mdw          | 2.635             | 10.043                            | 37.725   | -105.647  | 1                         |
| 127     | Medano Ranch Ditch Near Housing       | Slt          | 2.340             | 13.718                            | 37.713   | -105.677  | 1                         |
| 128     | Middle Sand Creek                     | Mdw          | 0.650             | 0.588                             | 37.761   | -105.663  | 2                         |
| 129     | Middle Sand Creek                     | Mdw          | 3.247             | 0.848                             | 37.755   | -105.673  | 1                         |
| 130     | Middle Sand Creek                     | Mdw          | 1.713             | 0.843                             | 37.758   | -105.670  | 1                         |
| 131     | North Of Big Spring Crk               | Mdw          | 1.798             | 2.242                             | 37.746   | -105.680  | 1                         |
| 132     | North Of Big Spring Crk Ditch         | Slt          | 17.784            | 0.566                             | 37.742   | -105.673  | 1                         |
| 133     | Big Spring Crk Ditch                  | Mdw          | 0.889             | 105.884                           | 37.734   | -105.684  | 1                         |
| 134     | Big Spring Crk Ditch                  | Mdw          | 6.092             | 0.285                             | 37.729   | -105.670  | 1                         |
| 135     | North Of Hosa House                   | Mdw          | 6.559             | 82.079                            | 37.725   | -105.688  | 1                         |
| 136     | North Of Sand Creek                   | Mdw          | 1.866             | 10.240                            | 37.752   | -105.717  | 1                         |

**Table 19. GRSA WEI survey sites (48) on the sandsheet with type complex and catchment area and the number of full sample events in 2010. Two fen, 7 wet meadow and 11 marsh sites selected by the survey but treated as sentinel or gradient sites are given in Table 21 and Table 23. Sites are ordered by Site ID. See text for further explanation, continued.**

| Site ID | Site Name             | Wetland Type | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Latitude | Longitude | Number Full Visits (2010) |
|---------|-----------------------|--------------|-------------------|-----------------------------------|----------|-----------|---------------------------|
| 137     | North Of Sand Creek   | Mdw          | 19.174            | 9.640                             | 37.759   | -105.709  | 1                         |
| 138     | Medano Ranch          | Mdw          | 11.939            | 1.181                             | 37.739   | -105.699  | 1                         |
| 139     | Medano Ranch          | Mdw          | 13.319            | 0.608                             | 37.735   | -105.694  | 1                         |
| 140     | Medano Ranch          | Slt          | 3.283             | 1.117                             | 37.705   | -105.674  | 1                         |
| 141     | Medano Ranch          | Mdw          | 9.071             | 48.617                            | 37.705   | -105.694  | 1                         |
| 142     | Lower Sand Creek      | Mdw          | 1.941             | 2.243                             | 37.732   | -105.709  | 1                         |
| 143     | North Of Hosa House   | Mdw          | 43.002            | 1.042                             | 37.726   | -105.699  | 1                         |
| 144     | Southern Medano Ranch | Slt          | 14.225            | 25.841                            | 37.686   | -105.655  | 1                         |
| 145     | Lower Medano Ranch    | Slt          | 1.329             | 26.140                            | 37.690   | -105.663  | 1                         |
| 146     | Baca Ranch            | Mdw          | 1.634             | 0.998                             | 37.904   | -105.729  | 1                         |
| 147     | Baca Ranch            | Mdw          | 0.560             | 0.526                             | 37.908   | -105.729  | 1                         |
| 148     | King Well             | Mdw          | 1.923             | 0.618                             | 37.737   | -105.637  | 1                         |

is advantageous in linking the two design forms.

#### Site Selection

Sentinel complexes were located subjectively based on a suite of criteria developed by ROMN staff, collaborators (especially scientists who have been working in GRSA wetlands for decades), and most importantly, GRSA staff. All sentinel complexes were represented in the survey sample frame, so while they cannot be used as is in design-based inference, future work could add sample sites following design requirements and do so.

Key criteria used to select complexes include the following: Allocation of complexes across five important wetland types, including fens and wet meadows in the mountains plus sandsheet, riparian wetland, marshes, wet meadows, and salt flats; allocation of complexes across geographic classes (elevation, topography, park region); representativeness of a complex for wetland type(s) and/or geographic context; uniqueness (somewhat in contrast to the above) of a complex; use of existing wetland monitoring locations (especially established groundwater wells); and management importance or utility of a

wetland for the park (i.e., a wetland strongly influenced by ungulates, usefulness for visitor interpretation, etc.).

Within a selected complex, the specific locations of plots are based on a similar suite of criteria as used in ROMO. These include use of existing plot locations, allocation of plots across wetland types within a complex, allocation of plots across vegetation and hydrologic types within a complex, placing plots on both edges and interior locations of the complex, and placing plots in locations useful for park management (i.e., inside and outside of exclosures). Most of these are not knowable until a complex is accessed and evaluated.

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

At the time of publication, models to assess the power to detect trend using GRSA sentinel sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 20). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

Table 20. Final GRSA sentinel design revisit structure. Values in cells are sample sizes. As detailed in the text, the realized sample sizes in 2010 were different than shown here. Future years will adjust sample effort to the values shown here. The design repeats indefinitely through time.

[illegible]

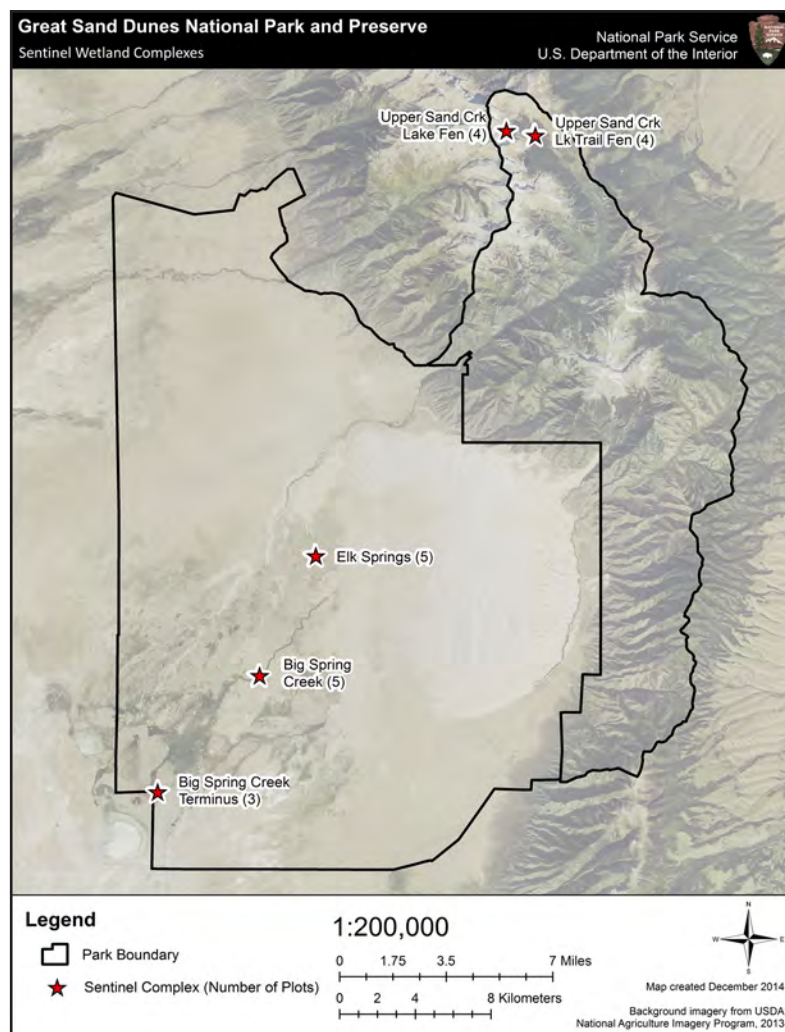


**Figure 20.** GRSA sentinel complexes. As of 2013, each complex had from 3 to 5 individual plots (see Table 21 and Figure 21).

### GRSA Sentinel Sites

Sentinel complexes in GRSA (Figure 20) include: Upper Sand Creek Lake, Upper Sand Creek Lake Trail, Elk Springs, Big Spring Creek, and the terminus of Big Spring Creek (see Table 21 and Figure 21 for specific plots). Elk Springs and Big Spring Creek have a long history of wetland research. The Upper Sand Creek Lake sites are new locations for wetland work but incorporate high elevation wetlands into the array of GRSA sentinel sites. The Big Spring Creek terminus site is co-located with a deep well monitoring the closed aquifer that is sampled by park staff on a weekly basis.

### **GRSA Gradient**

The GRSA gradient design closely mirrors the gradient design used in ROMO and is similar to WEI sentinel designs in some aspects including (1) an expert opinion

or judgment based selection of wetland complexes, and (2) no intention to make inference beyond the sites or the sentinel wetland 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 wetland condition at the extremes of anthropogenic and natural drivers that influence wetland ecology. Therefore sites are targeted to wetlands we expect to be under stress or in pristine condition.

### 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 GRSA wetlands for decades), and most importantly, GRSA staff. Key criteria used to select gradient sites included the allocation of complexes across important wetland types, geographic contexts, and existing wetland monitoring locations (especially established groundwater wells). Sites were also targeted to wetlands that were expected to be either highly disturbed or in a more pristine state. Unlike in ROMO, this was done without any a priori scoring and was based largely on expert opinion, often in situ while visiting other sites. In GRSA, the disturbances targeted included invasive plant cover, direct evidence of bison and elk disturbance (i.e., herbivory), and hydrologic alteration (largely irrigation). Less impacted sites were targeted largely based on the absence of these three disturbances.

### 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 for 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 WEI survey design sample frames may be used to locate gradient sites. Using the same frame for survey, sentinel and gradient

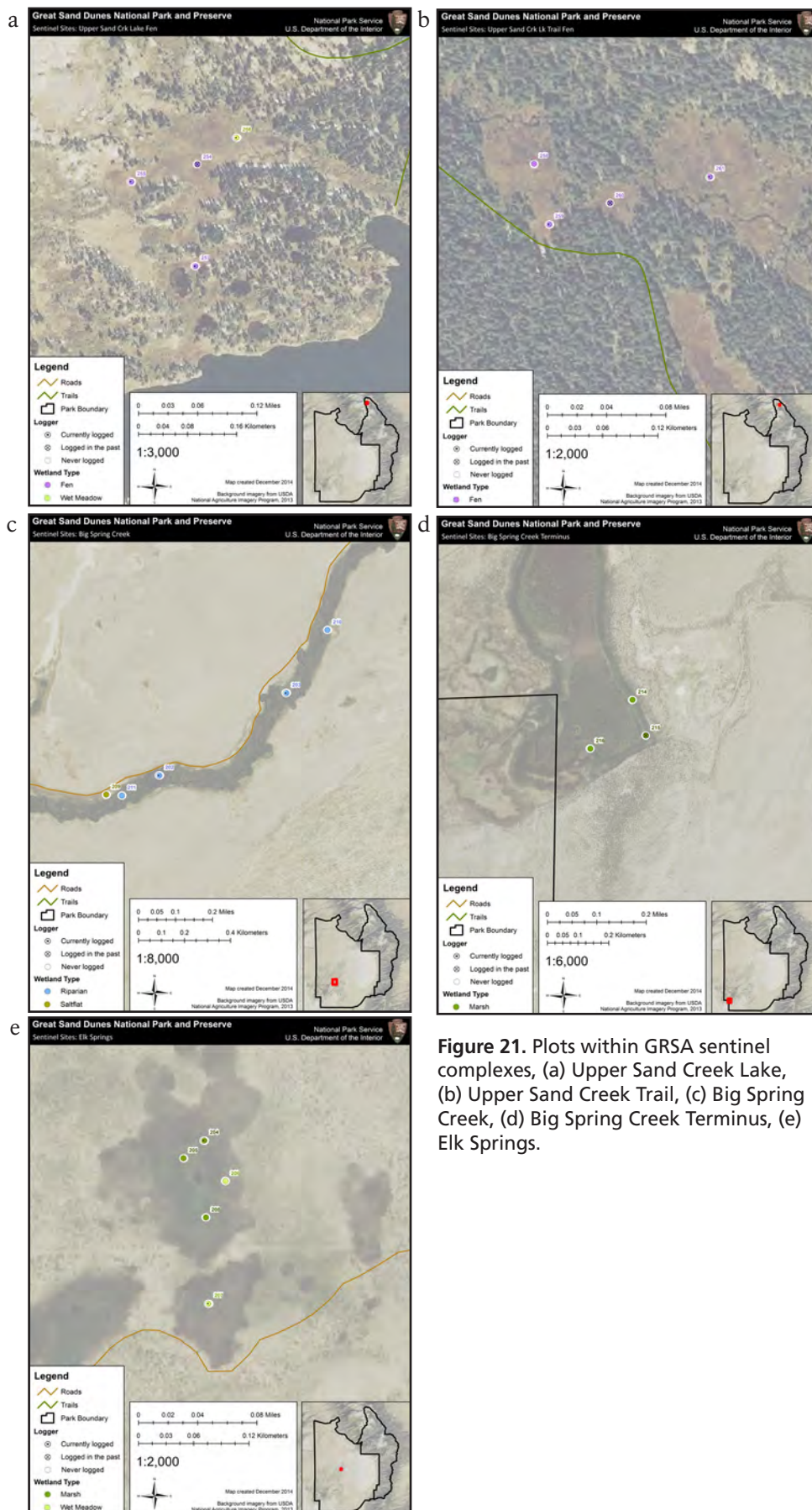


**Figure 21.** Plots within GRSA sentinel complexes, (a) Upper Sand Creek Lake, (b) Upper Sand Creek Trail, (c) Big Spring Creek, (d) Big Spring Creek Terminus, (e) Elk Springs.

**Table 21. GRSA WEI sentinel sites (21) with key site selection criteria and full sample events from 2010 to 2013. Plots in bold are inside an ungulate exclosure. The final revisit design structure as shown above is to be implemented 2015 and/or 2016. \*Site selected by the survey design but treated as a sentinel site.**

| Complex Size                                | Elev. Zone     | General Topography                                     | Park Region | Disturbance Regime(s)                                                                      | Historical Monitoring                                   | Resource Management Issues                                                                              | Site ID | Type | Latitude | Longitude | # Full Events (2010-2013) |
|---------------------------------------------|----------------|--------------------------------------------------------|-------------|--------------------------------------------------------------------------------------------|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|------|----------|-----------|---------------------------|
| Upper Sand Creek Lake (4 sites as of 2014)  |                |                                                        |             |                                                                                            |                                                         |                                                                                                         |         |      |          |           |                           |
| Small (2.1 ha)                              | High (3,590 m) | Flat sub alpine fen and wet meadow; complex topography | High elev.  | Human: little to no historical use; light to medium current use; Natural: medium elk use   | No historical wetland monitoring                        | Ungulate management (hunting, habitat use), visitor interpretation                                      | 254*    | Fen  | 37.943   | -105.542  | 3                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 255     | Fen  | 37.942   | -105.543  | 4                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 256     | Mdw  | 37.943   | -105.541  | 4                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 257     | Fen  | 37.941   | -105.542  | 4                         |
| Upper Sand Creek Trail (4 sites as of 2014) |                |                                                        |             |                                                                                            |                                                         |                                                                                                         |         |      |          |           |                           |
| Small (2.6 ha)                              | High (3,433 m) | Flat sub alpine fen and wet meadow                     | High elev.  | Human: little to no historical use; light to medium current use; Natural: medium elk use   | No historical wetland monitoring                        | Ungulate management (hunting, habitat use), visitor interpretation                                      | 258     | Fen  | 37.941   | -105.529  | 3                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 259     | Fen  | 37.941   | -105.529  | 4                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 260*    | Fen  | 37.941   | -105.528  | 3                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 261     | Fen  | 37.941   | -105.527  | 4                         |
| Big Spring Creek (5 sites as of 2014)       |                |                                                        |             |                                                                                            |                                                         |                                                                                                         |         |      |          |           |                           |
| Medium to Large (43.6 ha)                   | Low (2,312m)   | Riparian corridor with adjacent salt flat wetland      | Sand sheet  | Human: heavy historical use; medium to heavy current use; Natural: heavy bison and elk use | Relatively recent groundwater and vegetation monitoring | Ungulate management (ranching, habitat use), restoration of hydrologic dynamics, visitor interpretation | 202     | Rip  | 37.735   | -105.662  | 5                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 203     | Rip  | 37.738   | -105.657  | 5                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 209     | Slt  | 37.735   | -105.664  | 5                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 210     | Rip  | 37.740   | -105.655  | 4                         |
|                                             |                |                                                        |             |                                                                                            |                                                         |                                                                                                         | 211     | Rip  | 37.735   | -105.663  | 4                         |

**Table 21. GRSA WEI sentinel sites (21) with key site selection criteria and full sample events from 2010 to 2013. Plots in bold are inside a ungulate enclosure. The final revisit design structure as shown above is to be implemented 2015 and/or 2016. \*Site selected by the survey design but treated as a sentinel site, continued.**

| Complex Size                                   | Elev. Zone   | General Topography                               | Park Region | Disturbance Regime(s)                                                                      | Historical Monitoring                                   | Resource Management Issues                                                                              | Site ID | Type | Latitude | Longitude | # Full Events (2010-2013) |
|------------------------------------------------|--------------|--------------------------------------------------|-------------|--------------------------------------------------------------------------------------------|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|------|----------|-----------|---------------------------|
| Big Spring Creek Terminus (3 sites as of 2014) |              |                                                  |             |                                                                                            |                                                         |                                                                                                         |         |      |          |           |                           |
| Large (169.8 ha)                               | Low (2,296m) | Flat, large marsh                                | Sand sheet  | Human: heavy historical use; medium to heavy current use; Natural: heavy bison and elk use | Relatively recent groundwater and vegetation monitoring | Ungulate management (ranching, habitat use), restoration of hydrologic dynamics, visitor interpretation | 214*    | Msh  | 37.692   | -105.708  | 4                         |
|                                                |              |                                                  |             |                                                                                            |                                                         |                                                                                                         | 215*    | Msh  | 37.692   | -105.707  | 4                         |
|                                                |              |                                                  |             |                                                                                            |                                                         |                                                                                                         | 216*    | Msh  | 37.691   | -105.709  | 4                         |
| Elk Springs (5 sites as of 2014)               |              |                                                  |             |                                                                                            |                                                         |                                                                                                         |         |      |          |           |                           |
| Small (2.3 ha)                                 | Low (2,312m) | Isolated interdunal area with complex topography | Sand sheet  | Human: light to medium historical and current use; Natural: medium elk and some bison use  | Relatively recent groundwater and vegetation monitoring | Maintenance and restoration of hydrologic dynamics, visitor interpretation                              | 204*    | Msh  | 37.782   | -105.633  | 4                         |
|                                                |              |                                                  |             |                                                                                            |                                                         |                                                                                                         | 205*    | Msh  | 37.782   | -105.633  | 4                         |
|                                                |              |                                                  |             |                                                                                            |                                                         |                                                                                                         | 206*    | Mdw  | 37.782   | -105.633  | 4                         |
|                                                |              |                                                  |             |                                                                                            |                                                         |                                                                                                         | 207*    | Mdw  | 37.781   | -105.633  | 4                         |
|                                                |              |                                                  |             |                                                                                            |                                                         |                                                                                                         | 208*    | Msh  | 37.781   | -105.633  | 3                         |

designs is advantageous in linking the ROMN WEI design forms.

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

At the time of publication, models to assess the power to detect trend using GRSA gradient sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 22). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

**GRSA Gradient Sites**

Figure 22 shows the 14 gradient sites across the park and Table 23 shows select attributes of each site. Most gradient sites were in wetland polygons represented in the survey design sample frame, so while they cannot be used in design-based inference as is, future work could be structured following design requirements and incorporate these sites into design based approaches.

Figure 22. GRSA WEI gradient sites.

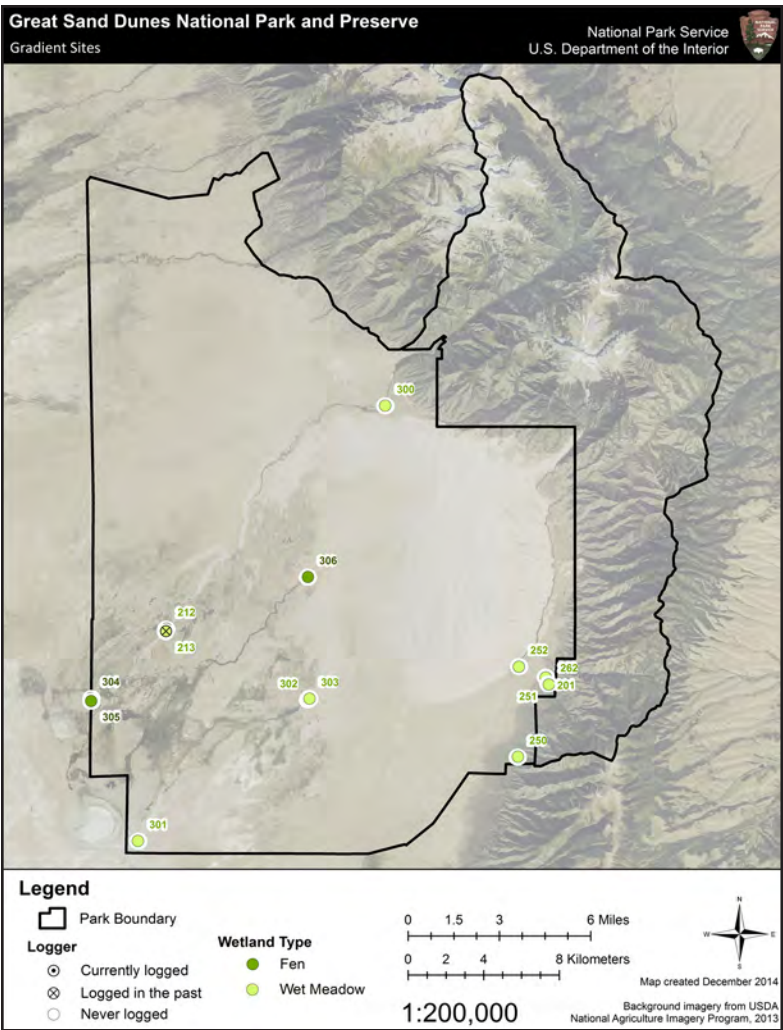


Table 22. Final GRSA gradient design revisit structure. Values in cells are sample sizes. As detailed in the text, the realized sample sizes in the first implementation of the gradient design (in 2007-2009) were slightly different than shown here. Future years will adjust sample effort to the values shown here. The design repeats indefinitely through time.

