National Park Service
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Natural Resource Stewardship and Science

Sierra Nevada Network Lake Monitoring Protocol

Protocol Narrative

Natural Resource Report NPS/SIEN/NRR—2012/551



ON THE COVER
Lake in the Upper Kern Watershed, Sequoia National Park.
Photograph by: Bob Meadows

Sierra Nevada Network Lake Monitoring Protocol

Protocol Narrative

Natural Resource Report NPS/SIEN/NRR—2012/XXX

Andrea M. Heard[1], Leigh Ann Harrod Starcevich[2], James O. Sickman[3], Meryl Goldin Rose[1], and Donald W. Schweizer[1]

[1]National Park Service, Sierra Nevada Network
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

[2]Oregon State University
Corvallis, OR 97331

[3]University of California, Riverside
Department of Environmental Sciences
Room 2324 Geology
Riverside, CA 92521

March 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Heard, A. M., L. A. H. Starcevich, J. O. Sickman, M. Goldin Rose, and D. W. Schweizer. 2012. Sierra Nevada Network Lake Monitoring Protocol: Narrative report. Natural Resource Report NPS/SIEN/NRR—2012/XXX. National Park Service, Fort Collins, Colorado.

Revision History Log

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

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Acronyms and Abbreviations

AA	Atomic absorption spectrophotometry
ANC	Acid Neutralizing Capacity
CEDEN	California Environmental Data Exchange Network
DEPO	Devils Postpile National Monument
DIN	Dissolved inorganic nitrogen
DON	Dissolved organic nitrogen
EPA	Environmental Protection Agency
GIS	Geographic Information System
GPS	Global Positioning System
GRTS	Generalized Random Tessellation Stratified
HBN	Hydrologic Benchmark Network
I&M	Inventory and Monitoring
IC	Ion chromatography
ICP	Inductively coupled plasma
LAKES	Lake Alkalinity Evaluation in the Sierra Nevada
N	Nitrogen
NHD	National Hydrography Dataset
NPS	National Park Service
NPSEDD	National Park Service STORET Electronic Data Deliverable
NPS-WRD	National Park Service-Water Resources Division
NRDT	Natural Resources Database Template
P	Phosphorus
PN	Particulate nitrogen
PP	Particulate phosphorus
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RWQCB	Regional Water Quality Control Boards
S	Sulfur
SCA	Student Conservation Association
SEKI	Sequoia and Kings Canyon National Parks
SIEN	Sierra Nevada Network
SKT	Seasonal Kendall Test
SOP	Standard Operating Procedure
SWAMP	Surface Water Ambient Monitoring Program
TBD	To be determined/developed
TDN	Total dissolved nitrogen
TN	Total nitrogen
TP	Total phosphorus
UC	University of California
VERP	Visitor Experience Resource Protection Program
WLS	Western Lakes Survey
YLF	Yellow-legged frog
YOSE	Yosemite National Park

Acknowledgments

The Sierra Nevada Network's Lake Monitoring Protocol could not have been completed without the commitment, hard work, technical expertise, and generosity of many people.

We thank Danny Boiano, Annie Esperanza, Jim Roche, and Harold Werner (SIEN's water work group) who made significant contributions including making key decisions regarding objectives, sample design, methods, and logistics. The amphibian work group composed of Danny Boiano, Lara Rachowicz, Steve Thompson, and Harold Werner made significant contributions to integrate amphibian monitoring. We would also like to thank additional park staff who have contributed time and expertise: Pat Lineback, Lee Tarnay, and Jeff Maurer.

We thank Linda Mutch, SIEN I&M Coordinator, for all her contributions at the SIEN I&M program-level and her strong support, guidance, and review of the lake protocol. We thank the SIEN Science Committee for their invaluable input and guidance, Sandy Graban and George Durkee for GIS work, and Tani Meadows for administrative support.

We thank the National Park Service, Water Resources Division for their technical guidance and especially would like to acknowledge Roy Irwin, Barry Long, Gary Rosenlieb, and Dean Tucker.

We thank Rose Cook for her significant data management contributions particularly all her work on SIEN's water database. We also thank Karl Jacobs and Lizette Cook (both CA Dept. of Water Resources), Cassandra Lamerdin and Stacey Swenson (both with the SWAMP Program at Moss Landing Marine Laboratories), and Dean Tucker (NPS-WRD) who provided technical support for the database project.

We received invaluable statistical consulting through a shared Cooperative Ecosystem Units agreement within the Pacific West Region. We thank Lisa Garrett and Tom Rodhouse (both NPS) for coordinating this agreement and Kirk Steinhorst (Univ. of Idaho) for coordinating and providing statistical consultation.

There are many agencies and universities conducting water quality, hydrology, and amphibian monitoring and research in the Sierra Nevada. We worked with multiple cooperators who donated time and expertise and shared their knowledge, data sets, and protocols. We thank Neil Berg (USDA Forest Service, Pacific Southwest Research Station), Cathy Brown (USDA Forest Service, Stanislaus National Forest), Dave Clow (USGS, Water Resources Division), Gary Fellers (USGS), Allan Gallegos (USDA Forest Service, Sierra National Forest), Sharon Grant (USDA Forest Service, Stanislaus National Forest), Roland Knapp (Sierra Nevada Aquatics Research Lab), Alisa M. Mast (USGS, Water Resources Division), and Trent Procter (USDA Forest Service, Region 5).

Information from existing I&M water quality protocols contributed significantly to SIEN's lake protocol; in many instances we adapted portions of these protocols for SIEN's purposes. We are very appreciative of the hard work from the networks that came before us and acknowledge their protocols:

Cooprider, M. A. 2005. San Francisco Bay Area Network freshwater quality monitoring protocol, Version 2.01, National Park Service, Point Reyes Station, CA. 51 pp. Plus appendices. http://science.nature.nps.gov/im/units/sfan/.

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Fong, D. 2007. San Francisco Bay Area Network Stream Flow Monitoring Protocol V2.82. San Francisco Bay Area Network, Inventory and Monitoring Program. National Park Service. http://science.nature.nps.gov/im/units/sfan/.

