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Wetlands Ecological Integrity Monitoring Protocol for Sierra Nevada Network Parks

Version 1.4 Draft (*September 2009*)

Natural Resource Report NPS/XXXX/NRR—20XX/XXX

ON THE COVER
Installation of a wetlands monitoring plot in Yosemite National Park. Photo by Peggy Moore.

Wetlands Ecological Integrity Monitoring Protocol for Sierra Nevada Network National Parks

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Natural Resource Report NPS/XXXX/NRR—20XX/XXX

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Contents

Figures

Tables

Appendices*

**Appendices are not currently part of this document, and are included as separate documents.*

Standard Operating Procedures*

**Standard Operating Procedures are not currently part of this document, and are included separately in a zip file: WetlandsEcologicalIntegrityProtocol_SOPs_sien_20090913.zip.*

Abstract

The National Park Service, through its vital signs monitoring program, has been charged with developing a series of monitoring protocols to evaluate the condition and trend of key ecological resources in National Parks. The Sierra Nevada Network, including Yosemite National Park (YOSE), Sequoia and Kings Canyon National Parks (SEKI), and Devils Postpile National Monument (DEPO), has identified 13 vital signs for possible monitoring. Three of these pertain to wet meadow and fen ecosystems (generically referred to in the document as "wetlands"): macroinvertebrate assemblages, wetland plant communities, and surface/groundwater dynamics. In this document, we present a protocol for monitoring these vital signs.

Following a standard format used by monitoring programs nationally, the document consists of a narrative section and a series of standard operating procedures (SOPs). The protocol narrative provides an overview of the vital signs monitoring program and detailed treatments of topics specific to the wetland monitoring protocol including specific monitoring objectives, statistical design, field data collection methods, crew safety, data management, and basic analysis and reporting. SOPs provide more specific guidance for protocol tasks, and are presented as a simplified series of steps intended to facilitate the task completion.

This protocol is designed to provide basic information on the condition of wet meadows and fens, and to allow for the evaluation of long-term trends of key ecological variables in Sierra Nevada parks. Biotic and abiotic variables are measured, with the expectation that some variables will react differently to potential anthropogenic stressors than others, thereby more effectively characterizing wetland ecological integrity. The protocol outlines field methods for sampling vascular and nonvascular plants, terrestrial and aquatic invertebrates, and hydrologic regime. Additional approaches, including selected rapid condition assessment metrics and the collection of photo points are also described.

Two distinct sampling designs are used. A spatially randomized two-staged survey design (Generalized Randomized Tessellated Stratification or GRTS) is used to develop park wide inferences regarding fen and wet meadow integrity. The first stage of this design involves a GIS analysis of key ecological drivers of wetland distribution and functional characteristics such as geology, climate, past glaciation, and slope. Agglomerative cluster analyses are then used to develop a classification of watersheds across individual parks. The GRTS design is then used to select watersheds for sampling. Within selected watersheds, stereo pair aerial photograph analysis and existing data sets, such as the NPS vegetation map coverage and National Wetlands Inventory data sets, are used to develop a sampling frame for wet meadows and fens across Park landscapes. GRTS is then used to select individual wetland points for site level evaluation. Sample sites selected through the GRTS design represent what we refer to as "extensive" sites.

A second design type is also specified by the protocol. "Index" sites are hand-picked sites that are sampled more intensively than extensive sites. These are selected across the main ecological and elevation gradients in a park. The goals of index site sampling include providing an improved understanding of the natural range of variability and key physical and ecological processes in wetlands. Index site data can also be used in interpretation and hypothesis generation regarding patterns and trends in data from the extensive design. Index sites may be

used in the future to provide additional data to refine models relating vegetation and invertebrate communities to key site-level ecological drivers such as hydrologic regime or water chemistry. However, these procedures are not in place and are not discussed in this document. If employed in the future, multi-metric integrity indices, such as the Index of Biotic Integrity (EPA 2002b, Rocchio 2006b), can also be calibrated using index site data.

Acknowledgements

This protocol benefited from the hard work and extensive technical input of numerous individuals. We thank NPS staff at the Rocky Mountain Network-- Brent Frakes, Billy Schweiger, and Mike Britten, for technical assistance and advice, especially in cost surface development and sample design issues.

We gratefully acknowledge the insights provided by previously produced I&M protocols. Certain sections (e.g. data management, statistical design) borrowed heavily from other protocols, in particular, the SIEN Lakes Protocol (Heard et al. 2008), the Rocky Mountain Network Wetland Ecological Integrity Protocol (Schweiger et al. 2009), the Central Alaska Network Vegetation Structure and Composition Monitoring Protocol (Roland et al. 2004), and the North Coast and Cascades Network Forest Vegetation Monitoring Protocol (Woodward et al. 2009).

We thank SIEN Physical Scientist Andi Heard for her advice regarding sample design issues and decisions, and her willingness to share her expertise. SIEN Biological Science Technician Sandy Graban provided both GIS and field data collection support, and was instrumental in the cost surface development for Sequoia and Kings Canyon National Parks. Jutta Schmidt-Gengenbach (White Mountain Research Station) spent many hours sampling, sorting, and identifying invertebrates, and occasionally brought fine chocolate to meetings. Meryl Goldin Rose, former SIEN Ecologist, provided critical support during the first pilot data collection season in Yosemite, and participated in many early protocol work group meetings and conference calls. Lisa Acree, Yosemite Botanist, provided logistic support during pilot data collection efforts, participated in the wetlands work group, and wrote the Wilderness Minimum Requirement Analysis for the wetlands pilot work in Yosemite. Jason Love and Lyra Pierotti (White Mountain Research Station) provided excellent field and lab support for the invertebrate portion of the protocol. Georgia Doyle lent her expert botanical skills to the 2008 field data collection effort, and Erik Frenzel (SEKI Biological Technician) provided critical field and database assistance. Liz Ballenger (YOSE Botanist) and Martin Oliver (YOSE Biological Technician) provided field support and helpful reviews of the SOPs. Jim Roche, YOSE Physical Scientist, participated in wetlands work group meetings, reviewed and revised wetland well and data logger installation and monitoring SOPs, and provided guidance for index site location at Devils Postpile. Patrick Flaherty, on detail from Appalachian Highlands Network, completed the draft MS Access database. Sandy Graban, SIEN Biological Science Technician, provided field and GIS support in 2009. Tani Meadows, SIEN Administrative Assistant, provided administrative support and assisted with SOPs, appendices, and citations.

Kathren Murrell Stevenson and Michael Barbour co-authored a report for the network with Sylvia Haultain, providing a literature review and evaluation of existing montane meadow monitoring programs that informed some of the early decisions for our protocol approach (Murrell-Stevenson et al. 2006).

We thank Editor Kris Freeman for assisting us with formatting this document.

1 - Background and Objectives

1.1 Introduction

Ecological monitoring is a key element of park stewardship. Effective monitoring allows managers to identify and track the status and trend in the condition of key park resources, evaluate the efficacy of resource management activities, improve understanding of natural variation in ecological patterns and processes, and provide an early warning of potential threats to ecological integrity and sustainability. Through its vital signs monitoring program, the National Park Service (NPS) has begun numerous initiatives across the country aimed at tracking key physical, chemical, and biological elements and processes in park ecosystems (Fancy et al. 2008). A vital sign can be any measurable feature of the environment that provides insight into the condition and functioning of an ecosystem. Vital signs are selected to provide a measure of the overall condition of park resources and to help elucidate possible effects of known or hypothesized stressors.

To achieve greater efficiency in the design and implementation of inventory and monitoring work, and to foster the exchange of ideas and information among parks in a similar ecoregional context, the NPS has grouped parks and monuments into monitoring networks. The NPS Sierra Nevada Network (SIEN) includes Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (Figure 1). Using a collaborative process involving the input of NPS managers and outside scientists, 13 vital signs were identified for protocol development in the SIEN (Table 1).

Table 1. Vital signs that were selected for protocol development by the Sierra Nevada Network, organized into categories as defined by the NPS Inventory and Monitoring Program. Bolded vital signs are those that will be included in the wetlands ecological integrity protocol. See Mutch et al. (2008a) for a complete list of high-priority vital signs.

Level 1	Level 2	Vital Sign
Air and Climate	Weather and Climate	Weather and Climate
		Snowpack
Water	Hydrology	Surface water dynamics
		Wetland water dynamics
	Water Quality	Water chemistry
Biological Integrity	Invasive Species	**Non-native invasive plants**
	Focal Species or Communities	**Wetland plant communities**
		Macroinvertebrates (wetlands)
		Amphibians
		Birds
		Forest population dynamics
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire regimes
	Landscape Dynamics	Landscape mosaics

Each vital sign was selected as a potential candidate for the development of a monitoring protocol. However, there is considerable overlap among the vital signs in terms of topical focus and specific physical or ecological systems involved. For example, “wetland plant communities” intersects with several other vital signs including wetland water dynamics, macroinvertebrates, and nonnative invasive plants. Thus, wetlands provide an opportunity to monitor an integrated set of vital signs that will provide information about a primary physical driver (water) and the responses of both plant and animal communities to ecosystem change.

In this document we present a protocol that will serve as the initial basis for the long-term monitoring of wetland plants, macroinvertebrates, and hydrologic regimes in SIEN parks. However, due primarily to budget constraints, the protocol is restricted to two types of wetlands: **wet meadows and fens**. Together these two wetland types form what are commonly referred to as ‘meadows’ in the Sierra Nevada. The term ‘meadow,’ however, is rather expansive, including multiple ecosystem types with significant functional differences. Thus throughout this protocol we will refer to the more specific terms used to describe the component wetlands–fens and wet meadows. It is important to note that this protocol does not describe methods for monitoring riparian ecosystems, which often occur within or adjacent to wet meadows and fens, nor does it provide for monitoring marshes, which are scarce except where associated with the margins of lakes, ponds, and some streams.

The document is organized following standards established nationally by the NPS Inventory and Monitoring program (Oakley et al. 2003), and is comprised of two parts. The first is the protocol narrative, which provides an overview of the monitoring protocol, the rationale for the specific design elements and monitoring components, and a detailed examination of statistical and field methods.

The second part of the document is composed of specific standard operating procedures (SOPs). These provide relatively simple instructions for executing specific components of the protocol. Although considerable effort has been made to provide the most defensible and effective monitoring approach possible given time and resource constraints, future developments will likely necessitate modification of the methods presented here. Therefore, a change history log is presented for both the narrative section and each individual SOP in the protocol, where all modifications and their rationale are to be recorded.

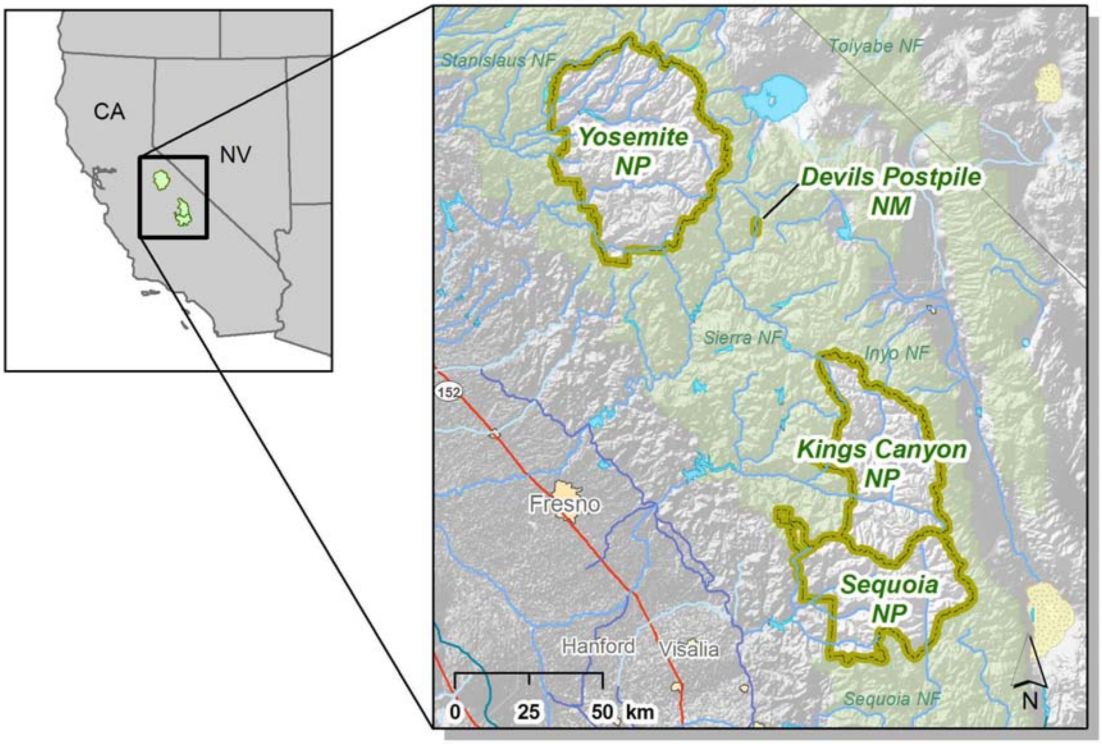


Figure 1. NPS units in the Sierra Nevada Network and the surrounding region.

1.2 Rationale and Justification

The National Park Service has a legal mandate "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (16 USC § 1). To fulfill this mandate requires knowing the condition of park resources, a task that can be accomplished with an effective natural resources monitoring program. To gain the most monitoring benefit with limited fiscal resources, individual NPS units were grouped into networks. SIEN is one of 32 networks throughout the NPS. The Sierra Nevada Network Inventory & Monitoring (I&M) Program has a legal mandate to monitor the ecological condition of constituent parks. The vital signs program has been developed in response to the long recognized need for better tools to characterize and evaluate trends in the condition of ecosystem elements.

Parks may be vulnerable to stressors originating outside of their boundaries such as air and water pollution, invasive species, and climate change (Figure 2). To effectively address the effects of anthropogenic stressors on park resources in managing and planning activities, it is essential that the NPS be able to characterize the current conditions and trends in key ecosystem parameters. Monitoring approaches that emphasize multiple physical and biotic elements are needed because no single process or scale is appropriate for all system components and processes. Wetlands fulfill these criteria, integrating a range of physical and biotic processes potentially useful as indicators of broader ecological change (Figure 2).

The key physical driver influencing wetland plant and animal communities is the hydrologic regime (Figure 2). Water table gradients strongly influence vegetation composition and structure in wetlands (Allen-Diaz 1991, Svejcar and Riegel 1998, Dwire et al. 2004). Spatial and temporal variability in hydrologic characteristics also strongly controls basic ecological processes such as plant production and decomposition (Thormann and Bayley 1997, Thormann et al. 1999, Martin and Chambers 2001, Chimner and Cooper 2003). Saturated environments are also critical to the biogeochemical transformation of key elements such as nitrogen in the landscape (Zak and Grigal 1991).

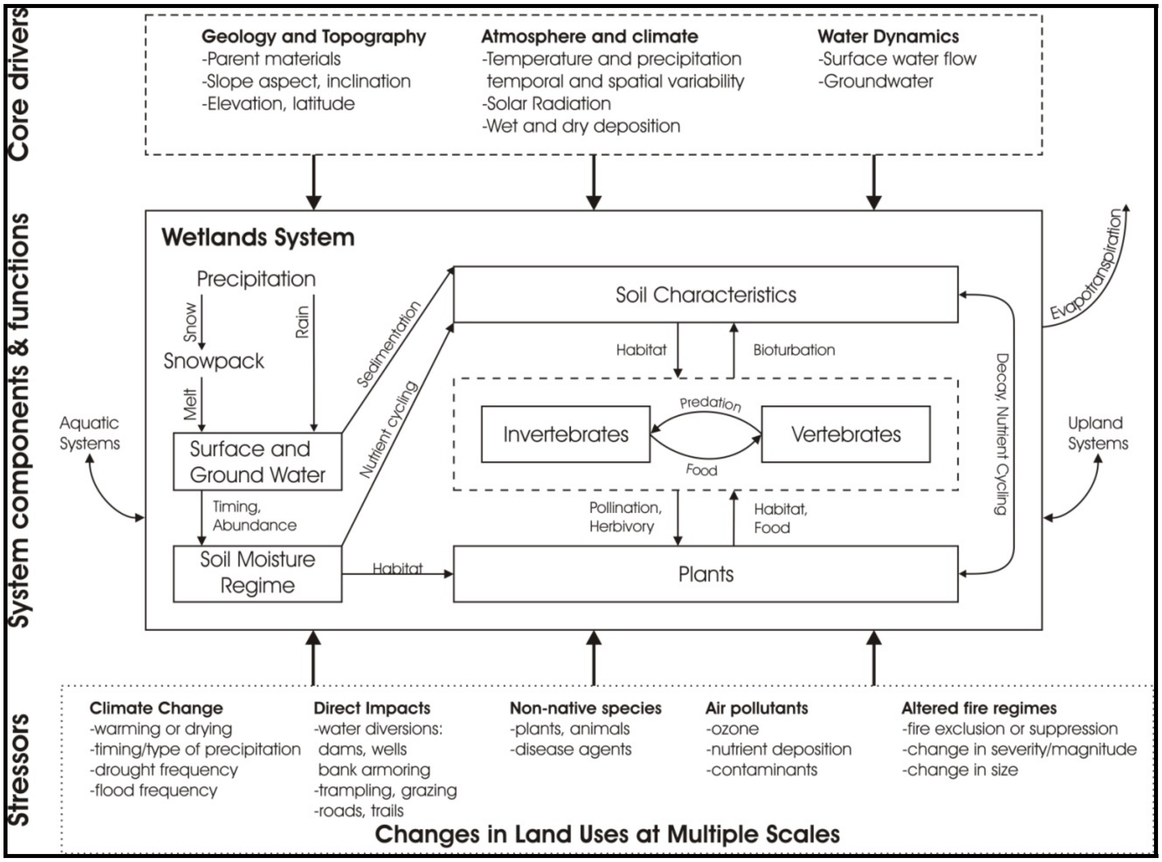


Figure 2. Wetland ecosystem conceptual model (from Mutch et al. 2008b).

The *Wetland Ecological Integrity Monitoring Protocol* addresses three of the vital signs selected for monitoring in the Sierra Nevada Network: hydrology, vegetation, and invertebrate fauna. By incorporating plant composition and structure, invasive/non-native plants, groundwater and surface water hydrology, and macroinvertebrate composition and abundance, the monitoring project can assess stressor impacts on wetlands at individual trophic levels and at a community level. Each component alone has utility for monitoring, reflecting different environmental gradients and stressors to yield information regarding ecological integrity. Variables can also be analyzed together to yield secondary indicators for monitoring effects from stressors (Fore et al. 1996, Jones 2004, Niemi and McDonald 2004, Faber-Langendoen et al. 2006, Miller et al. 2006).

Wetland plants are important indicators of basic physical processes such as hydrologic regime and water/soil chemistry (Mitsch and Gosselink 2007, Cooper 1990, Goslee et al. 1997, Dwire et al. 2006, Cook and Hauer 2007). Vegetation is also responsive to natural and anthropogenic disturbance and can provide important insights into the effects of ecological stressors.

Invertebrates influence productivity, decomposition, nutrient cycling, physical processes, and disturbance regimes (Coleman and Hendrix 2000). Invertebrates are essential prey items for many vertebrate species and exert a strong influence on plant community dynamics as seed dispersers, seed predators, and pollinators (Janzen 1987). They provide important linkages between the soil, litter, and plant canopies, as well as between aquatic and terrestrial systems (Holmquist et al. 1998, Coleman and Hendrix 2000).

In addition to their ecological significance, invertebrates can be extremely sensitive to anthropogenic disturbance, providing a useful indicator of the impact of stressors on ecological integrity (Guntenspergen et al. 2002, Holmquist 2005, Angeler and Garcia 2005, Dziock et al. 2006, Holmquist and Schmidt-Gengenbach 2006). Sampling invertebrate fauna directly provides a more complete picture of wet meadow and fen condition than sampling vegetation alone (Holmquist 2004, Holmquist and Schmidt-Gengenbach 2006).

In California's Sierra Nevada range, wet meadows and fens occupy less than one per cent of the total land area (Davis and Stoms 1996). Despite comprising such a small area, these wetlands are widely recognized for the numerous important functions they provide. They are local and regional centers of biodiversity, and support species found nowhere else across western landscapes (Ratliff 1982, Debinski et al. 2000). Wetlands provide critical habitat for a variety of wildlife, play an important role in the life cycle of many invertebrate and amphibian species, and provide a wide variety of ecosystem services such as nutrient retention, flood control, and sediment storage (Johnston 1991, Richardson 1994, Smith et al. 1995, Semlitsch and Bodie 1998, Zedler and Kercher 2005). Wet meadows and fens are also important aesthetic elements of Sierra Nevada landscapes and provide important forage for wildlife and recreational and administrative pack stock.

While wet meadows and fens superficially appear similar and can occur adjacent to one another, they are driven by different hydrologic processes. Fens are perpetually saturated or flooded from various sources of groundwater. Wet meadows depend on precipitation, and they can be dry for much of the year. Fens accumulate peat, sequestering carbon; wet meadows do not. Differences in hydrology underlying these two wetland types are likely to result in different responses to stressors that affect the delivery of water, either as snow or rain. Thus more can be learned about the effects of ecosystems stressors on ecological integrity by sampling within each of these distinct communities.