[illegible]

**Table 23. GRSA gradient sites (14) with key attributes and number of full sample events in 2010. \*Site selected by the survey design but treated as a gradient site. See text for further explanation.**

| Site ID | Site Name                           | Wetland Type | Complex Area (ha) | Catchment Area (km <sup>2</sup> ) | Latitude | Longitude | Number Full Visits (2010) |
|---------|-------------------------------------|--------------|-------------------|-----------------------------------|----------|-----------|---------------------------|
| 201     | Visitors Center Below Horse Barn    | Mdw          | 6.952             | 0.628                             | 37.730   | -105.511  | 2                         |
| 212     | Middle Sand Creek                   | Mdw          | 4.241             | 0.765                             | 37.748   | -105.691  | 1                         |
| 213     | Middle Sand Creek                   | Mdw          | 0.552             | 0.811                             | 37.747   | -105.691  | 1                         |
| 250*    | Denton Spring                       | Mdw          | 0.284             | 0.142                             | 37.700   | -105.524  | 2                         |
| 251*    | Horse Barn                          | Mdw          | 0.581             | 0.404                             | 37.728   | -105.510  | 1                         |
| 252*    | Medano Island Near Mosca Confluence | Mdw          | 12.270            | 110.101                           | 37.734   | -105.524  | 1                         |
| 262*    | Horse Barn                          | Mdw          | 0.581             | 0.398                             | 37.727   | -105.510  | 1                         |
| 300*    | Mitchell Pond 1                     | Mdw          | 0.423             | 15.844                            | 37.832   | -105.587  | 1                         |
| 301*    | South Of Twin Lakes                 | Mdw          | 5.318             | 69.796                            | 37.668   | -105.705  | 1                         |
| 302     | Little Spring Crk Interdunal Swale  | Mdw          | 0.414             | 0.839                             | 37.721   | -105.624  | 1                         |
| 303*    | Little Spring Crk Interdunal Swale  | Mdw          | 0.414             | 0.835                             | 37.722   | -105.623  | 1                         |
| 304*    | West Of Dollar Lake                 | Msh          | 8.475             | 3.110                             | 37.722   | -105.727  | 1                         |
| 305*    | West Of Dollar Lake                 | Msh          | 8.475             | 3.105                             | 37.721   | -105.727  | 1                         |
| 306*    | Indian Spring                       | Msh          | 0.363             | 0.733                             | 37.768   | -105.624  | 1                         |

## Florissant Fossil Beds National Monument

FLFO has locally extensive wetland, especially in valley bottoms and along stream and former pond margins. Wetlands are, after upland grassland and woodland, the park's most important ecological resource. We use only a sentinel design type at FLFO to monitor wetlands. Between 2010 and 2013 there were 10 sentinel sites established in the park, sampled 34 times. Most sites also had many partial events over the years (not included in the numbers given here).

### FLFO Sentinel

The FLFO sentinel design closely mirrors the sentinel design used in ROMO and GRSA. The most important distinguishing features are (1) an expert opinion or judgment based selection of wetland complexes, (2) an annual or biannual sample frequency, and (3) no intention to make inference beyond the sites or the sentinel wetland complex.

## Target and Sample Populations

The target population for sentinel site monitoring is the site. When a complex has sufficient sites (around 10 in larger more heterogeneous complexes) the target population can also be the wetland complex that a set of sites is located in. 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 for 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 WEI survey design sample frames may be used to locate sentinel sites and to assist in

delineation of the wetland complex in which specific sites are located. Using the same frame for both survey and sentinel designs is advantageous in linking the two design forms.

### Site Selection

Sentinel complexes were located subjectively based on a suite of criteria developed by ROMN staff, collaborators (especially scientists who have been working in FLFO wetlands for decades), and most importantly, FLFO staff.

Key criteria used to select complexes include the following (because FLFO is a much more homogenous and smaller park than ROMO or GRSA, these are simpler than in other parks): Allocation of complexes across two important wetland types (fens and wet meadows); representativeness of a complex for wetland type(s) and/or geographic context; uniqueness (somewhat in contrast to the above) of a complex; and management importance or utility of a wetland for the park (i.e., a wetland likely to be part of future restoration, usefulness for visitor interpretation, etc.).

Within a selected complex, the specific locations of plots are based on a similar suite of criteria as used in ROMO and GRSA. These include use of existing plot locations, allocation of plots across wetland types within a complex, allocation of plots across vegetation and hydrologic types within a complex, and placing plots on both edges and interior locations of the complex. Most of these are not knowable until a complex is first accessed and evaluated.

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

At the time of publication, models to assess the power to detect trend using FLFO sentinel sites were being revised and updated. Therefore, we only present the final revisit design (or sample sizes through time; Table 24). Future revisions will include estimates of the power to detect trend and a more refined estimate of the precision of status estimates possible from the final design.

### FLFO Sentinel Sites

Sentinel complexes in FLFO (Figures 23 and 24, Table 25) include: a wet meadow complex near the Red Barn, a fen and wet meadow complex adjacent to the historic Hornbeck Ranch homestead, and a riparian and wet meadow wetland accessed from the Barksdale picnic area.

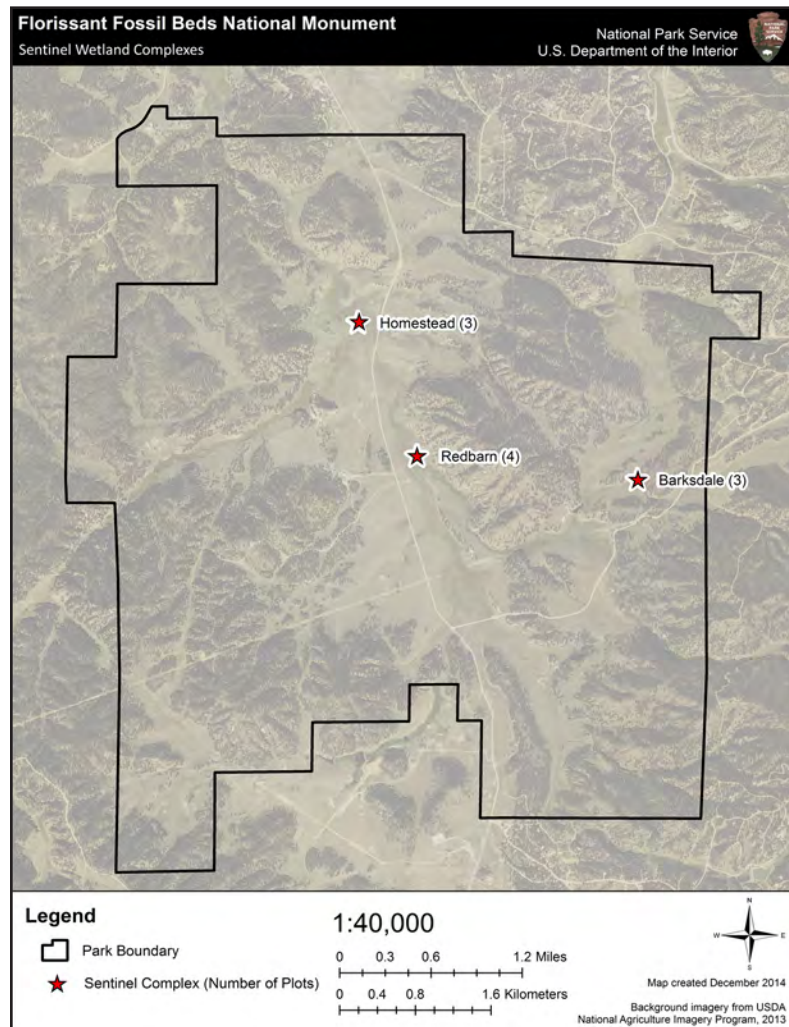


**Figure 23.** FLFO sentinel complexes. As of 2013, each complex had from 3 to 4 individual plots (see Figure 24 and Table 25).

**Table 24. Final FLFO sentinel design revisit structure. Values in cells are sample sizes. As detailed in the text, the realized sample sizes in 2010 were different than shown here. Future years will adjust sample effort to the values shown here. The design repeats indefinitely through time.**

|                         | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|-------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Barksdale 1             | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |
| Barksdale 2             |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      |
| Homestead 1             | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |
| Homestead 2             |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      | 3    |      |
| Redbarn 1               | 4    |      | 4    |      | 4    |      | 4    |      | 4    |      | 4    |      | 4    |      | 4    |
| Big Redbarn 2           |      | 4    |      | 4    |      | 4    |      | 4    |      | 4    |      | 4    |      | 4    |      |
| Samples per year        | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 10   |
| Cumulative unique sites | 10   | 20   |      |      |      |      |      |      |      |      |      |      |      |      |      |

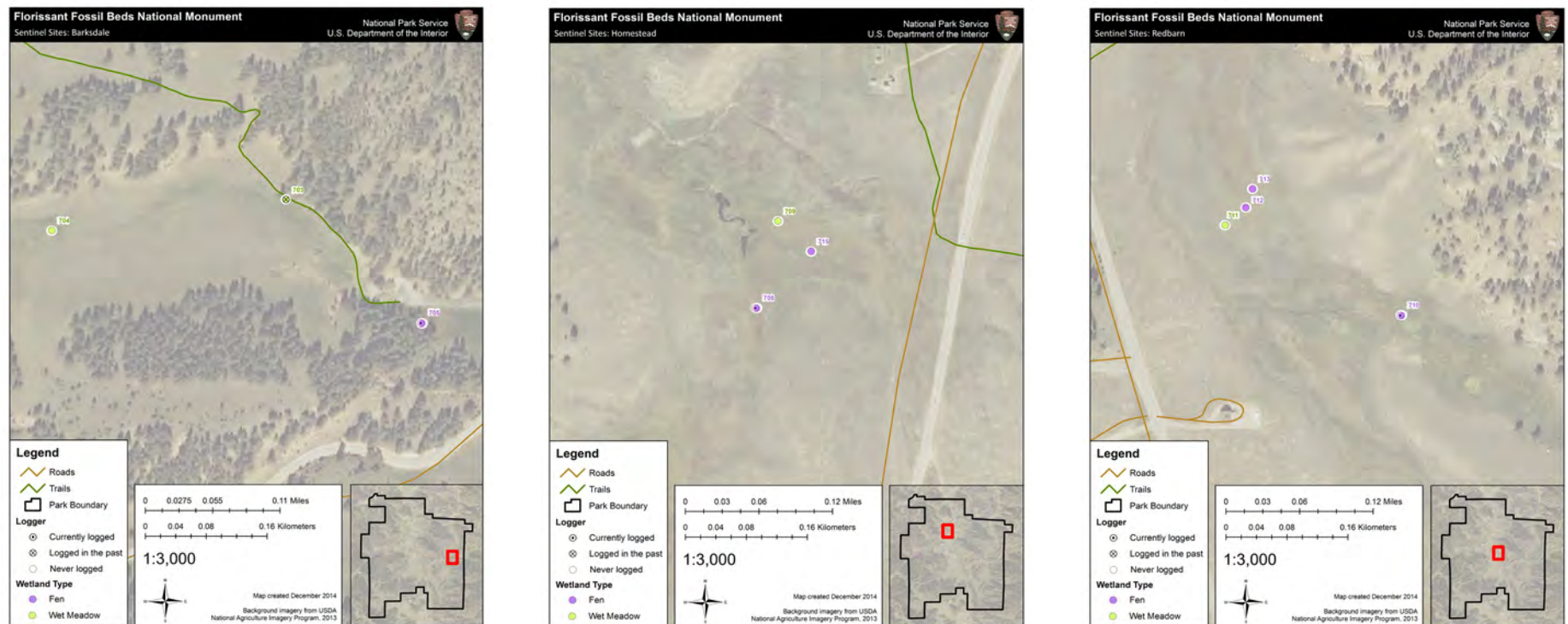


**Figure 24.** FLFO sentinel complexes: (left to right) Barksdale, Homestead, and Redbarn.

**Table 25. FLFO WEI sentinel sites (10) with key site selection criteria and full sample events from 2009 to 2013. The final revisit design structure as shown above is to be implemented 2015 and/or 2016.**

| Complex Size                   | Elevation | General Topography                              | Disturbance Regime(s)                                                             | Historical Monitoring                                    | Resource Management Issues                             | Site ID | Type | Latitude | Longitude | # Full Events (2009-2013) |
|--------------------------------|-----------|-------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------|---------|------|----------|-----------|---------------------------|
| Barksdale (3 sites as of 2014) |           |                                                 |                                                                                   |                                                          |                                                        |         |      |          |           |                           |
| Small (2.7 ha)                 | 2,605 m   | Small heterogeneous complex, some woody canopy  | Human: heavy historical use; light current use; Natural: medium elk use           | No historical wetland monitoring                         | Visitor interpretation                                 | 703     | Mdw  | 38.913   | -105.257  | 3                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 704     | Mdw  | 38.913   | -105.260  | 4                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 705     | Fen  | 38.912   | -105.256  | 4                         |
| Homestead (3 sites as of 2014) |           |                                                 |                                                                                   |                                                          |                                                        |         |      |          |           |                           |
| Medium to Large (22.4 ha)      | 2,525 m   | Medium homogenous complex, hummocks             | Human: heavy historical use; light to medium current use; Natural: medium elk use | Relatively recent ground water and vegetation monitoring | Ongoing hydrologic restoration, visitor interpretation | 708     | Fen  | 38.924   | -105.284  | 4                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 709     | Mdw  | 38.925   | -105.284  | 3                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 715     | Fen  | 38.925   | -105.284  | 3                         |
| Redbarn (4 sites as of 2014)   |           |                                                 |                                                                                   |                                                          |                                                        |         |      |          |           |                           |
| Medium to Large (23.1 ha)      | 2,545 m   | Medium heterogeneous complex, dry and wet sites | Human: heavy historical use; light to medium current use; Natural: medium elk use | No historical wetland monitoring                         | Visitor interpretation                                 | 710     | Fen  | 38.914   | -105.277  | 4                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 711     | Mdw  | 38.915   | -105.280  | 3                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 712     | Fen  | 38.915   | -105.279  | 3                         |
|                                |           |                                                 |                                                                                   |                                                          |                                                        | 713     | Fen  | 38.915   | -105.279  | 3                         |

## Glacier National Park

GLAC wetland can be locally extensive but in general is a less common habitat across the park because of shallow, often new glacial soils and generally steeper terrain than in other ROMN parks. Given this, while wetland is a valuable resource to the park, it may be less on the radar than other systems in the park. As of publication, we were evaluating two sentinel design options to monitor wetlands in Glacier. The first is essentially the same as in ROMO and GRSA—sites are subjectively located in several wetland complexes across the

park based on ecological context, existing monitoring and management importance criteria. The second subjectively selects sites in alpine riparian wetland within three hydrologic regimes and has a more explicit focus on the role of climate change in wetland vegetation condition. This second design is referred to as Alpine Wetland Ecological Integrity (AWEI) monitoring. AWEI also uses a slightly different set of field methods to accommodate these unique wetlands. *Future updates to this protocol will include the resolution of this choice and all associated supporting materials.*

# Field Methods

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

## ROMN Shared Standard Operating Procedures

ROMN standard administrative operating procedures (Table 26) 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 found 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 via the ROMN website (<http://science.nature.nps.gov/im/units/romn/>).

## Managing the Sample Season

A standard workflow or timeline for a sample season is followed when implementing the WEI protocol in a park (Table 27). More detail is in the standardized ROMN shared SOPs (see Table 26) and select WEI SOPs.

### *Timing of Field 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 WEI 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 function as the most useful barometer of a vital sign or of the condition of target populations within a given sampling interval (Larsen et al. 1995, Landers et al. 1988, Messer et al. 1991). Index-period sampling

**Table 26. 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                 |

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**Table 27. Key events and timeline in the WEI 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 |
| Field work                                                                                                         | May-September*       |
| Season wrap-up (including winterization of loggers)                                                                | August-September     |
| 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     |

\*often shorter depending on park and annual conditions

may also reduce inter-annual variability since crews will be sampling at similar phenological times each year, reducing effects of seasonal variation.

The WEI index period for vegetation-based methods is the weeks nearest the peak of the growing season within a given park (other methods, such as initiating a logger, will happen on a different schedule). This should be established for each park at the beginning of each field season since the timing may vary with year given precipitation and other variables. A sampling schedule will be prepared by ROMN staff and/or collaborators prior to the start of field work for survey and sentinel sites.

### Resource Protection Overview

All efforts aimed at minimizing the impact of crew members on ROMN wetlands should

be taken. Care must be taken that cultural, paleontological, or rare biological resources are not impacted. The following guidelines should be implemented:

- No archeological relicts, paleontological, or historical features will be disturbed.
- Wells are to be installed with minimal soil disturbance using an auger when possible.
- Soil will be placed on a tarp and returned to holes and excess scattered.
- Well casings to be cut within 6" of ground surface, painted, and capped.
- When a plant cannot be identified in the field, a single specimen will be collected for later examination. If <10 individuals of the plant are noted, it will be photographed rather than collected.

- No flagging or other markers beyond those necessary for protocol will be left onsite.
- All staff and volunteers will be instructed in appropriate safety and “leave-no-trace” practices of backcountry travel and camping.
- To minimize transfer of organisms among wetlands, footwear and other gear will be dipped in a bucket with a bleach or Sparquat solution at the end of each day and gear examined and cleaned as necessary for seeds or other propagules.

Site impact is mitigated by using the groundwater well as one of the plot markers. Wells are easily hidden by cutting risers close to the ground and painting (Figure 25, Figure 26). Data loggers are installed within well casings 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 plot markers (other than the well).

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.

## Safety

Safety is an overarching concern for the NPS and ROMN. The network has a Safety Plan (available upon request) that provides a 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, field work, etc. The plan includes NPS and ROMN safety policies, SOPs, Job Hazard Analyses (JHAs), and requirements for training.



**Figure 25.** Painted, capped, and tagged groundwater monitoring well in wet meadow. The short elevation of well casings (<6 in.) and high plant productivity typically render wells nearly invisible.



**Figure 26.** Example of camouflaged well (center bottom of photo as indicated by the red circle).

## Quality Assurance and Quality Control: Field

The ROMN WEI protocol includes various quality assurance and quality control (QAQC) procedures. These are detailed in relevant WEI SOPs and summarized below and in Table 28. Analytical methods focused on developing statistical estimates of QAQC are summarized in the analysis section.

**Table 28. WEI quality control and quality assurance measures.**

| <b>QAQC Activity</b>                                            | <b>Description</b>                                                                                                                                                                                                                                                                                                          |
|-----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Documentation                                                   | Documentation via protocol, SOPs, methodology, etc. are readily accessible.                                                                                                                                                                                                                                                 |
| Training                                                        | Field crew completes pre-season training.                                                                                                                                                                                                                                                                                   |
| Field datasheets                                                | Datasheets have standardized codes, precision guidelines for measured values, and clearly documented methodology to complete the form.                                                                                                                                                                                      |
| Field oversight                                                 | Crew leader/protocol lead provides oversight during the field season and/or periodically during data collection.                                                                                                                                                                                                            |
| Field datasheet review                                          | Conduct end of day or end of week quality assurance reviews of field datasheets for completeness, recording errors, and legible handwriting.                                                                                                                                                                                |
| 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).                                                                              |
| 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 SOP WEI: Quality Control and Quality Assurance.                                                                    |
| Quality assurance post-analyses                                 | Quality assurance tests completed for derived data prior to uploading to the database. All tests and procedures are documented in SOP WEI: Quality Control and Quality Assurance.                                                                                                                                           |
| 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 SOP WEI: Quality Control and Quality Assurance. |
| 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.                                                                                                                                          |
| Lab data quality assurance                                      | Chain of custody forms are cross-walked 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.                                                                                                                          |
| Species lists                                                   | At the end of the field season, the species list, with additions from the current year, are cross-walked and updated with code and names as listed in NPSpecies, ITIS, CNHP, Weber, and USDA Plants. Database is updated prior to data entry.                                                                               |

At the time of publication, a detailed Quality Assurance Performance Plan (QAPP) for the ROMN Stream Ecological Integrity Protocol (SEI) was under review by the U.S. Environmental Protection Agency. As some methods are similar or identical between the SEI and WEI protocols, we reference this draft document within the WEI protocol where possible. The ROMN SEI QAPP provides an overview of all measurement and data quality objectives (which are identical between the SEI and WEI protocols). These objectives assure that the WEI protocol generates data of known and documented quality, resulting in complete, accurate and transferable information. Data credibility necessary for long-term monitoring of wetlands 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 and ROMN staff, 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 1-2 days and includes lectures, field demonstrations, and numerous field sampling exercises. WEI 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.