Larsen, A., J. Houghton, J. Black, D. Verbyla, C. Ruedebusch, and R. McGinnis. 2004. Shallow lake limnology monitoring protocol, Central Alaska Network, National Parks and Preserves, Alaska. Version 1.00. Fairbanks, Alaska: National Park Service. http://science.nature.nps.gov/im/units/cakn/.

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Sharrow, D., D. Thoma, K. Wynn, and M. Beer. 2005. Water quality vital signs monitoring protocol for park units in the Northern Colorado Plateau Network. Moab, Utah: National Park Service. http://science.nature.nps.gov/im/units/ncpn/.

Executive Summary

The Sierra Nevada Network (SIEN) monitors high-elevation lakes throughout Sequoia, Kings Canyon, and Yosemite National Parks as part of the National Park Service's Inventory and Monitoring (I&M) Program. The purpose of the I&M Program is to develop and provide scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. This is accomplished through park-wide inventories and a long-term monitoring program. In establishing a service-wide natural resources inventory and monitoring program, the National Park Service (NPS) created networks of parks that are linked by geography and shared natural resource characteristics. Working within networks improves the efficiency of inventory and monitoring because parks are able to share budgets, staffing, and other resources to plan and implement an integrated program. The Sierra Nevada Network includes four NPS units: Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI)—two distinct parks managed as one unit, and Yosemite National Park (YOSE).

The Sierra Nevada Network, through a series of workshops involving park staff and collaborators, selected a suite of "vital signs" (ecological indicators) to monitor for the long-term (Mutch et al. 2007). Vital signs are a subset of physical, chemical, and biological elements and processes of ecosystems that are selected to represent the overall health or condition of park resources. SIEN monitors long-term trends for a suite of ecological indicators as part of the following monitoring efforts: lakes, rivers, high-elevation white pines, wetlands, birds, and climate. Three of the selected vital signs are sampled at SIEN lakes: water chemistry, surface water dynamics, and amphibians. The Lake Monitoring program incorporates two of SIEN's high priority indicators---water chemistry and surface water dynamics. The water chemistry objectives were the primary driver of the monitoring design, with the hydrologic objectives second in priority. In addition, we collect limited amphibian survey information at our lake sites that are used by the parks and cooperators to supplement ongoing research and monitoring. Amphibian survey procedures are described in a separate protocol.

Sierra Nevada Network parks protect over 4,500 lakes and ponds and thousands of kilometers of rivers and streams that have some of the highest water quality in the Sierra Nevada. High-elevation lakes are critical components of the parks' ecosystems, popular visitor destinations, and habitat for aquatic and terrestrial organisms including declining amphibian species. Lake ecosystems were selected for monitoring because they are 1) valued for their ecological importance, contribution to Wilderness character, recreational opportunities, and importance to regional water supplies, 2) threatened by multiple stressors, and 3) sensitive to environmental change.

This protocol describes the SIEN Lakes Monitoring program and procedures in detail. It includes background information on the resource, the rationale for monitoring lakes and selected measures, description of the sampling design, power analysis, field procedures, laboratory requirements, data analysis procedures, data management guidelines, reporting schedules and procedures, annual budget, and operational details. The protocol narrative provides an overview and detailed procedures are described in a series of Standard Operating Procedures.

1. Background and Objectives

The purpose of the Inventory & Monitoring (I&M) Program is to develop and provide scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. As part of the National Park Service's effort to "improve park management through greater reliance on scientific knowledge," a primary role of the Inventory and Monitoring Program is to collect, organize, and make available natural resource data and to contribute to the Service's institutional knowledge by facilitating the transformation of data into information through analysis, synthesis, and modeling.

The five goals of the I&M Program are to (Fancy 2007):

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

These goals are accomplished through park-wide inventories and a long-term monitoring program. In establishing a service-wide natural resources inventory and monitoring program, the National Park Service (NPS) created networks of parks that are linked by geography and shared natural resource characteristics. Working within networks improves the efficiency of inventory and monitoring because parks are able to share budgets, staffing, and other resources to plan and implement an integrated program. The Sierra Nevada Network (SIEN) includes four NPS units: Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI)—two distinct parks managed as one unit, and Yosemite National Park (YOSE).

Sierra Nevada Network parks are located on the western slope of the Pacific Crest in the Sierra Nevada Mountains and span seven major watersheds (**Figure 1**). These watersheds, from north to south, are the Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule, and Kern. Runoff from these watersheds drains into the San Francisco Bay/ Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south. The Sierra Nevada parks protect a diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs, and karst springs.

The Sierra Nevada Network, through a series of workshops involving park staff and collaborators, selected a suite of "vital signs" (ecological indicators) to monitor for the long-term (Mutch et al. 2007). Vital signs are a subset of physical, chemical, and biological elements and processes of ecosystems that are selected to represent the overall health or condition of park

resources. SIEN elected to co-locate some vital signs and monitor them at the same locations. Three vital signs are co-located at SIEN lakes: water chemistry, surface water dynamics, and amphibians.

The Sierra Nevada Network Lake Monitoring protocol describes monitoring procedures for water chemistry and surface water dynamics. The water chemistry objectives were the primary driver of the monitoring design, with the hydrologic second in priority. This protocol includes detailed procedures for chemistry and hydrology monitoring.

Pilot amphibian monitoring is being collocated at our lake monitoring sites. The amphibian vital sign cannot be adequately addressed with current protocol funding-levels. Our intent is to supplement ongoing research and monitoring and further document the presence of amphibians at sampled lakes. The usefulness of these limited data to support other amphibian efforts will be re-evaluated after a few years. As a result, amphibian survey methods are not described in this protocol. We use methods described in Rose (2010).