1.2.1 Threats to Wetland Ecological Integrity

Wetlands are among the most significantly altered ecosystems in North America. Recognizing the effects of historic and contemporary anthropogenic stressors on the structure and function of fens and wet meadows can provide important contextual information useful for understanding the current status of wetlands, monitoring trends in their condition over time, and providing adaptive management solutions. Anthropogenic impacts, including changes in hydrology due to flow regulation, pumping, fill placement, historical grazing by domestic livestock, atmospheric deposition of pollutants, and exotic species invasion, have drastically altered the structure and function of many wetlands (Patten 1998, Zedler and Kercher 2005, Mutch et al. 2008b). Historic impacts to wet meadows and fens in the Sierra Nevada from sheep grazing have likely pushed species assemblages and ecosystem dynamics outside of their natural range of variability in many areas (Dull 1999). In addition, wet meadows and fens may be particularly vulnerable to forecasted changes in climate (Winter 2000, Weltzin et al. 2000, Poff et al. 2002, Baron et al. 2002, Weltzin et al. 2003).

Direct impacts to wetlands affect their structure and function via on-site effects on vegetation, macroinvertebrates, or hydrologic regime. Alteration of hydrologic regime due to the effects of ditching or ground water pumping can deleteriously impact biota and alter fundamental ecosystem processes such as production and decomposition (Cooper 1990, Cooper et al. 1998, Cooper and Wolf 2006b, Patterson and Cooper 2007). Indirect hydrologic impacts can also occur due to changes in land cover in surrounding watersheds (Troendle and King 1987, Stednick 1996).

Grazing–Livestock use in the Sierra Nevada was historically concentrated in wetlands (Rundel et al. 1988), with very heavy stocking rates of both cattle and sheep in the late 19th and early 20th centuries leading to severe degradation (Ratliff 1985, Dull 1999). Many wetlands still show evidence of these effects nearly a century later. For example, overgrazed wet meadows may support greater cover of herbaceous dicots and fewer grasses and sedges than ungrazed meadows (Cooper et al. 2006).

Sheep and cattle grazing no longer occur in SIEN parks, but pack stock use does and has been documented to have severe impacts to wet meadows and fens (Cooper et al. 2005). Pack stock impacts include physical changes to wetlands, such as soil compaction or erosion, as well as impacts to vegetation. Pack stock selectively graze, changing plant community composition as well as meadow wetland productivity (Cole et al. 2004).

Despite the direct and negative consequences of grazing to wetland ecosystems, this protocol is not designed to address these impacts. Profound differences among the network parks in intensity and spatial distribution of pack stock grazing within wetlands preclude the ability to investigate grazing effects at a network-wide level. Furthermore, natural resource personnel within the SIEN parks are engaged in park-specific studies to assess grazing impacts. The sample frame from which study sites were chosen, therefore, excludes moderately to heavily grazed wet meadows and fens.

Invasive species– Non-native plants pose a tremendous threat to many Sierra Nevada ecosystems. Although high elevation wet meadows and fens in the Sierra Nevada have a low incidence of invasive non-native plant species, the threat of invasion is present. For example, lower elevation wetlands (particularly those on the drier end of the hydrologic gradient) often support dense swards of naturalized introduced pasture grasses such as Kentucky bluegrass (*Poa pratensis)* and redtop (*Agrostis gigantea)* (Gerlach et al. 2003). In recent years a number of montane wet meadows in Kings Canyon, Sequoia, and Yosemite National Parks have also been successfully invaded by velvet grass (*Holcus lanatus)* and reed canary grass (*Phalaris arundinacea).* Invasive animal species also pose a threat to wetland community integrity. This protocol is designed to detect exotic plant and macroinvertebrate species invasions and document temporal changes in associated community composition and structure.

Climate change–Continued atmospheric warming poses a particularly pernicious threat to fen and wet meadow communities primarily by modifying the timing, duration, and magnitude of precipitation in the Sierra Nevada. Changes in precipitation patterns will affect hydrologic regimes. An alteration of the underlying hydrology of local systems, through changes in the timing and amount of snowmelt, has the potential to shift species composition of mountain wetlands. Experimental manipulations in the Rocky Mountains demonstrate that increased temperatures can lead to a general drying down of mountain wetlands with subsequent invasion by woody species such as sagebrush, altered carbon fluxes (Saleska et al. 1999), and changes to the phenology of wetland species (Dunne et al. 2003). By measuring groundwater depth over time, this protocol will provide site-level hydrologic data that can be compared with local precipitation data (e.g., annual snow course results). Thus, putative relationships of climate-hydrology-species composition can be explored.

Pollution–Nitrogen pollution from atmospheric deposition has the potential to affect productivity and species composition of wetland vegetation, and depending on seasonal timing, may affect aquatic organisms such as algae and microbes. Affects to the primary producers of the aquatic food chain have the potential to significantly alter all wetland biota. Atmospheric deposition of pesticide contaminants has the potential to adversely impact aquatic biota through estrogenic effects from low concentrations, and also bioaccumulation. Currently, this protocol is not designed to specifically address impacts of pollution, by, for example, coupling water chemistry analyses with changes in macroinvertebrate composition. However, the protocol design allows for easy modification (i.e., additional sampling) if funding and priorities change in the future.

1.3 Ecosystem types and Key Ecological Characteristics

1.3.1 Wetland Definitions and Classification

As noted earlier, this protocol has been developed for application to two kinds of wetlands: wet meadows and fens. Note that this usage differs from some commonly used definitions of meadows, which may also include non-wetland ecosystems (Ratliff 1982, Ratliff 1985). Upland meadow community types are not covered by the protocol, nor are riparian areas, which often occur as part of wetland complexes. To minimize the variation in data sets and allow for maximum inferential ability, field crews must be able to distinguish between uplands and wetlands, and between individual wetland types.

Because of their high ecological diversity, special legal status, and their intersection with different scientific fields, a variety of definitions have been developed for wetlands (National Research Council 1995, Tiner 1999, Mitsch and Gosselink 2007). The general characteristics of different definitions are driven in large part by their purpose. For example, the definition used by the U.S. Army Corps of Engineers to administer section 404 of the Clean Water Act aims to provide consistent and uniform criteria for field delineation (Environmental Laboratory 1987), while the Cowardin (1979) classification was developed for national wetland inventory and mapping efforts.

The definition used by the National Research Council (National Research Council 1995) is relatively broad in scope, emphasizing the unique suite of hydrological, chemical, and biological characteristics which differentiate wetlands from uplands. The definition used by National Wetlands Inventory (NWI) program contains elements found in both the Corps of Engineers and NRC definitions (Cowardin et al. 1979). All definitions recognize, to one degree or another, the key role of hydrologic processes in wetland formation and the resulting suite of soil and vegetation characteristics. In practice, precise wetland boundaries can be difficult to identify. The timing and duration of soil saturation may vary among years and plant species may have individualistic responses to the changing environmental conditions, producing complex distribution patterns (Tiner 1991).

Wetlands vary widely in their functional and structural characteristics (Mitsch and Gosselink 2007). Terminology is often ambiguous, with different classifications variably lumping different ecosystem types together. Although this protocol is concerned with fens and wet meadows, it is important to realize that other wetland types such as marshes and riparian wetlands occur in SIEN parks. Each type differs in basic hydrologic characteristics, in turn driving differences in floristic composition, vegetation structure, and biogeochemical functioning, and presumably, response to natural or anthropogenic stressors.

Various classification schemes have been applied to wetlands, and the criteria used to classify features differ among classification systems. Examples include dominant vegetation, hydrologic characteristics, geomorphic setting, and water chemistry. Classifications based on vegetation include the National Vegetation Classification System used by state Natural Heritage programs across the U.S. and form the basis of many mapping efforts (Grossman et al. 1998).

National Wetlands Inventory (NWI) data are widely available and provide a useful base for understanding the broad distributional patterns of wetlands. However, maps in many areas are decades old and were drawn using relatively poor imagery. In addition, the Cowardin system used by NWI is of limited utility for discriminating functional wetland types. 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 not always available or accurate for maps (Cowardin et al. 1979).

Different wetland types such as fens, marshes, and wet meadows function within a range of hydrologic, geomorphic, and chemical characteristics, although there can be high variability within each type in response to localized landforms, elevation and temperature gradients, and available species pools (Windell et al. 1986, Mitsch and Gosselink 2007). These functional differences are important determinants of the sensitivity of wetland resources to natural and anthropogenic disturbances and are important to consider when evaluating wetland condition (Bedford 1996, Johnson 2005). Wetland ecosystem functions are influenced by processes occurring across spatial and temporal scales, with large-scale processes such as climate and geology acting to constrain small-scale processes such as disturbance or seasonal water table fluctuations (Frissell et al. 1986, Imhof et al. 1996, Stendera and Johnson 2006).

Because individual indicators may not always be reliable, multiple characteristics should be used to differentiate wetland types in the field. For example, vegetation is generally indicative of wetland type but not always, particularly in marginal or disturbed settings. More detailed information about differentiating wetland types in the field is presented in SOP 6 (Determining Target Status Type in the Field).

1.3.2 Main Wetland Types

Several general wetland types occur in the Sierra Nevada including riparian wetlands, marshes, wet meadows, and fens. The main characteristic unifying riparian ecosystems is the presence of unidirectional moving water, which has the potential to erode and transport sediment, with the potential energy contained in flowing water a key variable influencing ecosystem structure and function. Marshes are characterized by highly variable, surface water-dominated hydrologic regimes, including periods of moderate to deep inundation. Examples include cattail-dominated basins at low to mid elevations, and emergent grass or sedge dominated communities fringing lakes, ponds, or artificial reservoirs (Windell et al. 1986, Mitsch and Gosselink 2007). Neither riparian areas nor marshes are included in this protocol.

FENS–also known as Peatlands, are distinguished from other wetland types by the dominance of organic soils, are among the most common wetland types globally. However, outside of boreal landscapes, they typically represent a small proportion of total wetland area. Peatlands have been classified using a variety of criteria such as vegetation, water chemistry, and hydrology (Wheeler and Proctor 2000). The depth of peat required to be classified as a fen is not strictly defined in the literature. To be classified as a Histosol (organic soil type) by the NRCS in its soil taxonomy system (USDA NRCS 2005), there must be 40 cm of peat in the upper 80 cm of the soil profile. However, wetlands not strictly satisfying this criterion may still function as fens and support fen biota; therefore, wetlands with at least 30 cm of peat in soil profiles were classified as peat-accumulating wetlands in this protocol, and will be analyzed as fens rather than wet meadows.

An additional distinction within peat-accumulating wetlands is that of bogs versus fens. Bogs are hydrologically supported exclusively by precipitation, while fens are supported by groundwater (Cooper and Wolf 2006a, Mitsch and Gosselink 2007). Because of higher evapotranspiration rates in the Sierra Nevada compared to boreal regions, true bogs do not occur and all peatlands in the range are properly classified as fens. Fens in the Sierra Nevada network parks are placed into the Mediterranean California Subalpine-Montane Fen ecological system type by NatureServe (NatureServe 2008).

Using the Cowardin classification, fens would generally be classified as either (1) palustrine, emergent, persistent, with a saturated water regime and organic soils, or (2) palustrine, scrub-shrub with a saturated water regime and organic soils where multistemmed woody species dominate. Wet meadows also fall within the palustrine system, and, depending upon their vegetation, may be placed in the emergent or scrub-shrub class (Cowardin et al. 1979).

Fens have stable groundwater driven hydrologic regimes with high water tables that retard organic matter decomposition and promote peat accumulation (Cooper 1990, Bedford and Godwin 2003, Cooper and Wolf 2006a). As groundwater-driven ecosystems, they vary considerably in the chemical content of their source water and pH depending upon the geological characteristics of the watershed supplying their water (Chapman et al. 2003, Tahvanainen 2004).

In the Sierra Nevada, fens develop in several geomorphic settings. Basin fens are typically flat and are associated with open water features such as small lakes or ponds. They may support floating mats that rise and fall with fluctuating water levels, maintaining contact between the peat surface and the water level. Sloping fens form at the base of hills or on hillslopes where ground water discharges from alluvial fans, glacial moraines, and other aquifers (Cooper and Wolf 2006a). Constant groundwater flow is needed to maintain soil saturation due to high drainage rates.

Fens may also develop in association with distinct springs. These spring mound fens are typically small but are morphologically and ecologically distinct from slope or basin fens. Spring mound fens may form within a sloping fen complex, and indicate the presence of localized groundwater discharge (Cooper and Wolf 2006a).

Fens support a wide variety of vegetation types (Table 2). Vascular species may include clonal monocots such as sedges (*Carex* spp.) or herbaceous dicots such as *Oxypolis* spp. Fens commonly support a well developed bryophyte flora. Fens with basic or circum-neutral water chemistry typically support species in “brown moss” genera such as *Drepanocladus* and *Aulacomnium.* In fens with more acidic water chemistry, species in the *Sphagnum* genus may dominate.

Table 2. Preliminary classification of Sierra Nevada fens (Cooper and Wolf 2006a). Note, associations are not necessarily recognized by the National Vegetation Classification System (NatureServe 2008).

Fen Association
Carex lasiocarpa
Carex vesicaria
Dulichium arundinacea
Calamagrostis canadensis – Carex utriculata
Camassia quamash - Sphagnum subsecundum
Carex alma - Drepanocladus aduncus
Carex amplifolia - Drepanocladus aduncus
Carex capitata – Sphagnum subsecundum
Carex echinata – Sphagnum subsecundum
Carex jonesii – Sphagnum subsecundum
Carex illota - Philonotis fontana
Carex lenticularis – Aulacomnium palustre
Carex limosa – Drepanocladus aduncus
Carex luzulina - Philonotis fontana
Carex nebraskensis – Perideridia parishii ssp. latifolia
Carex scopulorum – Saxifraga oregana
Carex simulata – Carex utriculata
Carex simulata – Aulacomnium palustre
Carex simulata – Philonotis fontana
Carex utriculata (monocultures or with aquatic bryophytes)
Eleocharis pauciflora – Aulacomnium palustre
Eleocharis pauciflora – Drepanocladus aduncus
Eleocharis pauciflora – Philonotis fontana
Eriophorum criniger – moss
Ledum glandulosum – Kalmia polifolia – Pinus contorta (acid shrub fens)
Mimulus guttatus (springs)
Narthecium californicum – Tofieldia occidentalis
Oxypolis occidentalis – Philonotis fontana
Phalacroseris bolanderi – Philonotis fontana – Sphagnum subsecundum
Platanthera leucostachys – Carex luzulina
Rhynchospora alba – Tofieldia occidentalis
Rhynchospora capitellata – Eleocharis pauciflora
Salix eastwoodii – Carex scopulorum
Scirpus microcarpus
Senecio triangularis – Oxypolis occidentalis (springs)
Thalictrum alpinum – Scirpus pumilum (extreme rich fens)
Tofieldia occidentalis – Sphagnum subsecundum
Vaccinium uliginosum – Aulacomnium palustre

Multiple factors affect fen formation and function, with the relative importance of each varying depending on the spatial and temporal scale. At the broadest scales, the regional flora, climate, and geology are most important (Major 1951), while at intermediate and fine spatial scales, chemical and hydrological gradients, as influenced by geomorphic setting, are key (Cooper and Andrus 1994, Tahvanainen et al. 2002). Biotic interactions, microtopography, and disturbance processes all influence patterns of vegetation and succession (Mulligan and Gignac 2002, Kennedy et al. 2003).

Because fens rely on stable water tables near the ground surface for peat accumulation, fens may be sensitive to shifts in climate (Weltzin et al. 2000, Bubier et al. 2003, Weltzin et al. 2003). Precipitation, temperature, and evapotranspiration vary as a function of elevation (Hauer et al. 1997), and fens are typically more abundant at higher elevations. Physiography can also be important, with watershed characteristics indirectly influencing hydrologic processes such as snow accumulation and the rate of melting.

Geologic factors such as bedrock geology and glacial history can influence fen abundance, distribution, biota and functions. Because fens receive inputs of ground water, the mineralogy of watersheds can be an important influence on water chemistry, thereby affecting biotic composition (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 and metamorphic rocks often support fens with acidic pH, while watersheds composed of limestone, dolomite, or shale produce circumneutral to basic pH and higher concentrations of mineral ions (Windell et al. 1986).

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 2003). While fens often occur in stream valleys as part of larger wetland complexes, unlike riparian ecosystems, fens do not experience high velocity surface flows or sediment deposition from fluvial processes. In contrast to marshes, fens do not experience deep inundation, although some microsites 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, springs discharge zones, or on floating mats (Demars et al. 1997, Bragazza and Gerdol 1999, Drexler et al. 1999). 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.

Water tables may drop in the mid to late summer in many fens, although it is rare for them to drop below a meter (Cooper 1990, Cooper and Wolf 2006a). Water tables may decline more steeply during extreme droughts, but if such conditions persist for extended periods of time, soils will dry and oxidation of peat will occur, eventually leading to the loss of peat. Many wetland types have high water tables through June; however, only sites with a water table within 30 cm of the soil surface during July and August accumulate peat (Cooper 1990, Chimner and Cooper 2003). This may represent a hydrologic threshold distinguishing wet meadows from fens.

Fens receive some water via direct precipitation, although much of this may be lost through evapotranspiration (Gorham and Hofstetter 1971). Accumulated snow pack overlying some fens may be an important source of water to subalpine fens, particularly in the Sierra Nevada with its deep snowpacks relative to other mountain systems. Surface water inputs to fens can occur as sheet flow or channelized flow. However, large channelized streams do not occur because high energy streams erode peat, preventing any significant organic matter accumulation. Sheet flow from seasonal snow melt may contribute a significant amount of water to fens and may coalesce to form water tracks around the margins of peat bodies (Heinselman 1970, Crum 1988).

Because of climatic constraints and the small size of many contributing fen watersheds, the most important source of water to fens is groundwater. Groundwater in the peat bodies of fens is hydraulically connected to underlying mineral soils resulting in elevated mineral ion concentrations compared to either surface water or precipitation (Siegel 1983, Siegel 1988). Aquifers supporting fens can be local to regional in size and the specific flow paths taken by groundwater can be complex, influenced by factors such as the lithology and physiography of contributing watersheds (Winter 2001, Chapman et al. 2003). Fractures in bedrock may lead to spring formation, and coarse glacial deposits with high permeability can link recharge and discharge areas, transmitting ground water to fens (Almendinger and Leete 1998).

The mineralogy of surrounding landscapes is an important factor influencing fen water chemistry, contributing ions and influencing the pH of fens through the ability of mineral bases to neutralize organic acids produced by decomposing organic matter (Shotyk 1988, Tahvanainen 2004). Differences in the quality and quantity of groundwater entering fens drive much of the spatial and temporal variability in water as organic acids found in surface water mix with inorganic solutes contributed by ground water discharge, often with a significantly different pH (Chapman et al. 2003, Siegel et al. 2006). In microsites dominated by *Sphagnum* species, processes of active cation exchange are important (Clymo 1963, Spearing 1972).

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 (N2) fixation, and denitrification control the nitrogen flux (Williams and Wheatley 1988, Beltman et al. 1996, Oien 2004). Atmospheric inputs have likely increased relative to historic conditions as a result of increased industrial and agricultural inputs (Bytnerowicz and Fenn 1996, Vitousek et al. 1997, Baron et al. 2000, Kittel et al. 2002, Fenn et al. 2003, Landers et al. 2008).

Disturbances are relatively rare in fens compared to other wetlands types such as riparian areas. Although fire and grazing may affect fens, there are few historical data available to describe these effects. These can include plant mortality, as well as indirect effects through changes in hydrologic or chemical characteristics of surrounding watersheds. Fire, though uncommon, can maintain open conditions in some fens by selectively killing woody species (Jacobson et al. 1991). Subsequent increases in water and sediment yield may affect fen function, as a flush of nutrients such as nitrogen following fire (Anderson and Menges 1997, Dikici and Yilmaz 2006).

The predominant organic matter input in peatlands is from vegetation growing on site, although surrounding areas can also contribute large amounts of organic matter (e.g. trees falling in from the margins; cones and needles transported downslope). Factors like basin size, stability of the water level, slope processes, and landform morphology may influence fen development and succession and the developmental trajectory of fens in larger basins can differ from those in smaller basins, even within the same small watershed (Cooper et al. 2002). As a result, the sensitivity of fens to environmental change likely varies (Bauer et al. 2003). Differential production and decomposition in fens can result in the formation of distinct microtopographic features that strongly influence fine-scale vegetation patterns. Commonly, different suites of species are observed among these different landform types.

Clonal sedges are among the most common fen dominants. Grasses and rushes are less common, and are often most prevalent along fen margins, particularly where fens abut other wetland types such as wet meadows. Dicots such as *Oxypolis* spp. are dominants in certain community types, as are shrub-dominated communities, sometimes referred to as carrs. Forested fens ("treed fens") also occur in some environments (Zoltai and Johnson 1985, Johnson 1996, Johnson 1997).

WET MEADOWS–are abundant in western North America, occurring across a broad elevational gradient (Windell et al. 1986, Mitsch and Gosselink 2007). They are characterized by seasonally saturated soils, but lack the perennial high water tables and organic soils of fens or the large seasonal and inter-annual water table fluctuations characteristic of marshes. Wet meadows lack peat soil but have significantly more organic matter than soils in surrounding forests. NaturesServe places most Sierra Nevada wet meadows into the Temperate Pacific Subalpine-Montane Wet Meadow ecological system type (NatureServe 2008).

Wet meadows, like fens, are important breeding grounds for invertebrates, which are key elements of many food chains (Holmquist and Schmidt-Gengenbach 2006, Mutch et al. 2008b). Wet meadows provide important food and habitat for vertebrate species such as small mammals. These, in turn, provide an important prey base for raptors (van Riper and van Wagtendonk 2006).