Operational details of sampling that facilitate QAQC include 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 wells or other infrastructure). 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, especially of vegetation to test the quality of species identifications and cover estimates. Similarly, where more than one well exists in a plot, replicate depth to water loggers should be established. 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 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 wetland types and contexts.

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. These details are provided in WEI SOPs.

QAQC is a key responsibility of laboratories that perform analyses of WEI samples. As of the time of publication the ROMN uses the Soil, Water and Plant Testing Laboratory at Colorado State University. Detailed QAQC procedures for all soil tests are available from this facility or the ROMN.

QAQC continues with data entry and multiple automated procedures within the ROMN WEI 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 WEI SOPs.

## **Justification for Core Response Measures**

The suite of responses measured within the WEI protocol was derived from the vital sign development process the ROMN followed with a long list of collaborators and partners over two years (Britten et al. 2007). Many WEI measures are similar to other wetland monitoring programs and the long record of research by David Cooper and his students in GLAC and GRSA.

The protocol emphasizes the dominant biological feature (vegetation) and the key driver of wetlands (hydrology) with sufficient collection of covariates (especially soil) to enable a synthetic understanding of wetland condition. Describing and quantifying the interactions among vegetation assemblages and hydrology will provide the best insight into wetland condition and will support the best management of wetland in ROMN parks. This general strategy is known as bioassessment. This is in contrast to a functional assessment, such as the Hydrogeomorphic Approach (HGM), which is designed to estimate the functions that wetlands provide, such as water storage, nutrient cycling, and wildlife habitat (Brinson et al. 1995). Bioassessments are designed to evaluate wetland condition, while functional assessments are primarily designed to inform management decisions involving the dredge and fill of wetlands and restoring wetlands to compensate for wetland losses. Functional assessments tend to focus on the physical structure and habitat features of a wetland. In addition, functional assessments may not detect damage to wetlands caused by many subtle stressors, such as nutrient deposition or toxic chemicals.

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

### **Vegetation**

Vegetation is a fundamental attribute of wetland ecosystems, driving basic ecosystem processes such as productivity, decomposition, and biogeochemical cycling. Plants largely control the exchange of gases such as O<sub>2</sub> and CO<sub>2</sub>, affect processes of soil development, and as primary producers, influence the distribution of energy for higher trophic levels (Turetsky 2003). Wetland vegetation communities are speciose, with a diverse set of life histories that can respond in measurable ways to disturbance. Vegetation is easy and cost effective to measure, with a large literature on taxonomy, field methods, and analytical approaches. Vegetation is more or less immobile, so there are fewer issues than with mobile species regarding spatial disconnect between response and disturbance. Vegetation can be an excellent indicator of changes in key environmental drivers such as climate mediated hydrologic regime (Cooper 1990, Ahn et al. 2004). Wetland plant communities are very responsive to changes in surface water levels (Cooke and Lefor 1990, Keough et al. 1999). Water levels are, in turn, often responsive to changes in climate. In freshwater wetlands, water levels typically increase during cool periods and decrease during warm periods (Winter 1988, Winter and Rosenberry 1995). Wetland vegetation can serve as an indicator of a variety of other wetland processes. For example, vegetation diversity is often related to patterns in groundwater flow and chemistry (Glaser et al. 1990, Shedlock et al. 1993). Vegetation is responsive to environmental change—in hydrology, soil condition, and land use—and can be a highly visible indicator of stress (Guntenspergen et al. 2002, Chipps et al. 2006). Conversely, wetland vegetation can also affect wetland function; invasive plants may change wetland geomorphology, hydrology, biogeochemistry, productivity, and biodiversity (Zedler and Kercher 2004). In general, vegetation appears to be an excellent indicator of different combinations of climatic and hydrogeologic factors (Bedford 1996).

### **Hydrology**

Hydrologic regime is the primary site-level ecological driver in wetlands, strongly influencing vegetation, biogeochemistry, and ecosystem processes such as primary production and decomposition (Keddy and Keddy 2000, Mitsch and Gosselink 2007). Several hydrologic variables are key drivers of wetland and riparian ecosystem dynamics (Gage and Cooper 2013). They include whether soils are saturated, deeply inundated, or subject to erosive, high energy floods, and the timing of water availability, referring to both the seasonality and length of saturation or inundation. These factors act as a primary filter on the pool of potential species capable of occupying a wetland, allowing only those species with the required physiological, morphological, or life history adaptations to establish and be recruited (Keddy and Keddy 2000). The source of water supporting a wetland or riparian area, that is, whether it is principally precipitation, surface, or groundwater, and the flow paths taken before and after entering the system, can also affect a variety of important ecological functions.

Changes in water level occur from both natural and anthropogenic sources of disturbance in wetlands, and wetland vegetation communities can be modified by local changes in water level (Ehrenfeld and Schneider 1991, van der Valk et al. 1994). Moreover, since water level in most wetlands is affected by processes occurring throughout the catchment, water level is also a good indicator of disturbance on a larger scale. Hydrologic regime is typically the most important factor influencing vegetation patterns and dynamics in wetlands. Individual species vary in their response to water table gradients, with some species capable of growing along a wider range of water table depths than others (Dwire et al. 2006, Hajkova and Hájek 2004, Bayley and Mewhort 2004). Water table dynamics are also important drivers of community-level characteristics such as species richness and total plant cover (Dwire et al. 2006). For all of these reasons, water table and vegetation data collected in tandem improve understanding of natural variability in wetland ecosystem properties (Winter et al. 1990).

Despite the importance of groundwater to many wetlands, long-term datasets are relatively rare for most wetland and riparian ecosystems (Winter et al. 2001). Where available, these data are typically of short duration, although even these provide important insights into wetland functions (Cooper et al. 2003, Winter and LaBaugh 2003). The WEI protocol will partially address this shortcoming for ROMN parks, especially at sentinel sites. Groundwater data that we develop over time will be very helpful for understanding the natural hydrologic functions of different wetland types and their susceptibility to anthropogenic change in ROMN parks in our sentinel wetlands.

### Soil

Wetland soil is both the medium in which many chemical transformations take place and the primary storage area of available chemicals for most wetland plants (Mitsch and Gosselink 2007). Soil characteristics are important for wetland classification and provide useful indicators of wetland function. Fens, for example, are distinguished chiefly by the occurrence of organic soils. Certain soil indicators also provide information about hydrologic regime. For example, redoximorphic features like mottles are most likely to occur in soils that cycle between anaerobic (reduced) and aerobic (oxidized) conditions (NRCS 2006). By contrast, strongly gleyed soils suggest prolonged anaerobic conditions. Soil organic matter, carbon, pH, and plant nutrient concentrations can provide a powerful index of productivity and ecosystem processes and are often determinants of vegetation structure (Sollins et al. 1999). Global and local disturbances can alter soil chemistry, which may result in altered vegetation composition.

*Soil color* is often the most diagnostic indicator of hydric soils because color is strongly influenced by the frequency and duration of soil saturation. Mineral hydric soils can be gleyed, which are gray and are created by pronounced chemical reduction of iron and manganese. Mineral soils that are not saturated long enough to result in gleying may contain red mottling and/or low matrix chroma. Soils that have brightly colored mottles and a low matrix chroma are

indicative of a fluctuating water table (redox cycle). Examination of *soil horizons* reveals the processes that led to the soil's formation as well as the processes that continue to influence the soil. *Soil texture* is a description of the percent sand, clay, and silt in a soil and is a critical component of soil monitoring (Elliott et al. 1999). Numerous soil properties are influenced by texture including: drainage, susceptibility to erosion, organic matter content, cation exchange capacity, and pH buffering capacity. For instance, soil with a high percentage of silt and clay particles has a greater erodibility than a sandy soil under the same conditions. The ability of soils to retain positively charged ions is referred to as *cation exchange capacity* (CEC). Essential plant nutrients, such as calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), and potassium ( $\text{K}^{+}$ ) are cations and CEC describes the ability of negatively charged clays and organic matter in the soil to hold on to these cations. Mineral deficiencies are more likely to occur and soil pH tends to decrease faster in soils with low CEC (Robertson et al. 1999). *Soil organic matter* is the fraction of the soil that consists of plant or animal tissue in various stages of decomposition. Soil organic matter enhances aggregate stability, CEC, the soil's capacity to hold water, nutrient availability, and pH buffering capacity (Sollins et al. 1999). *Soil pH* measures the activity of hydrogen ( $\text{H}^{+}$ ) ions in soil solution. Many plant nutrients become less available to plants in acidic soils and atmospheric N deposition may lead to changes in soil pH (Robertson et al. 1999). We will also estimate the concentration of plant mineral nutrients in the soil. Productivity is often linked to the availability and balance of plant nutrients. Finally, *total N and C* and *organic content* will also be measured and can be a useful indicator of ecosystem processes such as C sequestration, decomposition, and the potential for a site to leach nitrate.

### Sampling Frequency of Core Response Measures

We discuss sample frequency by design type and park in the Sample Design section above. In addition, some types of responses are sampled at different intervals given known or expected patterns in variation. Table 29 provides a summary of these details.

**Table 29. Sample frequency for core response measures.**

| Type of Response                        | Sample Frequency                                                                                                                | Notes                                                             |
|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| Vegetation, vascular                    | Annual or biannual at sentinel sites<br>Decadal at most survey and gradient sites (annually at sites revisited during a survey) | At peak growing season                                            |
| Vegetation, non-vascular                | Every 5 years at sentinel sites<br>Decadal at most survey and gradient sites                                                    | At peak growing season                                            |
| Woody structure and damage              | Annual or biannual at sentinel sites<br>Decadal at most survey and gradient sites (annually at sites revisited during a survey) | At peak growing season                                            |
| Disturbance and context                 | Annual or biannual at sentinel sites<br>Decadal at most survey and gradient sites (annually at sites revisited during a survey) | At peak growing season                                            |
| Site photos                             | Annual at sentinel sites<br>Decadal at most survey and gradient sites (annually at sites revisited during a survey)             | Collected multiple times per summer as possible at sentinel sites |
| Hydrology, point in time depth to water | Annual at sentinel sites<br>Decadal at most survey and gradient sites (annually at sites revisited during a survey)             | Collected multiple times per summer as possible at sentinel sites |
| Hydrology, continuous depth to water    | Hourly at a subset of sites (usually sentinel sites)                                                                            | Logged                                                            |
| In situ water chemistry                 | Annual or biannual at sentinel sites<br>Decadal at most survey and gradient sites (annually at sites revisited during a survey) | At peak growing season                                            |
| Soil chemistry                          | Every 5 years at sentinel sites<br>Decadal at most survey and gradient sites                                                    | At peak growing season                                            |
| Soil profile                            | Decadal                                                                                                                         | At peak growing season                                            |

### WEI Standard Operating Procedures: Field Methods

To collect WEI response measures, a common set of methods defined within 20 SOPs are followed (Figure 27 and Table 30). SOPs help ensure that all data are collected, are of the highest quality possible, and that over time (and as personnel change) methods remain consistent to reduce bias and variance introduced by the observers (Oakley et al. 2003). The general sequence of field methods is largely the same regardless of sampling design (survey, sentinel, or gradient) or wetland type. The first visit to a site involves several additional steps, including well installation and the establishment of plot monuments. Partial sample events (i.e., checking data loggers) involve a subset of the WEI SOPs. Details regarding the steps involved in plot establishment and data collection are presented in individual SOPs. The elements of the core field methods are summarized in

the following sections, with methodological details provided in individual SOPs.

#### **Field Forms and PDA-Based Data Collection**

A variety of WEI field data forms (Table 31) are provided for field data collection. Several types of data are collected within a PDA application called EcoNab (WEI SOP 3: Use of Electronic Data Recorders). Even where the use of a hand-held computer for data collection is preferred, an adequate supply of back-up paper forms will be carried by crews so that sampling is still possible if circumstances prevent use of electronic equipment. Some forms are common to all wetland types and sampling designs, while others are only completed in a restricted set of circumstances. More specific instructions for completing data forms are provided in the individual SOPs describing protocol metrics.

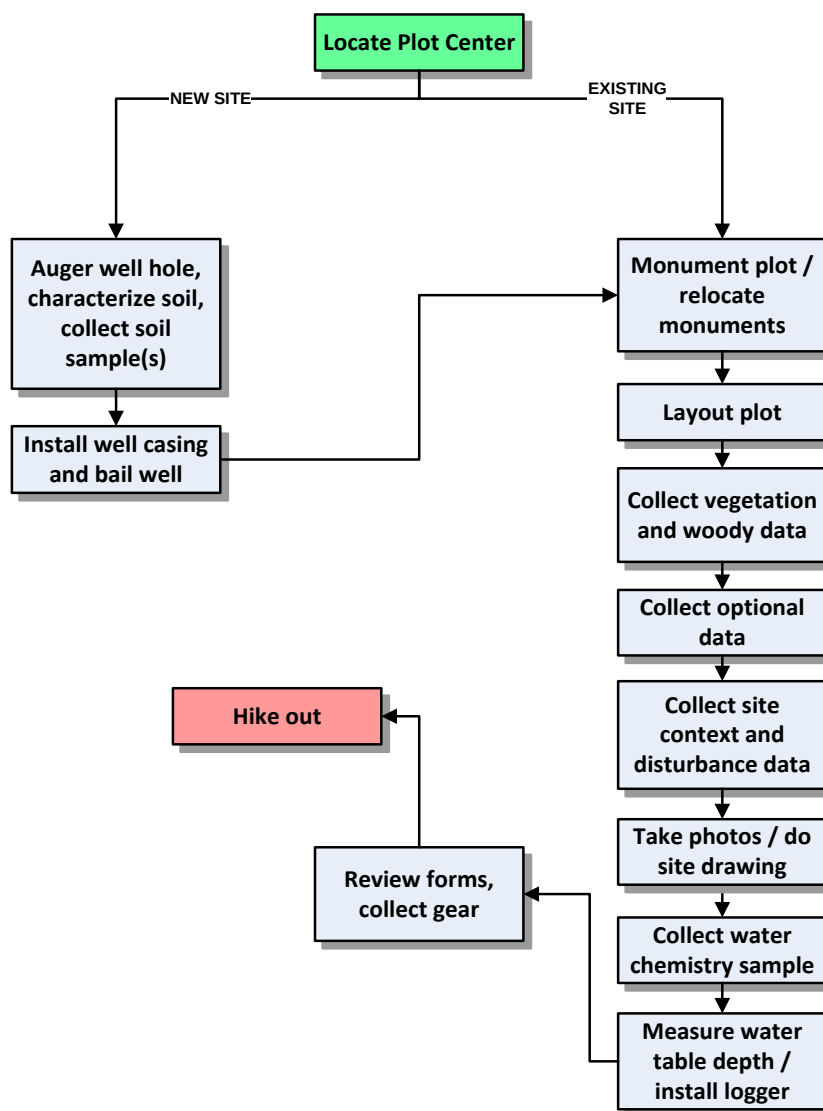
## Determining Site Status and Replacing Sites

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 a WEI 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 wetland), 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 wetland, 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 WEI SOP 4: Verification of Site Status.

Dossiers, which are maps of each site and relevant metadata, such as driving directions and estimated travel time, will be prepared for sites prior to the start of field work. All site coordinates will be loaded into crew GPS units for navigation. These include the series of steps followed to evaluate the required number of third stage points in a wetland complex. If a point and at least 90% of the area of any plot established around it are of a target type and the plot can be contained within the wetland boundaries, the point is marked as the plot center and sampling is conducted. If the point is not of the target type, the next point on the numbered list is selected and evaluated using the same steps described above. If no points meeting the criteria for inclusion are encountered, the wetland is abandoned and the oversample list is consulted for the first available replacement site with the same wetland type as the original site.

### Field Plots

Pilot work conducted at ROMO (Schweiger et al., unpublished data; Figure 28) in 2007 suggested species accumulation curves were optimized at around a 100 m<sup>2</sup> plot size with three scales of nested plots. There are, of course, many other examples of plot designs in the ecological literature. Many are complex (e.g., the modified-Whittaker design (Stohlgren et al. 1995)) and not appropriate for remote WEI sites where a sample event,



including travel to and from the site, must be completed by a crew of two in a single day. Other sampling strategies, such as transects, were rejected to facilitate the integration of vegetation and hydrology data (transects would likely spatially disconnect vegetation and groundwater data). Survey and gradient sites consist of one 10x10 m plot. Sentinel sites use the same plot size and layout, but the relevant scale for sentinel sites is the wetland complex, therefore multiple plots can be established in sentinel wetlands and combined in analysis (Peet et al. 1998).

Details of the WEI plot design follows from Peet et al. (1998) and Rocchio (2007) and consist of a 10x10 m plot with three scales of nested subplots (Figure 29). The largest, outer plot or “macroplot” contains one “subplot” (16 m<sup>2</sup>) with four 1 m<sup>2</sup>

**Figure 27.** Overview of workflow at confirmed target sampleable site.

**Table 30. List of WEI SOPs. See the ROMN website for current SOPs. Data management and analysis SOPs are listed separately.**

---

|                                                                                                   |
|---------------------------------------------------------------------------------------------------|
| WEI SOP 1: Pre- and Post-Season Workflow                                                          |
| WEI SOP 2: Pre- and Post-Sample Event Workflow                                                    |
| WEI SOP 3: Use of Electronic Data Recorders                                                       |
| WEI SOP 4: Verification of Site Status                                                            |
| WEI SOP 5: Plot Layout and Site Photos                                                            |
| WEI SOP 6: Groundwater Monitoring Well Installation                                               |
| WEI SOP 7: Manual Reading of Water Table Height                                                   |
| WEI SOP 8: Installing and Reading Continuous Depth-to-Groundwater Data Loggers                    |
| WEI SOP 9: In Situ Water Physiochemistry                                                          |
| WEI SOP 10: General Soil Characterization and Chemistry                                           |
| WEI SOP 11: Vegetation Composition and Cover                                                      |
| WEI SOP 12: Woody Structure and Herbivory                                                         |
| WEI SOP 13: Meso-scale Landscape Context, Site-scale Disturbance, and Site-scale Characterization |
| WEI SOP 14: Large-scale Landscape Context, Disturbance, and Characterization                      |
| WEI SOP 15: Field Sheet Scanning                                                                  |
| WEI SOP 16: Data Entry                                                                            |
| WEI SOP 17: In-Situ Groundwater Depth Logger Processing                                           |
| WEI SOP 18: In-Situ Water Physiochemistry Logger Processing                                       |
| WEI SOP 19: Data Analysis                                                                         |
| WEI SOP 20: Revising the Protocol                                                                 |

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**Table 31. Forms needed for a full ROMN WEI sample event.**

---

| Form                                                        | Notes                                                                             |
|-------------------------------------------------------------|-----------------------------------------------------------------------------------|
| WEI Form #0 Calibration and Error Check                     | Used for both calibration and error check of water chemistry sondes               |
| WEI Form #2 Survey Site Extent Evaluation                   | Used only for new or QAQC survey site sample events                               |
| WEI Form #3 Event: Site Establishment / Well / Logger / DTW | Multiple copies may be needed for sentinel complexes or for sites with many wells |
| WEI Form #4 Water Table Depth, Water Quality and Soil       | Multiple copies may be needed for sentinel complexes or for sites with many wells |
| WEI Form #5 Vegetation Composition and Cover                | Rarely used, but multiple copies may be needed for sites with many species        |
| WEI Form #6b: Herbivory and Woody Structure                 | Multiple copies may be needed for sites with many species                         |
| WEI Form #8: Landscape                                      | Can apply to multiple plots in a complex                                          |

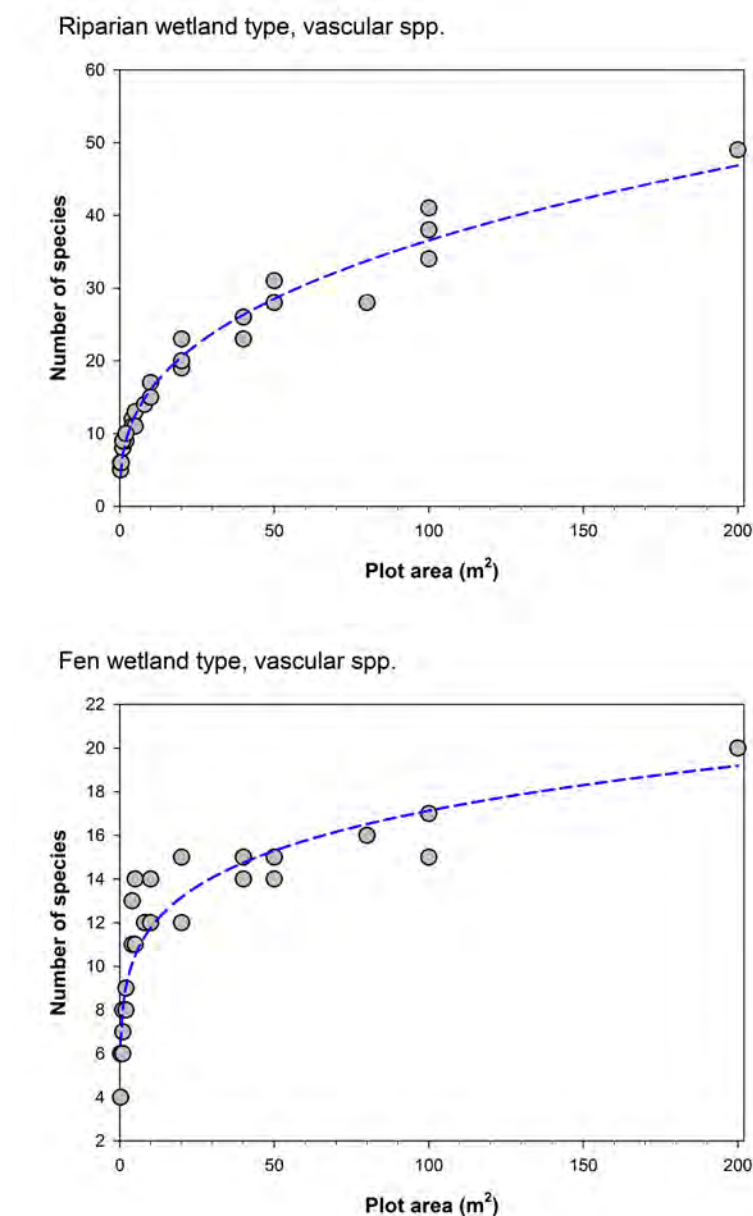
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“microplots” nested within the subplot. At most sites, a groundwater monitoring well is in the center of the nested plots. Each cardinal direction corner of the macroplot is monumented with an approximately 20-40 cm long piece of ½ in. diameter rebar, capped with an aluminum survey marker stamped with ROMN and plot information. When possible, markers are pounded flush with the ground surface. In rare cases, the square layout is not ideal or possible. A more linear or “stretched” alternate is shown in Figure 30. Detailed instructions for plot layout are provided in WEI SOP 5: Plot Layout and Site Photos.