1.1. Sierra Nevada Network Lakes

The majority of Sierra Nevada Network lakes occur at higher elevations (above 2500 m). SIEN lentic waterbodies range from less than 1 ha to exceeding 90 ha in area. SIEN, for the purposes of this protocol, distinguished lakes from ponds by defining lakes as greater than/equal to 1 ha in area and greater than/equal to 2 m at the maximum depth. The average SIEN lake is between 5 and 6 hectares (**Figure 2**). Lakes vary in depth from 2 m to well over 30 m. Water dynamics in the Sierra Nevada are a critical component of both the parks' ecosystems and the larger California freshwater infrastructure. Most of the precipitation falls during the winter months and at higher elevations (i.e. greater than 1700 m), it primarily falls as snow. The resulting snowpack acts as a natural reservoir, accumulating and storing precipitation during winter months that will be released during the warmer and drier months. Peak snowmelt runoff typically occurs late May to early June. Runoff is captured and stored for later use in a series of reservoirs that line the Sierra Nevada foothills. Reservoirs are primarily located downstream of park boundaries, although there are exceptions, including Hetch Hetchy and Lake Eleanor in Yosemite and four lakes with small dams in the Mineral King area of Sequoia. Primary downstream water uses include irrigated agriculture, domestic water supplies, hydroelectric power, recreation, and tourism.

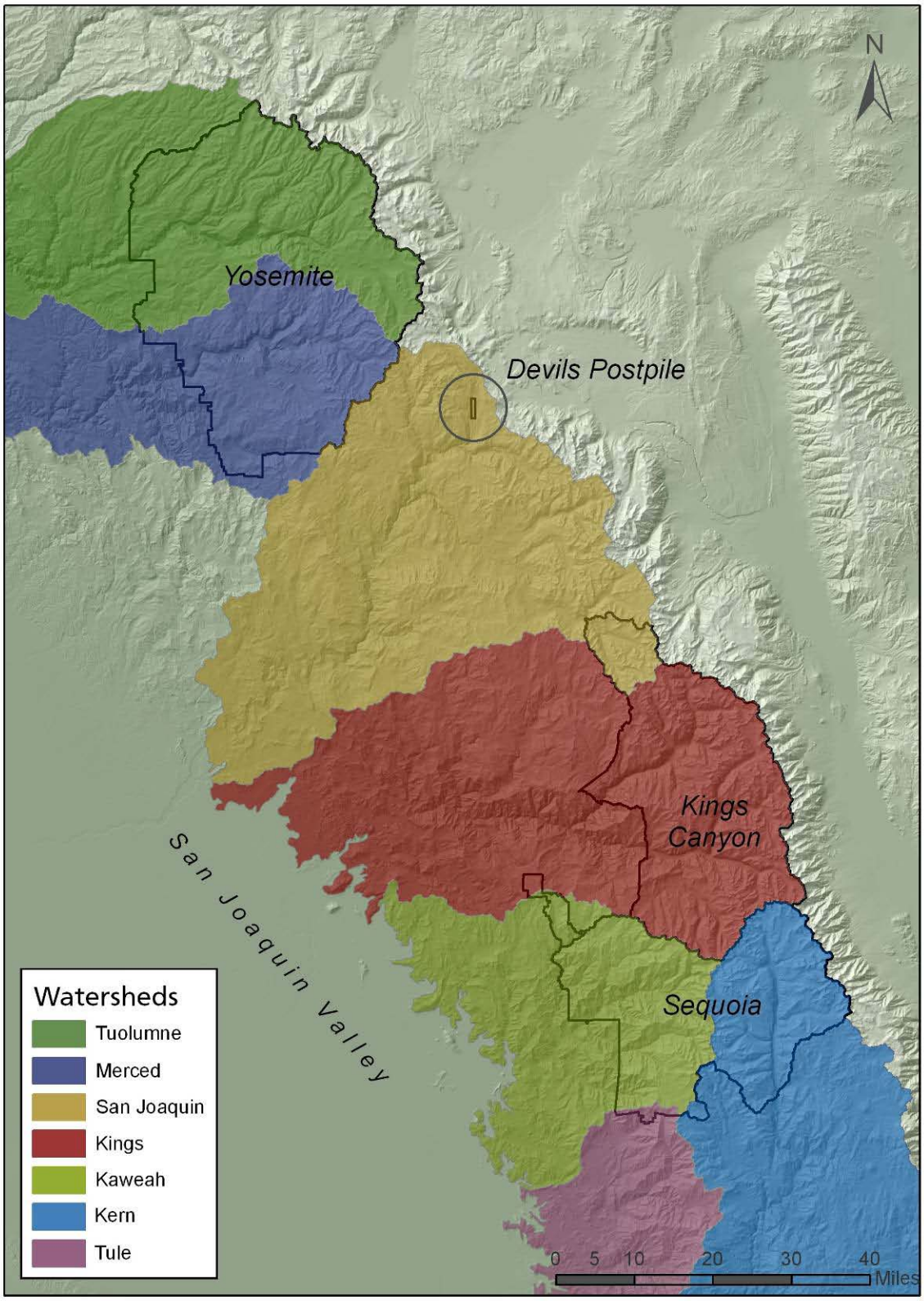
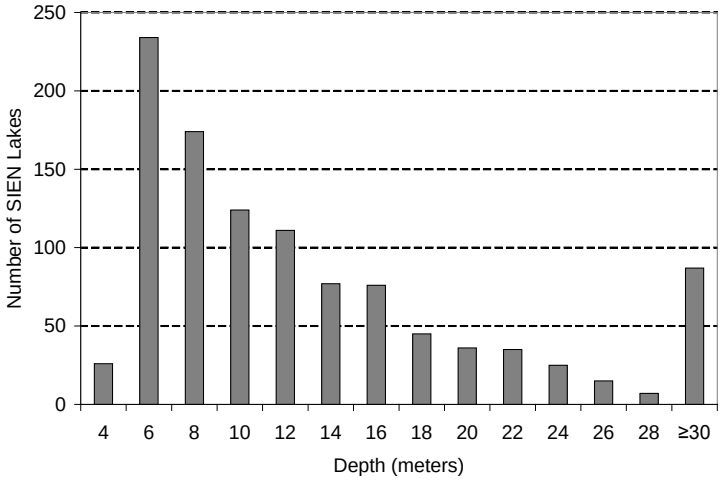
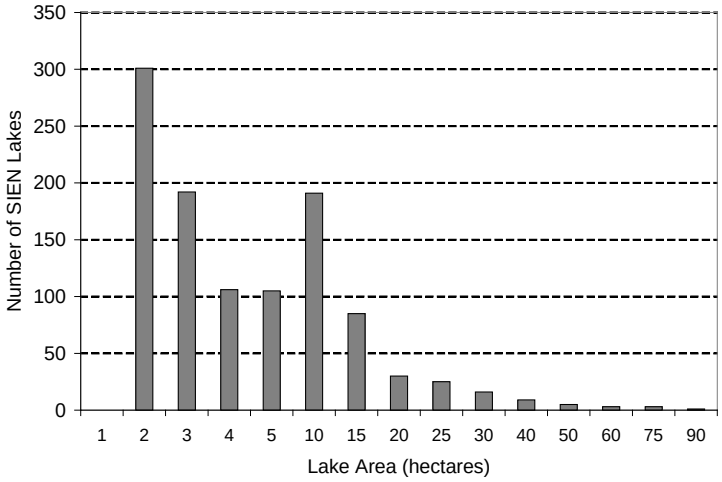