Temperature generally declines with increasing elevation, although aspect and rugged topography create a great deal of spatial variability in temperatures in mountainous areas. In alpine meadows, temperatures may be relatively stable near freezing for much of the spring and autumn, with water availability limited more by freezing than drying (Costello and Schmidt 2006). In the alpine, strong winds and complex topography create variable patterns of snow accumulation (Billings and Bliss 1959). Differences in the timing of melt are important for plants, influencing key phenological events like the initiation of growth (Galen and Stanton 1995, Walker et al. 1995, Yamagishi et al. 2005).

Summer precipitation is an important driver of hydrologic regimes in wet meadows of the Rocky Mountains, but likely of less importance in the Sierra Nevada due to the relatively low frequency of summer rain events. Flood frequency in wet meadows is low, with hydrologic regimes influenced more by groundwater than surface water (Mitsch and Gosselink 2007). Wet meadows typically occur in sites where soils are seasonally saturated, but unlike fens or marshes, lack perennially high water tables or seasonally deep water.

Wet meadows frequently occur in stream valleys as part of larger wetland complexes, but unlike riparian ecosystems, are subject to high velocity surface flows or sediment deposition from fluvial processes. High water tables early in the summer are maintained in part by snowmelt, but water tables may drop to a meter or more below the soil surface in July and August, in contrast to fens, where they typically remain within ~20-40 cm of the soil surface (Cooper 1990, Chimner and Cooper 2003).

Soils in wet meadows are often fine textured and have high organic matter content. Anaerobic conditions lead to the formation of hydric soil indicators such as mottles and oxidized root channels, and these features can be used to distinguish wet meadows from dry meadows, particularly where vegetation has been disturbed (Tiner 1999, NRCS 2006). Because water and nutrients are generally more abundant than in adjacent uplands, wet meadows tend to be highly productive.

Soil pH and the concentration of cations and nutrients vary within and among sites in relation to factors such as mineral soil particle size distribution, organic matter content, and hydrologic regime (Johnston et al. 1995, Blank et al. 2006). In watersheds where relatively soluble minerals are dominant, groundwater may contain abundant dissolved solids, while areas composed of relatively insoluble minerals will typically have lower concentrations of ions.

Compared to riparian areas or marshes, abiotic disturbances such as floods are less important in wet meadows. Fires can affect meadow vegetation, leading to short-term instability in community composition, but promoting their long-term stability by reducing the encroachment of forests (DeBenedetti and Parsons 1979, DeBenedetti and Parsons 1984).

Biotic disturbances from small mammals can be significant. Through their burrowing and foraging, pocket gophers and other small mammals can affect patterns and rates of soil development, nutrient availability, microtopography, demography and abundance of plant species, and plant diversity (Ellison and Aldous 1952, Ward and Keith 1962, Huntly and Inouye 1988, Sherrod and Seastedt 2001). Pocket gophers can restrict the expansion of woody plants into meadows (Cantor and Whitham 1989). Other mammals such as marmots or voles can also influence wet meadows (del Moral 1984, Howe and Lane 2004, Austin and Pyle 2004).

As with fens, plant species distribution in wet meadows varies along hydrologic and edaphic gradients (Benedict 1983, Allen-Diaz 1991, Dwire et al. 2006). In the wettest wet meadow communities, obligate hydrophytes tolerant of seasonal flooding, shallow water table depths, and anaerobic soil conditions generally dominate. In contrast, competition and other biotic interactions likely play a greater role in determining species composition and vegetation structure in the more diverse moist and dry meadow communities (Dwire et al. 2004). Wet meadow communities dominated by sedges (*Carex* spp.) may have lower species richness and diversity compared to dry meadow communities, which are composed of a mix of mostly grasses and herbaceous dicots (Dwire et al. 2006).

Palynological and stratigraphic evidence suggests that many wetlands are relatively stable elements of Sierra Nevada landscapes, although composition of plant communities has varied in relation to natural and anthropogenic factors such as 19th century grazing and shifts in climate (Koehler and Anderson 1994, Dull 1999, Kim and Rejmankova 2001).

1.4 Monitoring Questions and Measurable Objectives

1.4.1 Network-Level Monitoring Questions Relevant to Wetland Communities

This section provides the broader context within which the wetland monitoring protocol exists. The Sierra Nevada Network identified a set of broad monitoring objectives and related questions as part of the Vital Signs Monitoring Plan (Mutch et al. 2008a). By combining wetlands monitoring with monitoring of other SIEN systems, the network will be able to address these larger questions. The Sierra Nevada Network's broad monitoring questions that are appropriate to (and could be addressed by) a wetland monitoring protocol include:

- How are climate trends affecting timing of key phenological events in plants and animals?
- How resistant to change are Sierra Nevada ecosystems?
- How do concentrations of persistent organic pollutants vary spatially in aquatic systems?
- How are water dynamics changing in response to climate and fire regimes?
- How are surface water volumes changing in lakes and wetlands?
- How are height and supply of shallow groundwater and flow regimes changing in wet meadows and other wetlands?
- How are plants and animals responding to changes in nutrient concentrations, heavy metals and toxins, sediment loads, and water temperature? What effects are these responses having on aquatic food chains and biological diversity?
- How do the structure, composition, and distribution of plant communities change in response to variation in climate, fire regime, and human use?
- How are abundance and distribution of non-native plant species changing, and what impacts are these having on native plant and animal communities?
- How are wetlands and wet meadows changing in size, species composition, and productivity in relation to changes in human use and climate? How are associated animal communities affected by these changes?
- How is net primary productivity changing in aquatic and terrestrial systems in relation to changes in climate, fire regime, and human use?

1.4.2 Ecosystem Stressors and a Protocol Sampling Caveat

Wetland communities in the Sierra Nevada Network are susceptible to the same stressors implicated in altering the state of other network vital signs. The working systems-level conceptual relationship is given by:

Stressor → Major Ecological Driver → Vital Sign

Sierra Nevada Network stressors are 1) climate change, 2) altered fire regimes, 3) invasive species, 4) air pollution, and 5) habitat fragmentation and human use.

Due to contemporary constraints on funding, this protocol was primarily designed to address how the stressor–climate change influences the major ecological driver–hydrologic regime. This, however, does not suggest that climate change is the only threat to wetlands (see section 1.2.1). If additional resources become available in the future, careful attention should be given to modifying the present protocol to accommodate additional measurements. For example, air pollution and deposition into wetland systems could greatly influence the persistence and composition of the biotic community, as well as alter species interactions. Measuring water quality would allow for analysis and interpretation of putative relationships. The second stressor addressed by the protocol is invasive species (plant and animal). It is not anticipated that invasive species will affect the other vital signs by altering local hydrology. Changes in local hydrology could, however, increase the likelihood of specific species invasions. Impacts of invasive species will most likely result from site-level interspecific interactions, structural and compositional change, and modification of edaphic conditions.

1.4.3 Specific Monitoring Questions and Hypotheses

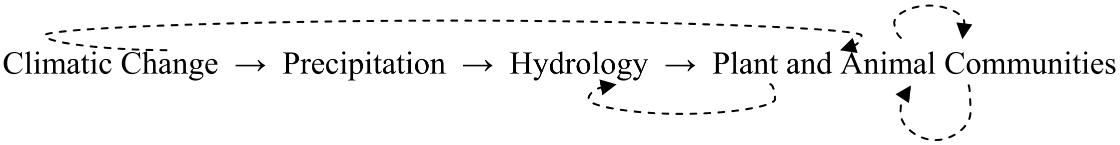
Simulation models of climate change suggest that predicted warmer temperatures will alter water availability due to changes in the type of precipitation and timing of snowmelt in the Sierra Nevada (Knowles and Cayan 2001, Dettinger et al. 2004). Since the underlying hydrology of local systems would likely be affected by these changes, climate change has the potential to shift composition and relative abundance of wetland species through the mediation of the hydrologic regime.

Monitoring Questions:

1. Are hydrologic processes (e.g., duration, depth, and timing) in wetlands changing?
2. Are there changes in wetland plant communities (e.g., structure, composition, and abundance)?
3. Is the composition, abundance, or trophic structure of aquatic or terrestrial invertebrate communities changing in wetland ecosystems?
4. Are introduced species (plants and invertebrates) expanding or declining in wetlands?
5. Are observed changes in flora and or fauna correlated with changes in water table depth?

Hypotheses:

Our specific systems-level conceptual relationship is:



Climatic Change → Precipitation → Hydrology → Plant and Animal Communities

where dashed arrows indicate the direction of diffuse interactions.

Hypothesis 1: Climate change will act to change wetland hydrology (duration, depth, and timing).

Hypothesis 2: Changes in wetland hydrology will alter species composition and relative abundance within vascular and non-vascular plant, as well as macroinvertebrate communities.

1.4.4 Monitoring Objectives

For wet meadow and fen extensive sites in Sierra Nevada Network parks we will:

1. Determine temporal changes in hydrology by:
    - measuring the distance between the ground surface and top of the water table (cm)
2. Estimate temporal changes in species composition and abundance of wetland vascular and non-vascular plants, and bare ground by quantifying:
    - relative ground cover composition
    - woody plant invasion
    - vegetation structure
    - vascular and non-vascular plant species richness
3. Evaluate temporal changes in the composition and relative abundance of wetland macroinvertebrate (arthropods and molluscs within size constraints) populations by measuring:
    - aquatic macroinvertebrate abundance and Family richness
    - terrestrial macroinvertebrate abundance and Family richness
    - ant (Family Formicidae) abundance and species richness
4. Determine temporal changes in exotic plant species cover and dominance in structural plant layers
5. Quantify and compare the status of fen and wet meadow wetlands by measuring water table depth; plant structure, species composition and abundance; bare ground; and aquatic and terrestrial macroinvertebrate abundance and richness
6. Compare rates of change in wetland community characteristics between fen and wet meadow sites

The same above objectives are applied to wet meadow and fen index sites in Sierra Nevada Network parks, with the important distinction that inference will be limited to the index sites themselves (as opposed to the whole of Sierra Nevada Network parks). Moreover, at the time of writing this protocol, index sites are the only sites that are fitted with data loggers to record daily groundwater depths. It is anticipated that these data will help to identify the relationship between change in plant and animal communities and hydrologic change at a finer temporal resolution than achieved in extensive sites. Information about ostensible correlations among these components of wetlands may then be used to interpret results at extensive sites, where hydrology is measured annually in annual sites and once every four years at the other panel sites. Specific hydrologic modeling, and/or spatial variogram modeling will be explored in future years in an effort to couple observed dynamics in index sites with changes to extensive sites.

1.5 Overview of Monitoring Approach

The wetland ecological integrity protocol seeks to monitor changes in the structure and function of wet meadows and fens as they are influenced by natural and anthropogenic system drivers. Metrics involving physical drivers such as hydrology, as well as vegetation and evidence of known stressors will be monitored. This protocol incorporates measures of invertebrate community composition, plant community composition and structure, groundwater and surface water hydrology, non-native plants, and landscape context. The protocol narrative and associated SOPs include activities related to site selection and instrumentation, field data collection, and basic data analysis and management.

The emphasis is on the measurement of community level floristic composition and vegetation structure, terrestrial and aquatic invertebrate community composition, hydrologic metrics, and qualitative or categorical indicators of condition. Individual data sets can be analyzed for trends. In addition, data can be used to generate multi-metric indices of wetland ecological integrity, which facilitates comparisons of ecosystems with dissimilar species composition (EPA 2002b, Jones 2004, Faber-Langendoen et al. 2006, Rocchio 2006a, Rocchio 2006b, Rocchio 2007).

The protocol uses two complementary methods for locating sample sites: randomly-selected extensive sites and subjectively-chosen index sites. Watersheds were characterized based upon a set of physical drivers that are known to influence the distribution, type and abundance of wetlands (Winters et al. 2005, Wohl et al. 2007), separately determined for each park by consensus of network scientists and university cooperators. For each park, the proportion of intermediate-scale catchments was analyzed using spatial data for each driver. These watersheds were evaluated using an objective statistical procedure, agglomerative cluster analysis, to classify the watersheds into groups reflecting similarity in the class of drivers dominating each watershed. The watersheds for wetland monitoring were then selected using a spatially balanced probability survey design (generalized random tessellation stratified sampling - GRTS) (Stevens and Olsen 2004). A more detailed description of the process used to evaluate watersheds and select watersheds and wetlands for field sampling is presented in Appendix 1.

Index sites have been established in all SIEN units. Sites chosen are subject to more spatially and temporally intensive measurement than extensive sites. The survey design underlying the selection of extensive sites will allow valid statements of trend at the park scale, while index sites will improve understanding of natural variability, provide a link to existing long term monitoring data, and facilitate more accurate models of drivers, anthropogenic stressors, and condition metrics. Due to the small size and limited extent of individual wetlands within Devils Postpile, and the predominance of riparian wetlands, implementation of this protocol in that unit focuses on the establishment and monitoring of one index site at the largest wetland.

Extensive and index sites share basic protocols for assessing invertebrate community composition, vegetation composition and structure, and supporting habitat information (e.g. water table dynamics). Vegetation will be assessed using a series of nested plots centered on a groundwater monitoring well. Index site protocols will share the same plot design used in extensive sites, but will be monitored more frequently and will use continuous loggers for groundwater dynamics. Index sites can also be used to help calibrate multi-metric integrity indices.

It is difficult to predict which metrics will be most sensitive to future stressors. By integrating multiple lines of evidence into a single measure of integrity, multi-metric approaches may provide a useful analytical tool for evaluating condition. Biological integrity has been defined as the ability of a wetland to "support and maintain a balanced adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region" (Karr and Dudley 1981). Currently, the development of a multi-metric index is not an explicit goal of the SIEN wetland monitoring protocol; however, the varied data sets and rigorous statistical design used in the protocol will allow future development of one.

Vegetation is an important influence on a variety of wetland functions. Plants are conspicuous elements of the landscape and are good integrated indicators of hydrology, soils, and water chemistry. In addition, plants are sensitive to anthropogenic stressors and disturbance, thus providing a useful indicator of condition. Vegetation data can be analyzed in a variety of ways to evaluate trends. For example, changes in species richness or species dominance can be analyzed in terms of individual species or functional types, such as wetland indicator status (Reed 1997).

Similar kinds of approaches can be taken with invertebrate data. As with vegetation, diversity metrics may be useful for contrasting sites. Functional groups of species can be evaluated as indicators of condition (Scrimgeour and Kendall 2003, Whiles and Goldowitz 2005). In addition, diagnostic or indicator species may also present useful tools for inferring condition.

Because hydrologic regime is so important to the function of wetlands, the protocol calls for explicit evaluation of hydrologic regime through the use of ground water monitoring wells. Logistical constraints prevent high frequency measurements in extensive sites. However, even sparse hydrologic data is useful if collected in the mid to late summer. In index sites, the use of continuous data loggers will provide higher resolution data useful for understanding seasonal variation in water table elevations. These data will provide an important linkage between extensive and index site hydrologic data, and allow for improved conceptualization and quantification of important hydrologic thresholds influencing wetland condition and ecological processes such as peat accumulation.

1.6 Historical Monitoring

Wet meadows and fens are a conspicuous component of Sierra Nevada landscapes; however, there has been relatively little historical monitoring. Long-term monitoring, as part of programs such as the Forest Inventory and Analysis Program (FIA) and National Forest Health Monitoring program (FHM) (USDA Forest Service 2005, McRoberts et al. 2005), poorly capture wetlands. Survey sampling designs such as the EPA’s Environmental Monitoring and Assessment Program (EMAP) (Ernst et al. 1995, Urquhart et al. 1998, Whigham et al. 2007) have focused on wetlands, but extensive sampling has not occurred in Sierra Nevada parks.

Rapid assessment approaches such as the California Rapid Assessment Method (CRAM) have been implemented on a limited scale within the Sierra Nevada (Sutula et al. 2006, Collins et al. 2006, Denn and Shorrock 2009). However, no systematic assessments using a rigorous statistical design have been done in SIEN parks, limiting inferences that can be made regarding wetland condition at broad spatial scales. The approach presented in this protocol differs from most rapid assessment techniques by emphasizing the collection of quantitative data from long term, fixed-area plots, particularly hydrologic data, to maximize the precision of data collection and the ability to detect change over time.

There is a long history of terrestrial vegetation inventory, research, and monitoring work in SEKI and YOSE. Most work has focused on evaluating the effects of management such as fire, non-native plant control, restoration, recreation (especially pack stock grazing), and air pollution (Goldin-Rose 2008). With the exception of long term fire effects monitoring conducted by SEKI fire ecologists, DEPO has lacked the staffing or resources to carry out extensive long-term vegetation monitoring.

Vegetation maps of SIEN parks provide general baseline data for monitoring (Aerial Information Systems 1997, National Park Service 2007). Additional vascular plant and rare plant surveys have occurred in SEKI and YOSE (Graber et al. 1993, Moore et al. 2005, Haultain in prep., Goldin-Rose 2008), and a vascular plant inventory has been completed in DEPO (Arnett and Haultain 2004). None of these efforts have focused specifically on wet meadows or fens. However, a wetlands inventory and condition assessment was recently completed for DEPO (Denn and Shorrock 2009) that will inform consideration of additional wetland monitoring needs specific to management objectives for the monument.

In the Sierra Nevada, only a limited amount of work in wetlands has been done. In SEKI, most of this has been focused on monitoring the effects of pack stock grazing on vegetation in wilderness meadows, and has been conducted in a limited number of sites (Haultain 2008, 2009; Goldin-Rose 2008). In YOSE, there have been several wetland restoration projects that have involved the collection of monitoring data, but again, only for a limited number of sites (Goldin-Rose 2008).

Relatively few site-level studies of wet meadows and fens have been conducted in SIEN parks. Detailed groundwater data are limited, for example, to only a handful of sites in Yosemite National Park such as Yosemite Valley, Crane Flat, and Tuolumne Meadows (Cooper et al. 2006, Cooper and Wolf 2006b). In Sequoia National Park, detailed groundwater data are available from a small number of montane meadow sites in the Giant Forest and Halstead Creek areas (Cooper et al. unpublished data) and from subalpine meadows in the Rock Creek drainage (Leonard et al. 1969; Giffen et al. 1970). These sites can be usefully incorporated into an index site design, but are neither numerous enough nor distributed in a sufficiently rigorous statistical design to allow park-level inferences of wetland resources.

2 - Sample Design

2.1 Introduction

We include two complementary sampling designs in the wetland protocol incorporating two types of sites: extensive sites and index sites. Extensive sites are chosen randomly as part of a probabilistic sampling design. In contrast, index sites are chosen subjectively based on factors such as the presence of data from historical monitoring, representativeness, or ease of access. Inference regarding park- and network-level response will be made from the probabilistic sample of wetland vegetation, hydrologic regime, and macroinvertebrates. In addition, at each site, a set of semi-quantitative rapid wetland condition indicators are recorded and a set of photo points collected.

Extensive sites are visited infrequently with individual site visits to be completed in less than 1 day. Site-level sampling involves the use of a nested plot design centered on a groundwater monitoring well. A core set of metrics (vegetation, hydrology, macroinvertebrates) are collected. Index sites use the same nested plot design and core set of Standard Operating Procedures (SOPs) used in the extensive design, but differ in several regards. Index sites may be spatially sampled more intensively, or support special analyses or pilot work not done in extensive sites.

General procedures for sampling extensive and index sites are presented below, with specific procedures presented in the SOPs. Some protocol elements such as plot design or well installation methods are the same across all SIEN parks. However, more complicated analyses such as the watershed classification, cluster analysis, sample frame development, panel design, and GRTS analysis will vary somewhat. Although the overall approach will be similar, differences in available data, park management priorities, and logistical issues may necessitate adaptation.

2.2 Spatial Design

A spatial design, also referred to as the membership design, refers to how sample sites are located and defines the area of statistical inference. Different spatial designs are used for extensive and index site analyses. The design used for extensive sites in YOSE and SEKI is a probabilistic design, with the goal of spatially distributing sampling points in a random pattern across park landscapes. The approach will allow design-based analysis of data with an inference level at the scale of entire park landscapes (Dixon et al. 1998, Edwards 1998, McDonald 2003). In contrast, index sites were selected subjectively and are not intended to provide inferences to wetland condition across the park units.

2.3 Target Population and Sampling Frame

The goal of this protocol is to obtain inference on the condition of fen and wet meadows within the NPS units included in the Sierra Nevada monitoring network. While the large parks (SEKI and YOSE) have wet meadows and fens as important wetland types, the smallest SIEN unit, Devils Postpile National Monument (DEPO), has predominantly riparian wetlands that are small in size (Denn and Shorrock 2009); thus, we are only installing an index site at the monument's largest wetland (Soda Springs Meadow). For YOSE and SEKI, an amended two-stage design adapted from the Rocky Mountain Network protocol (Schweiger et al. 2009) for wetland monitoring was used to select sampling sites for the extensive design (Figure 3).

The sampling frame is initially defined as the population of watersheds (subwatersheds as identified by CalWater, 1999) in SEKI and YOSE. The SEKI sampling frame is further defined as those wetlands that have not received more than an average of 0.5 nights/acre of grazing use over the past 18 years. This restriction was added to avoid random selection of wetlands in substantially grazed areas that would not yield valid information necessary for monitoring or that would confound trend analysis with grazing effects. The scope of inference in SEKI is therefore restricted to the population of ungrazed and lightly-grazed meadows.

Watershed strata were based upon a set of physical drivers that are known to influence the distribution, type and abundance of wetlands (Winters et al. 2005, Wohl et al. 2007). The specific drivers used for watershed classification include annual precipitation from the PRISM data set, elevation and slope layers derived from national digital elevation models, and surficial geology (Daly et al. 2000, Gesch et al. 2002, PRISM Group 2007).