All survey and sentinel sites have shallow groundwater monitoring wells. WEI wells consist of a perforated section of PVC pipe installed vertically in the ground in the center of the plot. Perforations in the PVC extend from just below the ground surface to the bottom of the pipe, which is capped with a PVC cap with a hole drilled for drainage. Water levels inside the pipe result from the integrated water pressures along the entire length of perforations. Water table heights in wells are measured by hand or logged with data loggers.

### Vegetation

Vegetation data are collected in each of the three scales of plots at a site (see Figure 29 and WEI SOP 11: Vegetation Composition and Cover). Ocular cover estimates of all vascular and non-vascular taxa are estimated in the four small microplots (1 m<sup>2</sup>) the subplot (16 m<sup>2</sup>) and the 100 m<sup>2</sup> macroplot. Wetland vegetation can be highly heterogeneous, with a variety of specialized micro-habitats supporting different suites of species (especially non-vascular taxa) and the nested plots may help isolate and control for this structure. Cover is defined as the vertically projected outline of the foliage, ignoring any normal spaces occurring between the leaves of plants, and expressed as a proportion of plot area (Daubenmire 1959). Cover classes are not used; rather, estimates are made along a continuous scale. This allows more flexibility in post hoc binning and classification. Nested, plot-based ocular estimates may be preferable to frequency data or transect based approaches



when including rare species in the sample is important (Peet et al. 1998).

Cover measurements are useful because they recognize the contribution of small species, are directly related to the biomass of most plant functional types, and are easily visualized and intuitive (Elzinga et al. 1998). Moreover, cover is often used as an indicator of changes in plant community composition, directly correlates with primary productivity, and is linked to ecological processes such as carbon and nitrogen cycling (Herrick et al. 2005). Finally, estimating cover remains one of the most common methods in vegetation studies, allowing for comparisons between

**Figure 28.** Results from ROMO pilot sampling in 2006 showing species accumulation as a function of plot size in two wetland types. Red lines show asymptotes at the 100 m<sup>2</sup> size used in the final WEI plot design.

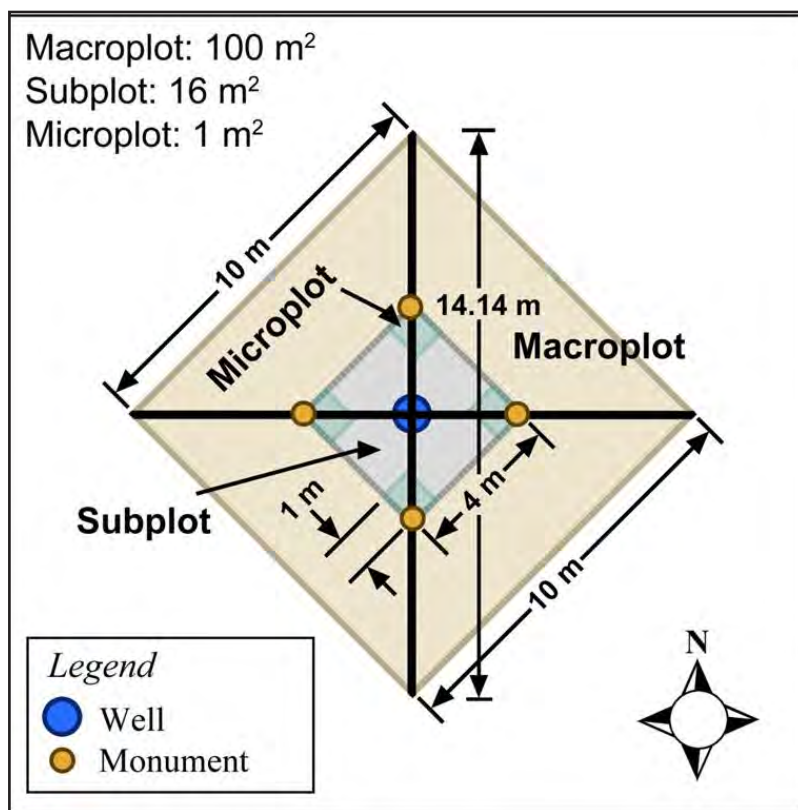


**Figure 29.** Default WEI sample plot. Plots are always oriented with North at the top of the plot. Rebar is capped with a standard ROMN monument cap. The center of the plot is groundwater well (except in most gradient sites). Pins are placed temporarily to aid in plot layout and then removed following sampling.

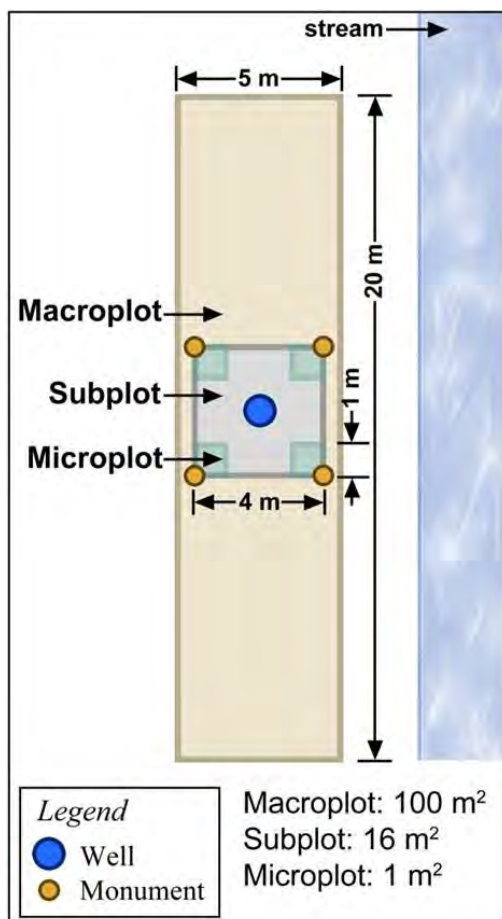


**Figure 30.** Modified WEI plot layout.

our work and other national and local inventories.

Frequency may be derived from the occurrence of a species across the nested plots at each site. Frequency is the percentage of total possible plots occupied by each species being measured and is a repeatable measurement that performs equally well in a range of habitats featuring different growth forms. Because it is not as sensitive to annual biomass changes, frequency measurements are more robust to annual and seasonal changes in plant individuals. Additionally, frequency measurements may be taken any time after germination; this consequent independence from peak phenology creates a larger sampling window. However, with only six plots (at three scales), random variation in species occurrence will likely be important in frequency estimates and it will take a large change to produce a statistically detectable result.

Crews use regional floras and park specific identification guides. In Colorado parks, nomenclature follows that used by the Colorado Natural Heritage Program (Rocchio 2007), which is derived from Weber and Wittmann (2001). At GLAC nomenclature must follow the Montana Natural Heritage Program which is derived from Lesica (2002). Under no circumstances will field crews be allowed to use any other nomenclature. Both Heritage Program naming systems are cross-walked to USDA PLANTS (USDA and NRCS 2010) and NPSpecies (NPS 2010) to allow functional connection to other naming systems.

Specimens of all plants that cannot be confidently identified to the species level are collected off-plot and submitted to herbaria for subsequent identification (ROMN SOP: Specimen Tracking and Vouchering). Following Belland and Vitt (1995), we use an approach whereby small samples of any non-vascular plants (mosses, etc.) are collected from subplots, packaged, and sent for outside identification by experts.

### Woody Structure and Damage

Woody structure is a particularly important vegetation-based variable influencing the suitability of habitat for both vertebrate and

plant species in wetlands. Large ungulate herbivory impacts ecosystem structure and function via trophic relationships and nutrient cycling (Hobbs et al. 1996, Augustine 2003). ROMN WEI methods will provide data to help understand the various issues associated with ungulate populations on the condition of willow communities and beaver demography that occur in several ROMN parks (Allen 1983, Baker et al. 1997, Mitchell et al. 2000, Peinetti et al. 2002, Westbrook et al. 2006).

The WEI protocol includes methods for evaluating woody stand composition and three general indicators of ungulate impacts and other sources of stress on woody species. These methods are general and rapid in their implementation and are not intended to generate rigorous site-specific estimates of utilization of woody species by ungulate herbivores such as off take (see Bilyeu et al. 2007). Current methodological details can be found in WEI SOP 12: Woody Structure and Herbivory.

Crews enumerate woody stems by taxa and general age/size classes for key woody species (or morphospecies) along two edges of the 10x10 m plot. All individuals are counted and placed in size classes. Herbivory and other damage to woody stems is evaluated by estimating three general assays of woody plant condition directly or indirectly affected by vertebrate herbivores or other forms of physical damage. These measures include the percentage of stems originating from below ground that are clearly dead, the percentage of the crown that has dieback, and the percentage of live stems that have evidence of ungulate browse.

### ***Groundwater Hydrology***

The WEI protocol includes field methods for manual, episodic reading of groundwater depths at all sites and continuous logging over time at a subset of sites. Manual reading is done with simple hand tapes or voltmeter-based tools. Continuous measurement over time allows for a more precise evaluation of hydrologic regime, but is expensive and is therefore usually only done at sentinel sites or at survey sites being revisited during a survey implementation. A continuous record of water level in groundwater

monitoring wells or stream stage is obtained through the use of instruments capable of recording water-surface elevation. WEI SOP 7: Manual Reading of Water Table Height and WEI SOP 8: Installing and Reading Continuous Depth-to-Groundwater Data Loggers provide detailed instructions describing each of these processes.

### ***In Situ Water Chemistry***

We include three of the four core NPS Water Resource Division (NPS 2002) measurements: temperature, specific conductance (SC), and pH (given cost and lack of clear justification in wetland, dissolved oxygen is not included in ROMN WEI monitoring). Conductivity and pH typically respond to hydrologic disturbance in wetlands (Forman and Alexander 1998, Chipps et al. 2006) and are easy to measure with inexpensive probes. Conductance and pH are also important in classification of wetland sites (Cowardin et al. 1979). Collecting meaningful in situ temperature from groundwater using WEI methods is more problematic given often severe diel variation; we collect temperature data, but only use this information when extreme values might be an indication that more careful work is needed.

WEI water chemistry methods involve collecting water samples in situ and analysis with a multiprobe sonde. Sondes are calibrated and error checked according to NPS guidance (NPS 2002). WEI SOP 9: In Situ Water Physiochemistry provides more detailed information.

### ***Soil***

Soil is assessed from holes dug to the water table (usually the same in which the well is placed) in each site. A background in soil profiling is useful, but not necessary for the WEI soil methods; crews will be trained to describe soils in a general way. Most methods are generalized or simplified from (USDA 2005, Schoeneberger et al. 2002) and these references should be consulted for more detail. Soil color, texture, structure, and consistency are used to distinguish and identify soil layers (generalized horizons). Peats are also characterized using the Von Post system (Von Post 1924). Soil organic

matter, carbon, pH and plant nutrient concentrations are measured in samples processed at a lab (Sollins et al. 1999). Results characterize the storage, cycling, and abundance of nutrients and water available to plants, and the potential for acidification of the soil from the deposition of pollutants. WEI SOP 10: General Soil Characterization and Chemistry provides more detailed information. To better understand soil condition and wetland classification, an initial soil characterization at each site will be done with the first sample event at site. Following the initial characterization, full soils characterization will be completed every five to ten years.

### ***Disturbance and Context Data***

An important part of the WEI protocol is a characterization of a suite of human

and “natural” disturbance measures in and around each wetland site and complex. These data are synthesized into a semi-quantitative Human Disturbance Index (HDI) and a Natural Disturbance Index (NDI) that provide independent measures of wetland condition against which vegetation attributes are assessed to determine their relationship with increasing human disturbance. The component metrics in the HDI and NDI (Table 32) are rapidly employed measures largely extracted from the Ecological Integrity Assessment (Faber-Langendoen et al. 2006, Rocchio 2007), other rapid wetland condition assessment methods (Mack 2001), or developed by the ROMN. They are mostly categorical with some degree of subjectivity, but crews do not make judgment calls on wetland condition in the field. Many of the measures are evaluated both in the field and in the office within a

**Table 32. List of WEI Human Disturbance Index (HDI) and Natural Disturbance Index (NDI) measures.**

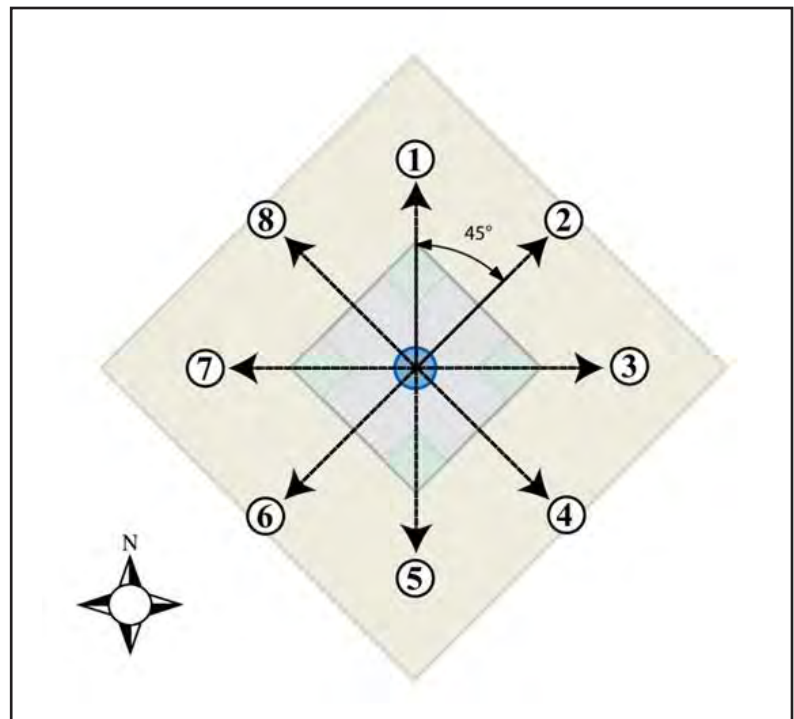
| <b>Alterations within Buffers and Landscape Context</b>                               |
|---------------------------------------------------------------------------------------|
| Average Buffer Width ( <i>Field and GIS</i> )                                         |
| Land Use in 100 m Buffer ( <i>Field and GIS</i> )                                     |
| Percentage of Unfragmented Landscape within 1 km (0.6 miles) ( <i>Field and GIS</i> ) |
| Riparian Corridor Continuity ( <i>Field</i> )                                         |
| <b>Hydrological Alterations</b>                                                       |
| Upstream Surface Water Retention ( <i>Field and GIS</i> )                             |
| Upstream/Onsite Water Diversions/Additions ( <i>Field and GIS</i> )                   |
| Floodplain Interaction ( <i>Field</i> )                                               |
| <b>Physical/Chemical Disturbances</b>                                                 |
| Substrate/Soil Disturbance ( <i>Field</i> )                                           |
| Complex Land Use ( <i>Field</i> )                                                     |
| Bank Stability ( <i>Field</i> )                                                       |
| Algal Blooms ( <i>Field</i> )                                                         |
| Invasive Monoculture ( <i>Field</i> )                                                 |
| Sediment/Turbidity ( <i>Field</i> )                                                   |
| Toxics/Heavy Metals ( <i>Field</i> )                                                  |
| <b>Natural Disturbances</b>                                                           |
| Beaver ( <i>Field and GIS</i> )                                                       |
| Native Ungulates ( <i>Field</i> )                                                     |
| Frost Heave ( <i>Field</i> )                                                          |
| Rodents ( <i>Field</i> )                                                              |
| Fire ( <i>Field and GIS</i> )                                                         |
| Pests/Pathogens ( <i>Field and GIS</i> )                                              |
| Landslides ( <i>Field and GIS</i> )                                                   |

GIS (as in some cases GIS data will be more precise and accurate). We also include a suite of physical context measures with the HDI and NDI methods given similarity in the scale at which these measures are collected in the field. These include largely categorical metrics describing the dominant hydrology, landform, and topography in and around a WEI site.

Rigorous adherence to the methods presented in WEI SOP 13: Meso-scale Landscape Context, Site-scale Disturbance, and Site-scale Characterization will remove as much of the bias in these methods as possible, but they are not used in analyses that require a great deal of site-level precision (Schweiger et al. 2015). One purpose of these procedures is to provide data that are complementary to wetland monitoring efforts conducted by ROMN partners in and around ROMN parks (e.g., by the EPA or the Colorado Natural Heritage Program; U.S. EPA (2011), Lemly and Rocchio (2009)). This provides a comparative context for both WEI and our partners' monitoring data that can then be evaluated to generate information useful to managers across multiple jurisdictions.

### Site Photos

Photographs provide a valuable tool for evaluating ecological change (Mast et al. 1997, Horsted and Grafe 2002). For



example, processes such as tree or shrub invasion are readily visible on photographs (Zier and Baker 2006). Properly framed and documented images are also useful for relocating monitoring sites. The WEI protocol involves collecting eight photo points at fixed azimuths from the center of the plot module (Figure 31). The camera is placed directly over the well at 1.5 meters and angled slightly downward to capture both the plot and the surrounding landscape (see Figure 32 for examples).

**Figure 31.** Overview of photo points taken at sampling sites. Photos are taken in clockwise sequence from due north from the macroplot/subplot center.



NPS/BILLY SCHWEIGER



NPS/KATIE DRIVER

**Figure 32.** Examples of site photos, GRSA 2010. The top image is looking due north from plot center, and the bottom image looks due south from plot center.



# Data Management

## Overview

The goal of ROMN information management is to develop high-quality WEI datasets according to standards established in the ROMN Data and Information Management Plan and Standard Operating Procedures (NPS 2007a). The data management system that supports the WEI protocol is designed to ensure that the field and electronic data collection systems are operated in a standardized format and the procedures are well documented. Data management prior to, during, and after the field season ensures that all data collected and used in analysis and reporting have been subject to quality control verification and validation processes to establish data integrity. Additional details are in the following sections and in the Data Management SOPs (Table 33; also available online from the NPS Integrated Resource Management Applications (IRMA), [irma.nps.gov](http://irma.nps.gov)). Updates and changes to the protocol over time will be reflected in the SOPs as these are updated annually or as needed.

## 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. Table 34 is a complete list

of the information management tasks and identifies the responsible ROMN staff.

## Information Lifecycle

Data management is a continuous effort that is implemented during each step of monitoring wetland ecological integrity. The annual information lifecycle (Figure 33) ensures data are accurate, consistent, and comprehensive. 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 (ROMN SOP: Folder Structure and File Naming). Datasheets are scanned, entered, and archived. The data management team assures the quality of the data entered (WEI SOP 16: Data Entry), processes logger data (WEI SOP 17: In-Situ Groundwater Depth Logger Processing and WEI SOP 18: In-Situ Water Physiochemistry Logger Processing), and imports the species and soil data into the WEI Data Entry Database. 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 WEI 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.