Figure 1. Sierra Nevada Network parks and watersheds.





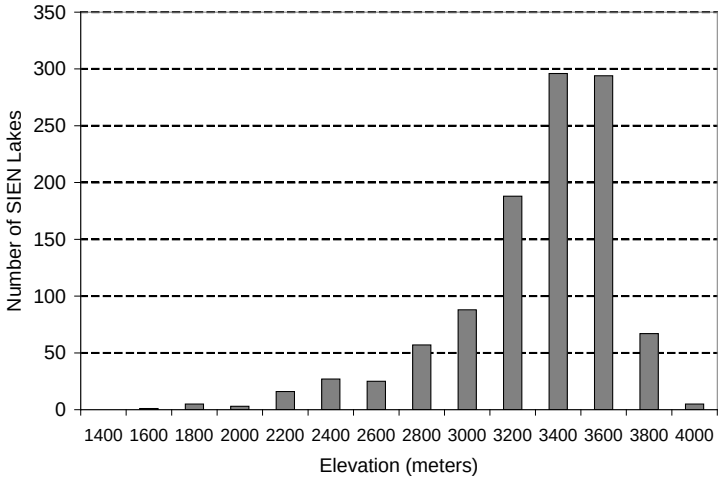


Figure 2. Physical characteristics of SIEN lakes. (Knapp 2003b). Lakes defined as ≥1 ha in area and ≥2 m at maximum depth.

1.2. Clean Water Act

The State Water Resources Control Board and nine Regional Water Quality Control Boards, under the Porter-Cologne Water Quality Control Act (1969), are responsible for the protection and enhancement of California's water resources. Each Regional Water Quality Control Board adopts Basin Plans, which contain beneficial use designations, water quality objectives, and implementation programs. Sierra Nevada Network parks fall under the jurisdiction of the Central Valley Regional Water Quality Control Board (RWQCB) and have waters contained in both the Sacramento–San Joaquin Delta and Tulare Lake Basins.

Pursuant to the federal Clean Water Act (1972), water quality standards comprise two parts: 1) designated uses—referred to as *beneficial uses* by the State of California, and 2) water quality criteria to protect those uses—or under California Water Code, *water quality objectives*. The RWQCB designates beneficial uses for SIEN waterbodies by major river basins: Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule, and Kern (Table 1). Water quality objectives are defined as "...the limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area" [Water Code Section 13050(h)]. Water quality objectives are adopted by the RWQCB. Objectives for SIEN waters may be found in the Basin Plan for the Central Valley Region (Bruns 1998).

Under sections 305(b) and 303(d) of the Clean Water Act, California is required to assess the overall health of the State's waters and identify waters that are not attaining water quality standards. The State must compile water quality impaired waters in a 303(d) list and initiate the process to bring listed waters back into compliance. Sierra Nevada Network parks do not contain any 303(d) listed waters (State Water Resources Control Board 2002). The State also has the authority to designate waters as Outstanding Natural Resource Waters. This designation affords the highest level of protection, under the Clean Water Act. At present, Sierra Nevada Network parks do not have any Outstanding Natural Resource Waters; however, national park waters are strong candidates for this designation.

Table 1. Beneficial uses for SIEN waterbodies (California Regional Water Quality Control Board Central Valley Region 1995, 1998).

			Beneficial Uses										
Park	**Watershed**	**Stream Segment**	**MUN**	**AGR**	**POW**	**REC1**	**REC2**	**WARM**	**COLD**	**WILD**	**RARE**	**SPWN**	**FRSH**
DEPO	San Joaquin	Sources to Millerton Lake	X	X	X	X	X	X	X	X			
SEKI	San Joaquin	Sources to Millerton Lake	X	X	X	X	X	X	X	X			
	Kings	Main Fork, Above Kirch Flat	X			X	X	X	X	X	X	X	X
	Kaweah	Above Lake Kaweah	X		X	X	X	X	X	X	X	X	X
	Tule	Above Lake Success	X	X	X	X	X	X	X	X	X	X	X
	Kern	Above Lake Isabella	X		X	X	X	X	X	X	X	X	X
YOSE	Merced	Source to McClure Lake		X	X	X	X	X	X	X			
	Tuolumne	Source to (new) Don Pedro	X	X	X	X	X	X	X	X			

MUN: Municipal and domestic supply
AGR: Agricultural supply
POW: Hydropower generation
REC1: Water contact recreation
REC2: Non-contact water recreation
WARM: Warm freshwater habitat
COLD: Cold freshwater habitat
WILD: Wildlife habitat
RARE: Rare, threatened, or endangered species
SPWN: Spawning, reproduction, and/or early development
FRSH: Freshwater replenishment

1.3. Rationale for Monitoring High-elevation Lakes

Sierra Nevada Network parks protect over 4,500 lakes and ponds and thousands of kilometers of rivers and streams that have some of the highest water quality in the Sierra Nevada. High-elevation lakes are critical components of the parks' ecosystems, popular visitor destinations, and habitat for aquatic and terrestrial organisms including declining amphibian species. Lake ecosystems were selected for monitoring because they are 1) valued for their ecological importance, contribution to Wilderness character, recreational opportunities, and importance to regional water supplies, 2) threatened by multiple stressors, and 3) sensitive to environmental change.