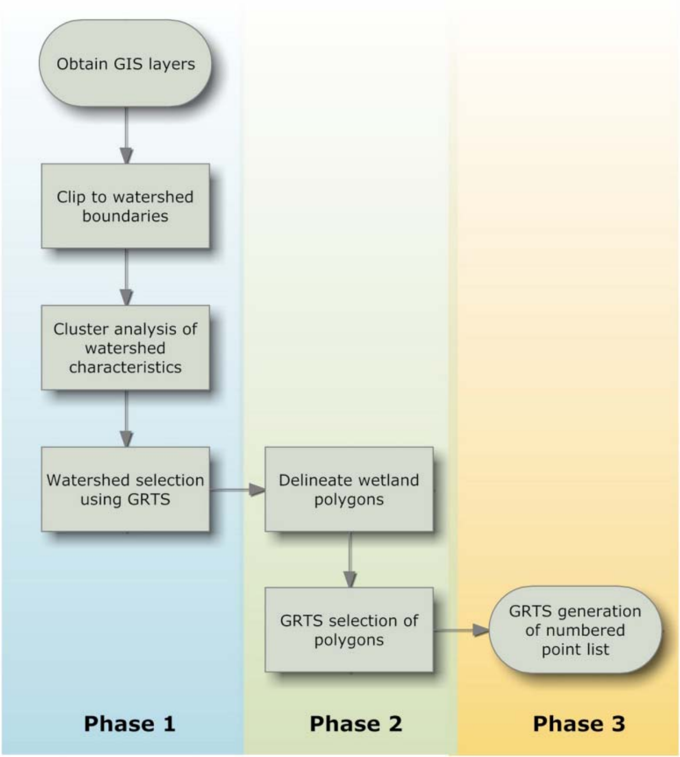


Figure 3. Overview of main survey design.

The portion of each California hydrologic subregion polygon (CalWater 1999) with a particular driver characteristic was calculated in a GIS, and the resulting values used as species cover analogues in an agglomerative cluster analysis using PC-ORD software (McCune and Mefford 2006). Based on the results of the cluster analysis, watersheds were segregated into different cluster groups (Figure 4) for sampling using spsurvey package with the GRTS function in the R statistics package (Stevens and Olsen 2004). Three equally weighted watersheds from each cluster group were selected based on park size. See Appendix 1 for more detail on watershed selection.

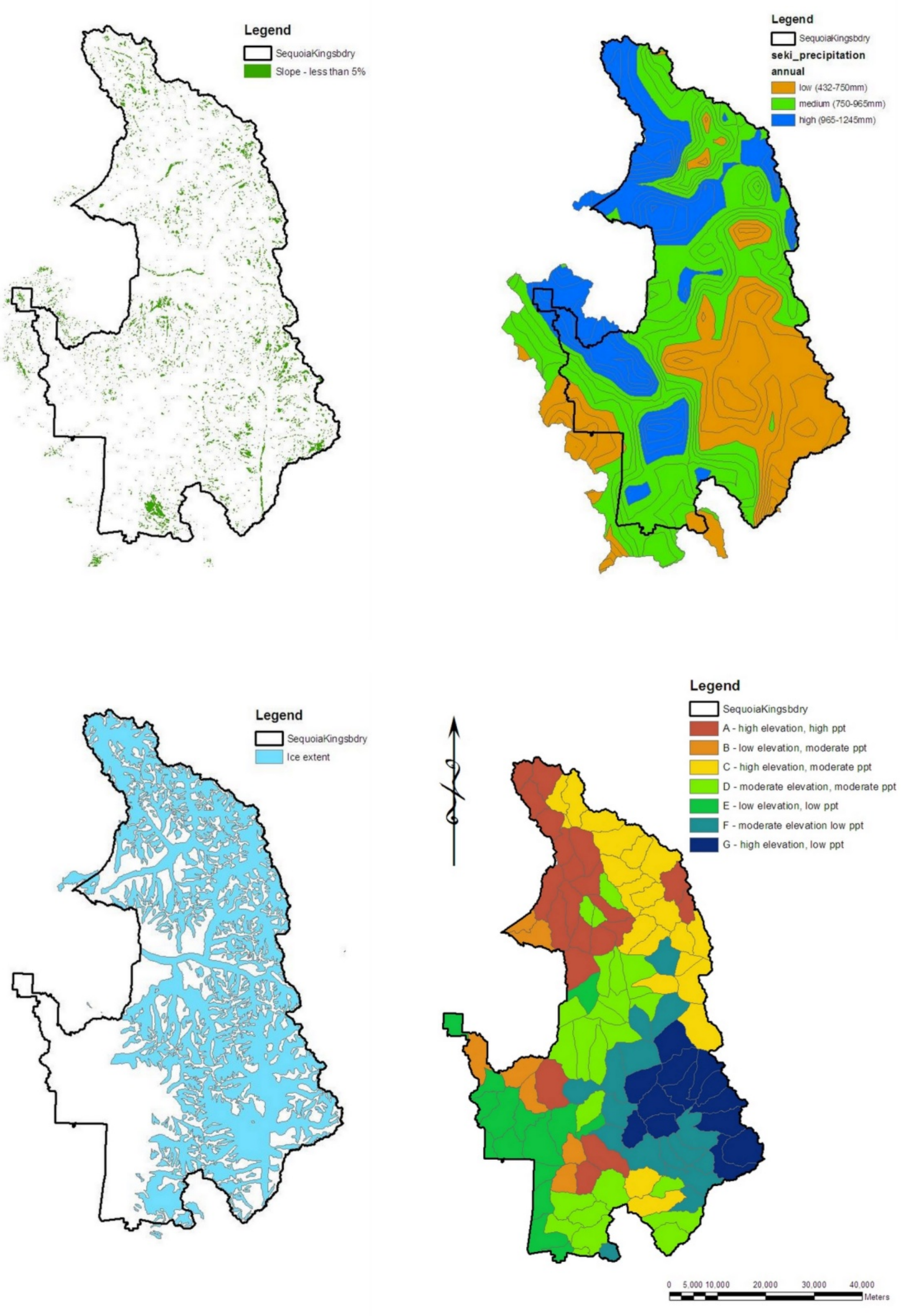


Figure 4. Drivers used in watershed analysis and resulting cluster groupings from SEKI.

For each park, a sampling frame that included wet meadows and fens was developed by delineating features using stereo aerial photograph pairs (National Agriculture Imagery Program [NAIP] 2005, www.apfo.usda.gov) and data from existing GIS layers as reference (e.g. NPS vegetation maps, NWI data) (Figure 5; Table 3). Within selected watersheds, individual sites for field sampling were selected from the sampling frame using the GRTS design (Urquhart et al. 1998). Separate sampling frames have been completed for YOSE and SEKI.

As noted above, a key difference between the sampling frames in YOSE and SEKI involved pack-stock grazing. The sampling frame in YOSE includes all delineated wet meadows and fens. In contrast, wetlands subject to moderate to heavy pack-stock use were excluded from the SEKI frame because of concerns regarding the difficulty of collecting species level data from recently grazed sites, and desire to avoid the potentially confounding effect of grazing.

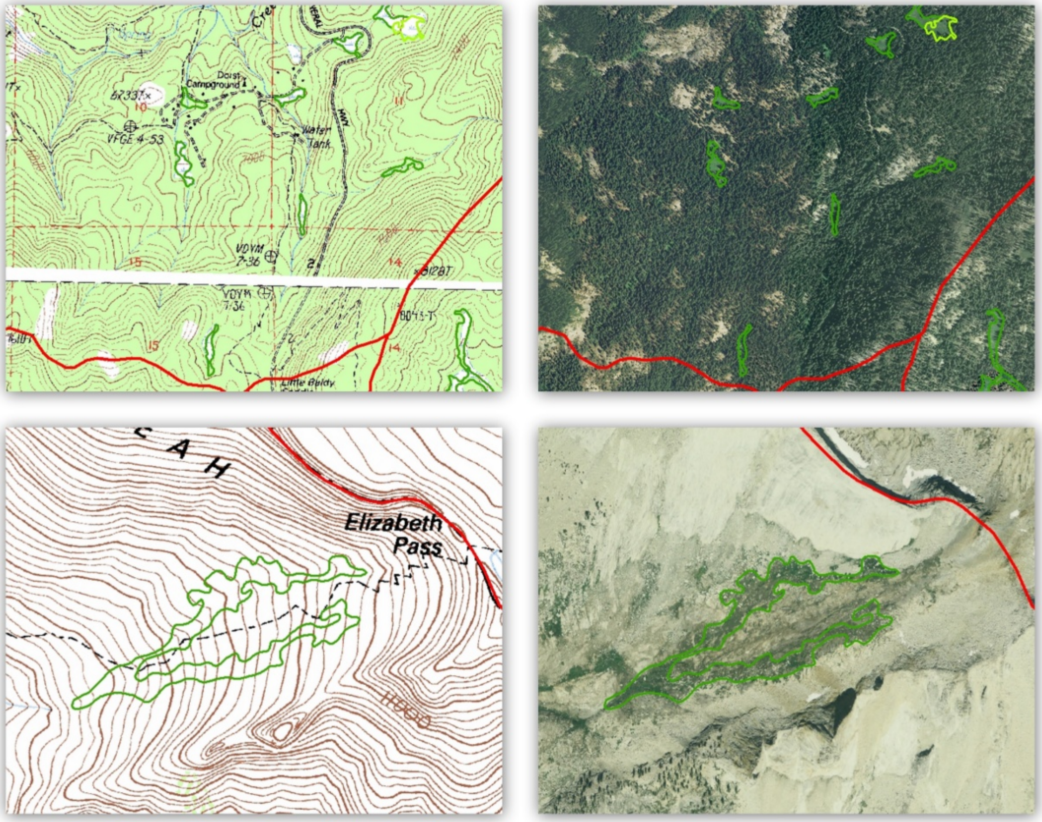


Figure 5. Examples of sampling frame developed in SEKI. Digital Raster Graphics (DRGs) (left panels) and Natural Agriculture Imagery Program (NAIP) imagery (right panels) for two areas illustrate delineated wetlands (green polygons). Red lines indicate watershed boundaries.

Separate cost surface models were developed for YOSE and SEKI and were used to improve sampling efficiency by selecting sampling sites based on travel time and difficulty of access criteria (Figure 6). Cost-surface models based on existing GIS data layers were used to compute relative travel times to sites based on factors such as vegetation type, slope, and the presence/absence of trails (Frakes et al. 2007). These cost estimates were binned into 14 cost classes and used as a multi-density category for an unequal probability GRTS sample of wetlands using the spsurvey package in R. For each wetland in the target population, the inclusion probability is inversely proportional to the travel time, so sites that are easier to access have a higher probability of being selected. All wetlands in the sampling frame have a nonzero probability of inclusion so that inference may be made to the larger population. However, remote and hard-to-access sites are assigned a smaller inclusion probability so that survey resources are used more efficiently. Hence, the GRTS sample was drawn using unequal probability sampling based on classes formed by wetland type and cost class. All wetlands within a specific wetland type and cost class had the same probability of inclusion. Fens had higher inclusion probabilities than wet meadow, and fen plus wet meadow types.

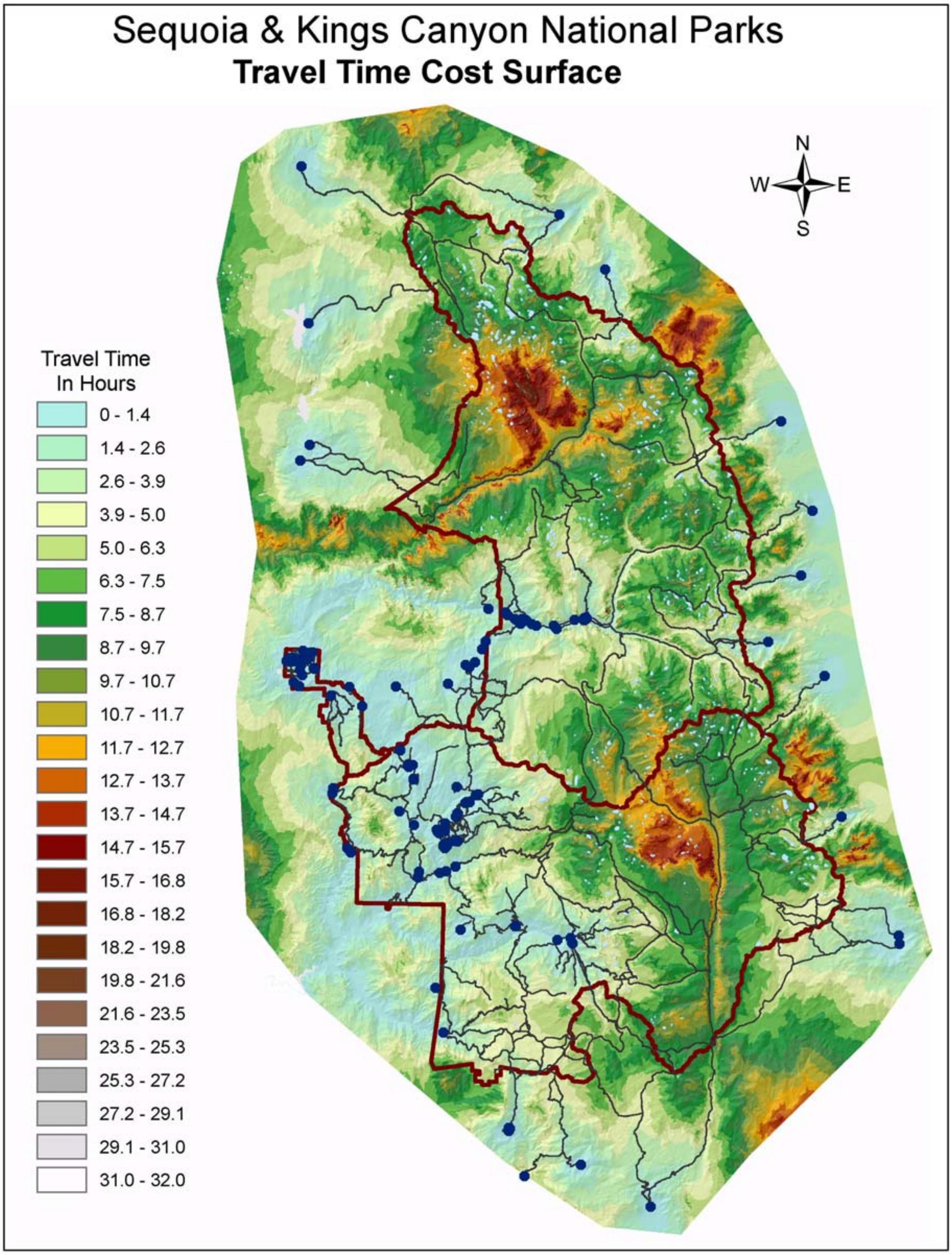


Figure 6. Cost surface model applied to Sequoia and Kings Canyon. A similar model was developed for Yosemite and used in the selection of extensive sites. Note that blue dots represent trailheads.

Table 3. Diagnostic characteristics of different wetland types used to differentiate wetland types from one another in aerial photographs and in the field.

	Wetland characteristics	Wet meadow	Fen
Aerial photos	Geomorphic context	Moderate slopes, valley bottoms, saddles	Glacial lake basins, potholes, slopes associated with springs, toeslope settings
	Imagery characteristics	Difference in tonal characteristics from dry meadows and fens, landscape position	Difference in tonal characteristics from other wetland types; presence of hummocks or other microtopographic features
Field	Hydrologic		
	Mean water table depth	-30 to -150 cm	-30 cm to slightly inundated
	Seasonal variation in water table depth	Low to moderate	Low to moderate
	Primary hydrologic source	Groundwater	Groundwater
	Vegetation		
	Physiognomy	Herbaceous, shrub	Herbaceous, low shrub, forested
	General characteristics	High cover of facultative hydrophytes, often perennial grasses, sedges, and rushes; variable herbaceous dicot cover	High cover of obligate hydrophytes, typically clonal sedge.; bryophytes common
	Soils	Hydric mineral, often redoximorphic features indicative of fluctuating water tables, upper soils may or may not be saturated	Organic soils (histosols) or 30 cm of peat in upper 80 cm of profile; peat may be formed largely from either sedges or bryophytes
	Other characteristics	Pocket gopher mounds	Microtopographic features (flarks, strings, water tracks)

A classic two-stage sampling design would then employ a random sample of wetlands within each selected watershed. In the 2007 YOSE survey, the sample was drawn from the pooled set of all wetlands within first-stage watersheds. The SEKI 2008 second-stage sample was drawn in the same way to maintain consistency within the network. This amended two-stage design will not provide design-based estimates of variability within watersheds because wetlands were pooled across watersheds for the sample draw. However, park- and network-level inference will be unbiased if the inclusion probabilities accurately reflect the amended second stage randomization. The final phase of the extensive site design involved the development of sample and wetland extent verification points within polygons delineated in phase 2. Within each selected fen, wet meadow, or fen/wet meadow complex, a numbered list of points for sampling was generated using GRTS. Points were visited sequentially at a given site and classified as either upland, or if wetland, by specific wetland type. The lowest numbered site of the targeted type for that complex, fen or wet meadow, was sampled. If the site was targeted as fen and wet meadow, the lowest number of each type was sampled. The point sampled must contain >80% of the targeted wetland type, if the area around the point is <80% of the target type, crews must move to the next point in the list. If no point in the GRTS list is found to contain >80% of the targeted wetland type, the lowest number on the GRTS list that can be moved <20 meters into the target type is used for sampling (see SOP 6 for more detail).

2.4 Response Design

Data are collected using a site-level response design developed to measure plant and macroinvertebrate community characteristics, and water table depth. Site-level sampling involves randomly generated points used to direct objective sampling in a nested plot design centered on a groundwater monitoring well. The reader is referred to Chapter 3, SOPs 9, 10, 12, 13, 16, 17, and 18 for more detailed descriptions of the procedures involved in the extensive site response design.

2.5 Revisit Design

The revisit design outlines the pattern of temporal sampling for the selected sites (MacDonald 2003). Sites are randomly assigned to panels that are visited annually, visited a set number of times then dropped, or visited on an alternating schedule. When a panel is sampled, all sites within a panel are visited within the same year. Panel designs provide balanced replication of sites over time so that spatial and temporal effects may be modeled and trend may be accurately estimated.

Notation for panel designs will be as defined by MacDonald (2003). Revisit schedules are summarized by the number of consecutive visits followed by the number of years the panel is not visited. Multiple revisit patterns are separated by a comma. For example, a revisit schedule of [1-0] indicates that the sites within the single panel will be revisited each year and never rotated out of the schedule. A revisit schedule of [(1-0), (2-3)] indicates that the revisit design includes an annual panel that is visited every year as well as a set of panels that are visited for two consecutive years then not visited for the following three years before being rotated back into the design. Several revisit designs were considered for this monitoring project and are described in Figure 7 for a maximum of 48 sites per park.

Figure 7. Four revisit designs examined in the power analysis.

Year

Panel	1	2	3	4	5	6	7	8	9	10	11	12
1	48	48	48	48	48	48	48	48	48	48	48	48
ANNUAL TOTAL	48	48	48	48	48	48	48	48	48	48	48	48

(A) Design [1-0] with 48 sites visited annually.

Year

	1	2	3	4	5	6	7	8	9	10	11	12
1	12	12	12	12	12	12	12	12	12	12	12	12
2	18		18		18		18		18		18	
3		18		18		18		18		18		18
ANNUAL TOTAL	30	30	30	30	30	30	30	30	30	30	30	30

(B) Design [(1-0),(1-1)] with 36 sites visited annually.

Year

	1	2	3	4	5	6	7	8	9	10	11	12
1	12	12	12	12	12	12	12	12	12	12	12	12
2	9				9				9			
3		9				9				9		
4			9				9				9	
5				9				9				9
ANNUAL TOTAL	21	21	21	21	21	21	21	21	21	21	21	21

(C) Design [(1-0),(1-3)] with 21 sites visited annually.

Year

	1	2	3	4	5	6	7	8	9	10	11	12
1	12	12	12	12	12	12	12	12	12	12	12	12
2	6						6					
3		6						6				
4			6						6			
5				6						6		
6					6						6	
7						6						6
ANNUAL TOTAL	18	18	18	18	18	18	18	18	18	18	18	18

(D) Design [(1-0),(1-5)] with 18 sites visited annually.

Revisit designs should be chosen by considering the outcome of interest and the time frame within which a trend estimate is desired. Periodicity in the outcome of interest should be considered when determining the time between survey visits for a panel. If measurements from sites are highly correlated between consecutive years, survey revisits may be spaced to avoid duplication of information unless the measurement of that correlation meets a specific monitoring goal. If trend is more desirable than status, sites should be visited more often. If status is more important, then more sites should be visited each year. MacDonald (2003) cited several sources indicating that the annual revisit panel should use roughly 50% of annual resources. However, Urquhart et al. (1993) found that 10-20% of annual resources could be used for sites visited every year.