**Table 33. Standard Operating Procedures for WEI data management.**

---

|                                                             |
|-------------------------------------------------------------|
| WEI SOP 1: Pre- and Post-Season Workflow                    |
| WEI SOP 2: Pre- and Post-Sample Event Workflow              |
| WEI SOP 3: Use of Electronic Data Recorders                 |
| WEI SOP 15: Field Sheet Scanning                            |
| WEI SOP 16: Data Entry                                      |
| WEI SOP 17: In-Situ Groundwater Depth Logger Processing     |
| WEI SOP 18: In-Situ Water Physiochemistry Logger Processing |
| ROMN SOP: Photo Management                                  |
| ROMN SOP: Archive Format Standards for Network Data         |

---

**Table 34. WEI 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 species lists, site descriptions, maps, and field sheets                                                                                                        | Data Management                   |
| 5     | Collect data, QA field sheets, turn in field sheets, upload all electronic data to the shared drive (e.g., PDA, GPS, camera, logger)                                  | Field Crew Leader Field Crew      |
| 6     | Scan, enter, and QA data                                                                                                                                              | Data Management                   |
| 7     | 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 WEI cabinet)   | Data Management                   |
| 8     | Identify unknown species and archive specimens following the species handling SOPs                                                                                    | Field Crew Leader                 |
| 9     | Run vegetation summaries, import vegetation data into the yearly field data database                                                                                  | Data Management                   |
| 10    | Process and baromerge logger data using WinSitu software and import logger data into the yearly logger database                                                       | Data Management                   |
| 11    | Update the site lookup table with the most recent GPS data                                                                                                            | Data Management                   |
| 12    | Rename photos using the WEI photo database                                                                                                                            | Data Management                   |
| 13    | Send soil samples to the lab and save the lab deliverable on the shared drive                                                                                         | Field Crew Leader Protocol Lead   |
| 14    | Format soil data and import into the yearly soil database                                                                                                             | Data Management                   |
| 15    | Assure the quality and completeness of the logger, soil, and field data                                                                                               | Data Management Protocol Lead     |
| 16    | Certify and archive yearly vegetation, logger, soil, and field data databases and ensure the link between the yearly field database and the logger and soil databases | Data Management                   |
| 17    | Import new data into the master logger, soil, and WEI field data databases                                                                                            | Data Management                   |
| 18    | Run summary marcos for analytical inputs and conduct analysis                                                                                                         | Protocol Lead                     |
| 19    | Write and publish WEI report                                                                                                                                          | Protocol Lead                     |

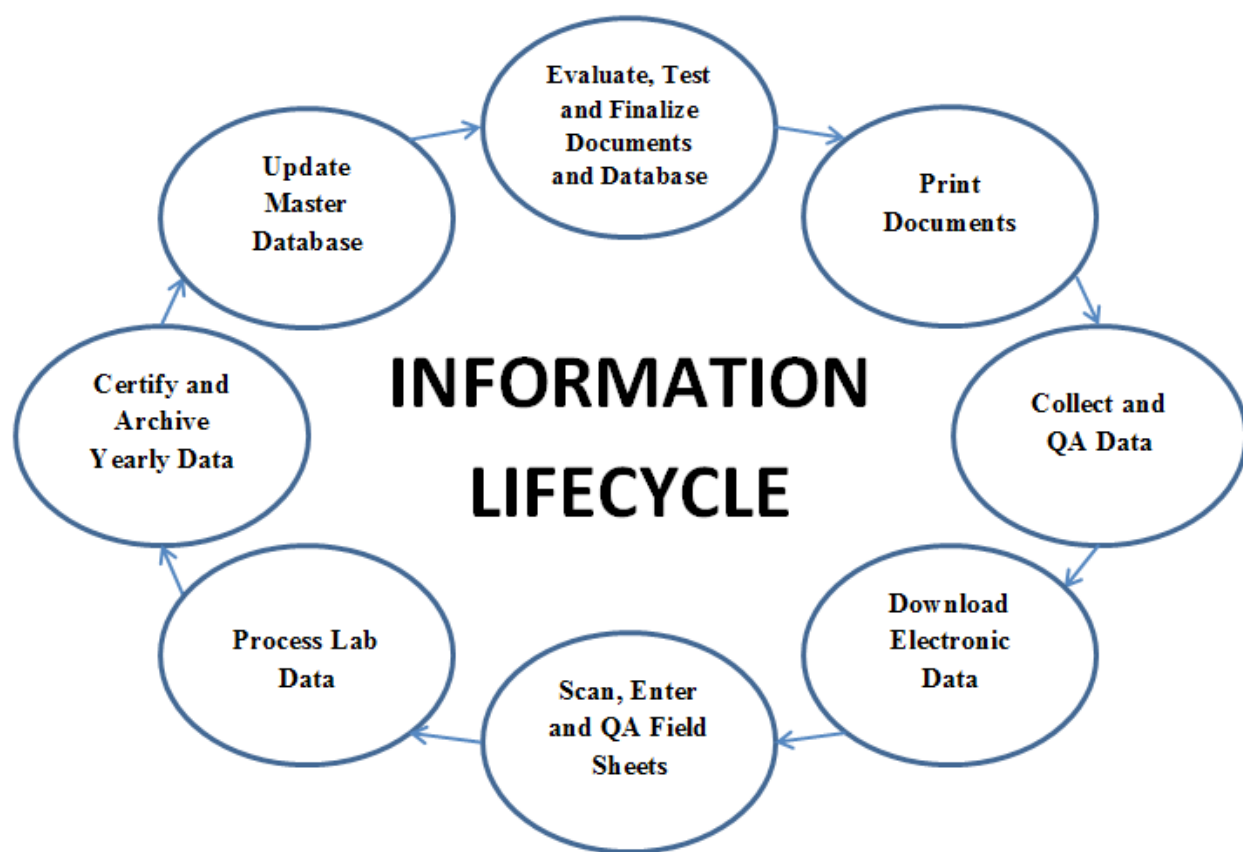


**Figure 33.** Information lifecycle.

## Data Workflow

This section describes the specific processes involved in planning, collecting, certifying, archiving, and disseminating data (Figure 34).

### Plan

The Data Manager is responsible for preparing field gear and databases as outlined in WEI SOP 1: Pre- and Post-Season Workflow and WEI SOP 2: Pre- and Post-Sample Event 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, soils, EcoNab, and photos.

### Collect and Compile

There are six sources of data associated with the WEI protocol: field sheet, PDA, logger, GPS, lab, and camera. To accommodate the various formats of data input and quantities of information, there are five annual databases and multiple file types maintained in a defined folder structure on a shared

drive (Figure 35). The shared drive is located on a server maintained by the Fort Collins Washington Office IT department, which is responsible for proper storage, restore in the case of system failure, and archive retrieval according to NPS policies.

### 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 WEI Field QA box; if additional quality review is needed. Once the sheets have been thoroughly examined, they are turned in to the WEI Scan box. The data management team will scan the field sheets and place them into the WEI Data Entry box (ROMN SOP: Scanning). The digital files will be named in accordance to the ROMN SOP: Folder Structure and File Naming (e.g., WEI\_GLAC\_505\_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 WEI Data QA box. A different member of the data management team will then

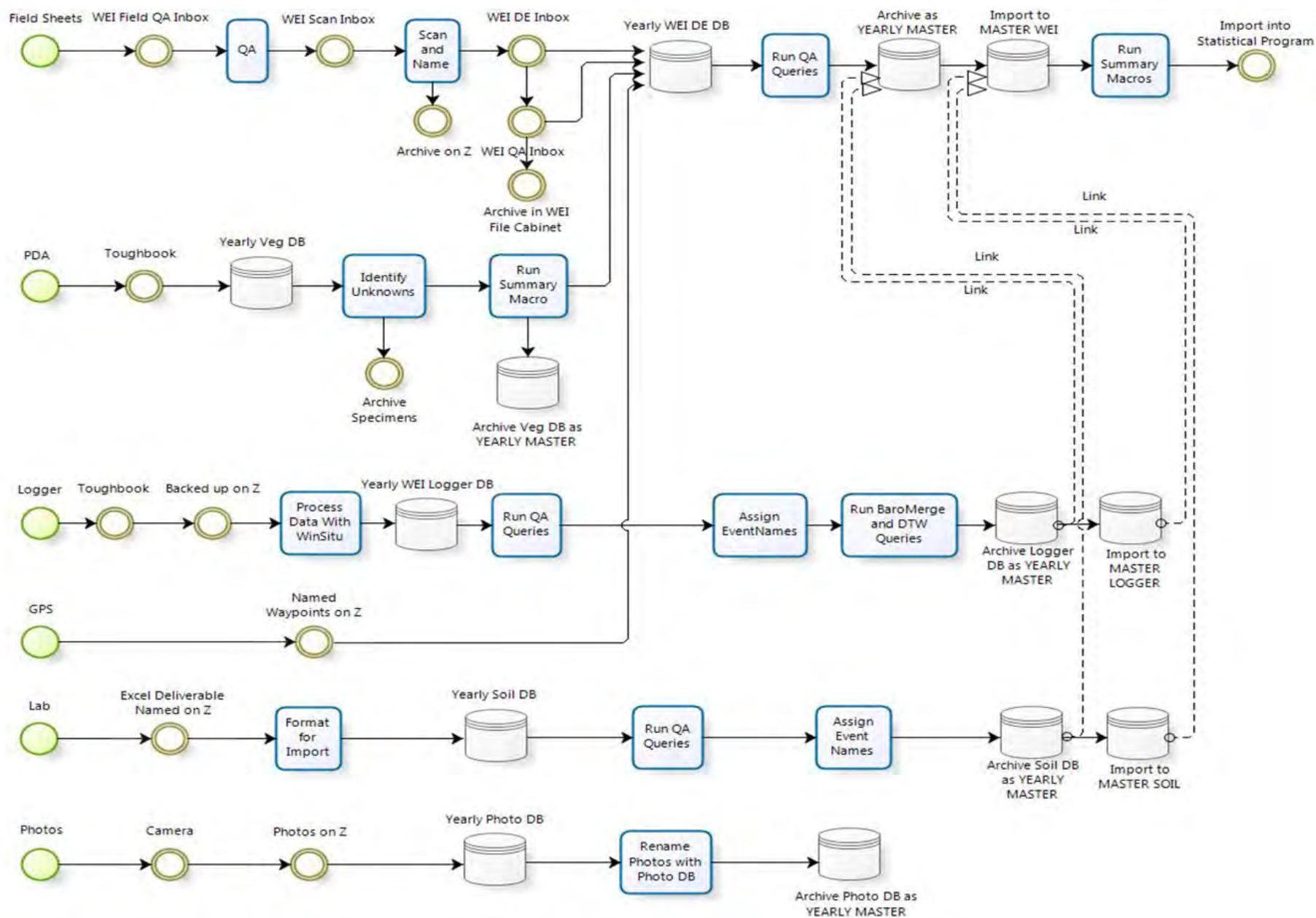


Figure 34. Data workflow.

|                    |                                                                                                                                                                          |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wetlands.....      | No files here. Only subfolders are populated.                                                                                                                            |
| Analysis.....      | Subfolders for: Inputs, Outputs, Tools                                                                                                                                   |
| Data.....          | No files here. Only subfolders are populated.                                                                                                                            |
| Certified.....     | Master databases and subfolders for yearly archives.                                                                                                                     |
| FY##.....          | Archived zip package.<br>WEI Database, Logger Database, Vegetation Database, Scans, Core Photos, sample documentation and deliverables, ReadMe text files                |
| CorePhotos.....    | Certified core photos.                                                                                                                                                   |
| Databases.....     | Certified yearly databases.<br>WEI Database, Logger Database, Vegetation Database, Photo Database                                                                        |
| Scans.....         | Certified field sheet scans.                                                                                                                                             |
| DataGathering..... | No files here. Only subfolders are populated.                                                                                                                            |
| DataEntry.....     | Yearly data entry of monitoring data.<br>• Contents of this folder are archived in yearly package.                                                                       |
| Lab.....           | Yearly deliverable from a lab after the close of the field season.<br>• Contents of this folder are incorporated into the database and archived in yearly package.       |
| Logger.....        | Yearly data downloaded from loggers in the field.<br>• Contents of this folder are incorporated into the database and archived in yearly package.                        |
| Waypoints.....     | Yearly GPS data collected in the field.<br>• Contents of this folder are incorporated into the database and transferred to the Geospatial folder at the end of the year. |
| Scans.....         | Yearly digitized field forms.<br>• Contents of this folder are archived in yearly package.                                                                               |
| Photos.....        | Photo database.                                                                                                                                                          |
| Core.....          | Yearly renamed core photos.                                                                                                                                              |
| Misc.....          | Yearly renamed miscellaneous photos.                                                                                                                                     |
| ReadyToRename..... | Raw camera downloads waiting to be processed.                                                                                                                            |
| Tools.....         | Code, templates, and tools used for processing data outside of the databases.                                                                                            |
| Design.....        | Files used for the design of the protocol.                                                                                                                               |
| Documents.....     | Subfolders for: Briefs, Presentations, Protocol, Reference, Reports, SOPs                                                                                                |
| Field Forms.....   | Database for the most current field forms.                                                                                                                               |
| Geospatial.....    | No files here. Only subfolders are populated.                                                                                                                            |
| GeoDatabases.....  | All GIS data specifically related to the protocol.                                                                                                                       |
| MXDs.....          | All GIS map files specifically related to the protocol.                                                                                                                  |
| Tools.....         | All GIS models, templates, and code specifically related to the protocol.                                                                                                |
| Images.....        | No files here. Only subfolders are populated.                                                                                                                            |
| Graphics.....      | Exported map images, figures, graphs, formatted report tables.                                                                                                           |
| Photos.....        | All miscellaneous photos.                                                                                                                                                |

**Figure 35.** WEI folder structure on the shared drive.

assure the data were transcribed accurately. Refer to the WEI SOP 16: Data Entry 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 WEI filing cabinet. Hard copy documents from the field data collected will be managed as directed in NPS Director's Order 19: Records Management and appendix, NPS Records Disposition Schedule (NPS 2005).

### PDA

Species data are collected electronically in the EcoNab application installed on a PDA. To minimize the risk of data loss, the EcoNab database is backed up on an SD card at the end of each day. The cumulative data records for the season are downloaded onto a Toughbook or other machine with HotSync installed. Refer to the EcoNab documentation located in the

MONITORING\Wetlands\Documents\EcoNabEssentials folder on the shared drive for detailed guidance in preparing, recording, editing, and downloading vegetation data. Once the field crew is back in the office, the most recent database is saved in the EcoNab folder on the shared drive. If Toughbooks are used, then an external drive will be needed to transfer the database to the network drive. After the last sampling event, the Field Crew Leader will identify all unknown specimens and update the EcoNab database. Once all necessary data edits have been completed, the Data Manager will be notified that the species data are ready to be integrated into the WEI monitoring database.

### Logger

In-Situ loggers (through 2012 we used models from In-Situ, YSI and Hanna) are used to measure continuous pressure and temperature data. The field crew downloads the logger files onto a Toughbook in the

field. Once the crew is back in the office, the entire contents of the Backups folder on the Toughbook is loaded to an external drive and transferred to the Backups folder on the shared network drive without being renamed. Refer to the WEI SOP 17: In-Situ Groundwater Depth Logger Processing, WEI SOP 18: In-Situ Water Physiochemistry Logger Processing, ROMN SOP: YSI Logger, and ROMN SOP: HOBO Logger for detailed instructions on how to prepare the data for input into the annual logger database.

### GPS

GPS devices are used to navigate to existing sites and document the precise location of new sites. If the coordinates used for navigation prove to be inadequate, then a new waypoint is taken. Once the field crew is in the office, the cumulative waypoints for the season are downloaded using DNR Garmin and are saved in the Waypoints folder using the standard file naming convention (e.g., WEI\_ROMN\_Waypoints\_20120726). At the end of the field season, the .dbf file is temporarily 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

Soil samples collected during multiple monitoring protocols are sent to the Soil, Water and Plant Testing Laboratory at Colorado State University at the close of the field season. After a few months, the lab returns a single Excel file containing the analyzed data for all ROMN samples. Because multiple protocols are processed together, a folder structure on the shared drive has been created for soil data (Figure 36). The deliverable from the lab is saved in

the Lab folder. The Excel file is formatted using the template in the Tools folder. The resulting file is named in accordance with the ROMN file naming standards (e.g., Soil\_ROMN\_ProcessedData\_FY12\_20130115) and saved in the Data Entry folder. Each tab of the document is imported into the annual soil database which is collocated with the processed Excel file in the Data Entry folder.

### Camera

Photographs are taken in accordance with the requirements of the field procedures specified in the WEI protocol. When the field crew returns to the office, all photographs are downloaded to the ReadyToRename folder. The core photographs are renamed using the WEI photo database. Refer to the ROMN SOP: Photo Management for details on how to utilize the photo database. 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 WEI 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

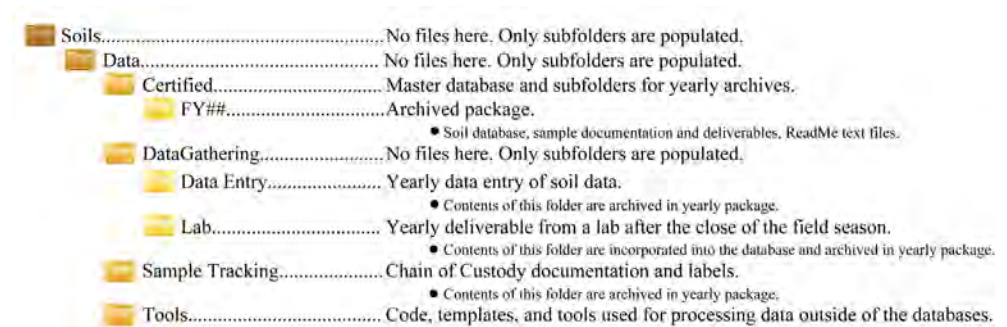


**Figure 36.** Soil folder structure on the shared drive.

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 vegetation, soil, and logger records. Once all the data are in compliance with our data standards, the vegetation data are summarized and incorporated into the yearly data entry database, and the soil and logger data are linked to the data entry database. These connections trigger the process of archiving each Yearly Master database.

All digital data acquired and derived are archived annually according to the procedures and standards in NPS National Data Management Plan (NPS 2008), ROMN Data Management Plan (NPS 2007a), and ROMN SOP: Archive Format Standards for Network Data. 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 WEI Protocol requires the maintenance of five Yearly and Master databases: WEI Monitoring, Vegetation, Logger, Soil, and Photos. The data in each Yearly Master database are added to the corresponding Master databases. Because the Master WEI database contains or links to all historical data, the final, predefined data summaries are generated using an interface developed within the Master WEI database. The outputs from this tool are used as inputs into other statistical packages such as R scripts. The protocol, databases, and reports will be distributed to IRMA.

### **Database Design**

The WEI database is designed to ensure quality control, quality assurance, long-term data integrity, access, reporting, and storage. The structure is a modified version of the Natural Resource Database Template (NRDT), version 3.2 (NPS 2007b). Each database developed for a ROMN monitoring protocol shares 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 integrated into each database. The master database holds all years of collected data with interfaces for extracting summarized information, while the annual database stores a single year of data and includes an integrated set of forms for data entry. The database structure is 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.

Figure 37 outlines the basic table structure of the WEI database. The WEI database includes the standardized parent tables: `tbl_Events`, `tbl_Crew`, `tbl_Times`, `tbl_PointsPhotos`. The WEI database also incorporates unique parent tables: `tbl_Landscape`, `tbl_SiteDescription`, `tbl_Measurements`, `tbl_NewSite`, `tbl_Soil`, `tbl_VegData`. More detailed data can be recorded in child tables, which are related to each parent table. In addition to these data collection tables, there are multiple lookup, import, and summary tables with user interfaces that execute custom macros and code. Refer to the ROMN SOP: Database Design for details about the purpose and quality control of these additional database objects.

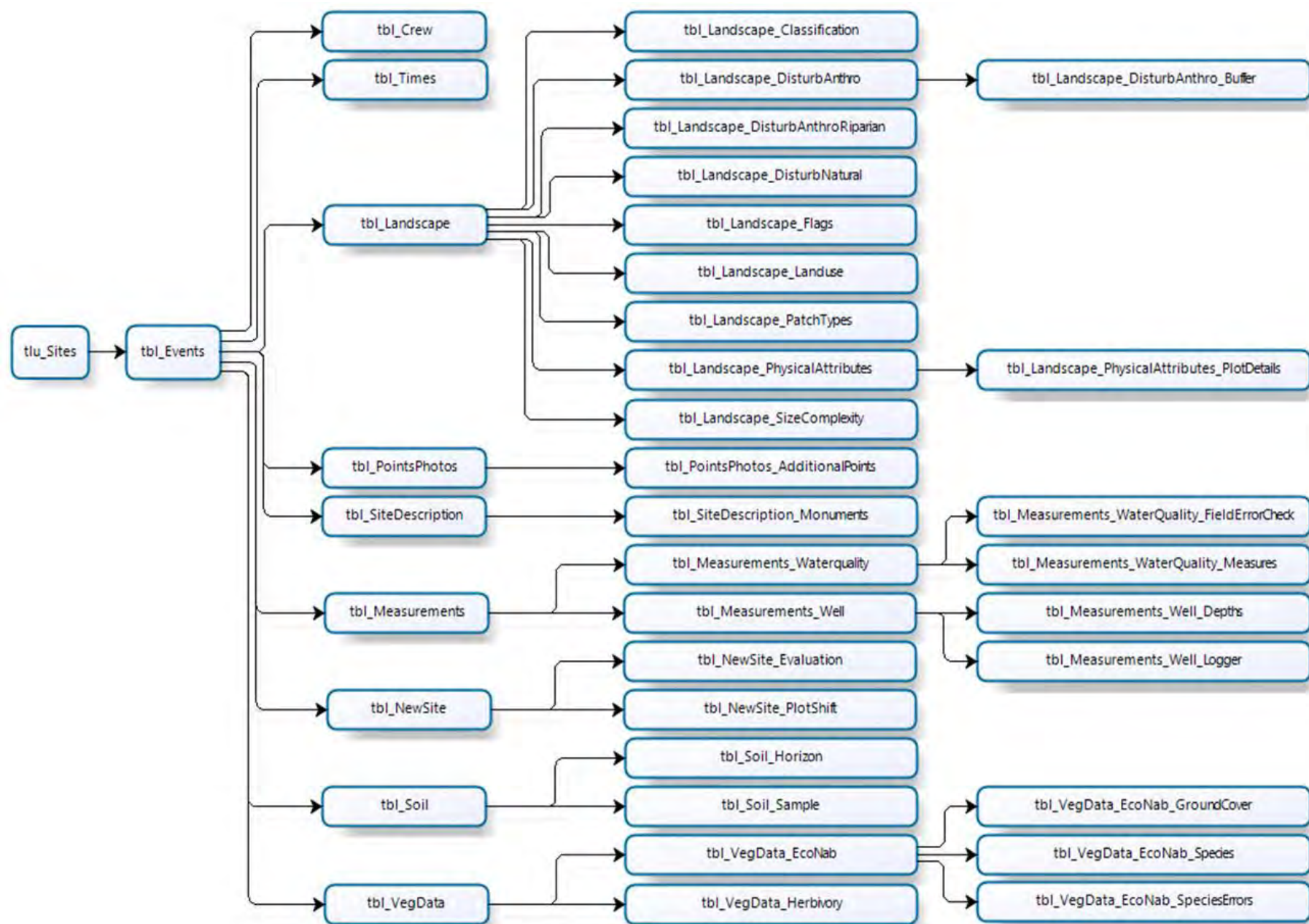


Figure 37. WEI database design.