1.3.1. Importance and Value

Sierra Nevada lakes are chemically dilute and characterized as oligotrophic, especially in the sub-alpine and alpine basins where there is sparse vegetative cover, shallow soils, and small contributing area. Despite the low productivity, these lakes still support a variety of flora and fauna. Aquatic wildlife include amphibians, fish (primarily non-native), macro-invertebrates, zooplankton assemblages, and micro-crustaceans (Boiano et al. 2005).

Sierra Nevada Network lakes are habitat for several amphibian species, including the yellow-legged frog (*Rana muscosa* and *Rana sierrae)*, Yosemite toad (*Bufo canorus*), and Pacific treefrog (*Hyla regilla*). The yellow-legged frogs and Yosemite toad are of particular concern to the network because of their precipitous decline over the last few decades and potential listing as 'endangered' under the Federal Endangered Species Act. The yellow-legged frog, once the most common vertebrate in the high elevation Sierra Nevada (Grinnell and Storer 1924), is a keystone species in high-elevation lakes. The loss of yellow-legged frogs is likely to have measurable impact on the natural functioning of lakes within their historic range.



Yellow-legged frog

Historically, few Sierra Nevada lakes supported native fish populations (Knapp 2005). Steep stream gradients, cascades, and waterfalls prohibited fish from naturally migrating up to higher elevation waterbodies. The exception are native Little Kern Golden Trout, which may occasionally be found in lakes located in the Kern; although, lakes are not their primary habitat.

Network lakes and streams are habitat for over 100 identified invertebrate taxa (National Park Service 1989), the majority being aquatic insects. The Sierra Nevada itself contains the majority of invertebrate biodiversity in California (SNEP 1996). Invertebrate communities in and near SIEN lakes include the zooplankton in the mid-water of lakes, the benthic macroinvertebrates of lake bottoms, the terrestrial and aquatic meadow invertebrates that live in marshes on the edges of lakes, shoreline and terrestrial invertebrates that live near and on the edges of lakes, invertebrates that live on the surface of waters, and airborne species that forage over lakes. Aquatic macro-invertebrates common to Sierra Nevada lakes include stoneflies, mosquitoes, caddis flies, mayflies, back swimmers, water boatman, whirligig beetles, and predaceous diving beetles. In a survey conducted by Kubly (1983), the most abundant groups of zooplankton included 19 taxa of rotifers, 14 taxa of cladocerans, and 13 taxa of copepods. In addition SIEN lakes contain species of clams and sponges.

Few inventories of aquatic flora have been conducted in SIEN lakes. However, it is known that aquatic vegetation, particularly phytoplankton, is an important component of these systems. Phytoplankton contribute the bulk of biomass suspended in the water column and account for the majority of a lake ecosystems' primary productivity.

Riparian and wetland vegetation along lake shorelines, inlets, and outlets are areas of high ecological importance. The vegetation helps regulate shoreline lake water temperatures, provides shelter and shade for aquatic and riparian species including yellow-legged frog, Yosemite toad, terrestrial and aquatic invertebrates, numerous bird species, and terrestrial garter snakes.



Gaylor Lakes, Yosemite
Photo: R. Thiel

Lakes are popular visitor destinations and provide recreational opportunities including camping, fishing, hiking, photography, and horseback riding. Nearly all of SIEN lakes are located within Wilderness; these ecosystems contribute to the value of protected areas and their Wilderness character. The majority of the parks are designated Wilderness: 85% of Sequoia and Kings Canyon and 94% of Yosemite.

Aquatic ecosystems and water dynamics in the Sierra Nevada Network are critical components of the larger Sierra Nevada ecoregion and California's water infrastructure. Sierra Nevada ecosystems produce approximately $2,200,000,000 in annual revenue. Water accounts for more than 60% of these dollars (SNEP 1996). Primary uses include irrigated agriculture, domestic water supplies, hydroelectric power, recreation, and tourism. Water resources and associated aquatic and riparian habitats have high regional ecological value. Approximately 21% of the vertebrates and 17% of plants in the Sierra Nevada are associated with riparian habitats (SNEP 1996). The Sierra Nevada Ecosystem Project (SNEP) concluded that aquatic and riparian systems were the most altered and disturbed habitat type in the Sierra Nevada. The primary reasons for deterioration are changes in flow regimes, disturbances from land use practices such as grazing and mining, and introduction of non-native organisms. Although park lakes have been subjected to anthropogenic disturbances throughout the years, including fish stocking and grazing, disturbance is lower than in lakes in adjacent public and private lands. When put in a regional context, the value of SIEN lakes is even more evident, and the need to conserve them more critical.

Characteristic of a Mediterranean climate, the region receives most of its precipitation during winter months (**Figure 3**). Winter precipitation falls predominantly as snow at middle and high elevations. The resulting snowpack acts as a natural reservoir, storing water that will be released during the warmer and drier months. Melted snow travels through SIEN soils, groundwater systems, lakes, streams, and/or rivers before it reaches downstream waterbodies. Peak runoff typically occurs in late May to early June; however, melting continues throughout the summer at a slower rate (**Figure 4**). Water is captured and stored for summer and fall use in a series of reservoirs that line the Sierra foothills. Downstream water from the parks is used primarily for

irrigated agricultural in California's Central Valley, municipal water supplies, including the City of San Francisco, and hydroelectric power. Water from the Merced and Tuolumne River basins and the Kings River basin during high flow years, flow into the Sacramento–San Joaquin Delta, a critical California habitat.

Despite numerous impacts on Sierra Nevada aquatic habitats, overall hydrologic processes and water quality remain in relatively good condition in Network parks. Protecting the headwater lakes and streams in Sierra Nevada Network parks helps maintain high water quality for state uses and for park and regional ecosystems.