Preliminary power analysis of WEI indicators demonstrated that the power to detect trend is similar for the revisit designs described in Figure 7. Revisit designs incorporating augmenting panels produce tests of trend that are nearly as powerful as tests based on revisit designs for which sites are visited every year, the most powerful revisit design for trend detection (Urquhart and Kincaid 1999). Of the four revisit designs under consideration, the [1-0] and [(1-0),(1-1)] designs required substantial annual effort to obtain a total sample of 48 sites. These revisit designs would also incorporate fewer unique sites for estimation of annual status. The [(1-0),(1-5)] design would require six years to complete a full cycle. Up to 15 years would be necessary to complete data entry, data analysis, and reporting for trend estimation of two complete replications of the [(1-0),(1-5)] revisit design (Urquhart et al. 1993). The [(1-0),(1-3)] design was chosen because it optimized a shorter reporting cycle (4 years) and larger sample for status estimation. Figures 8–10 illustrate the final revisit design for the total SIEN sample, the annual sample within each wetland type, and the annual sample within each wetland and park combination. This design results in a total sample of 104 unique sites across wetland types, with 52 sites within each park (see Table 11 for details). Each year a total of 44 sites will be visited with 24 sites in the annual panel and 20 sites from one of four alternating panels. Maps showing the sites distributed into panels for SEKI and YOSE are in Appendix 2.

Year

	1	2	3	4	5	6	7	8
1	24	24	24	24	24	24	24	24
2	20				20			
3		20				20		
4			20				20	
5				20				20
ANNUAL TOTAL	44	44	44	44	44	44	44	44

Figure 8. Final [(1-0),(1-3)] SIEN revisit design across wetland types.

Year

	1	2	3	4	5	6	7	8
1	12	12	12	12	12	12	12	12
2	10				10			
3		10				10		
4			10				10	
5				10				10
ANNUAL TOTAL	22	22	22	22	22	22	22	22

Figure 9. Final [(1-0),(1-3)] SIEN revisit design within each wetland type.

Year

	1	2	3	4	5	6	7	8
1	6	6	6	6	6	6	6	6
2	5				5			
3		5				5		
4			5				5	
5				5				5
ANNUAL TOTAL	11	11	11	11	11	11	11	11

Figure 10. Final [(1-0),(1-3)] revisit design within each wetland type and park.

The distribution of index sites across park landscapes is the result of a subjective selection process. Some of the criteria used in index site selection include the availability of existing data, management priority, elevation, vegetation types present, and access. Five index sites were identified and established in YOSE in 2007. Long-term maintenance of index sites will likely be limited to four sites. In SEKI, four sites were identified, two of which were established in 2008, and two in 2009. In DEPO, one index site was established in 2009.

2.5.1 Power Analysis

Network and park staff are interested in monitoring changes in wetland indicators over time. In addition to estimating the multiplicative trend of an indicator, SIEN staff plan to test a two-sided alternative hypothesis to determine if the estimated change is statistically significant. Hypothesis testing is subject to two types of errors: Type I errors and Type II errors. The Type I error rate is the probability that the null hypothesis is rejected when it is actually true. The Type II error rate measures the probability that a false null hypothesis is not rejected. Power is generally denoted as 1- β, where β is the probability that a Type II error is made. The power of a trend test measures the probability of detecting a significant trend given that a trend actually exists. Power may be calculated as a function of the Type I error rate, the precision of the tested estimate, and the desired effect size (Cohen 1988). Power calculations are specific to a particular hypothesis test, so the trend test should reflect management needs for accurate power estimation.

2.6 Hypothesis Tests for Trend Detection

The power to detect trends in vegetative, invertebrate, and hydrological outcomes was computed to inform decisions regarding the survey design, sample size, effect size, and Type I error rate. SIEN ecologists are most interested in testing the null hypothesis $H_o:\beta=0$ versus the alternative hypothesis $H_o:\beta\neq0$. A number of nonparametric techniques are available for testing trend (Theil

1950, Yue and Pilon 2004) and are useful for providing a range of trend estimates for comparison, but these approaches do not allow estimation of components of variance that affect the ability to detect trend. Variance component estimation will be helpful if power is reassessed in the future using data obtained from the probabilistic survey design. The linear mixed model is used to estimate and test the significance of linear trend as well as to estimate the variance components across time and space.

The linear mixed model is a versatile modeling tool that incorporates fixed effects of the mean structure and random effects that form the variance structure. Variance sources may include site-to-site variation, year-to-year variation, random slopes over time for each site, and site-by-year interactions. We use the linear mixed model that omits within-year revisits as proposed by Piepho and Ogutu (2002):

$$y_{ij} = \mu + w_j\beta + b_j + a_i + w_jt_i + e_{ij},$$

where $i = 1,..,m_a$; $j = 1,..,m_b$; and

m_a = the number of sites in the sample;

m_b = the number of consective years in the sample;

w_j = constant representing the j^{th} year (covariate);

μ and β = fixed intercept and slope of the linear time trend;

b_j = random effect of the j^{th} year;

a_i = random intercept of i^{th} site, independent and identically distributed as $N(0,\sigma_a^2)$;

t_i = random slope of i^{th} site, independent and identically distributed as $N(0,\sigma_t^2)$;

e_{ij} = unexplained error, independent and identically distributed as $N(0,\sigma_e^2)$.

The outcome of interest, y_{ij}, is calculated as the natural logarithm of the outcome at site *i* and year *j*. The logarithmic transformation allows straightforward calculation of multiplicative annual change and net change. Variance components are estimated from this model. For some indicators, site-to-site variation is measured from a pilot data set with good spatial coverage, and year-to-year variation is modeled from pilot data with replication over time. The use of multiple pilot data sets may result in estimates of total error that exceed the true amount for more conservative power approximations. However, the relative sizes of spatial and temporal variance components are important factors affecting power to detect trend, so this conservative approach was deemed appropriate.

The hypothesis test for trend detection is the F-test (or corresponding t-test) of the linear fixed slope estimate. When data are unbalanced as in a serially-augmented panel design, Spilke, et al.

(2005) recommend using Kenward-Rogers (1997) degrees of freedom with restricted maximum likelihood estimation.

2.6.1 Power Calculations

Estimated variance components were used in large-sample power approximations for the [(1-0),(1-3)] revisit design over a 30-year monitoring period for increasing trends of 1%, 2%, 3%, and 4% annually. Code for approximating power was provided by Tom Kincaid of the Environmental Protection Agency and modified to include a random slope effect. The Type I error rate was set at 0.2 because the cost of erroneously detecting a trend that does not exist is less expensive than missing a real trend. A Type I error level of this size is reasonable for long-term monitoring of resources (Buhl-Mortensen 1996; Gibbs, et al. 1998; Mapstone 1995).

Since the spatial distribution of the outcomes is unknown, incorporating GRTS into the power analysis would require simulating each outcome in space and drawing spatially-balanced samples from this surface for analysis. This approach would introduce unnecessary error into the power analysis, so the GRTS membership design was not incorporated into the power analysis. Because GRTS variance estimates should be smaller than variance estimates from simple random sampling (Stevens and Olsen 2003), variances obtained assuming a simple random sampling design provide conservative power approximations.

2.6.2 Pilot Data for Power Analyses

Three indicators are of interest for invertebrate monitoring in SIEN wetlands: Margalef's family richness (MFR), percent dominance (PD), and percent predators (PP). All three indicators are measures for terrestrial invertebrates, while only MFR and PD are measured for aquatic invertebrates. Variance components affecting trend detection for these three indicators were estimated from SIEN pilot data. Surveys conducted in Tuolumne Meadows from 2004 through 2007 were used to estimate the variation of year random effects. Probabilistic surveys conducted in YOSE and SEKI in 2007 and 2008, respectively, were used to estimate site-level random effects and their variances. Different survey methods were used during this period in Tuolumne Meadows (Table 4), and any added variability in the outcomes of interest between the two methods will result in a conservative power approximation.

Table 4. Summary of invertebrate pilot data locations and methods by year.

Year	Location	Aquatic Survey Methods	Terrestrial Survey Methods
2004	Tuolumne Meadows	Throw-trapping	Vacuum netting
2005	Tuolumne Meadows	Throw-trapping	Vacuum netting
2006	Tuolumne Meadows		Vacuum netting
2007	YOSE (including Tuolumne Meadows)	D-frame netting	Sweep-netting
2008	SEKI	D-frame netting	Sweep-netting

Vegetation indicators of interest included percent cover measurements, species richness, and prevalence. Percent cover was measured for bare ground; bryophytes; perennial, herbaceous dicots and non-graminoid monocots; annual dicots; graminoids; and National Wetland Inventory (NWI) wetland species categories. Pilot data for vegetation indicators were obtained from the probabilistic surveys conducted in YOSE and SEKI in 2007 and 2008, respectively. These data provided the basis for estimates of site-to-site variation. A second data set taken from a long-term study of three SEKI meadows allowed estimation of temporal random effects variances for percent bare ground and overall species richness. NWI vegetation categories are provided in Table 5.

Table 5. NWI wetland indicator categories*.

Wetland Type (Indicator Code)	Definition
Obligate Wetland (OBL)	Occurs almost always (estimated probability 99%) under natural conditions in wetlands
Facultative Wetland (FACW)	Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands
Facultative (FAC)	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%)
Facultative Upland (FACU)	Occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%)
Obligate Upland (UPL)	Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the regions specified. If a species does not occur in wetlands in any region, it is not on the National List.

*Accessed from, http://plants.usda.gov/wetinfo.html

Two pilot data sets were used to estimate variance components affecting power to detect trend in a single hydrological indicator, well depth. One pilot data set was obtained from a three-year study in Tuolumne Meadows, and the other pilot data set resulted from a four-year study of six meadows in SEKI (Table 6).

Table 6. Summary of hydrology pilot data.

Dataset characteristics	YOSE Meadows	SEKI Meadows
Years	2006-2008	2005-2008
Number of meadows	1 (Tuolumne)	6 (Cabin, Crescent, Dorst, Halstead, Log, Round)
Total number of wells	47	45

2.6.3 Power Analysis Results

The variance components estimated from the pilot data described above provide the basis for large-sample power calculations. Complete results are provided in the power report given in

Appendix 2. To summarize the results, Tables 7–9 provide estimated power for four levels of annually increasing trends (1%, 2%, 3%, and 4%) after 15 years of sampling with the [(1-0),(1-3)] revisit design.

Several indicators demonstrated exceptional power for trend detection. These indicators include well depth; the NWI prevalence index; and percent cover of perennial, herbaceous dicots and non-graminoid monocots. Power to detect trends as low as 1% annually may reach 80% in less than 15 years for these indicators. Indicators that appear highly variable for long-term monitoring include percent predators for terrestrial invertebrates and percent bare ground for vegetation surveys. Power of 80% or more is achieved for the remaining indicators by sampling consecutive years over a 20 to 30 year period.

This power analysis underscores the need for consistent sampling over a long time period for powerful trend detection. The most effective approach for achieving high power to detect trends over time is to ensure that at least the annual panel is surveyed each year using methods that are consistent over time.

Table 7. Power to detect trend after 15 consecutive survey years in SEKI for four levels of annual population increase (11 sites sampled annually for each wetland type).

Data Type	Indicator	Fens				Wet Meadows			
		1%	2%	3%	4%	1%	2%	3%	4%
Invert.	MFR (Aq.)	0.35	0.67	0.90	0.98	0.34	0.65	0.88	0.98
Invert.	MFR (Terr.)	0.26	0.42	0.62	0.80	0.26	0.42	0.62	0.79
Invert.	PD (Aq.)	0.33	0.63	0.87	0.97	0.49	0.89	0.99	1.00
Invert.	PD (Terr.)	0.66	0.98	1.00	1.00	0.73	0.99	1.00	1.00
Invert.	PP (Terr.)	0.21	0.23	0.27	0.31	0.21	0.23	0.26	0.31
Veg.	Pct bare ground	0.22	0.28	0.36	0.47	0.22	0.27	0.35	0.46
Veg.	Pct cover of bryophytes	0.30	0.55	0.79	0.93	0.32	0.60	0.85	0.96
Veg.	Pct cover of "forbs"	1.00	1.00	1.00	1.00	0.54	0.93	1.00	1.00
Veg.	Pct cover of graminoids	0.62	0.97	1.00	1.00	0.36	0.70	0.92	0.99
Veg.	Pct cover of Cyperaceae	0.29	0.52	0.76	0.91	0.52	0.91	1.00	1.00
Veg.	Pct cover of Juncaceae	0.71	0.99	1.00	1.00	0.32	0.58	0.83	0.95
Veg.	Pct cover of Poaceae	0.48	0.87	0.99	1.00	0.27	0.44	0.65	0.82
Veg.	Pct cover of annual dicots	0.38	0.72	0.94	0.99	0.34	0.63	0.87	0.97
Veg.	Cover sum of NWI OBL	0.67	0.98	1.00	1.00	0.29	0.51	0.75	0.90

Table 7. Power to detect trend after 15 consecutive survey years in SEKI for four levels of annual population increase (11 sites sampled annually for each wetland type).

Data Type	Indicator	Fens				Wet Meadows			
		1%	2%	3%	4%	1%	2%	3%	4%
Veg.	Cover sum of NWI FACW	1.00	1.00	1.00	1.00	0.29	0.51	0.74	0.90
Veg.	Cover sum of NWI FAC	0.57	0.95	1.00	1.00				
Veg.	Cover sum of NWI FACU					0.26	0.41	0.61	0.79
Veg.	Cover sum of NWI UPL								
Veg.	Sp. richness of NWI OBL	1.00	1.00	1.00	1.00	0.60	0.96	1.00	1.00
Veg.	Sp. richness of NWI FACW	1.00	1.00	1.00	1.00	0.76	1.00	1.00	1.00
Veg.	Sp. richness of NWI FAC	0.46	0.85	0.99	1.00	0.49	0.89	0.99	1.00
Veg.	Sp. richness of NWI FACU					0.38	0.72	0.94	0.99
Veg.	Sp. richness of NWI UPL								
Veg.	Overall species richness	0.54	0.93	1.00	1.00	0.50	0.90	0.99	1.00
Veg.	NWI prevalence index	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00
Hydro.	Well depth	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 8. Power to detect trend after 15 consecutive survey years in YOSE for four levels of annual population increase (11 sites sampled annually for each wetland type).

Data type	Indicator	Fens				Wet Meadows			
		1%	2%	3%	4%	1%	2%	3%	4%
Invert.	MFR (Aq.)	0.36	0.68	0.91	0.99	0.34	0.63	0.87	0.97
Invert.	MFR (Terr.)	0.26	0.41	0.61	0.79	0.26	0.41	0.61	0.79
Invert.	PD (Aq.)	0.41	0.78	0.96	1.00	0.93	1.00	1.00	1.00
Invert.	PD (Terr.)	0.91	1.00	1.00	1.00	0.43	0.81	0.97	1.00
Invert.	PP (Terr.)	0.21	0.23	0.26	0.31	0.21	0.23	0.26	0.31
Veg.	Pct bare ground	0.22	0.27	0.34	0.44	0.22	0.27	0.35	0.45

Table 8. Power to detect trend after 15 consecutive survey years in YOSE for four levels of annual population increase (11 sites sampled annually for each wetland type).

Data type	Indicator	Fens				Wet Meadows			
		1%	2%	3%	4%	1%	2%	3%	4%
Veg.	Pct cover of bryophytes	0.32	0.60	0.84	0.96	0.29	0.52	0.76	0.91
Veg.	Pct cover of perennial forbs	0.98	1.00	1.00	1.00	0.97	1.00	1.00	1.00
Veg.	Pct cover of graminoids	1.00	1.00	1.00	1.00	0.60	0.96	1.00	1.00
Veg.	Pct cover of Cyperaceae	0.99	1.00	1.00	1.00	0.77	1.00	1.00	1.00
Veg.	Pct cover of Juncaceae	0.44	0.82	0.98	1.00	0.89	1.00	1.00	1.00
Veg.	Pct cover of Poaceae	1.00	1.00	1.00	1.00	0.80	1.00	1.00	1.00
Veg.	Pct cover of annual dicots	0.35	0.67	0.90	0.99	0.38	0.73	0.94	0.99
Veg.	Cover sum of NWI OBL	0.81	1.00	1.00	1.00	0.69	0.99	1.00	1.00
Veg.	Cover sum of NWI FACW	0.51	0.91	1.00	1.00	0.89	1.00	1.00	1.00
Veg.	Cover sum of NWI FAC					0.78	1.00	1.00	1.00
Veg.	Cover sum of NWI FACU					0.54	0.93	1.00	1.00
Veg.	Cover sum of NWI UPL								
Veg.	Sp. richness of NWI OBL	0.98	1.00	1.00	1.00	0.93	1.00	1.00	1.00
Veg.	Sp. richness of NWI FACW	0.30	0.55	0.79	0.93	1.00	1.00	1.00	1.00
Veg.	Sp. richness of NWI FAC	0.51	0.90	0.99	1.00	0.83	1.00	1.00	1.00
Veg.	Sp. richness of NWI FACU					0.92	1.00	1.00	1.00
Veg.	Sp. richness of NWI UPL								
Veg.	Overall species richness	0.55	0.94	1.00	1.00	0.55	0.94	1.00	1.00
Veg.	NWI prevalence index	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hydro.	Well depth					0.97	1.00	1.00	1.00

Table 9. Power to detect trend after 15 consecutive survey years in SIEN for four levels of annual population increase (11 sites sampled annually for each wetland type).

		Fens				Wet Meadows			
Data type	Indicator	1%	2%	3%	4%	1%	2%	3%	4%
Invert.	MFR (Aq.)	0.36	0.68	0.91	0.99	0.36	0.68	0.91	0.99
Invert.	MFR (Terr.)	0.26	0.42	0.63	0.80	0.26	0.42	0.62	0.80
Invert.	PD (Aq.)	0.45	0.84	0.98	1.00	0.67	0.98	1.00	1.00
Invert.	PD (Terr.)	0.83	1.00	1.00	1.00	0.69	0.99	1.00	1.00
Invert.	PP (Terr.)	0.21	0.23	0.27	0.31	0.21	0.23	0.26	0.31
Veg.	Pct bare ground	0.22	0.28	0.37	0.49	0.22	0.28	0.37	0.48
Veg.	Pct cover of bryophytes	0.40	0.77	0.96	1.00	0.40	0.76	0.95	1.00
Veg.	Pct cover of "forbs"	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Veg.	Pct cover of graminoids	0.88	1.00	1.00	1.00	0.79	1.00	1.00	1.00
Veg.	Pct cover of Cyperaceae	0.77	1.00	1.00	1.00	0.94	1.00	1.00	1.00
Veg.	Pct cover of Juncaceae	0.67	0.98	1.00	1.00	0.99	1.00	1.00	1.00
Veg.	Pct cover of Poaceae	0.73	0.99	1.00	1.00	0.96	1.00	1.00	1.00
Veg.	Pct cover of annual dicots	0.51	0.90	0.99	1.00	0.49	0.89	0.99	1.00
Veg.	Cover sum of NWI OBL	0.89	1.00	1.00	1.00	0.83	1.00	1.00	1.00
Veg.	Cover sum of NWI FACW	0.99	1.00	1.00	1.00	0.99	1.00	1.00	1.00
Veg.	Cover sum of NWI FAC	0.81	1.00	1.00	1.00	0.95	1.00	1.00	1.00
Veg.	Cover sum of NWI FACU					0.75	1.00	1.00	1.00
Veg.	Cover sum of NWI UPL					0.96	1.00	1.00	1.00
Veg.	Sp. richness of NWI OBL	1.00	1.00	1.00	1.00	0.92	1.00	1.00	1.00
Veg.	Sp. richness of NWI FACW	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Veg.	Sp. richness of NWI FAC	0.67	0.98	1.00	1.00	0.97	1.00	1.00	1.00

Table 9. Power to detect trend after 15 consecutive survey years in SIEN for four levels of annual population increase (11 sites sampled annually for each wetland type).

		Fens				Wet Meadows			
Data type	Indicator	1%	2%	3%	4%	1%	2%	3%	4%
Veg.	Sp. richness of NWI FACU					1.00	1.00	1.00	1.00
Veg.	Sp. richness of NWI UPL					0.91	1.00	1.00	1.00
Veg.	Overall species richness	0.52	0.91	1.00	1.00	0.57	0.95	1.00	1.00
Veg.	NWI prevalence index	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hydro.	Well depth								

More information about the power analyses can be found in Appendix 3.

3 - Field Methods

3.1 Introduction

This section provides an overview of field season preparation, site level methods used in the protocol, and post-season processing of samples and data. More detailed descriptions of procedures are provided in individual SOPs.

3.2 Pre-Season Preparation

There are a wide variety of logistical issues related to protocol implementation that require significant preplanning if a sampling season is to be successful. For example, hiring of personnel must generally begin months before the actual start of field sampling. Housing is generally competitive and must be secured well in advance. However, factors such as snowpack depth and the rate of melt, which influences accessibility and the appropriate index period for sampling vegetation and macroinvertebrates, can vary widely from year to year, necessitating a certain amount of flexibility in scheduling.

Given these issues, it is important that all appropriate preseason preparations be made as far ahead of time as feasible. Some important considerations include effective communication with park staff. Specific issues that may need to be addressed include housing for personnel, logistical support in the form of assistance from park employees, access to radios or other communication equipment, and any special access issues. Research permits (required for NPS staff in Yosemite but not in SEKI or DEPO) and Wilderness compliance (minimum requirement/minimum tool analysis) approval must be obtained well before the start of field work. Note that these internal approvals require precise documentation of the number and location of proposed sampling sites.

3.3 Sampling Strategy and Response Design

The ideal field sampling strategy is one that allows for the collection of accurate and unbiased data in the most efficient manner possible. No single sampling design is the best in all environments. Factors such as vegetation type influence the performance of different plot types for the collection of vegetation data. Different sampling methods are needed for different invertebrate functional groups, e.g. terrestrial versus aquatic insects.