## Data Standards

We intend to meet the following standards for all data collected and received for WEI monitoring as a basis for scientific credibility (USDOI 2007): (1) qualitative accuracy, (2) completeness, (3) consistency, (4) precision, (5) timeliness, (6) uniqueness, and (7) validity. To facilitate convergence with these standards, we use quality control measures and documented quality assurance measures to facilitate local data management. Data qualifiers are 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 analysis requirements may be met by migrating to a different database program such as 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: Data Management

The Data Manager and the Protocol Lead coordinate to develop measures of QAQC relevant to data management throughout the lifecycle of the protocol (Figure 38 and Table 35). Specific QAQC elements relevant to field operations are given above. The Data Manager is responsible for ensuring the quality control measures and quality assurance review queries are implemented according to the standards established in ROMN SOP: Quality Control and Quality Assurance. Due to the nature of the lab data, the Protocol Lead is responsible for quality assurance of the lab data received from the contract lab. It is assumed that the contract lab has quality control standards that meet or exceed the published standards for the sample analyses.

### Sensitive Data Management

National guidance for sensitivity restricts general public accessibility to data determined to be sensitive by park management (NPS 2007a). Therefore, the WEI protocol follows these established guidelines for managing sensitive information and contains measures for identifying and flagging sensitive data, and provides a means of collecting data that does not jeopardize the sensitive resources.

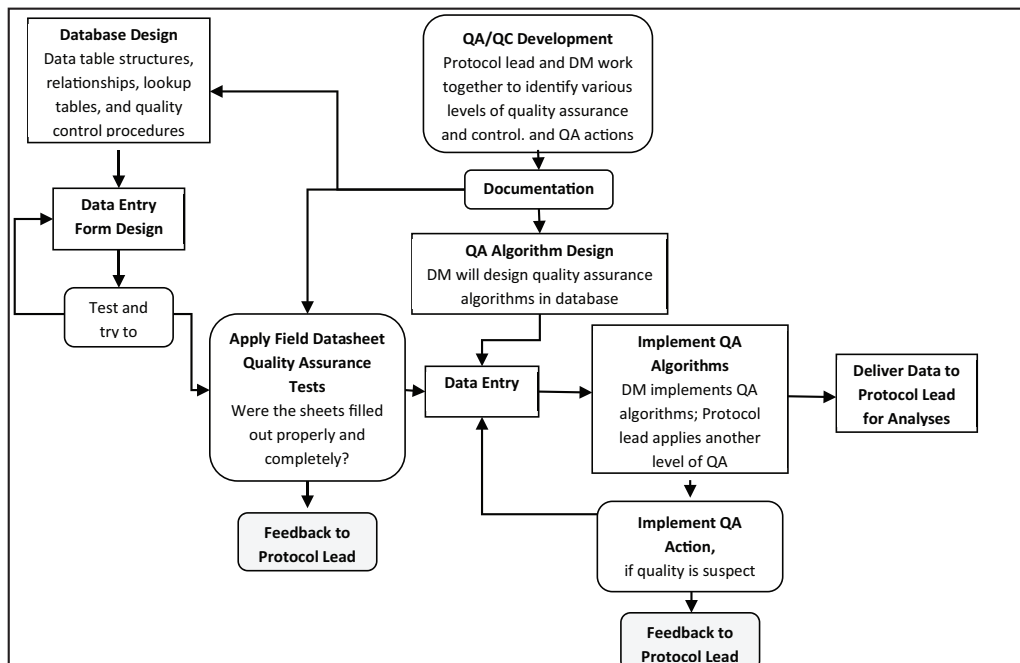


**Figure 38.** Quality Assurance and Quality Control workflow within WEI data management.

**Table 35. Roles and responsibilities for Quality Assurance and Quality Control within WEI data management.**

| <b>Core QAQC Measure</b>                                        | <b>Description of the Action</b>                                                                                                                                                                                                                                                                                                  | <b>Responsible Party</b>           |
|-----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| Documentation                                                   | Documentation via protocol, SOPs, methodology, etc., readily accessible                                                                                                                                                                                                                                                           | Protocol Lead                      |
| Training                                                        | Pre-season training of field crew                                                                                                                                                                                                                                                                                                 | Protocol Lead                      |
| Field datasheets                                                | Datasheets with standardized codes, precision guidelines for measured values, and clearly documented methodology to complete the form                                                                                                                                                                                             | Protocol Lead Data Manager         |
| Field oversight                                                 | Crew leader/protocol lead oversight during the field season and or periodically during data collection                                                                                                                                                                                                                            | Field Crew Leader<br>Protocol Lead |
| Field datasheet review                                          | End of the day or end of week quality assurance review of field datasheets for completeness, recording errors, and legible handwriting                                                                                                                                                                                            | Field Crew Leader<br>Protocol Lead |
| Data entry quality control                                      | Data entry quality control measures, including electronic data collection devices, to eliminate misspellings, to standardize entry, and reduce errors (drop down menus, value range, limited lists, check boxes, and species lists, etc.)                                                                                         | Data Manager                       |
| Quality assurance post-data entry                               | Quality assurance review following ROMN SOP: Quality Control and Quality Assurance<br>Queries are applied to the data post-data entry to isolate errors. All tests and procedures should be documented in ROMN SOP: Quality Control and Quality Assurance                                                                         | Data Manager<br>Protocol Lead      |
| Quality assurance post-analyses                                 | Quality assurance tests for derived data prior to uploading to the database. All tests and procedures should be documented in ROMN SOP: Quality Control and Quality Assurance                                                                                                                                                     | Data Manager<br>Protocol Lead      |
| 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 should be documented in ROMN SOP: Quality Control and Quality Assurance | Data Manager<br>Protocol Lead      |
| Lab data quality control                                        | Protocol methodology establishes quality control pertaining to the sample collection<br>ROMN assumes contract labs maintain a level of quality control that is tractable internally                                                                                                                                               | Data Manager<br>Protocol Lead      |
| Lab data quality assurance                                      | Chain of custody forms are cross-walked 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                                                                                                                                 | Data Manager<br>Protocol Lead      |
| Species lists                                                   | At the end of the field season, the species list, with additions from the current year, are cross-walked and updated with code and names as listed in NPSpecies, ITIS, CNHP, Weber, and USDA Plants. Database is updated prior to data entry                                                                                      | Data Manager<br>Protocol Lead      |

# Reporting

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

Three types of WEI reports will be produced: (1) relatively simple data summary reports, produced every two years, (2) comprehensive extensive status (and eventually trend) reports, produced as soon as possible after the initial implementation of the ROMO or GRSA survey and thereafter every ten

years, and (3) comprehensive trend reports for sentinel sites in all ROMN parks with WEI 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 Data Summary or Natural Resource Report series and available on the NPS Washington Support Office (WASO) data and information management and delivery systems (IRMA) the ROMN website (<http://science.nature.nps.gov/im/units/romn/>). More details on the content of WEI reports are provided in WEI SOP 19: 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 wetlands within a park.

Data Summary Reports will:

- List project personnel and their roles.
- List sites sampled during the current year.
- Provide a summary history of the number of sites, park units, and wetland types 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 vegetation metrics, hydrology, and soil), summarized by wetland type and park unit.
- Include simple trend results for sentinel sites, eventually.
- Discuss results, including management implications.
- Include a summary condition table (see below), as directed by park management.

Also every two years, the 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 biannual 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 wetland condition (and eventually trend) for ROMO and GRSA 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 vegetation community structure and relationships with management relevant needs (i.e., ungulates at GRSA). Trend reports for sentinel sites will include more detailed analyses of patterns in ground water hydrology. Reliable trend estimates for sentinel sites will be possible sooner than for extensive populations of wetlands in ROMO and GRSA.

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 vegetation structure over time or differences among sites should be examined in relation to two primary stressors—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 the condition of wetlands.
- Identify any changes in spatial patterns of wetlands.
- Include a summary condition table (see below).

# Summary Condition

As discussed in the Assessment section above, ROMN WEI 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), along with our confidence in the result. We will include simple graphic symbols; see Figure 39 for a draft legend for a summary condition table. These are a considerable simplification of details presented in even Data Summary Reports and should be used with caution.

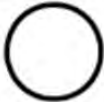
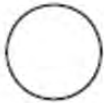
| Status                                                                                                                                                                                                                                             | Trend                                                                                                                                                                                                           | Confidence                                                                                                                                                                                                                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <div>  <div> Non-reference <div> (key model parameter; <math>p &lt; 0.05</math> in comparison to non-reference assessment point) </div> </div> </div>             | <div>  <div> Improving <div> (slope coefficient <math>&gt; +/- 1.0</math> ; <math>p &lt; 0.05</math>) </div> </div> </div>     | <div>   <div> High, <math>p &lt; 0.05</math> </div> </div> |
| <div>  <div> Intermediate <div> (key model parameter; <math>p &lt; 0.05</math> in comparison to reference or non-reference assessment point) </div> </div> </div> | <div>  <div> Unchanging <div> (slope coefficient <math>\sim 0</math>; <math>p &lt; 0.05</math>) </div> </div> </div>           | <div>   <div> Med., <math>p &lt; 0.1</math> </div> </div>  |
| <div>  <div> Reference <div> (key model parameter; <math>p &lt; 0.05</math> in comparison to reference assessment point) </div> </div> </div>                     | <div>  <div> Deteriorating <div> (slope coefficient <math>&gt; +/- 1.0</math> ; <math>p &lt; 0.05</math>) </div> </div> </div> | <div>   <div> Low., <math>p &gt; 0.1</math> </div> </div>  |
| <div>  <div> Unknown or Indeterminate </div> </div>                                                                                                              | <div> <div> No symbol </div> <div> Unknown or Indeterminate </div> </div>                                                                                                                                       |                                                                                                                                                                                                                                  |

**Figure 39.** Draft symbology and terminology for summary conditions.

Notes:

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. However, in other cases a summary condition statement is largely qualitative and no test is performed.

Confidence is ideally a function of the p values or other statistical parameter (i.e., 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.



# Analysis

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

In this section we provide an outline of the major steps and types of analyses conducted to meet WEI objectives. Additional details are given in WEI SOP 19: Data Analysis.

## Overview

The analysis phase of WEI monitoring begins with the delivery of fully quality-assured data from ROMN data management (see the Data Management section above and Table 28) 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 don't make ecological sense.

Once a quality-assured dataset is available, a series of steps follow, including metric estimation, various models, and hypothesis tests, as discussed below. All analyses, indirectly or directly, are structured to address or support WEI 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 wetland complex. Because sentinel sites will have a much greater sample frequency than surveys, however, 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 data points are collected with each WEI sample event. These include both indicators of wetland response to disturbance and those that are predictors or drivers of wetland response (although many might arguably fall into both of these groups). WEI data may be grouped in to measures that 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 data analyzed within the WEI protocol is metrics, 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 loading, 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 36 presents examples of measures and metrics grouped by objective.

### **Bioassessment**

Two of the more important types of metrics in WEI monitoring are derived from bioassessment (Barbour et al 1999) and include output from (1) a multimetric model of integrity (MMI, also known as an Index of Biotic Integrity), and (2) a multivariate model known as River Invertebrate Prediction and Classification system (RIVPACS; note that this name is somewhat misleading as the technique may be applied to any assemblage including wetland vegetation, but it is established in the literature so we use it). Both of these approaches are well accepted and commonplace in stream bioassessment and MMIs have been successfully applied to wetland vegetation communities, including to pilot data from GLAC and GRSA (Schoolmaster et al. 2012; Schoolmaster, Grace, Schweiger, Guntensbergen et al. 2013; Schoolmaster, Grace, Schweiger, Mitchell et al. 2013; Grace et al. 2012). RIVPACS models have not seen much use in wetland monitoring but as of publication we were actively exploring their application.

### **Multimetric**

We developed a novel approach to creating MMIs as part of the WEI protocol development. We only summarize these methods here; see Schoolmaster et al. (2012) and Schoolmaster, Grace, Schweiger, Mitchell et al. (2013) for more details. 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 wetland condition. Despite the widespread use of MMIs, there is uncertainty about when this approach can be effective. We developed

a quantitative theory that illustrates how the properties of candidate metrics relates to MMIs generated from those metrics. We used this theory to generate an optimal number of metrics to comprise an MMI, to deal with correlations among metrics and their impacts on the performance of an MMI index derived from those metrics, and to decide whether a metric will improve the performance of an index or not. In general, the criterion defining such conditions depends nonlinearly on the signal of the disturbance gradient, the noise (error) of the metric, and the correlation of the metric errors. We construct MMIs from a set of candidate vegetation metrics and a measure of human disturbance (HDI). The algorithm uses each metric to inform a candidate MMI, and then uses information-theoretic principles to select MMIs that capture the information in the multidimensional system response from among possible MMIs. Such an approach creates a purely empirical MMI or can, optionally, be influenced by expert opinion or biological theory through the use of a weighting vector to create value-weighted MMIs. When compared to other methods, our algorithmic approach results in MMIs that are more predictive and comprise fewer metrics. We control for the potentially confounding influences of environmental covariates in the construction of WEI MMIs. Most common approaches to handling covariates are based on simple notions of statistical control, leaving the causal implications of covariates and their adjustment unstated. We use graphical models to examine some of the potential impacts of environmental covariates on the observed signals between human disturbance and potential response metrics. Environmental covariates can both obscure and exaggerate the effects of human disturbance on individual metrics, potentially having very misleading effects on identifying system responses. We use a “whole set” solution that models both environmental and human disturbance effects simultaneously. This whole-set modeling approach requires fewer assumptions and is more efficient with the given information than the more commonly applied reference-set approach; thus, it represents a major advance for identifying metrics of system response.

**Table 36. Example WEI measures and metrics by objective.**

| Objective                                                                                                                           | Parameter                                                                                                       | Measure or Metric | Units                        |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-------------------|------------------------------|
| Determine the status in wetland areal extent using survey site extent data and/or park-scale imagery data.                          | Wetland complex area derived from a GIS using remotely sensed imagery, existing vegetation maps or similar data | Measure           | m <sup>2</sup>               |
|                                                                                                                                     | Classification of 3rd stage points by wetland type                                                              | Measure           | %                            |
| Determine the status and trend in wetland condition using a suite of vascular and non-vascular vegetation-based measures or metrics | Absolute species cover                                                                                          | Measure           | m <sup>2</sup>               |
|                                                                                                                                     | Relative species cover                                                                                          | Metric            | %                            |
|                                                                                                                                     | Species frequency                                                                                               | Metric            | %                            |
|                                                                                                                                     | Relative frequency                                                                                              | Metric            | %                            |
|                                                                                                                                     | Species presence/absence                                                                                        | Measure           | Categorical                  |
|                                                                                                                                     | Relative cover of life history or functional group (graminoids, tolerant taxa, wetland obligates, etc.)         | Metric            | %                            |
|                                                                                                                                     | Percent of species count as a life history or functional group (forbs, <i>Salix</i> spp., bryophytes, etc.)     | Metric            | %                            |
|                                                                                                                                     | Species richness by life history or functional group (total, woody taxa, native taxa, invasive taxa, etc.)      | Metric            | Count                        |
|                                                                                                                                     | Taxonomic diversity (multiple types of indices)                                                                 | Metric            | Shannon-Weiner index         |
|                                                                                                                                     | Evenness (multiple types of indices)                                                                            | Metric            | Peilou index, J              |
|                                                                                                                                     | Coefficient of Conservation based indices (multiple index forms; by life history or functional group)           | Metric            | Mean C                       |
|                                                                                                                                     | Floristic Quality Indices (multiple types of indices)                                                           | Metric            | FQA, AFQA                    |
|                                                                                                                                     | Multimetric Index (ecoregion, state- or park-scale model)                                                       | Metric            | Unitless                     |
|                                                                                                                                     | Observed:Expected or Bray-Curtis Index from RIVPACS* model (ecoregion, state- or park-scale model)              | Metric            | Unitless                     |
|                                                                                                                                     | Woody species stand composition (by size class)                                                                 | Measure           | Count                        |
|                                                                                                                                     | Percent die back, percent live browse and percent dead woody stems                                              | Measure           | %                            |
|                                                                                                                                     | Cover of rock, vascular plants, lichens, bryophytes, bare ground, litter                                        | Measure           | %                            |
| Determine the status and trend in wetland condition via groundwater hydrology<br><br>[Note many hydrologic metrics are TBD]         | Depth to groundwater (peak vegetation phenology)                                                                | Measure           | cm                           |
|                                                                                                                                     | Hydrograph-based metrics (phenology of inundation/drawdown, monsoon timing, seasonal variation)                 | Metric            | Various (cm, days, variance) |

**Table 36. Example WEI measures and metrics by objective, continued.**

| Objective                                                                                               | Parameter                                                                                         | Measure or Metric | Units                      |
|---------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|-------------------|----------------------------|
| Determine the status and trend in wetland condition via soil chemistry                                  | Depth to peat                                                                                     | Measure           | cm                         |
|                                                                                                         | Presence of mottles, sulfidic odor, gleying                                                       | Measure           | Categorical                |
|                                                                                                         | Texture                                                                                           | Metric (lab)      | NA                         |
|                                                                                                         | Sand, silt, and clay                                                                              | Measure (lab)     | %                          |
|                                                                                                         | pH                                                                                                | Measure (lab)     | pH                         |
|                                                                                                         | Cation exchange capacity                                                                          | Measure (lab)     | cmol <sub>c</sub> /Kg soil |
|                                                                                                         | Micro and macronutrients                                                                          | Measure (lab)     | %                          |
|                                                                                                         | Percent organic matter                                                                            | Measure (lab)     | %                          |
| Determine the status and trend in wetland condition via in situ water chemistry                         | C:N                                                                                               | Metric (lab)      | Ratio                      |
|                                                                                                         | pH                                                                                                | Measure           | pH                         |
|                                                                                                         | Specific conductance                                                                              | Measure           | µS/cm                      |
|                                                                                                         | Temperature                                                                                       | Measure           | °C                         |
| Determine the status and trend in anthropogenic and natural disturbance regimes in and around wetlands. | Meso- and landscape-scale habitat structure and composition (buffer size, distance to road, etc.) | Measure           | Various                    |
|                                                                                                         | Site-level topology (elevation, slope, aspect)                                                    | Measure           | Various                    |
|                                                                                                         | Beaver disturbance                                                                                | Measure           | Categorical                |
|                                                                                                         | Native ungulate disturbance                                                                       | Measure           | Ordinal                    |
|                                                                                                         | Natural disturbance index                                                                         | Metric            | Unitless                   |
|                                                                                                         | Human disturbance index                                                                           | Metric            | Unitless                   |

\* The River Invertebrate Prediction and Classification system, see text

### RIVPACS

The River Invertebrate Prediction and Classification system (RIVPACS; Hawkins et al. 2000, Van Sickle 2008) is more commonly applied to aquatic bioassessment, but it should be ideal for wetland monitoring as well. As of publication, we were still developing RIVPACS models for wetland vegetation.

RIVPACS models predict the specific taxa that should occur at a site given its natural (i.e., reference) environmental characteristics. Specifically, these models describe how probabilities of capture of all taxa of interest vary across naturally occurring environmental gradients. Expected taxa (E) are those that should occur in a sample collected from a site with specific environmental features assuming that site was in reference condition. By

sampling the actual or observed (O) assemblage at the site, the simple ratio of O and E estimates the taxonomic completeness of the assemblage. This is a fundamental aspect of biological integrity. The O:E ratio is both a site-specific and standardized index with values that theoretically range from 0 to 1. Values of 1 imply reference, and values <1 imply non-reference conditions (most applications define an assessment point less than 1 that actually is used in assessment). RIVPACS models are constructed with only reference site data, and the accuracy and precision of RIVPACS assessments depend solely on how well models predict the taxa expected under reference conditions. If reference sites are not in natural condition, then models predict the biota that should occur given the potentially non-reference quality of the sites used in modeling. We also include a Bray-Curtis measure of the

distance between O and E for each sample. This is an alternative way to measure the compositional dissimilarity between an observed and expected assemblage and may perform better as it can include low-probability taxa without reducing the power to detect non-reference conditions (Van Sickle 2008).