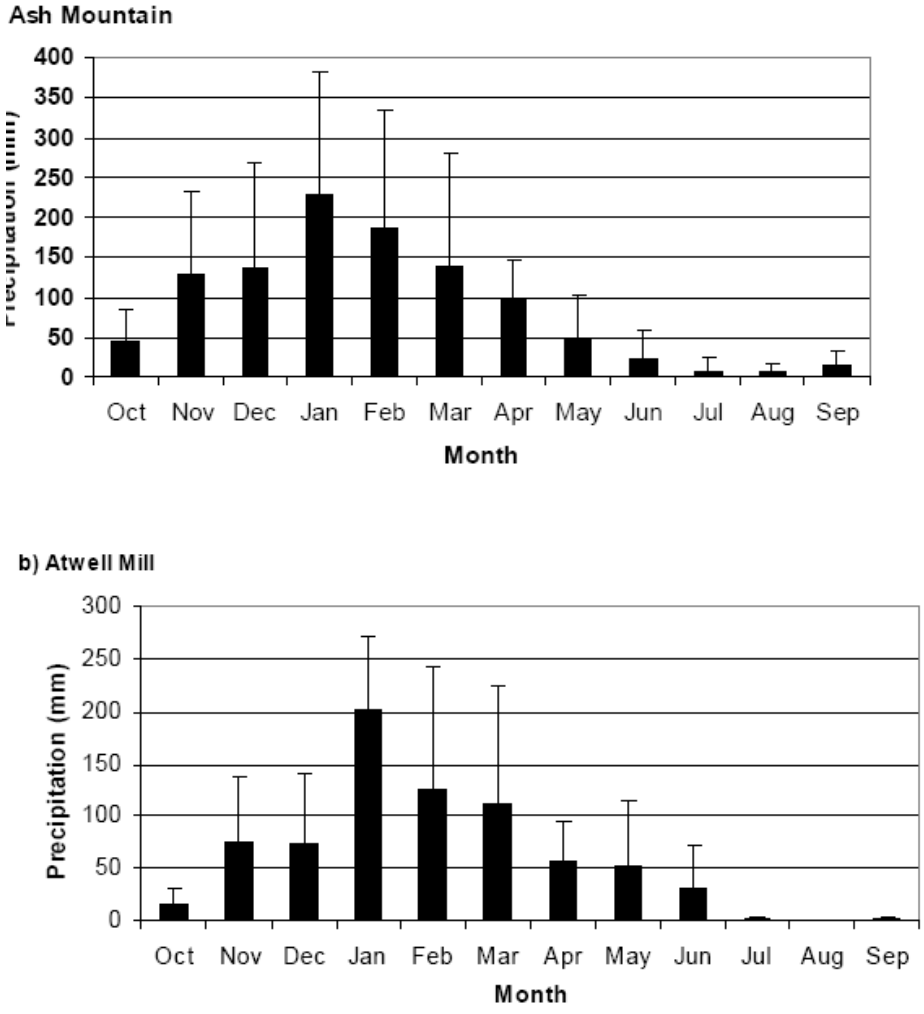


Figure 3. Mean monthly precipitation in Sequoia at a) low (Ash Mountain: 535 m) and b) middle (Atwell Mill: 1975 m) elevations.

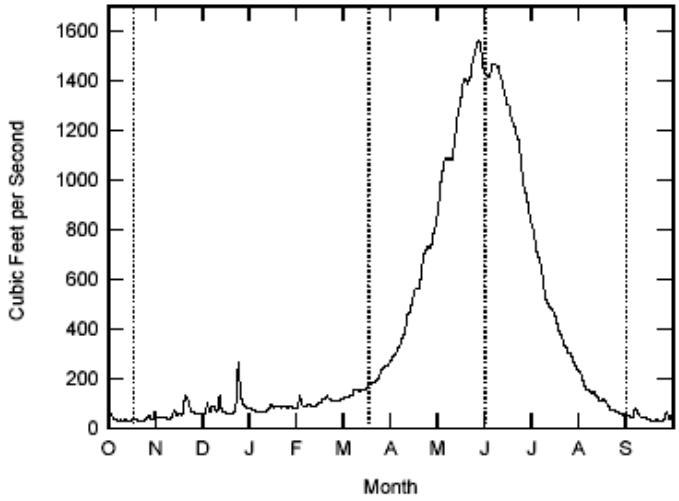


Figure 4. Representative mean annual hydrograph from the Merced River at Happy Isles in Yosemite National Park. (National Park Service 1998). Vertical lines divide the hydrograph into four seasons.

1.3.2. Threats and Issues

Sierra Nevada national parks protect many lakes, streams and rivers with unaltered flow regimes and good to high water quality. However, the parks' water resources are subjected to natural and anthropogenic disturbances that have the potential to modify the systems and degrade water resources. Some of these stressors are localized, threatening relatively small areas or specific water bodies, and may include visitor use impacts, small dams and diversions, or abandoned mines. Water resources in Sierra Nevada Network parks are also affected by systemic stressors, which occur at regional and ecosystem scales. Managers and researchers, using a substantial supporting body of research, the findings from the Sierra Nevada Ecosystem Project (SNEP 1996), and best professional judgment, identified five key systemic stressors that pose the greatest threat to Sierra Nevada parks: 1) loss of pre-Euroamerican fire regimes, 2) non-native invasive species, 3) air pollution, 4) habitat fragmentation, and 5) anthropogenic climatic change (Sequoia and Kings Canyon National Parks 1999). The stressors with the greatest impact on the parks' lake ecosystems are air pollution, non-native invasive species, climate change, and altered fire-regimes.

Relationships between stressors and SIEN lake ecosystem processes are illustrated in SIEN's conceptual ecosystem models. Refer to the Sierra Nevada Network Vital Signs Monitoring Plan, Appendix F (Conceptual Models).

Air Pollution: The western slope of the central and southern Sierra Nevada is impacted by some of the worst air pollution in the United States (Cahill et al. 1996). Contaminants and nutrients, produced from agricultural, urban, and industrial sources in the San Francisco Bay Area and the Central Valley, are transported by air currents into the Sierra Nevada where they are deposited as wet or dry deposition. High elevation lakes in the Sierra Nevada are particularly sensitive to change from atmospheric deposition because they occur in predominantly granitic basins with relatively little soil and vegetation.