The goal of providing park level inferences through a survey design places severe constraints on the sampling effort that can be expended in any particular site. As a consequence, there are unavoidable limits to features included in the site level response design. The minimum required sample sizes, the need for revisits for QA/QC purposes and model parameterization, and the logistical limitations imposed by working in large, wilderness parks, all contribute to the critical need that the response be simple to lay out and conducive to efficient data collection.

The response design that was selected after extensive review entails the establishment of long-term, nested plots centered on a groundwater monitoring well (Figure 11). To minimize variability and ensure the greatest statistical power for trend detection, it was decided that fixed plots were preferable to designs involving new plots for future revisits. A nested plot design was selected because no single plot size is ideal for all plant types. Achieving consistency and precision when making cover measurements in smaller plots is typically easier than in large plots; however, large plots are more effective at capturing species diversity. Thus, a nested plot design is used, combining the desirable features of both small and large plots (Stohlgren et al. 1997).

There are many examples of nested plot designs in the ecological literature. For example, the modified Whittaker design has been widely used in vegetation studies (Stohlgren et al. 1995, Stohlgren et al. 1997, Stohlgren et al. 1999). However, the time required to lay out the modified-Whittaker design in the field and to collect data from all the different subplots made direct adoption of the design impractical. Other sampling strategies, such as the use of transects, were rejected, in part to maintain focus on the groundwater monitoring well and facilitate the integration of vegetation, hydrology, and invertebrate data.

The final plot design that was selected incorporates three plot sizes (Figure 11). The largest plot, which we refer to as the macroplot, is square in shape and has an area of 100 m^2. Contained within it is a 16 m^2 "subplot", and, lastly, four 1 m^2 "microplots". More details regarding the site level design are presented in SOP 10 Laying Out a Site.

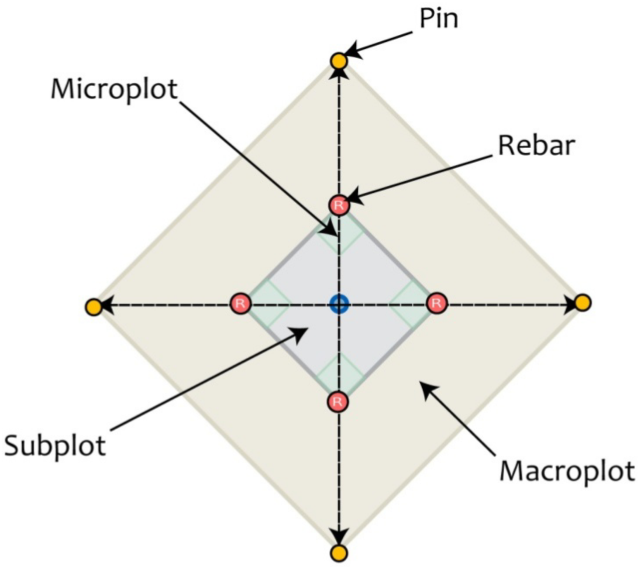


Figure 11. Diagram illustrating general plot layout. Long-term monumenting of plots is achieved via four capped rebar placed in the corners of the subplot and the capped groundwater monitoring well. Pins are placed temporarily to aid in plot layout, then removed following sampling.

The general sampling procedure is consistent, regardless of sampling design (i.e. index or extensive) or wetland type. The sampling schedule for extensive sites will be spread over several years using a panel design. Basic information regarding each extensive site will be codified onto site dossier forms. These will include maps, directions, and general descriptions of wetlands. In addition, during the process of extensive site establishment, a list of “over sample” wetlands will be prepared, for instances of sample frame error or inaccessibility.

The sampling schedule for index sites will involve one to several visits annually. Specific sampling frequency can vary, depending on whether loggers are present, availability of staff, and logistical factors. Index sites will generally be easy to access, so they can be more easily integrated into sampling schedules. Trained volunteers or NPS staff can also collect routine well measurements in index sites that are not instrumented. In general, vegetation and macroinvertebrates will be sampled annually at peak phenology.

3.4 Overview of Workflow at a Site

A standard workflow needs to be followed when collecting data in the field. This will help ensure that all data are collected and of the highest quality possible. Crews must take particular care to minimize disturbance in the course of laying out plots and collecting data. The general sequence of steps is the same regardless of sampling design (index or extensive) or wetland type. There are several additional steps involved in the initial site establishment. These include well installation and the establishment of plot monuments. However, data collection methods such as vegetation and invertebrate sampling are the same whether a site is newly established or being revisited (Figure 12). Details regarding the specific steps involved in plot establishment and data collection are presented in the individual SOPs.

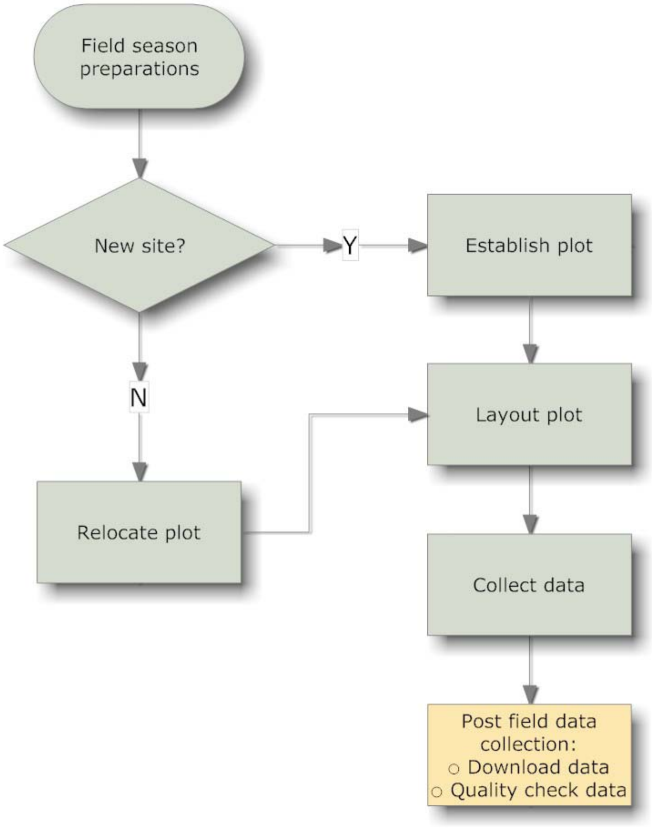


Figure 12. General sequence of steps taken during a field season by crews. Steps involved in each step (e.g. plot establishment, plot layout) are detailed in subsequent sections and in SOPs 7, 8, and 10.

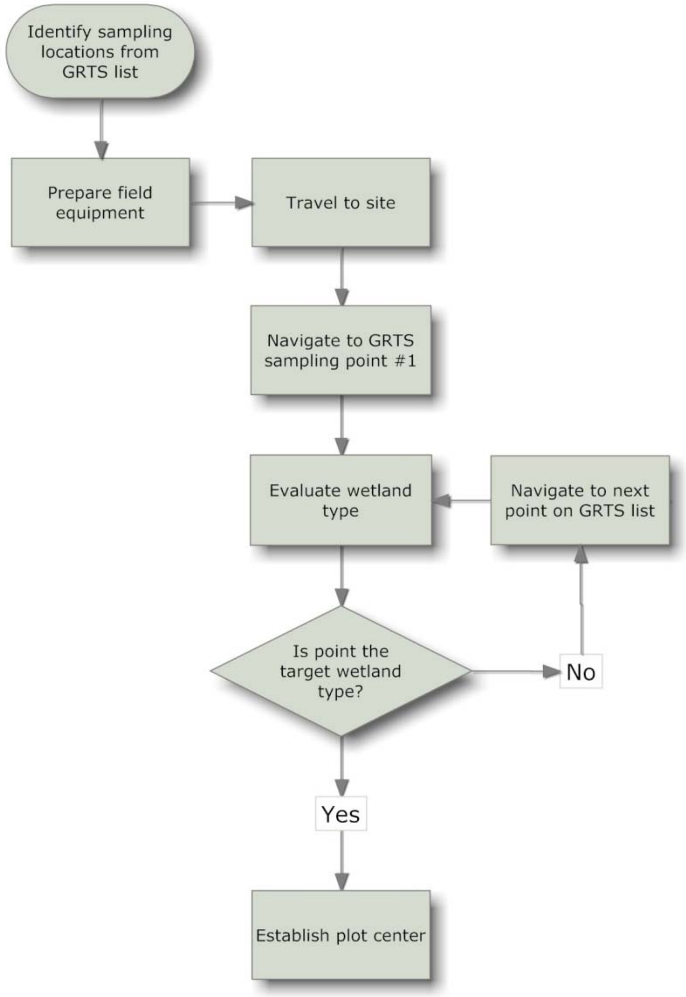


Figure 13. Flowchart indicating general sequence of steps for placing extensive sites within wetlands.

3.5 Resource Protection Overview

All efforts aimed at minimizing the impact of crew members on SIEN wetlands must be taken. The following guidelines will be implemented to ensure that no impacts to important cultural or biological resources occur:

- No historical or prehistorical archeological artifacts or historical features will be disturbed
- Wells will be installed with minimal soil disturbance using an auger when possible
- When wells are installed, soil will be placed on a polytarp and returned to holes with any excess scattered following installation

- Well casings will be cut within 8” of ground surface, capped and camouflaged with earthtoned spray paint

- Vouchers will be collected from outside the plot boundaries whenever possible. If <20 individuals of the plant are noted, plants will be photographed rather than collected

- No flagging or other markers beyond those specified by the protocol will be left on site

- All staff and volunteers will be instructed in appropriate safety and Leave-no-trace© practices of wilderness travel and camping

- Proper precautions, specified by the network or individual parks, will be taken to minimize transfer of organisms among wetlands. Boots and gear will be examined for seeds or other propagules between visits to different sites. Decontamination procedures aimed at preventing the spread of chytrid fungus will be followed.

The groundwater monitoring well serves as the main plot marker, indicating the macroplot center, with additional plot markers used to ensure plots revisited in the future are set up in the same location, reducing variability. Dataloggers, where used, will be installed within well casings with no additional installation required to support them. The protocol allows for adoption of methods with fewer impacts if new technologies become available, such as more precise global positioning system (GPS) technology which could obviate the need for plot markers. Should any sites be omitted from sampling in the future, the Network commits to removing all plot markers and the well.

Crews will be made aware of any threatened, endangered, or rare species that may be in the vicinity of sampling locations. During plot establishment, care will be taken to ensure that no sensitive resources are negatively impacted. Where potentially important or sensitive resources have been encountered, the location is recorded with a GPS waypoint and a photo taken. The location of any sensitive resources should not be communicated to anyone other than official staff.

3.6 Data Management in the Field

3.6.1 Use of Forms

A variety of field data forms are provided for field data collection. Electronic versions have been developed to facilitate data collection using a hand-held computer. Even where the use of a hand-held computer for data collection is preferred, an adequate supply of paper forms will be carried by crews so that sampling is still possible if circumstances prevent use of electronic equipment. A portion of field data forms should be copied to waterproof (e.g. Write-in-the-Rain©) paper in case of inclement weather.

Some forms are common to all wetland types and sampling designs (e.g. index and extensive), while others are only completed in a restricted set of circumstances. More specific instructions for completing data forms are provided in SOP 4 (Electronic Field Data Entry) and in the individual SOPs describing protocol metrics.

3.7 Establishing/Relocating Sites

3.7.1 Extensive Sites

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. Along with the sampling schedule, these will be used to generate the list of points for upload into a GPS unit. Once all pre-visit tasks are taken care of, the crew will use the GPS to navigate to the first target point in the GRTS sample point list when establishing a site or to the coordinates of the previously established site when revisiting.

Once on site, the crew will navigate to the first GRTS point and evaluate whether the point falls within the target wetland type (i.e. fen, wet meadow, or wetland complex; Figure 13). Methods for determining the target status are presented in SOP 6. If the point and at least 80% of the area of any plot established around it are of the 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.

If selected for sampling, the plot center and well location are temporarily marked. Distinctive witness features such as large trees or rock outcrops on the margins of the wetlands are identified and their coordinates are recorded using a GPS. The azimuth and distance from the well to witness features is determined using a compass and by pacing, or if practicable, running a tape. Distances and azimuths are recorded on a sketch map and any supplemental photographs useful for documenting site location are taken. If points are rejected, the reason why is recorded.

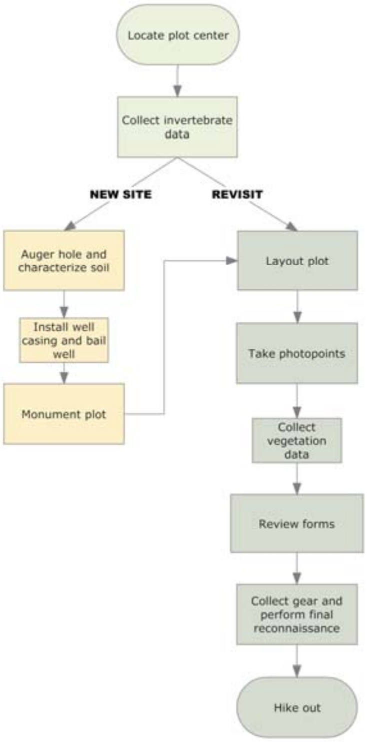


Figure 14. Overview of workflow on site.

As part of the initial assessment of the site during establishment, general soil characteristics (e.g. texture, color, etc.) and presence of hydric soil indicators of soils excavated from the well hole are recorded. Soils develop certain diagnostic characteristics when subject to extended periods of saturation and/or inundation. Termed hydric soil indicators, they are a primary indicator used to evaluate soil saturation and water table depth for wetland assessment and delineation procedures (Environmental Laboratory 1987, USDA NRCS 2006). Examples include gleyed soils or soils with abundant redoximorphic features such as oxidized root channels or mottles (Tiner 1999).

The crew member responsible for soil descriptions will create a sketch of the soil stratigraphy, noting the depth, texture, matrix color, presence and type of hydric soil indicators, and, in peat soils, the depth and degree of decomposition of peat layers. In fens, small soil samples are collected for organic matter analysis from the hole augured for the well. In peat soils, the degree of humification (decomposition) is also evaluated using the von Post scale, described in detail in SOP 8 Groundwater Monitoring Well Installation. The higher the value on the von Post degree of decomposition scale, the greater degree of decomposition. Hydraulic conductivity of peat soils decreases with greater levels of decomposition, influencing hydrologic patterns (Malterer et al. 1992).

3.7.2 Index Sites

Site dossiers will also be prepared for index sites. Unlike extensive sites, which have a single well and plot module, multiple wells and plot modules may be present in single index sites. Each well, whether selected from existing wells at a site, or newly established, will have a set of coordinates associated with it that will be uploaded into a GPS for navigation.

As with extensive sites, witness points need to be distinctive; examples include large trees or rock outcrops. Crews will record witness point coordinates as waypoints using a GPS, measure the distance (m) and azimuth from the well to the witness feature using a compass and tape or by pacing the distance, and photograph the witness features from the plot center/well. The distance and direction between wells should also be measured in the sequence they will be visited during sampling. All significant features (e.g., wells, witness trees, etc.) are drawn onto a sketch map of the site and any additional notes that may assist crews in relocating plots are recorded. Detailed instructions for index site layout are presented in SOP 10 Laying Out a Site.

3.7.3 Rejecting or Moving Sites

When first visited, sampling points are evaluated to confirm that they are of the target wetland type using information in SOP 6–Determining Target Status of a Site in the Field. If the point appears to be of the target type, but cannot be sampled because of safety or accessibility issues, then the point can be rejected. Crews must record why the site was rejected on the Site Establishment Form, and select a replacement point from the list of “oversample sites.” Points should generally not be moved unless extenuating circumstances exist, such as a safety or resource protection issue. No formal statistical constraints govern moving plot locations within index sites because of the subjective nature of their establishment.

3.8 Site Reconnaissance and Initial Assessment

Once a point has been selected for sampling, and the plot center/well location temporarily marked, invertebrate sampling is conducted. The crew then performs an initial site assessment and reconnaissance. The objective is to record data useful for classifying and characterizing sites, note the presence of stressors or disturbances, and record broad indicators of condition. Detailed directions for completing the reconnaissance and initial assessment are found in SOP 7 Site Establishment and Assessment.

3.9 Plot Layout

3.9.1 Extensive Sites

Once the plot center point/well location is established (or relocated for revisits) and the invertebrate sampling has been completed, the crew lays out the measuring tapes using a compass and establishes the outline of the plot. The general steps in plot layout are presented in Figure 15. Detailed instructions for plot layout are provided in SOP 10 Laying Out a Site. The methods used for index sites are identical to those used in extensive sites.

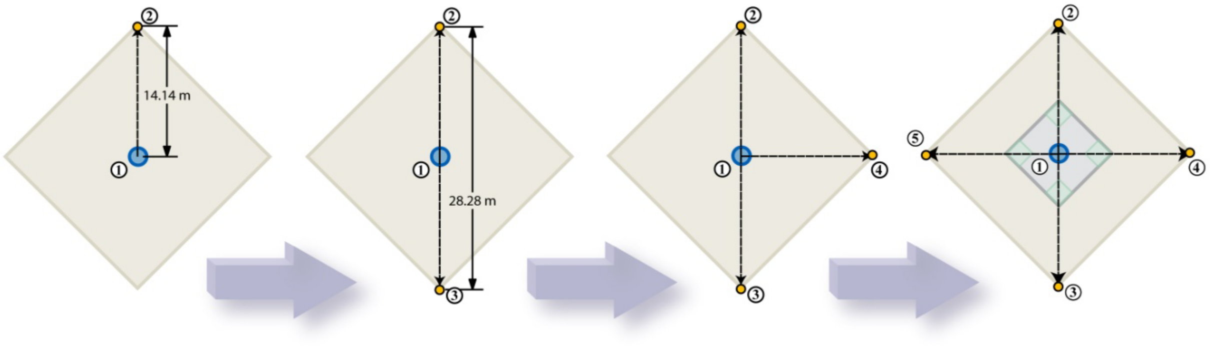


Figure 15. Overview of plot layout. Tapes are laid orthogonal to one another along cardinal directions. Once corners are established, tapes can be used to define the edges of the macroplot. Distances to subplot corners/microplot corners are measured from the well using tapes.

3.9.2 Index Sites

Index sites have a distinctly different purpose than extensive sites, providing data useful in interpreting data from the extensive design. The more intensive sampling possible in index sites helps in understanding the temporal variation in hydrologic, vegetation, and invertebrate metrics used in the extensive design. Continuous data loggers should be used where possible, as these provide superior data and are more cost-effective in the long term than relying on manual measurements.

Steps in plot layout are identical between index and extensive sites, with the main differences between designs related to the frequency of measurement. The procedure for plot layout at index sites with existing wells is no different than newly established ones. The modular plots are simply fit over those wells selected. Detailed instructions are presented in SOP 10 Laying Out a Site.

3.10 Site Photos

Although they have definite limitations, photographs provide a valuable tool for evaluating ecological change (Mast et al. 1997, Bradford 1998, Horsted and Grafe 2002). For example, processes such as tree or shrub invasion are readily visible on photographs (Jakubos and Romme 1993, Vale and Vale 1994, Zier and Baker 2006). Properly framed and documented images also can be useful for relocating monitoring sites.

The protocol involves collecting one photo of the entire macroplot 2-5 meters from the south corner of the plot (Figure 16A), eight photo points at fixed azimuths from the center of the plot module (Figure 16B), and a photo from plot center of any landmarks used to help locate the plot (Figure 16C). A detailed discussion of photographic points is presented in SOP 11 Photo Point Documentation. Specific methods for camera use will vary depending on model. Manufacturer instructions must be reviewed and followed.

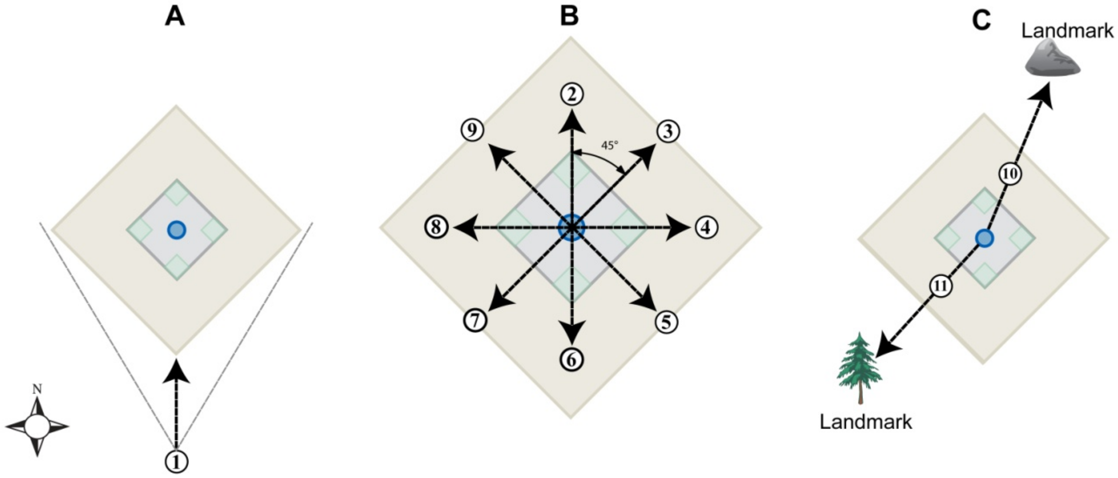


Figure 16. Overview of photo points taken at sampling sites. One photo is taken 2–5 meters south of the south plot corner (A). Photos are taken in sequence clockwise from due north from the macroplot/subplot center (B). Photos are taken from the well of landmarks used to relocate plot (C).