### ***Structural Equation Modeling***

Multimetric indexes provide condensed summaries of condition ideal for synthetic statements (i.e., in a summary condition table), but can 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 is not developed. To tackle this problem, we first developed a next-generation methodology for structural equation modeling (SEM) so that we could 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 the ROMN and our partners learn about the mechanisms controlling wetland condition and trend.

As of the time of this protocol's publication, we were developing a SEM to better understand the connections and linkages amongst wetland vegetation response (with ROMO as our test case), anthropogenic disturbance, and natural gradients or disturbance (in ROMO this includes an absence of beaver and too many ungulates). New methods within the model generalize 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 interpretation and application. This includes both retrospective analyses, such as attribution of current system properties to previous conditions, as well as prospective analyses that forecast future states, either under constant conditions or under modified conditions.

### ***Analyses for Status***

We define status as a “snap shot” evaluation of a WEI response at a single point or well defined and concise range in time (Britten et al. 2007). WEI status based objectives have been defined for all ROMN WEI parks. Status may be estimated using sentinel site data, in which case the results apply only to the target population of the sentinel site (or wetland complexes), or with survey data and inference to non-sampled wetland. Status can be estimated using either measures or metrics and a variety of statistics (e.g., means or proportions) and statistical methods (e.g., models, design-based). It is usually calculated over all monitoring sample events within a single or well-bounded temporal window. 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, standard 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 WEI 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 WEI monitoring in a park to identify a workable set of variables or metrics that best explain the status of wetlands among the vast possible sets, to aid in the refinement of existing hypotheses, and 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 that might be influencing these patterns. Typically, we first conduct cluster analysis to group vegetation 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 vegetation 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.

Multivariate exploratory analyses typically require or work best with large, spatially diverse data sets. Therefore, they are best

done with survey data available from GRSA and ROMO. However, because there is no statistical inference conducted within these techniques, we often include sentinel and gradient sites as well, with the caveat that these sites are not necessarily 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. Finally, MMI, RIVPACS and SEM modeling all heavily use multivariate techniques.

### ***Design-based Estimation of Status***

To generate proper inference of status (in ROMO for park-scale target populations of three types of wetland, and in GRSA for a sandsheet scale target population of one wetland type), 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 (Horvitz and Thompson 1952, 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. Anyone who reads the results of a national political poll is seeing a design-based analysis. The approach may be used to generate most statistics such as means, totals, proportions (i.e., of a population above or below an assessment point) of any WEI measure or metric.

### **Analyses for Trend**

Estimating trend in vital signs is central to several sentinel and survey site based objectives in multiple ROMN parks. 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 WEI 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 WEI analyses, therefore, use a conservative approach for detecting trend by estimating linear trend without asserting that a detected trend is linear (i.e., the underlying linear component will be different than zero when any 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, 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). Other methods include time-series analyses. 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). This model can simultaneously estimate trend, variance components, and the effects of covariates (Larsen 1997). Important sources of variance in the model include wetland (population variance), year, year\*wetland (interaction effects), and in some cases, within-wetland 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. True trend requires multiple revisits and will not be available for some time.

## Hypothesis Tests

The final type of analysis we introduce is comparison of the status or trend in a ROMN vital sign with assessment points through formal hypotheses that are developed and tested statistically. In scientific settings, hypothesis testing is a keystone approach used to compare results in an experimental context to determine effects of treatments. We use this method in the WEI 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 WEI 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).

Hypothesis 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 WEI protocol are suitable for hypothesis testing. For example, population-scale, design-based results can use nonparametric 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 Measures and Metrics

WEI data will be analyzed using various methods that help understand the utility, quality and efficiency of WEI measures and metrics. These include (1) simple statistics like coefficients of variation for a subset of response measures at revisited sites and within sample event replicated measures, and (2) a signal to noise (S:N) analysis. The S:N method is briefly summarized below.

### Signal to Noise

A key statistic used to investigate the value of WEI 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 ROMO and GRSA 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. Metrics 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 WEI data often require data not generated by the WEI protocol itself. We therefore collect auxiliary data from readily available NPS or partner sources and build these into the WEI database. Brief descriptions of these data and how they are used in conjunction with or in support of WEI analyses follow.

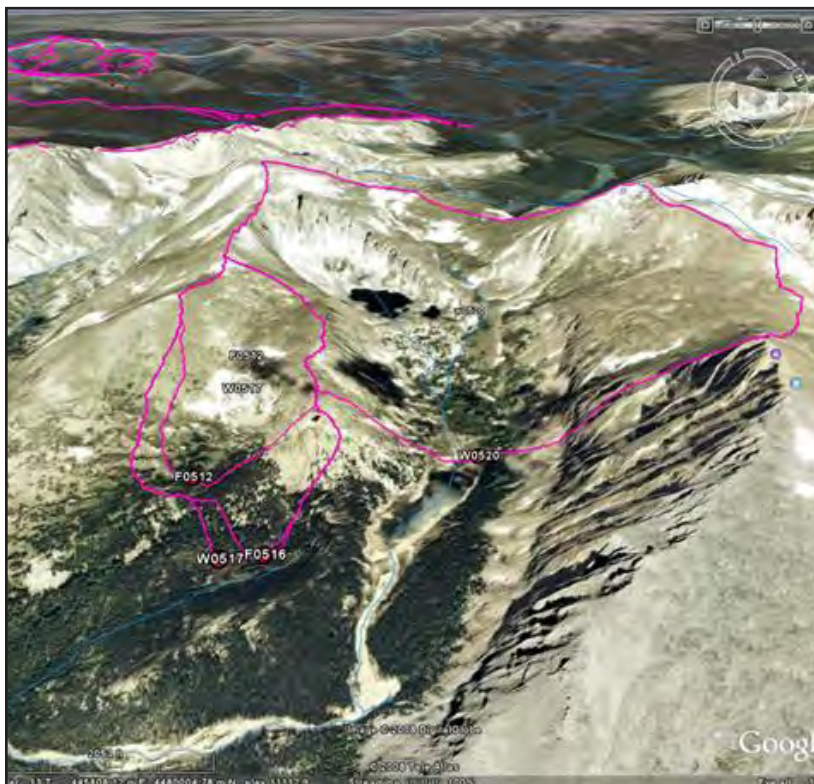
## Vegetation and Human Disturbance

We collect data for several vegetation and human disturbance measure and metrics from partner monitoring sites located in ecoregion(s) around ROMO, GRSA and FLFO. Similar data for GLAC WEI (or AWEI) will be developed in the future as possible. ROMN partners with comparable auxiliary data include CNHP, EPA and Colorado State University. Most sites are part of long-term monitoring conducted by these agencies (i.e., Lemly and Gilligan 2012, EPA 2011). Auxiliary data used have appropriate QAQC and identical or comparable field methods. In several cases, auxiliary data may have been sampled during different years than WEI data collection, and this is an important caveat on analyses that use these data. The EPA National Wetland Condition Assessment (EPA 2011) 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 WEI protocol.

## Catchment Disturbance, Landscape, and Climate

Many analyses of WEI data use covariate data summarized across supporting areas as ways to help understand patterns and lend insight into the factors controlling status and trend in a response. Two types of supporting areas are developed for all WEI sites: upstream or upslope catchments (see Figure 40 for a ROMO example) and simple buffers at a variety of scales (generally 100 m to 1 km). Table 37 gives example data developed from GIS modeling, other ROMN protocols, or ROMN collaborator research projects.

**Figure 40.** Example of catchments for four WEI sites in ROMO.



Most GIS derived indices are simple and generated using standard procedures within ArcMap or ArcView (ESRI 2000, 2011). We focus on simple measures that have well-established relationships with wetland response as suggested by conceptual modeling or other research. However, we also recognize that there is value in exploring statistical relationships amongst a suite of predictors and wetland response that may suggest interesting and useful ecological relationships. For some of the slightly more

complex GIS-based output we use the Analytical Tools Interface for Landscape Assessments (ATtILA; Ebert and Wade 2000, Riitters et al. 2000) modeling package within ArcView 3.2. While this is a now dated GIS modeling environment, its simplicity and portability were appropriate. ATtILA creates metrics of landscape characteristics, riparian characteristics, human stressors, and physical characteristics for defined units (i.e., catchments or buffer zones).

**Table 37. Example context, landscape composition and climate auxiliary data for analyzing WEI response.**

| Parameter                                                             | Units                             | Source                     |
|-----------------------------------------------------------------------|-----------------------------------|----------------------------|
| Reach Slope                                                           | Degrees                           | DEM                        |
| Site Elevation                                                        | m                                 | DEM                        |
| Catchment Size                                                        | m <sup>2</sup>                    | GIS                        |
| Mean Precipitation, (30-year normal)                                  | cm                                | PRISM Climate Group (2015) |
| Mean Precipitation (sampled year)                                     | cm                                | PRISM Climate Group (2015) |
| Min/Max/Mean USGS Modeled Stream Water Temperature in Catchment, 2008 | °C                                | USGS, Jones et al. (2013)  |
| Min/Max/Mean Ambient Air Temperature in Catchment                     | °C                                | PRISM Climate Group (2015) |
| Road Density                                                          | Length per unit area in catchment | TIGER                      |
| Road-Stream Crossing                                                  | Number per unit area in catchment | TIGER; ATtILA              |
| Agricultural Land Use                                                 | % of catchment                    | NLCD/VegMap                |
| Urban Land Use                                                        | % of catchment                    | NLCD/VegMap                |
| Percent Natural Vegetation                                            | % of catchment                    | NLCD/VegMap                |
| Phosphorous Load                                                      | Modeled from landcover            | NLCD/VegMap                |
| Nitrogen Load                                                         | Modeled from PRISM/NADP data      | Baron et al. (2011)        |
| Human Population Density                                              | Number residents per unit area    | CENSUS                     |
| Percent Impervious Surfaces                                           | %                                 | NLCD/VegMap                |
| Accessibility                                                         | Time                              | ROMN Model                 |
| Percent as Glacier                                                    | %                                 | NHD                        |
| Distance to Upstream Lake Outlet                                      | km                                | NHD                        |
| Percent of Watershed Burned over Last 5 and Last 25 yrs               | %                                 | GIS                        |



# Administration and Operations

The ROMN long-term ecological monitoring program developed over several years and is 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 signs, conceptual models, sample design, sampling protocols, data management, analysis and reporting, administration and implementation, schedule, and overall budget. It guides overall implementation of ROMN monitoring including WEI monitoring and provides overall guidance on program implementation and management, roles and responsibilities, partnerships, and budget.

The ROMN began WEI protocol development monitoring efforts in 2006 and we have conducted pilot monitoring in four ROMN parks through 2012. The cost estimates for field work and sample analysis are based on actual 2012 costs in ROMO, GRSA, FLFO, and GRSA, so the budget presented is suitable for projecting future costs, especially in the near term. As the ROMN continues WEI monitoring, we will estimate costs for each fiscal year (FY) using cost information from the previous FY through the annual ROMN work plan process. As the ROMN monitoring program evolves and we acquire and analyze WEI (and other monitoring) data, and as ROMN park and network monitoring priorities change, we will adjust our plans and budget allocation to best meet changing needs. We will strive to reduce field sampling and lab analysis needs over time as we accumulate and analyze WEI data and develop a better understanding of WEI in ROMN parks.

In this chapter, we focus on operational aspects of implementation of WEI monitoring and associated sample costs (e.g., field monitoring efforts and soil sample analyses conducted by outside partners). We document operational and administrative aspects of the WEI protocol

development and pilot monitoring efforts to date, describe roles and responsibilities for WEI field work, describe the field crew model (and qualifications and training for crews) for annual or operational WEI monitoring, provide two alternatives for conducting future WEI surveys in ROMO and GRSA, and provide budget estimates for field monitoring and sample analysis costs. We do not include estimates for internal data management, analysis, and reporting and communication of WEI data and results as described in the ROMN Vital Signs Monitoring Plan and elsewhere in the WEI protocol.

## Roles and Responsibilities

The WEI protocol requires effective management and oversight from network staff as well as support from local park staff to assist with crew training and tracking (for backcountry monitoring trips), logistics, permitting, and sentinel site sampling. Local park staff can also serve as field crew members and assist with interpreting and utilizing wetland monitoring data. Outside collaborators/experts are used for taxonomic expertise for some plant taxa (bryophytes, sedges) and for helping interpret wetland monitoring data. Field sampling is accomplished by temporary field crews of two to five people (seasonal employees or interns) led by the Field Coordinator or other ROMN staff. It is important that field crew members and teams have the necessary training (WEI monitoring, safety, park communication, and backcountry travel) and skills (plant identification and sampling, data logger use, data management) to work safely and effectively in the parks. Detailed information on hiring and training seasonal employees and interns for wetland field crews is in the ROMN field crew hiring, training, and management SOPs (ROMN SOPs: Seasonal Hiring; Training; Safety Preparation and Training).

Roles and responsibilities for the WEI protocol are described in Table 38. The ROMN Program Manager will assign a Protocol Lead who oversees and coordinates

**Table 38. WEI monitoring personnel and responsibilities.**

| <b>Role</b>                                        | <b>Responsibilities</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Protocol Lead                                      | Coordinate all protocol activities: advise Field Coordinator of annual field season monitoring targets and needs; validate and analyze data; write annual and comprehensive monitoring reports; manage protocol budget; work with ROMN Program Manager and Data Manager to meet reporting requirements, manage WEI database, and revise protocol, as needed.                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Data Manager                                       | Maintain database; provide technical support for database management, data quality assurance/quality control (QA/QC), data queries, data storage, archiving and dissemination, and data analysis procedures; provide GIS technical support.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Program Manager                                    | Coordinate with Protocol Lead to meet I&M Program requirements (e.g., budget, reporting, education/outreach, and others); integrate wetlands monitoring with the rest of Vital Signs Program.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Park Ecologists                                    | Assist with oversight, training, and support of field crew(s) in respective park; assist with field sampling.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Field Coordinator                                  | 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 WEI monitoring, safety, backcountry, and park communication. Ensure crews have proper field monitoring equipment and supplies. Schedule field monitoring for WEI (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 to the Program Manager as soon as possible. Report any monitoring issues to Program Manager.                                                                                                                                  |
| Crew Leader<br>(assigned by the Field Coordinator) | 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 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, soil, and hydrologic data following WEI 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                     | Plant identification (e.g., sedges, bryophytes). Consult with ROMN staff on analysis and interpretation of WEI data.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Park staff and local area experts                  | Provide guidance and technical assistance as needed; recommending cross-country hiking routes, permitting, Wilderness Minimum Requirements Analysis, and other tasks. Participate as members of field crews.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Park resource manager(s)                           | Assist in interpreting monitoring data and help ROMN staff develop management relevant reference conditions and thresholds for WEI data. Assist ROMN to obtain resources needed for monitoring (especially park-wide WEI survey efforts).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

all WEI monitoring activities. Currently, the ROMN Ecologist (GS-12) is the WEI Protocol Lead. The Protocol Lead will work with the Program Manager to determine and manage the annual WEI budget. The Protocol Lead will advise the Field Coordinator of annual WEI monitoring needs so s/he can manage all aspects of the field monitoring effort including hiring, supervising, and managing field crews; arranging field logistics; and purchasing, repairing, and organizing field gear. The Protocol Lead will work with the Data Manager to develop and manage and query the WEI database(s). The Protocol Lead is the primary person responsible for writing WEI status and trends reports.

### ***Field Crews for WEI Monitoring***

WEI field monitoring requires crew members to carefully, thoughtfully, and accurately observe and record biological, ecological, hydrological, and human disturbance data from sites (often remote wilderness sites) in a wide variety of environmental conditions. Crew members must be able to work together safely, effectively, and efficiently to access WEI sites, conduct field monitoring, collect and manage field data, and return to their quarters or duty station.

ROMN monitoring for all field protocols to date (2006-2013) has utilized a variety of field crew members including volunteers, Student Conservation Association interns, Utah State University (Tehabi Program) interns, graduate and undergraduate students (through cooperative agreements with universities), seasonal NPS Biological Science Technicians, and permanent ROMN staff. Based on this experience, we believe the most cost-effective and safest crew model is to utilize experienced NPS Biological Science Technicians for “operational” annual field monitoring (but not necessarily for more ambitious WEI surveys, see below).

### ***Qualifications for WEI Field Crews***

The ROMN will hire the best available WEI monitoring Biological Science Technicians. Important knowledge, skills and abilities, and experience include: plant identification (especially for wetland plants of the Rocky

Mountain region), wetland ecology, use of data loggers and other electronic data collection instruments and devices, navigation to remote sites using GPS and map and compass, backcountry travel in a wide variety of weather conditions and at high altitudes, safe driving, basic and wilderness first aid and CPR methods and techniques, safety and risk management, and working safely in areas with hazardous wildlife (especially grizzly and black bears and mountain lions).

### ***Field Crews for Annual WEI Sentinel Site Monitoring***

Our current field crew staffing model is to hire one ROMN Fort Collins-based field crew of two seasonal employees (one more experienced GS-6 or 7 Biological Science Technician as the crew leader and one GS-5 Biological Science Technician crew member) for all annual operational field monitoring in the Colorado parks (ROMO, FLFO, and GRSA). We pay for two GLAC Biological Science Technicians to conduct field monitoring in the Montana parks. Once we implement operational monitoring in GLAC, we will use GLAC Biological Science Technicians to conduct the field work. Other ROMN staff (primarily the Field Coordinator) and ROMN park staff and partners (such as student interns or volunteers) participate in annual WEI monitoring (although we don’t include these contributions in the budget). For the foreseeable future, we will use this crew staffing model to accomplish annual WEI monitoring in ROMN parks.

We will continue to solicit ROMN parks to provide field crew members (permanent staff, seasonal staff, interns, or park volunteers) for annual WEI monitoring whenever possible. This has several benefits, including (1) saving ROMN funds that can be used for additional inventory and monitoring needs; (2) providing park staff with a better understanding of ROMN methods, data, utility, and other information; and (3) providing ROMN staff with a better understanding of park management needs for the data and how to better address them.

Finally, we will seek well-qualified volunteers for annual monitoring from a

variety of sources, such as WASO NRSS and other agencies whenever possible. We don't assume there will be significant park staff contributions to accomplish WEI monitoring and we don't include volunteer contributions in our budget formulation.

### ***Training for WEI Field Crews***

ROMN field crew members all receive training in backcountry travel and communication with parks; safety, 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. WEI field crew members will be provided time to read and understand the WEI protocol and standard operating procedures and receive one day of WEI monitoring field training. They will also receive a half day of data management training so they can better understand how the data they collect is entered and used. Early in the field season, WEI crews will be provided on-the-job field training by the Field Coordinator as sampling occurs.

### ***Field Crews for WEI Surveys and Projects***

For future park-wide WEI surveys, we will evaluate the costs and benefits of (1) working with an institutional partner such as Colorado State Univ. or the Colorado Natural Heritage Program through a Cooperative Ecosystem Studies Unit Agreement to complete these ambitious efforts, or (2) doing the work in-house as described for annual WEI sentinel site monitoring. The advantages to the first option include (1) accessing the knowledge and experience of an outside subject matter expert; (2) accessing well-qualified students with a vested interest in accurately collecting, analyzing, and publishing WEI monitoring data on time; and (3) the ability to obligate funds in the initial FY of a large WEI monitoring project for monitoring over a five-year period. The advantages to conducting this work in-house include (1) saving "overhead" or indirect costs of 17.5% charged on all CESU agreements and (2) directly supervising those who will be conducting the WEI surveys.

## **Partnerships for Protocol Development**

The ROMN developed the WEI protocol through partnerships with many individuals and several institutions through cooperative and interagency agreements. These are listed, along with the funding sources and totals, in Table 39.

We see many advantages to increasing park participation in ROMN WEI monitoring. WEI monitoring costs are significant, especially if the network has to hire and train dedicated WEI crews for park WEI surveys. While we have been able to hire generally well-qualified crews, it takes time for them to gain the knowledge and expertise for WEI 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 the ROMN in crew costs and travel. The savings can be applied to other park monitoring needs.

An additional benefit of park participation in WEI 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 WEI data and information. Park participation also helps ROMN staff better understand park WEI issues and information needs.