Increased nitrogen and phosphorous inputs are contributing to long-term eutrophication, changes in nutrient cycles, and shifts in phytoplankton communities in Sierra Nevada lakes (Goldman et

al. 1993, Sickman et al. 2003). Sickman et al. (2003) described two trends in nitrate concentrations in Emerald Lake. During snowmelt, nitrate pulses (i.e., peak values during April) were related to snowpack depth and snowcover duration– the deeper the snowpack and the longer the period of snowcover, the greater the nitrate pulse. Nitrate entering the lake during snowmelt was a combination of nitrate found in the snowpack and nitrate produced in watershed soils during the winter by soil microbes. These data demonstrate a strong connection between climate, snow hydrology and water quality in the Sierra Nevada. The second pattern observed at Emerald Lake was a decline in summer/autumn lake nitrate concentrations to below detectable levels between the 1980s and 1990s. This late season decline occurred despite the fact that N deposition did not decrease. Instead, increased phosphorus loading allowed the phytoplankton to fully utilize nitrate during the summer/autumn seasons, driving them into an N-limited trophic state. The cause of increased phosphorus loading is unknown, but inputs from atmospheric deposition of P, changes in P cycling in soils, and sediments or changes in lower elevation fire frequency are possible explanations and the subject of ongoing research.

Episodic acidification threatens SIEN lake ecosystems at elevations above 3500 m. The major causes are elevated atmospheric deposition of sulfuric and nitric acids coupled with little or no soil in high elevation watersheds. Episodic acidification (i.e., ANC depression to zero for hours to days) occurs in the spring during snowmelt runoff when base cation concentrations decline and acid anions (i.e., nitrate and sulfate), retained in the snowpack and soils through the winter, move into receiving waters. ANC depression is also observed during 'dirty' summer and fall rain storms when N and S inputs are particularly high. Chronic acidification (i.e., ANC depression to zero for weeks to months) is currently not a problem; Sierra Nevada waters appear to be fairly resilient and able to buffer current and potentially increased inputs (Leydecker et al. 1999).

Every year millions of pounds of pesticides (net weight of active ingredient) are applied to crops in the adjacent California Central Valley (Pesticide use Database, managed by the California Dept of Pesticide Regulation, http://www.cdpr.ca.gov). Pesticides, or contaminants, volatilize then drift into parks on prevailing winds (LeNoir et al. 1999). Contaminants from global sources can also travel in the atmosphere and become deposited in high elevations of our parks (National Park Service Air Resources Division 2003). These contaminants have been detected in Sierra Nevada Network lakes both in waters and fish tissues. Some synthetic chemicals are endocrine disrupters (hormonal mimics) in concentrations of parts per trillion, potentially leading to altered wildlife reproductive capacity, longevity, behavior, cancer, and mutations. Synthetic chemical drift may also play a role in declining amphibian populations (Sparling et al. 2001, Davidson and Shaffer 2002).

Climate Change: Average global temperatures have increased over the last century. Climatologists and atmospheric scientists have attributed a majority of this increase to anthropogenic inputs of greenhouse gases to the atmosphere (IPCC 2007). Greenhouse gas concentrations and global temperatures are expected to continue to rise. It is predicted that even a modest temperature increase (2.5 °C) will significantly alter hydrologic processes globally. The most pronounced changes are earlier snowmelt runoff, earlier ice-out on lakes, reduced summer base flows and soil moisture (Dettinger et al. 2004), a lower snowpack volume at mid-elevations (Knowles and Cayan 2001), and increased flooding due to rain-on-snow events. The water infrastructure in California was built under the assumption that the Sierra Nevada snowpack would act as a temporary reservoir for the State's water and release it slowly during the spring

and early summer months. Changes in precipitation type and timing will result in longer and drier summers with less water available during the months it is most needed—for both people and ecosystems. Drier conditions may be reinforced by an increase in vegetative growth and evapotranspiration resulting from CO_2 fertilization (IPCC 2007). Water quality would be threatened by increased winter flooding and erosion and lower summer base flows. Prolonged summer drought increases the potential for high severity wildfires, further threatening water quality.

Altered Fire Regimes: Over 100 years of fire suppression polices have altered fire regimes in Sierra Nevada Network parks. In general, fire frequencies have decreased and the potential for higher severity wildfires has increased (Swetnam 1993, Caprio and Lineback 1997) (NPS, A.C. Caprio, fire ecologist, personal communication, 2004). Potential effects on water resources from a lack of fire are reduced flows resulting from increased evapotranspiration, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires have the potential to impair water resources. Potential impacts include increased flooding, erosion, sediment input, water temperatures (i.e., less shading by riparian vegetation), and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003). Eolian transport of ash particles in the surrounding landscape may increase nutrient inputs to oligotrophic waters (Spencer et al. 2003).

1.3.3. Lake Ecosystems As Sensitive Indicators

Water resources are critical components of the parks' ecosystems and indicators of aquatic and terrestrial ecosystem condition. Hydrological and water chemistry measures are good indicators of aquatic and terrestrial ecosystem condition and trend because they reflect changes within the larger watershed. High-elevation lakes of the western United States are especially sensitive to environmental change because the waters are oligotrophic and have a low buffering capacity. Sierra Nevada lakes have some of the lowest acid neutralizing capacity (ANC) concentrations in the western U.S. (Eilers et al. 1989). Changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes have been previously detected and attributed to increased nutrient inputs (Goldman et al. 1993, Sickman et al. 2003).

Change detected in high-elevation lakes can be an early indication of change that may eventually occur at lower elevations and other ecosystem types. For example, elevated nitrate concentrations in surface waters are a primary symptom of N-saturated ecosystems (Fenn et al. 1998). Watersheds located near the elevational extremes are less effective at retaining nitrogen than mid-elevation ecosystems (Stohlgren 1988, Melack et al. 2002, Fenn et al. 2003). Alpine and sub-alpine watersheds have been shown to have a low capacity to retain nitrogen primarily due to steep talus slopes, shallow soils, and sparse vegetation (Clow and Sueker 2000). Increased nitrogen deposition in the Transverse Ranges of southern California, low elevations in the southern Sierra Nevada, and high-elevations in the Colorado Rocky Mountains has already led to excessive leaching of nitrate into receiving waters (Fenn et al. 2003).