3.11 Vegetation

Vegetation can be an excellent indicator of changes in key environmental drivers such as hydrologic regime (Cooper 1990, Ahn et al. 2004, Auble et al. 2005). Given the objectives of the wetland monitoring protocol, we selected a sampling design using nested plots of varied size. Because hydrologic regime is such an important driver of vegetation in wetlands, plots are centered on the well casing. A fixed plot design is used, regardless of vegetation type, providing the largest plot and nested subplots fall completely within the target wetland type (i.e. fen or wet meadow). Ideally, stratification would also be done by vegetation community, allowing for the sampling of more homogeneous vegetation units; however, due to practical and statistical constraints, the protocol does not stratify at a finer scale than wetland type.

Cover of woody and herbaceous species is estimated in the small microplots (1 m^2) and subplots (16 m^2) and species presence is recorded in the 100 m^2 macroplot. Bryophyte cover by species species is estimated for microplots and subplots only. During dry periods, mosses are difficult to observe, reducing the accuracy of cover measurement. Therefore, when sampling during dry periods, crews will apply a misting of water using a spray bottle to microplots prior to assessing cover, and will record microplots receiving water, quantity of water applied, and the amount of time between water application and cover estimates. Bryophytes are difficult for most botanists to accurately identify in the field. However, they are an important part of the flora in many wetlands, particularly fens. The procedure for sampling bryophytes in the protocol employs an approach whereby samples of mosses are collected from outside of the macroplot, packaged, and sent for outside identification by bryological experts (Doubt and Belland 2000).

Woody species cover is estimated in all three sized plots. In addition, woody species establishment is evaluated in microplots. Methods are detailed in SOP 12. Voucher specimens of all vascular plants recorded in plots will be collected off-plot and submitted to herbaria for subsequent identification and archiving (SOP 14 Collecting Voucher Specimens, SOP 19 Processing Plant Collections).

3.12 Macroinvertebrate Sampling

Invertebrates are dominant wetland ecosystem components in terms of biodiversity, abundance, and trophic web structure. Wetland invertebrates are important food resources and processors of organic material and represent a “crossroads” for ecological flows between aquatic and terrestrial realms; disturbances can be transferred among habitats by this important invertebrate linkage. Invertebrate fauna produced by wetlands also subsidize upland assemblages.

Invertebrates are useful as vital signs because of their abundance, species richness, ubiquitous presence, and importance in ecosystem function (Holloway 1980, Rosenberg et al. 1986). Invertebrates are particularly sensitive to disturbance (Holmquist and Schmidt-Gengenbach 2004, Holmquist and Schmidt-Gengenbach 2008), expressed both by mortality and emigration. Response is often amplified by high reproductive potential. Also, the variety of trophic levels represented, even within a given taxon, provides great indicator sensitivity (Samways 1994). For these reasons, invertebrates are excellent rapid response “sentinel species” (New 1995). Indeed, after only three years of pilot data collection for both this vital sign effort and for a parallel effort in the White Mountains as part of the Global Observation Research Initiative in Alpine Environments, we believe that we are seeing rapid response of wetland arthropod abundance, richness, evenness, and dominance metrics to changes in snow water equivalent (Holmquist and Schmidt-Gengenbach 2008).

The techniques that we are using to sample macroinvertebrates integrate over a relatively large sampling area. A single sweep net sample (SOP 17) covers an area that is 20% greater than the associated macroplot, i.e., all of the macroplot, plus some habitat that directly adjoins the macroplot. Baits (SOP 18) attract ants and other fauna from the same area. Aquatic sampling (SOP 16) collects fauna from a 1.5 m^2 area.

3.13 End-of-Season Procedures for Processing Data and Samples

To establish and preserve data integrity, it is essential that field crews follow a basic set of procedures for processing samples and data collected in the field. Upon completion of sampling and prior to departing the field site, all electronic and paper data forms must be examined for completeness. A reconnaissance of the site must be conducted by crews to ensure that no equipment is left behind.

Field crews must follow a rigorous set of procedures to ensure that all data are properly downloaded, archived, and fully documented. All relevant metadata needs to be completed and included with data sets (see SOPs 4, 23, and 25 for details). All specimens that have been collected and identified must be properly catalogued. Specimens need to be sent to experts for taxonomic identification as soon as feasible.

Vegetation and invertebrate databases need to be updated to account for the identification of unknowns. For all vouchers, specimens need to be properly prepared and labeled for accession to herbaria or museum collection.

Plant specimens collected for identification should be identified as soon as possible. Voucher specimens require long-term storage and cataloging. Plants must be transferred from field presses to a wooden plant press promptly for proper storage and mounting. Specific guidelines for voucher specimen collection, preparation, identification and storage are detailed in SOP 14.

Soil samples, if collected, should be air dried in paper bags until they can be processed. All samples collected for laboratory analysis will be stored in a cool, dry location in the respective park laboratory until ready for analysis. The standards followed for archiving plant materials will vary by institution, but all labels must include details regarding the collector, date, and place of collection, purpose of collection, and other information as required. More detailed descriptions are presented in SOPs 16, 17 and 18 (invertebrates) and 19 (plants).

At the end of the field season, all equipment needs to be cleaned and inventoried for winter storage. Broken or obsolete equipment needs to be identified and repaired or replaced. Soil must be removed from shovels, augers, and other tools and lubricant (e.g. WD-40) applied to metal fittings to inhibit rust formation. Batteries must be removed from all electronic equipment prior to storage during the off-season.

4 - Data Management

This chapter describes the data management procedures for the Wetlands Ecological Integrity (WEI) monitoring protocol, including the data management roles and responsibilities for various staff involved with the protocol. Additional details and context for this chapter can be found in the SIEN Data Management Plan (Cook and Lineback 2008), which describes the overall information management strategy for the network.

4.1 Protocol Information Management Overview

Data go through successive stages as a project progresses. These stages can be viewed as a cyclic process tied to the annual collection and management of wetlands monitoring data. The major stages in this cycle are described and summarized below (Table 10) and illustrated in Figure 17.

Table 10. Data management activities and responsibilities associated with various stages of Wetland Ecological Integrity monitoring.

Activity	**Description**	**Responsibility**
Acquire data	Data are acquired in digital or analog form. Digital data can be recorded on handheld computers and PDAs, tablets, or laptop computers. Analog data are entered on field data sheets.	Protocol Lead, Crew Lead, Crew Members
Archive raw data	Copies of all raw data files are archived intact. Digital files are copied to the digital library (the set of LAN folders created for the project); hard copy forms are either scanned and placed in the digital library or are copied and placed in the archives. Archiving or scanning of hard copy data forms may occur at the end of a season as a means of retaining all marks and edits made during the verification and validation steps.	Crew Members, Crew Lead, Data Manger
Enter/import data	Analog data are entered manually and digital data files are uploaded to the working database.	Crew Members, Crew Lead,
Verify, process, and validate	Accurate transcription of the raw data is verified; data are processed to remove missing values and other flaws; and data are validated through visual inspection and queries to capture missing data, out-of-range values, and logical errors.	Protocol Lead, Crew Lead, Crew Members, Data Manager
Documentation and certification	Develop or update project metadata and certify the data set. Certification is a confirmation by the project leader that the data have passed all quality assurance requirements and are complete and documented. It also means that data and metadata are ready to be posted and delivered.	Data Manager, Protocol Lead

Upload data	Certified data are uploaded from the working database to the master project database. This step might be skipped for short-term projects where there is no need to distinguish working data for the current season from the full set of certified project data.	Data Manager
Archive versioned data set	The SIEN Project Data Certification Form is completed (Appendix 3A). Copies of the certified data and metadata are placed in the digital library. This can be accomplished by storing a compressed copy of the working database or by exporting data to a more software-independent format (e.g., ASCII text).	Data Manager
Disseminate data and update national databases	Certified data and metadata, and digital image products are posted to national repositories (the NPS Data Store, Biodiversity Data Store, NPS Focus) to make them more broadly available to others. National databases, including NPSpecies, NPSTORET, and ANCS+ are updated with data obtained from certified data sets.	Data Manager
Reporting and analysis	Certified data are used to generate data products, analyses, and reports, including semi-automated annual summary reports for monitoring projects. Depending on project needs, data might be exported for analysis or summarized within the database.	Protocol Lead (Staff Ecologist), Data Manager
Distribute information products	Information products such as reports, maps, and checklists are disseminated to the public through the SIEN website and NPS Focus, and catalogued in NatureBib.	Data Manager
Share data and information	Data, metadata, reports and other information products can be shared in a variety of ways – by FTP or mailing in response to specific requests, or by providing direct access to project records to park staff and cooperators.	Protocol Lead (Staff Ecologist), Data Manager
Track changes	All subsequent changes to certified data are documented in an edit log, which accompanies project data and metadata upon distribution. Significant edits will trigger reposting of the data and products to national databases and repositories.	Data Manager, Protocol Lead (Staff Ecologist)
Store products	Reports and other data products are stored according to format and likely demand, either in the digital library, on off-line media, or in the document archives.	Data Manager
Catalog project products	Catalog products and all information associated with a project, including results of analyses and paths of dissemination. Project tracking databases can be useful tools for this purpose.	Data Manager, Protocol Lead (Staff Ecologist)

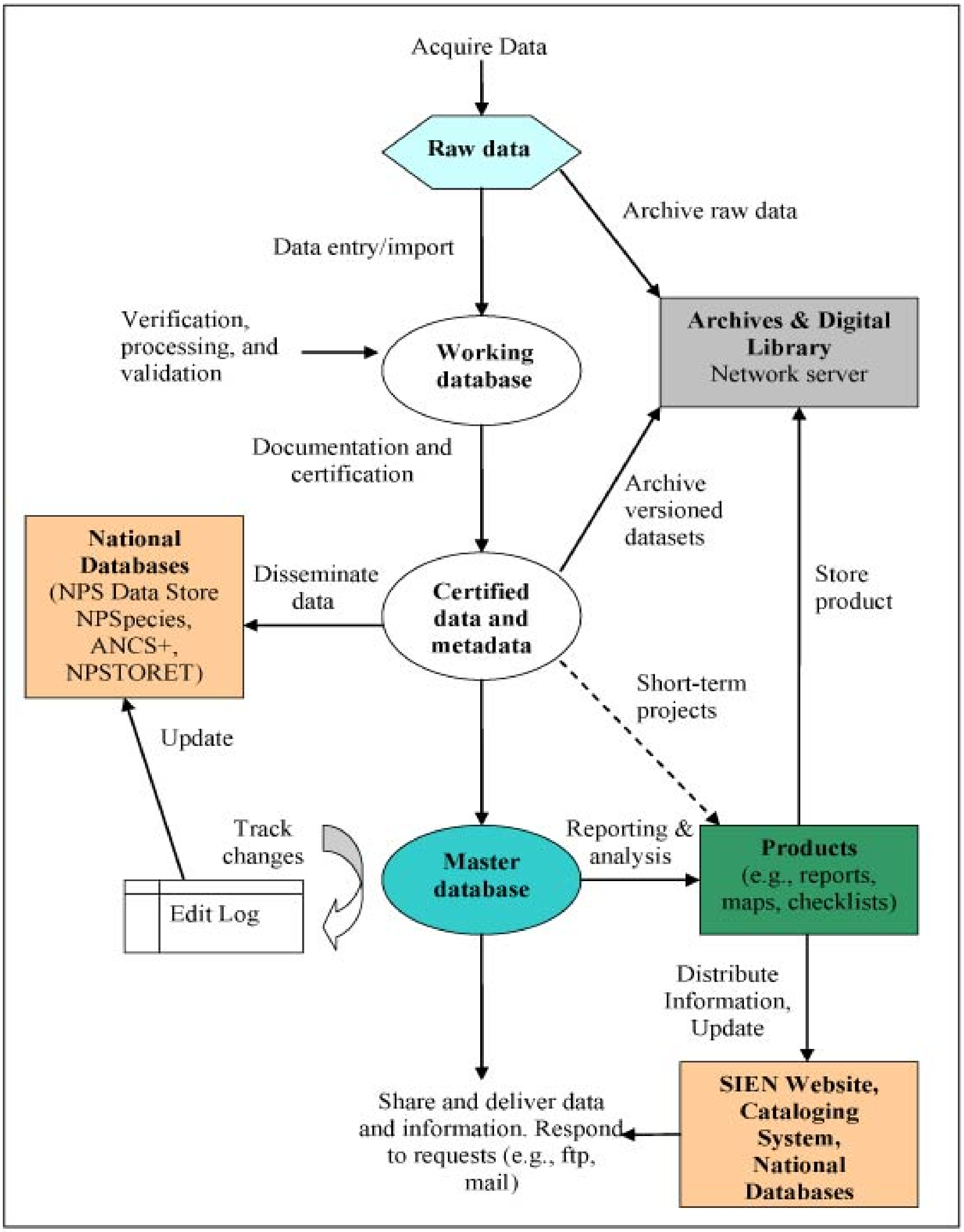


Figure 17. Flow diagram of the information management life cycle for Wetlands Ecological Integrity Monitoring in Sierra Nevada network parks (from Cook and Lineback 2008).

4.2 Overview of Database Design

The SIEN WEI monitoring database is a Microsoft Access 2003 application. Its design is based on the NPS I&M Natural Resource Database Template (NRDT) version 3.1 and is consistent with database standards described in the SIEN Data Management Plan (Cook and Lineback 2008). Two tables, tblWells and tblWellVisit, form the core of the database. They correspond to tblLocation and tblEvents, respectively; core tables at the heart of the NRDT. TblWells stores the location information for each sampling unit while tblWellsVisit stores data associated with individual sampling events at those sampling units. The remaining data tables in the database characterize wetland vegetation, hydrology, and invertebrates at the sampling unit for each sampling event.

The SIEN strategy for maintaining the integrity of the WEI database uses the "working copy/master copy" model adopted by other I&M networks. The data models for the "working copy" and the "master" (archive version) are identical. The "working copy" is used to store the current season's data while the "master copy" serves as a data archive suitable for multi-year analyses. Queries in the front-end working database application are used to validate and verify the data before it is certified and appended to the master copy of the database. The master copy of the database incorporates a front-end user interface with additional tools for generating summary information, reports and formatted export files.

In general, project staff have read/write access to the working copy of the database to perform data entry and data verification procedures. Read/write access to the master copy of the database is limited to the Database Manager and Protocol Lead. Access rights to both copies of the database are controlled by network level directory and file permissions.

4.3 Pre-Season Preparations

4.31 Set Up Project Workspace

A section of the networked file server at each host park is reserved for this project, and access permissions are established so that crew members have access to needed files within this workspace. Prior to each season, the Protocol Lead should make sure that network accounts are established for each new crew member, and that the Data Manager is notified to ensure access to the project workspace and databases.

4.32 GPS Loading and Preparation

The Data/biological tech and Crew Lead should work together to ensure that target coordinates and data dictionaries are loaded into the GPS units prior to the onset of field work, and that GPS download software is available and ready for use. Additional details on GPS use and GPS data handling may be found in SOP 3, GPS Useage and Appendix6-B_GlobalPositioningSystems, Sierra Nevada Network Data Management Plan (Cook and Lineback 2008).

4.33 Implement Working Database Copy

Prior to the field season, the Data Manager will implement a blank copy of the working database and ensure proper access on the part of the crew members. Refer to Appendix 4: Database design and documentation for additional information about the database design and implementation strategy.

4.4 Data Entry

The working copy of the database includes a front-end client application with tools and forms for uploading and entering the current field season's data. Before each field season, the Data Manager installs a clean copy of the working database on a network server, places a copy of the front-end database application in the project workspace on a network client computer accessible to crew members, and links the front and back ends. Crew members use the front end application on the client to upload electronic data from a PDA and enter data manually into the working copy of the back-end database on the server. Once data from a field season have been entered, validated, and certified, the Data Manager appends it to the master copy of the database on the network server.

4.5 Data Backup

Both the working copy and master copy of the database are backed up as part of the nightly network server backup. Once the current season's data has been validated and certified, that year's working database is also archived to CD or DVD.

In addition to procedures for backing up digital data, another vital step in ensuring the integrity of the WEI data is making backup copies of all original field forms and storing copies at off site locations to prevent data loss. Specific procedures for handling originals, making copies, and storing both analog and digital data are discussed in SOP 27, Archiving Data.

4.6 Quality Assurance and Quality Control (QA/QC)

Field data are currently recorded using a combination of handheld computers (PDAs) paper datasheets, and automated data loggers. Data are recorded on the PDA in an MS Access compatible application that employs electronic data entry forms. These forms incorporate validation rules, range limits, and pick lists that promote consistent and accurate data entry. Added advantages of entering data on PDAs include reducing the burden of subsequent data entry and minimizing the potential for data transcription errors. We will convert paper datasheets to electronic data entry forms wherever feasible.

In some cases, paper field forms are more suitable than electronic forms for recording data like sketches and lengthy narrative descriptions. When data must be transcribed from paper forms to digital format, they undergo rigorous data verification and validation procedures that are summarized below.

4.7 Data Verification and Validation

Data quality is appraised by applying verification and validation procedures. *Data verification* checks that the transcribed data match the source data. All data recorded on paper datasheets are subject to verification. Once data entry is complete, the Protocol Lead or a designee must verify the data to assure consistency between field forms and the database. This is accomplished by comparing the analog data to the digital version and resolving discrepancies.

Once verification is complete, the data set undergoes validation. *Data validation* checks that the data make sense. Although data may be correctly transcribed from the original field forms, they may not be accurate or logical. The process of reviewing computerized data for range and logic errors is one step in the validation stage. Validation procedures also seek to identify generic errors (e.g. missing, mismatched or duplicate records). Certain components of data validation are built into data entry forms (e.g. range limits). Validation can also be extended into the design and structure of the database through the use of look-up tables. Subsequent data validation is accomplished by a combination of visual inspection and queries in the database front end that are structured to find duplicates and logical inconsistencies. Although data entry and verification can be handled by project staff who are less familiar with the data, validation requires in-depth knowledge about the data and primary responsibility for validation is borne by the Protocol Lead. Verification and validation procedures are described in detail in SOP 26, Data Quality Control.

4.8 Data Documentation

Data documentation is an essential component of sound data management. Thorough documentation is essential for preserving the integrity and longevity of data and the products of its analysis. From project development through final delivery of information products, the Data Manger and Protocol Lead will place a high priority on documenting the aims, quality, and meaning of WEI data.

The process of documenting data creates a description of the data, how it was collected, and what it means. This information is collectively known as metadata. Wetlands Ecological Integrity metadata will adhere to content standards set by FGDC and NPS policy. The Protocol Lead will begin creating metadata at the onset of the project and set the tone for record-keeping throughout the course of the project. Crews will be trained to record decisions made in the field that affect data quality or meaning. The creation of WEI metadata will be guided by the practices described in SOP 25 Metadata Development, and the SIEN Data Management Plan (Cook and Lineback 2008)

4.9 Data Archival Procedures

Data sets are rarely static. Changes, improvements, or updates to the data may be required once a dataset has been archived. However, archived data can be changed only if three safeguards are in place: 1) data integrity must be maintained; 2) once archived, all changes to the data set must be documented; and 3) mistakes made during editing must be recoverable.

To maintain data integrity, original field forms should not be altered. Original entries on the data sheet are never erased. If corrections are needed, they are written in the margins with the date and initials of the person making the correction. Corrections on field forms can be reconciled with the database through the use of an edit log. Every change must be documented in an edit log and accompanied by an explanation that includes pre- and post-edit data descriptions.

Prior to any major changes in a digitally archived data set, a copy is stored with the appropriate version number, which allows for the tracking of changes over time. Versioning of archived data sets involves adding a decimal version number to the file name, with the first version being numbered 1.00. Each major version is assigned a sequentially higher whole number. Each minor revision is assigned a sequentially higher 0.1 number. With proper controls and communication, versioning ensures that only the most current version is used in any analysis. Frequent users of the data are notified of the updates and provided with a copy of the most recent archived version.

Any editing of archived data is accomplished jointly by the Protocol Lead and Data Manager. The reader is referred to Tessler and Gregson (1997) for a complete description of prescribed data editing procedures and an example edit log.

Secure data archiving is essential for protecting data files from corruption. Once a data set has passed the QA/QC procedures specified in the protocol, a new metadata record is created. Subsequently, an electronic version of the data set is maintained in a read-only format on the SEKI GIS server in the SIEN directory. Backup procedures for the WEI protocol follow those described in the Sierra Nevada Network Data Management Plan (Cook and Lineback 2008).

4.10 Data Dissemination

Currently, data are available for research and management applications on request for database versions where all QA/QC has been completed and the data have been archived. Data can also be transferred using e-mail (most Access files are smaller than 10 Mbytes or can be compressed into .zip files) or ftp where available. Eventually, Wetland Ecological Integrity monitoring data will be available for download directly from the NPS I&M Monitoring webpage. In addition, metadata will become available directly from the NPS I&M Data Store, the NPS I&M data and metadata server. Data requests should be directed to the SIEN Data Manager. Data summaries and analyses will be incorporated into annual reports and periodic trend analysis reports (described in Chapter 5).

5 - Data Analysis and Reporting

5.1 Data Analysis: Overview

Detailed descriptions of data analysis procedures are provided in SOP 28 (Data Analysis and Reporting).