## **Budget**

### ***Sentinel Site Monitoring***

Current ROMN plans are to monitor WEI in GLAC, ROMO, FLFO, and GRSA with annual or biannual sentinel site monitoring. Future power modeling will help understand the implications of affordable sample sizes to our ability to estimate status and trends. Currently, we monitor four wetland sentinel site complexes in ROMO, five in GRSA, and three in FLFO. GLAC sentinel site locations for long-term monitoring were still being determined at time of publication. In the future, if monitoring needs and funding allows, the network might also implement

**Table 39. ROMN WEI Agreement Summary, 2006-2012.**

| Year                         | Agreement or project title                                           | PI                                                 | Institution | Total            | Funding source                                   | Notes                                                            |
|------------------------------|----------------------------------------------------------------------|----------------------------------------------------|-------------|------------------|--------------------------------------------------|------------------------------------------------------------------|
| 2006                         | Wetland protocol development                                         | David Cooper/Edward Gage                           | CSU         | \$72,860         | ROMN Vital Signs funds                           |                                                                  |
| 2007                         | Wetland protocol development                                         | Cooper/Gage                                        | CSU         | \$55,231         | ROMN Vital Signs funds                           |                                                                  |
| 2008                         | Wetland pilot monitoring survey for ROMO                             | Katharine Driver/Cooper                            | CSU         | \$56,040         | ROMN Vital Signs funds                           |                                                                  |
| 2008                         | Wetland pilot monitoring survey for GRSA                             | Jennifer Jones/Cooper                              | CSU         | \$84,765         | ROMN Vital Signs funds                           | One agreement plus one modification                              |
| 2009                         | Wetland pilot monitoring survey for GRSA                             | Jones/Cooper                                       | CSU         | \$12,000         | ROMN Vital Signs funds                           |                                                                  |
| 2009                         | Soil sample analyses for wetlands and upland vegetation monitoring   | James Self                                         | CSU         | \$13,088         | ROMN Vital Signs funds                           | Total funding is \$26,176, with ~ half for wetland soil analysis |
| 2010                         | Wetland pilot monitoring project for GLAC                            | Cristina McKernan/Cooper                           | CSU         | \$44,219         | ROMN Vital Signs funds                           |                                                                  |
| 2010                         | Wetland monitoring data power analysis                               | Leigh Ann Starceovich                              | CSU         | \$7,050          | ROMN Vital Signs funds                           |                                                                  |
| 2011                         | Soil sample analyses for wetlands and upland vegetation monitoring   | William Schweiger                                  | CSU         | \$18,860         | ROMN Vital Signs funds                           | Total funding is \$37,720, with ~ half for wetland soil analysis |
| 2011                         | Wetland plant occurrence and abundance: linkage to hydrology project | Derek Shook/Cooper                                 | CSU         | \$5,000          | ROMN Vital Signs funds                           |                                                                  |
| 2011                         | Wetland plant occurrence and abundance: linkage to hydrology project | Shook/Cooper                                       | CSU         | \$5,000          | Rocky Mountain NP Research Learning Center funds |                                                                  |
| 2011                         | Wetland plant occurrence and abundance: linkage to hydrology project | Shook/Cooper                                       | CSU         | \$5,000          | Rocky Mountains Coop. Ecosystem Study Unit funds |                                                                  |
| 2012                         | Wetland pilot monitoring project for GLAC                            | McKernan/Cooper                                    | CSU         | \$62,013         | ROMN Vital Signs funds                           |                                                                  |
| 2012                         | Wetland data analysis and reporting for GRSA and FLFO                | Jones/Cooper                                       | CSU         | \$10,379         | ROMN Vital Signs funds                           |                                                                  |
| 2009                         | ROMO wetland analysis and modeling                                   | James Grace/Donald Schoolmaster/Glen Guntensbergen | USGS        | \$45,000         | USGS Status and Trends funds                     |                                                                  |
| 2009                         | ROMO wetland analysis and modeling                                   | Grace et al.                                       | USGS        | \$61,000         | USGS operational funds (in-kind contributions)   |                                                                  |
| 2010                         | ROMO wetland analysis and modeling                                   | Grace et al.                                       | USGS        | \$69,000         | USGS Status and Trends funds                     |                                                                  |
| 2010                         | ROMO wetland analysis and modeling                                   | Grace et al.                                       | USGS        | \$64,000         | USGS operational funds (in-kind contributions)   |                                                                  |
| <b>Total funding&gt;&gt;</b> |                                                                      |                                                    |             | <b>\$690,505</b> |                                                  |                                                                  |

WEI monitoring in Grant-Kohrs Ranch National Historic Site (GRKO) and Little Bighorn Battlefield National Monument (LIBI), likely focused on riparian wetlands. Note that the number and location of sentinel complexes in the parks may change depending on data analyses, park issues and needs, budgets, and ROMN priorities overall, but we use the figures in this chapter for budget planning purposes (Table 40).

We will continue the current ROMN field crew model described above for all ROMN field monitoring including WEI field monitoring. Cost estimates for field crew salary and benefits and travel for each park for annual sentinel site monitoring are presented in Table 41. We used actual FY2012 costs for field crew salary and benefits (rather than estimated costs from OPM salary tables) for these calculations. We estimated travel costs using the backcountry per diem rate of \$20/crew member/day.

### **Surveys**

Our pilot monitoring efforts for ROMO and GRSA were conducted cooperatively with David Cooper as the PI with Colorado State University; those agreements and costs are summarized in Table 39 above. We plan to repeat the ROMO and GRSA surveys in the future (at roughly five- to ten-year intervals, see the revisit design section), but do not plan WEI surveys at the other parks at this time.

For future WEI surveys, we will evaluate the costs and benefits of using a cooperator or doing the work entirely in-house before deciding on the preferred model. Working with a cooperator has all of the benefits outlined in the section, Partnerships for Protocol Development.

#### **ROMO WEI Survey Cost Estimate Using a ROMN Crew of Three Biological Science Technicians**

For ROMO, we will use the same design and methodology as for the 2007-2009 pilot survey. We will sample 50 survey sites, 30 sentinel sites, and conduct 10 partial sample events/logger downloads per year using this crew. We will do this for three field seasons (for a total of 150 survey site sample events, 90 sentinel site sample events, and 30 partial

sample events). The NPS crew will consist of a GS-7 Biological Science Technician crew leader and two GS-5 Biological Science Technician crew members. The annual cost for crew salary and benefits and travel is \$59,040, and the total cost over the three-year survey is \$177,120.

#### **GRSA WEI Survey Cost Estimate Using a ROMN Crew of Three Biological Science Technicians**

For GRSA, we will use the same (or similar) design and methodology as for the 2010 pilot survey. We will sample 40 survey sites and 21 sentinel sites per year using this crew. We will do this for two field seasons (for a total of 80 survey site sample events and 42 sentinel site sample events). The NPS crew will consist of a GS-7 Biological Science Technician crew leader and two GS-5 Biological Science Technician crew members. The annual cost for crew salary and benefits and travel is \$40,670, and the total cost for the 2-year survey is \$81,340.

### **Facilities, Supplies, and Equipment**

ROMN offices are co-located with the NPS WASO NRSS Directorate located in Fort Collins, Colorado. The ROMN field crews (for WEI and all Colorado park field monitoring) are duty stationed in Fort Collins and will use ROMN office space (two small cubicles with workstations) for WEI data management and administrative needs (e.g., travel and time and attendance processing).

In the future, we may consider duty stationing the crew at ROMO if the park has housing and work stations available and agrees to host the crew. This arrangement would be the most effective way to conduct future ROMO WEI surveys. Advantages to this arrangement include providing a more cost-effective housing alternative (currently the park charges \$8/day or ~\$240/month) for crew members and eliminating most travel costs. It also may increase our ability to hire and retain the best technicians. A ROMO duty station would also provide a better connection to park operations (for ROMO, but potentially all ROMN parks). The ROMN might also consider using ROMO Biological Science Technicians for

**Table 40. Number of sites, timing, and crew needed for annual sentinel site monitoring. Each complex contains four or more individual plots. Note: as of 2013 plans for GLAC are tentative.**

| Park | Number of complexes | June   |        |        |        | July   |        |        |        | August |        |        |        |
|------|---------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|      |                     | week 1 | week 2 | week 3 | week 4 | week 1 | week 2 | week 3 | week 4 | week 1 | week 2 | week 3 | week 4 |
| ROMO | 4                   |        | 3 days | 4 days |        | 2 day  |        |        |        |        |        |        | 2 days |
| FLFO | 3                   |        |        |        | 1 day  |        |        |        | 3 days |        |        |        |        |
| GRSA | 5                   |        |        |        |        |        | 9 days |        |        |        |        |        |        |
| GLAC | 8                   |        |        |        |        |        |        | 2 days | 2 days | 2 days | 2 days |        |        |

**Table 41. Annual WEI sentinel site monitoring costs for ROMN parks. Each complex contains four or more individual plots. Note: as of 2013 plans for GLAC are tentative.**

| Park | # Sites/<br>complexes | # Full sample<br>event days | # Partial sample<br>event days | Salary/benefits<br>for full sample<br>event | Salary/benefits<br>for partial<br>sample event | Travel cost per<br>day for full<br>sample event | Travel cost per<br>day for part.<br>sample event | Total annual<br>cost |
|------|-----------------------|-----------------------------|--------------------------------|---------------------------------------------|------------------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------|
| ROMO | 4                     | 9                           | 3                              | \$618                                       | \$381                                          | \$84                                            | \$56                                             | \$7,626              |
| FLFO | 3                     | 3                           | 1                              | \$618                                       | \$381                                          | \$84                                            | \$56                                             | \$2,542              |
| GRSA | 5                     | 9                           | 0                              | \$618                                       | \$381                                          | \$84                                            | \$56                                             | \$6,314              |
| GLAC | 8                     | 8                           | 4                              | \$446                                       | \$446                                          | \$0                                             | \$0                                              | \$5,347              |

**Table 42. 2012 ROMN GSA vehicle lease costs. Mileage rates include fuel and routine maintenance costs.**

| Vehicle                   | Monthly rate | Mileage rate |
|---------------------------|--------------|--------------|
| Ford Escape hybrid        | \$328        | \$0.24       |
| Ford crew cab 4WD pick-up | \$246        | \$0.25       |
| Jeep Cherokee             | \$323        | \$0.24       |

WEI monitoring in ROMO and FLFO and GRSA (following the Montana parks field monitoring model) if they have outstanding crew members and it makes sense to share them.

The network uses a small wet laboratory shared with the Water Resources Division and the Biological Resource Management Division for WEI monitoring sample processing. We do not pay for use of the lab and the ROMN Ecologist works cooperatively with these divisions to manage and equip the lab. We don't anticipate being charged for lab use in the foreseeable future.

The ROMN pays for ROMN-specific monitoring equipment/needs (including WEI monitoring needs) from the Vital Signs and Water Quality monitoring budget. Mostly, our field equipment monitoring needs are modest and, since we have already bought the equipment, annual costs are very low (on the order of \$200/year). The one exception is for equipment to monitor water table depth in wetlands. This includes slotted PVC pipe to line the wells and associated hardware and data loggers. Annual well PVC pipe and hardware costs are ~\$200 (replacement/maintenance) for all four parks. We currently use in situ Troll 300 data loggers (and one In-Situ barrologger per each of the four WEI monitoring parks) for annual sentinel site monitoring. The data loggers cost ~\$300 each and the barrologgers cost ~\$100 each. Annual data logger costs are ~\$2,000 (replacement/maintenance) for all four parks.

The ROMN stores all field equipment (including for wetland, stream, and vegetation and soils monitoring protocols) at a private storage facility, SecurCare Self Storage, approximately 1 mile west of our offices. The 2013 rate was \$79/month or \$948/year for a 5x10 square foot unheated storage space. The WEI share of this cost is ~\$237/year.

### **Vehicles**

To date, the ROMN has used ROMN staff personal vehicles (POVs), rental, GSA-leased, and CSU Motor Pool vehicles (for work done via cooperative agreement). GSA-leased vehicles are by far the most

cost-effective and preferred alternative (Table 42). A significant advantage to using GSA vehicles is that the cost does not count against the ROMN travel ceiling. Another advantage is that the ROMN can lease the type of vehicle that best meets specific monitoring needs. For example, for FLFO monitoring, a hybrid sport utility vehicle is preferable, but for GRSA a high clearance true 4WD vehicle is required.

### **Soils**

The WEI protocol includes soil chemistry sampling and analysis. This information is important to properly classify wetland type and especially for interpreting wetland plant and hydrological variations.

We work with the CSU Soil, Water, and Plant Testing Lab through the RM CESU agreement to analyze soils. Each chemistry sample costs \$129 and each organic matter sample costs \$10. For future annual soil sample analysis, we will assume we need to document soil chemistry for ten samples across all four parks per year (at new sites or as needed at existing sites). Complete resampling of soils will occur episodically (probably every five to ten years).

### **Overall WEI Operational Monitoring Budget**

The estimated total annual cost for ROMN WEI monitoring using NPS field crews (does not include cyclic WEI surveys) is \$27,370 (Table 43). This estimate is based on 2012 costs and projected annual WEI monitoring efforts in GLAC, ROMO, FLFO, and GRSA. Future estimates for all WEI field monitoring efforts will be done as part of the annual ROMN work planning and budget development process using specific information, such as scheduled OPM salary increases, scheduled step increases for returning Biological Science Technicians, GSA vehicle lease and mileage rate charges for each FY, and other factors. To give an approximate estimate of annual WEI field monitoring costs in five years and in ten years, we will assume a 2% annual increase for field crew salaries and benefits and a 3% annual increase in all other categories. Under those assumptions, the annual cost is \$30,634 in FY2018 and \$34,304 in FY2023.

## Publishing and Revising the Protocol

The WEI protocol document 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 WEI 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 WEI 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 published as an NPS Natural Resource Report.

**Table 43. Annual ROMN WEI field monitoring budget (does not include cyclic WEI surveys).**

| Field Crew Salaries and Benefits                           |                 |
|------------------------------------------------------------|-----------------|
| ROMN crew for Colorado Park WEI monitoring                 |                 |
| ROMO                                                       | \$6,702         |
| FLFO                                                       | \$2,234         |
| GRSA                                                       | \$5,558         |
| GLAC crew for GLAC WEI monitoring                          | \$5,347         |
| <b>Total field crew salary and benefits&gt;&gt;</b>        | <b>\$19,841</b> |
| Travel                                                     |                 |
| ROMO                                                       | \$924           |
| FLFO                                                       | \$308           |
| GRSA                                                       | \$756           |
| GLAC crew for GLAC WEI monitoring                          | \$0             |
| <b>Total field crew travel&gt;&gt;</b>                     | <b>\$1,988</b>  |
| GSA Vehicles                                               |                 |
| ROMO                                                       | \$329           |
| FLFO                                                       | \$420           |
| GRSA                                                       | \$292           |
| GLAC                                                       | \$574           |
| <b>Total vehicles&gt;&gt;</b>                              | <b>\$1,614</b>  |
| Supplies and Equipment                                     |                 |
| Basic field monitoring equipment (annual replacement cost) | \$200           |
| Well monitoring equipment                                  |                 |
| PVC and hardware                                           | \$200           |
| Data loggers                                               | \$2,000         |
| Monitoring equipment storage                               | \$237           |
| <b>Total supplies and equipment&gt;&gt;</b>                | <b>\$2,637</b>  |
| Sample Analysis, Soils                                     |                 |
|                                                            | <b>\$1,290</b>  |
| <b>Total sample analysis&gt;&gt;</b>                       | <b>\$1,290</b>  |
| <b>Grand total all annual WEI monitoring costs</b>         | <b>\$27,370</b> |



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# Appendix A: Previous Wetland Research in ROMN Parks

## Previous Wetland Research in ROMN Parks: Bibliography

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The following list (Table A1) and bibliography was compiled in December 2009 via searching Web of Science and NatureBib for articles that included the park names (Glacier, Great Sand Dunes, Rocky Mountain, Florissant Fossil Beds, Grant-Kohrs Ranch, or Little Bighorn) and key words related to wetlands (wetland, marsh, riparian, fen, wet meadow, peat, bog, amphibians). The investigator annual reports were found in December 2009 via the NPS research and reporting system (<https://irma.nps.gov/rprs/Home>).

**Table A1. Recent Investigator Annual Reports from ROMN parks pertaining to wetlands through December 2009.**

| Park | Year    | Investigator    | Subject                                                                                                                                                     |
|------|---------|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GRKO | 1997    | Huaer, R        | Model calibration of an hydrogeomorphic assessment of riverine wetlands                                                                                     |
| GRKO | 1998-99 | Hansen, P       | A second approximation of jurisdictional wetland status                                                                                                     |
| GRKO | 2003    | Hansen, P       | Sampling and analysis for validation of the Clark Fork River riparian evaluation system                                                                     |
| GRSA | 1997    | Rowlings, P     | Environmental history-riparian patterns                                                                                                                     |
| GRSA | 1998    | Harmon, E       | Expand well network to improve understanding of aquifer                                                                                                     |
| GRSA | 1998-99 | Cooper, D       | Determining the cause of interdunal wetland disappearance at Great Sand Dunes National Monument                                                             |
| GRSA | 2002    | Muths, E        | Amphibian and reptile inventory                                                                                                                             |
| GRSA | 2003-04 | Gitlin, A       | Factors influencing distribution and mortality of a dominant riparian tree, <i>Populus</i> spp.                                                             |
| GRSA | 2004-05 | Przeszlowska, A | Soil N mineralization and microbial respiration in riparian areas                                                                                           |
| GRSA | 2004-07 | Zuellig, R      | Inventory of aquatic insects and effects of antimycin                                                                                                       |
| GRSA | 2007    | Wanty, R        | Evaluation of the aquatic and riparian geochemical environment, water chemistry                                                                             |
| FLFO | 1996    | McMullen, A     | A classification of the riparian vegetation of the Lower South Platte and parts of the Upper Arkansas River basins, Colorado, Boulder Creek and Grape Creek |
| FLFO | 2007    | Miner, J        | Updating national wetlands inventory map                                                                                                                    |
| GLAC | 1991    | Cooper, D       | Wetland plant-soil-hydrology in Big Meadows                                                                                                                 |
| GLAC | 1991    | Stevens, D      | Aquatic resources survey                                                                                                                                    |
| GLAC | 1991-92 | Cooper, D       | Wetland restoration-measurement of short-term variables to measure long-term change                                                                         |
| GLAC | 1991-92 | Cottrell, T     | Niche differentiation of two willow species in wetlands                                                                                                     |
| GLAC | 1991-92 | Kittel, G       | Riparian vegetation distribution on Cache La Poudre River                                                                                                   |
| GLAC | 1993    | Taylor, J.      | Riverine riparian ecosystem valuation study                                                                                                                 |
| GLAC | 1997    | Emerick, J      | Assessment of hydrological and geochemical functions of wetlands in Colorado                                                                                |
| GLAC | 1997-99 | Cooper, D       | Hydrological and ecological effects of the Grand Ditch                                                                                                      |
| GLAC | 1997-00 | Stohlgren, T    | Landscape-scale Gap Analysis: a complementary geographic approach for land managers including field validation of wetland habitats                          |
| GLAC | 1998    | Singer, F       | Sustainability of natural vegetation communities grazed by elk                                                                                              |
| GLAC | 1998-99 | Elias, S        | Quaternary insect fossils used to reconstruct paleoclimate                                                                                                  |
| GLAC | 1998-00 | Kuhajek, J      | Survey of antifungal properties among roots of wetland plants                                                                                               |
| GLAC | 2000-02 | Cooper, D       | Constraints and opportunities for riparian willow establishment and growth                                                                                  |

**Table A1. Recent Investigator Annual Reports from ROMN parks pertaining to wetlands through December, 2009 (continued).**

| Park | Year    | Investigator | Subject                                                                                                                      |
|------|---------|--------------|------------------------------------------------------------------------------------------------------------------------------|
| GLAC | 2001    | Baker, B.    | Declining beaver populations                                                                                                 |
| GLAC | 2002    | Baker, B     | Effects of water diversion by the Grand Ditch on beaver ecology                                                              |
| GLAC | 2002-03 | Muths, E     | Amphibian and reptile inventory                                                                                              |
| GLAC | 2003-04 | Wright, GR   | Habitat use of moose and browsing effects                                                                                    |
| GLAC | 2004-05 | Oropeza, J   | Controls on soil acidity in Loch Vale                                                                                        |
| GLAC | 2005-07 | Brunswick, R | Paleoenvironmental research and long-term climate change based on lake and wetland cores and tree rings                      |
| GLAC | 2005-07 | Church, S    | Evaluation of the aquatic and riparian geochemical environment-Central Colorado Assessment                                   |
| GLAC | 2006-08 | Nelson, SM   | Develop methods to evaluate biological indicators in montane wetlands                                                        |
| GLAC | 2007-08 | Cooper, D    | Baseline data collection to evaluate willow response to the construction of a fence to exclude elk                           |
| GLAC | 2007-08 | Cooper, D    | Distinguishing hydrologic regimes and vegetation of fens and wet meadows                                                     |
| GLAC | 2007-08 | Johnson, P   | Linking land-use, biodiversity, and amphibian disease                                                                        |
| GLAC | 2007-08 | Polvi, L     | Characterization of geomorphic controls on riparian width in valleys of the Colorado Front Range                             |
| GLAC | 2007-08 | Skrypek, G   | Paleoclimate from carbon isotopes in peat cores                                                                              |
| GLAC | 2008    | Cooper, D    | Lulu city wetland data collection to guide restoration                                                                       |
| GLAC | 1995    | Butler, D    | Geomorphic and ecological relationships at alpine treeline and riparian meadows, and their relationships with climate change |
| GLAC | 1997    | Hartley, E   | Visitor impact on wet meadow vegetation a 30-yr study                                                                        |
| GLAC | 1997    | Stanford, J  | Ecology of the Nyack flood plain                                                                                             |
| GLAC | 2000    | Hauer, R     | Impacts of global change on hydrologic and biotic integrity in stream-wetland ecosystems                                     |
| GLAC | 2000    | Jones, M     | Ecologically significant wetlands in the North Fork Flathead river watershed                                                 |
| GLAC | 2000    | Lesica, P    | Monitoring rare plants in the Logan Pass Area                                                                                |
| GLAC | 2000-01 | Fagre, D     | Assessing the vulnerability of natural resources to climate and disturbance                                                  |
| GLAC | 2002    | Lesica, P    | Monitoring the effects of global warming using peripheral rare plants in wet alpine tundra                                   |
| GLAC | 2003-04 | Corn, S      | Status and trends of amphibian populations                                                                                   |
| GLAC | 2003-04 | Gitlin, A.   | Factors influencing distribution and mortality of a dominant riparian tree, <i>Populus</i> spp.                              |
| GLAC | 2006    | Lesica, P    | Map and characterize sensitive habitats                                                                                      |
| GLAC | 2007-08 | Skrypek, G   | Paleoclimate from carbon isotopes in peat cores                                                                              |



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