Two distinct types of sample sites are used in this protocol – index and extensive – that determine the appropriate analyses to be used. Index sites were subjectively chosen and inference from status estimation and trend analyses is limited to these specific sites. Extensive sites were randomly selected using the GRTS procedure (Table 11; see section 2.5 for detailed explanation). Data collected at the extensive sites are used to estimate status and trend at park and network levels. Within both extensive and index sites, two types of wetlands are considered: fens and wet meadows. Three distinct data sets are collected within each of the two wetland types: vegetation, invertebrate, and hydrology. This structure allows for analyses of each of these components, as well as community level analyses.

Table 11. Number of fen and wet meadow (WM) sites by park unit (SEKI= Sequoia Kings Canyon NP, YOSE=Yosemite NP, SIEN=Sierra Nevada Network).

Park unit	Annual panel sites		Other panel sites/year		Total sites/year		Total sites/cycle		Total unique sites	
	Fen	WM	Fen	WM	Fen	WM	Fen	WM	Fen	WM
SEKI	6	6	5	5	11	11	44	44	26	26
YOSE	6	6	5	5	11	11	44	44	26	26
SIEN	12	12	10	10	22	22	88	88	52	52

5.2 Index Sites

Status estimation for vegetation, invertebrates, and hydrology at fen and wet meadow index sites will be computed using standard descriptive statistics. Data will be analyzed and summarized by year and park unit. Daily data of water table depths will be recorded by data loggers and used to explore the possibility of linking observed daily fluctuations in index site hydrology with longer time frame (annual or four year) recordings at extensive sites.

5.3 Annual Status Summary: Extensive Sites

Status results will be summarized after each year of data collection. Standard summary statistics will be presented with content similar to that shown in Table 12, and will include measures of central tendency ($\bar{x}$), and spread (s) for vegetation, invertebrate, and hydrologic data. Within each wetland type, data will be summarized by park-unit and network levels. Graphical analysis of plots and maps will be performed as part of exploratory data analysis. This will be particularly important in the early years of the project to identify a workable set of variables or metrics that best explain the status of wetlands among the vast possible sets, and to aid in the refinement of existing hypotheses and generate new hypotheses about pattern and process.

Table 12: Relationship among the protocol objectives, data, and inference.

	Objective	Data		Inference Goal	
		Raw	Summarized	Trend	Statistic(s) for status
Describe and compare the status of wet meadow and fen wetlands Compare rates of change in wetland characteristics between fen and wet meadows	- Identify temporal change in wetland hydrology	Groundwater		Y	$\bar{x}$ depth (cm)
	- Estimate temporal change in wetland plant communities	Herbaceous spp		Y*	$\bar{x}$ % cover/sp; *p* plots/sp
			spp richness	Y	$\bar{x}$ richness
			Total herbaceous	Y	$\bar{x}$ % cover
			PI	Y	$\bar{x}$ index value
		Non-vascular spp		Y*	$\bar{x}$ % cover/sp; *p* plots/sp
			spp richness	Y	$\bar{x}$ richness
			Total non-vascular	Y	$\bar{x}$ % cover; *p* plots
		Woody spp		Y*	$\bar{x}$ % cover/sp; *p* plots/sp; $\bar{x}$ no./m^2
			Total woody	Y	$\bar{x}$ % cover; *p* plots; $\bar{x}$ no./m^2
			Total gymnosperms	Y	$\bar{x}$ % cover; *p* plots; $\bar{x}$ no./m^2
			Total angiosperms	Y	$\bar{x}$ % cover; *p* plots; $\bar{x}$ no./m^2
		Exotic spp		Y*	$\bar{x}$ % cover/sp; *p* plots/sp
			spp richness	Y	$\bar{x}$ richness
			Total exotics	Y	$\bar{x}$ % cover; *p* plots
		Litter		Y	$\bar{x}$ % cover
		Bareground		Y	$\bar{x}$ % cover
		Top canopy		Y	$\bar{x}$ ht (cm)
		Vertical structure		N	$\bar{x}$ & mode (3 classes)
		Peat		N	$\bar{x}$ depth (cm)
	- Estimate temporal change in wetland macroinvertebrate communities	Terrestrial macroinvertebrate Families		Y*	$\bar{x}$ no. indiv./Fam; *p* plots/Fam
			MFL	Y	$\bar{x}$ MFL
		Aquatic macroinvertebrate Families		Y*	$\bar{x}$ no. indiv./Fam; *p* plots/Fam
			MFL	Y	$\bar{x}$ MFL
		Ant spp		Y*	$\bar{x}$ no. indiv./sp; *p* plots/sp
			spp richness	Y	$\bar{x}$ richness

* Trend may be evaluated on key species for which necessary abundance values are known

$\bar{x}$ is the sample mean; *p* is the sample frequency (proportion of total); MFL is Margalef's Family richness; PI is National Wetland Inventory prevalence index; sp is species (singular); spp is species (plural); Y is yes; N is no.

5.4 Trend Analyses: Extensive Sites

Analyses of trend will be conducted following each four-years of sampling (i.e., after completion of one full panel rotation). The null hypothesis that no change in a given metric has occurred at the network level (H_0: $\beta_1=0$) will be tested using a mixed linear model with $\alpha=0.10$. The model was developed by VanLeeuwen et al. (1996) and Piepho and Ogutu (2002) specifically to address trend estimation for correlated data. The mixed model allows for consideration of both fixed and random effects. Fixed effects contribute to the mean of the outcome and random effects contribute to the variance. Random effects are used to estimate variation of linear trends among units (wetland sites) and over time (years).

5.5 Reporting

Detailed reporting guidelines and table structures are provided in SOP 28 (Data Analysis and Reporting).

The Sierra Nevada Network will produce two types of reports for the Wetland Ecological Integrity project. Annual summaries will be produced following each field season, and more comprehensive status and trend reports will be produced every four years following a full panel rotation.

Annual reports will:

- List project personnel and their roles.
- List sites sampled during the current year.
- Provide a summary history of the number of sites, their panel membership, park unit, and wetland type during each year of the project.
- Identify any data quality concerns and/or deviations from the protocol that affect data quality and interpretability.
- Include information on any rare native species or early 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 measured variables summarized by wetland type, park unit, and all of SIEN.
- Discussion of results, including management implications.

A more thoroughly detailed analysis and report will be produced every four years, as the full set of panels is completed. In addition to the above, the four-year report will:

- Document in-depth status and trend analysis results.
- 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 wetlands.
- Identify any changes in spatial patterns of wetlands.

Annual reports and four-year status and trend reports should use the NPS Natural Resource Publications template, a pre-formatted Microsoft Word template document based on current NPS formatting standards. Annual reports will use the Natural Resource Report template, and trend analysis and other peer-reviewed technical reports will use the Natural Resource Technical Report template. These templates and documentation of the NPS publication standards are available at: http://www.nature.nps.gov/publications/NRPM/index.cfm.

6 - Personnel Requirements and Training

The wetlands monitoring protocol requires effective management and oversight from core network staff as well as support from local park staff to assist with crew training, logistics, permitting, and index site sampling. Outside experts are also used for taxonomic expertise for invertebrates and some plant taxa (bryophytes, sedges). In addition to the key roles for long-term network staff and park staff, seasonal employees will be needed to accomplish field sampling. Considerable care needs to be taken to ensure that seasonal hires have the necessary field skills, dedication, and stamina.

6.1 Roles and Responsibilities

The wetlands ecological integrity protocol lead is the SIEN Ecologist, supervised by the Network Coordinator. Field monitoring is conducted by field technicians (biological science technicians).

Extensive site sampling requires two crews of two technicians each. One crew will be stationed at Yosemite and one at Sequoia and Kings Canyon. These crews will be able to assist with some of the index site sampling, but depending on the year and the panels of extensive sites being visited, a varying portion of the index site sampling will need to be done with help from Park Ecologists and Technicians and other I&M staff. The Yosemite crew will also sample the index site(s) at Devils Postpile. Roles and responsibilities for I&M and Park staff and cooperators for wetlands protocol major field-associated activities are summarized in Table 13.

Table 13. Anticipated roles and responsibilities of I&M seasonal crews, other Park or I&M staff, and outside experts for major field activities, estimated by numbers of 2-week pay periods (pp).

Activity	YOSE/DEPO I&M crew	SEKI I&M crew	Other Park or I&M staff	Outside Experts
Pre-season preparation and post-season sample processing and data management	2.0 pp (GS-05) 4.0 pp (GS-07)	2.0 pp (GS-05) 4.0 pp (GS-07)	1.0pp (Park) 4.0 pp (SIEN)	2.5 pp
Index site sampling	1.0 pp	1.0 pp	2.0 pp	1.0 pp
Extensive site sampling	4.5 pp	5.0 pp	1.0 pp	

The Wetlands Work Group, who was instrumental in the development of this protocol, will continue to be involved in advisory and support roles. Some members will participate more actively assisting with index site sampling and crew training. The network will continue to consult and work with area experts from universities and federal and state agencies.

Table 14 summarizes the broader roles and responsibilities of SIEN, Park, and seasonal staff and cooperators in the wetlands monitoring program. Should budget resources improve in the future, we will consider hiring a GS-09 Ecologist to help with crew hiring and training, logistics support, field work supervision, data management, and other standard tasks associated with multiple I&M protocols.

Table 14. Roles and responsibilities for SIEN, Park, and seasonal staff and cooperators for WEI protocol.

Role	Responsibilities
Protocol Lead (SIEN Ecologist)	Oversee all protocol activities; supervise field crews; train crews; support field sampling; verify, validate, and analyze data; write annual and comprehensive monitoring reports; manage protocol budget; work w/ Coordinator and Data Manager to meet I&M program level reporting requirements; manage database; revise protocol, as needed.
Data Manager	Maintain database; provide technical support for database management, data quality assurance/quality control, data storage and dissemination, and data analysis procedures; provide GIS technical support.
Network Coordinator	Coordinate with protocol lead to meet I&M Program requirements (e.g. budget, reporting, education/outreach); integrate wetlands monitoring with rest of Vital Signs program.
Park Ecologists	Assist with oversight, training, and support of field crew(s) in respective park; assist with index site sampling when crews are reading extensive sites.
Data/Biological Tech (SIEN staff)	Provide logistical support for field sampling; order and track supplies; assist with pre-field season prep; provide GIS support; participate in field sampling when needed (index sites, very remote sites); provide support for crew training (radio, GPS, map and compass training).
Crew Members	Prep for field sampling and wilderness travel; collect vegetation, invertebrate and hydrologic data following protocol procedures; fully document procedures and anomalies; enter field data into database; perform end-of-season procedures; ensure safety of self and crew members.
Crew Lead	All field tech responsibilities, plus: communicate with protocol lead regarding crew concerns and needs; ensure crews have all equipment before going into field; submit wilderness travel plans; take lead on decisions in the field regarding safety, logistics, and sampling; manage plant and invertebrate collections; sort and organize collections; and prepare voucher specimens.
Outside subject-matter experts	Invertebrate taxonomy, assistance with invertebrate data processing and analyses; plant taxonomy (some sedges, bryophytes).
Wetland Work Group	Provide technical guidance; coordinate with protocol lead on park-level logistics (e.g., Wilderness Minimum Requirement Analysis, research permitting, housing); assist in disseminating information as appropriate; provide review and evaluation.
Local area Experts	Provide guidance and technical assistance as needed – recommending cross-country hiking routes, permitting, Wilderness Minimum Requirement Analysis, etc.

6.2 Desirable Skills and Qualifications for Core Protocol Staff

The Protocol Lead will meet basic requirements for a GS-11 Ecologist position and will have education or experience in vegetation sampling, research or monitoring sample designs and analytical methods, strong communication skills, and ability to manage projects and field crews.

Essential field staff includes a lead botanist (GS-07) competent in plant identification, particularly grasses and sedges, and another biological technician (GS-05) capable of sampling invertebrates for export to a cooperator for identification and assisting with vegetation sampling which is the more time-consuming task at plots. Field crews need to be healthy and physically able to manage the work, which will include frequent travel to remote backcountry locations. The senior crew member must have experience working independently and leading others. This individual must also be competent using spreadsheets, GIS, and database programs, as they will be primarily responsible for field data quality control.

Collectively, crews will need to have the following skills or qualifications:

- B.S. or higher degree in botany, entomology, wetland ecology, field biology, or related field
- Strong plant identification skills, including sedges
- Invertebrate sampling skills; some basic invertebrate identification skills helpful, but the emphasis for crew members will be on plant taxonomy
- Ability to use dichotomous keys
- Familiarity with Sierra Nevada flora
- Ability to conduct field work safely, under strenuous circumstances, in remote backcountry areas
- Dedication, ability to work independently, and ability to follow specific protocols
- Good map reading, compass, and route-finding skills for off-trail hiking
- Strong hiker with physical stamina
- Excellent oral and written communication skills
- Strong proficiency in Microsoft Office Word, Excel; basic skills in MS Access and ArcGIS are helpful
- First aid or wilderness first responder training

The skills needed by cooperators who provide taxonomic expertise will be detailed in contract or task agreement documents.

6.3 Training

Proper training in protocol-specific SOPs and safe work practices is critical to the success of this monitoring project. Crews will be hired early enough to allow time for detailed training that gives them context for the work they are doing, familiarizes them with the protocol methods, and gives them the information and tools they need to conduct work safely in our large predominantly Wilderness parks.

The training SOP (20) and other sampling and data management SOPs provide more detail on specific training needs and procedures for crews.

Safety is a central aspect of our seasonal crew training (Safety SOP 21) and is addressed in the following components of beginning of season training:

- Participation in local park seasonal training with the Resources Management and Science Divisions
- Introduction to I&M program and the specific monitoring project(s) that crew will be involved with (include information about why we are monitoring what we are and make sure they understand the bigger picture of why what they are doing is important)
- Discussion of our vision and philosophy for safety and wellness at work, the roles and responsibilities each person has to create and maintain a safe work environment, and the fact that there are no I&M data worth risking injury or death to collect
- Review and discussion of Job Hazard Guidelines related to working in the parks and to the specific protocol(s) they will be working on
- Introduction to radio system and communications in parks; review of wilderness communication and check-in procedures
- Maintaining vigilance about safety – use of safety tailgate sessions, staying focused and mindful while working and traveling in the parks, communicating openly with supervisor and team members when you have a safety concern
- Provision of safety-related supplies and equipment, with clear instruction on how/when they are to be used, if appropriate (first aid supplies, radios, hiking poles, bear-proof food canisters, camping gear, etc.)
- Reporting of accidents and injuries, if they do occur
- Providing NPS emergency contact information, and obtaining emergency contact information from crew members, along with any concerns such as allergies to medications
- Hands-on training with the protocol (and safety issues) in the field
- First Aid and CPR training if feasible

For the wetlands protocol, crews will be given training and guidelines in the safe and proper use of sampling equipment and hand tools. Checklists will be provided for appropriate gear and field clothing for safe wilderness travel, and to the extent possible, SIEN will provide and check out work gear (such as bear canisters, tents, sleeping bags, hiking poles) to crew members for the season.

Other specific information and guidance are provided on:

- Trip plans: At a minimum, a trip plan for each field trip must be completed and left at a designated location in the office (see SOP 22). The trip plan should include the following information:
    - Field trip participants, including guests and observers, with emergency contact information
    - Departure and expected return time(s) and date(s)
    - Hotel and campground contact information (for overnight trips)
    - Basic itinerary, including where and when sampling will occur
    - Phone numbers for cellular or satellite phones, radio frequencies or repeaters to be used

- Field communications (radio use, satellite phones if available)—see SOP 22
    - provide park-specific instructions, call numbers, phone numbers

  - check-in procedures for field crews doing wilderness travel

- Handling medical emergencies
  "Call, Contact, Care" describes the required immediate response to an emergency. Crews are advised of the following:
  - Always call 911 or Park Dispatch first if the situation warrants.
  - Contact colleagues in the field, supervisor, and park staff to alert them to the incident and any relevant danger.
  - Care for injuries by getting or providing prompt medical treatment. All injuries that warrant compensation require paperwork.
  - Report all incidents of any type to supervisor.

7 - Operational Requirements

The wetlands monitoring protocol requires support from both Network and local Park staff as well as expertise from cooperators for specialized taxonomy (invertebrates, sub-sets of plant taxa). The fact that Network staff are duty-stationed in SIEN parks facilitates coordination of logistics, training, and field support with local Park staff.

7.1 Annual Workload and Field Schedule

The field sampling season is from approximately mid-June through late August (Table 15). Index sites are sampled once per month through the sampling season. Extensive sites are sampled from mid-June through mid- to late-August, and exact timing is dependent upon phenology and travel logistics. Data entry or upload occurs throughout the season and is completed by the end of October for most data. Some additional data entry will need to be finalized in January after specimen determinations have been completed. Data analysis and reporting occurs during winter months. Annual and comprehensive reports (produced every four years) are submitted to the Network Coordinator and Park staff by the end of April.

Table 15. Annual schedule.

Event	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
End of season wrap-up	■											
Field data entry	■			■						■	■	■
Sample processing and i.d.	■	■	■									
Data analysis/reporting				■	■	■	■					
Pre-season field prep							■	■				
Index site sampling									■	■	■	
Extensive site sampling									■	■	■	

7.2 Facility and Equipment Requirements

Wetlands protocol personnel use office space in both Sequoia (Ash Mountain) and Yosemite (El Portal). Parks provide office space at both Yosemite and Sequoia so crews may organize field gear, access email and phones, copy and file field forms, and complete data entry tasks. Staff also require use of the microscopes and lab space in both parks to sort and organize invertebrate samples for shipment to specialists and to identify plant specimens and prepare vouchers for herbaria. The SIEN Ecologist’s primary office is located in Yosemite; temporary office space is available when working in Sequoia and Kings Canyon. Facilities are provided by the parks. We will be looking into securing a satellite facility on the east side of the Sierra where samples could also be processed and shipped. The University of California White Mountain Research Station will be the most likely location where additional sample processing and identification could occur, especially on years where crews primarily access sites from eastside trailheads.

The field crews will be primarily in the wilderness for the field season so they may or may not have seasonal housing. For the limited time they are in the frontcountry they may be housed at the Ash Mountain Dormitory, Yosemite Bug Hostel, or park seasonal housing, if available. We are also pursuing housing options on the east side of the Sierra, where many of the trailheads are located, that crews could use for temporary housing between trips.

Equipment inventory and checklists are located in the individual field sampling SOPs.

7.3 Partnerships

A primary partnership will be with the University of California White Mountain Research Station for assistance with invertebrate specimen identification and support with data analysis and interpretation. Some continued statistical support from a university or consultant may be needed through the first years of protocol implementation to assist with refining data analysis methods. Other partnerships may include projects with wetlands specialists to answer questions that the monitoring data will generate or to assist us in defining thresholds for key metrics.

Reading a groundwater monitoring well. Yosemite National Park.

7.4 Budget

The WEI Monitoring Protocol annual budget is $140,885 (Table 16). The funding source is primarily from the Inventory and Monitoring Program Vital Signs funds, with some in-kind support (~$9,500) provided from park staff contributions to protocol oversight and management.

Table 16. Wetlands protocol annual budget.

Personnel					Operations	Management and Reporting	
	Unit	Number	Rate	# people		SIEN staff	Park staff
SIEN Ecologist- GS-11	pp	10.0	3,124	1		31,240	
Park Ecologist GS-11	pp	1.5	3,319	1			4,979
Park other support GS-07	pp	1.5	2,111	1			3,167
Park seasonal GS-06	pp	1.0	1,420	1			1,420
Data Manager	pp	2.0	3,612	1		7,224	
Data/Biological Technician	pp	3.0	2,111	1		6,333	
Coordinator	pp	1.0	3,979	1		3,979	
GS-07 seasonal botanist	pp	11.0	1,568	2	34,496		
GS-05 seasonal biotech	pp	7.5	1,264	2	18,960		
Subtotal					**53,456**	**48,776**	**9,565**
Other services							
Plant identification	job	1	1,500		1,500		
Invertebrate id**	sample	64	242		15,488		
Subtotal					**16,988**		
Travel							
Wilderness per diem/seasonals	day	50	20	4	4,000		
Wilderness per diem/others	day	10	20	1	1,000		
Subtotal					**5,000**		
Operations/Supplies							
Vehicles	season	2	1500		3,000		
Stock support	trip	6	500		3,000		
Supplies	season	2	500		1,000		
Shipping (plant/invert samples)			100		100		
Subtotal					**7,100**		
TOTAL					**$82,544**	**$48,776**	**$9,565**
Overall Total for Protocol=	**$140,885**						

*term/perm benefits = 35%

**includes index sites and annual panels/2 samples per site

The annual wetlands protocol budget does not include costs absorbed at the program-level or shared across protocols. Program level costs include, computers, travel to meetings, office supplies, equipment purchases/replacements that occur irregularly, and administrative support. The SIEN I&M program budget is outlined in the Sierra Nevada Network Vital Signs Monitoring Plan (Mutch et al. 2008a).

Significant portions of the wetlands protocol resources are put towards data management, primarily time from the Ecologist and crew members. The SIEN coordinator, data manager, and biological science technician also contribute time to the wetlands protocol to contribute to data management, logistics support, and outreach/communication needs.

A key component to the success of this protocol is involvement and support from park staff. However, due to current budget restraints and already more than full workloads, staff contributions to this protocol are mostly limited to the Plant Ecologist and her biological technician in Sequoia and Kings Canyon National Parks, and these staff will assist with sampling index sites in those parks and will participate in field crew training. Other Park staff contributions will primarily be through participation in the Wetlands Work Group, assisting with park-level logistical support as their time permits, and coordinating with Network staff to cost-share seasonal crews or other staff. Parks also provide significant resource support by providing office, herbaria, and housing facilities. The Work Group hopes that as the program continues to develop, park contributions will increase through time.

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