1.4. Monitoring Questions and Measurable Objectives

1.4.1. Monitoring Questions

The Sierra Nevada Network identified a set of broad monitoring objectives and questions as part of the Vital Signs Monitoring Plan (Mutch et al. 2007). We used these broad questions to guide us in defining specific monitoring objectives. The lakes protocol will not be able to answer all these questions. However, lake monitoring, in conjunction with the other monitoring protocols (e.g., Rivers and Streams, Weather and Climate, Landscape Dynamics), will provide information that will help the network parks address these questions. We have listed SIEN's broad monitoring questions that are relevant to lake monitoring to help make the link between the protocol and the Vital Signs Monitoring Plan:

- How are climatic trends affecting regional hydrologic regimes (snowpack depth, snow water equivalent, snowmelt, glacial extent, frequency and intensity of flood events and volume and timing of river and stream flows)?
- How do depositional patterns of nutrients (principally nitrogen and phosphorus) and other major cations/anions vary along elevation gradients, in aquatic and terrestrial systems, and through time?
- How are patterns of nitrogen cycling changing?
- Are episodic acidification events increasing and are these events altering aquatic communities?
- How are water dynamics changing in response to climate and fire regimes?
- How are surface water volumes changing in lakes and wetlands?
- How does water chemistry (concentrations and fluxes) vary spatially and temporally across network parks?
- How is water quality changing with respect to water quality standards?
- 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?

1.4.2. Monitoring Objectives

The Sierra Nevada Network Water Resources Work Group identified both trend and status objectives. We refined these objectives throughout the development process as preliminary power analysis results and more accurate budget and logistic estimates became available. We discussed the trade-offs between in-depth temporal sampling at single site locations and extensive sampling that enables us to answer status objectives and make status and trend inferences across SIEN's expansive landscape. Access, logistics, and safety were prominent considerations. Balancing these trade-offs, we settled on an approach that is composed of two site types: 1) *extensive sites*, which are probabilistically selected and sampled once every 1–4 years and, 2) *index sites*, which are judgmentally selected and sampled multiple times each year. The two site types address slightly different monitoring objectives.

The Sierra Nevada Network lake monitoring objectives, separated by site type, are:

Extensive sites:

- Detect long-term trends in lake water chemistry for Sierra Nevada Network lakes by measuring:
  - Temperature, pH, specific conductance, dissolved oxygen, acid neutralizing capacity (ANC)
  - Major ions: Ca, Na, Mg, K, Cl, SO_4
  - Dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), total dissolved nitrogen (TDN), particulate nitrogen (PN), total nitrogen (TN)
  - Total dissolved phosphorus (TDP), particulate phosphorus (PP), total phosphorus (TP)
  - Particulate carbon (PC)
- Detect long-term trends in trophic condition of SIEN lakes, using the following nutrient ratios as chemical indicators of trophic status: PN:PP, DIN:TP, and TN:TP.
- Characterize Sierra Nevada Network lakes.
- Determine the proportion of Sierra Nevada Network lakes with chemical characteristics above/below threshold values for selected constituents.
- Detect long-term trends in lake level for Sierra Nevada lakes.

Index sites:

- Detect intra- and inter-annual trends in lake water chemistry for Sierra Nevada Network index lakes by measuring:
  - Temperature, pH, specific conductance, dissolved oxygen, acid neutralizing capacity
  - Major ions: Ca, Na, Mg, K, Cl, SO_4
  - Dissolved inorganic nitrogen, dissolved organic nitrogen, total dissolved nitrogen, particulate nitrogen, total nitrogen
  - Total dissolved phosphorus, particulate phosphorus, total phosphorus
  - Particulate carbon
- Detect long-term trends in trophic condition of index sites, using the following nutrient ratios as chemical indicators of trophic status: PN:PP, DIN:TP, and TN:TP.
- Determine if index sites are above/below threshold values for selected constituents.
- Detect intra- and inter-annual trends in lake level for Sierra Nevada Network index sites.

1.4.3. Pilot Amphibian Monitoring

The network is conducting a pilot project to assess the feasibility of co-locating amphibian monitoring at the Lake Protocol sites. Currently crews are surveying amphibians in lake shoreline and adjacent habitats at extensive and index sites. Amphibian survey field protocols are described in Rose (2010).

SIEN recognized amphibians as an important vital sign for the parks, but currently does not have the resources to fund a robust, fully-independent amphibian protocol. Network and park staff with collaborating researchers determined that some monitoring data, albeit limited, collected at

lake monitoring sites is still valuable data that will inform park management and ongoing amphibian research and monitoring efforts. For example, during the lake protocols first field season, crews surveyed an unknown population of yellow-legged frogs at one of the extensive lake sites. Sequoia and Kings Canyon has since included this lake as one of their amphibian restoration sites and are actively removing fish from the lake. The pilot amphibian monitoring effort will be evaluated after several years of implementation.

1.5. Rationale for Selected Measures

In developing a Vital Signs monitoring program, SIEN's philosophy has been to focus on monitoring the condition of the resources and on water quality and ecosystem parameters that most strongly affect ecosystem function and are sensitive to multiple stressors, including future and unknown threats. Remote and rugged mountainous terrain makes site access difficult and is the largest cost associated with sampling. Sites can take 1–5 days to access and sample, often requiring cross-country travel in rugged terrain. As a result we selected a suite of constituents that are chemically stable to transport. The suite of parameters is:

Water Temperature is a master variable controlling many physical, chemical, and biological lake processes. A few examples of processes water temperature affects include lake stratification and mixing, chemical reaction rates, dissolved oxygen concentrations, algal productivity, and health and reproduction of aquatic life. Lake water temperature is particularly sensitive to climate change.

pH is the measure of hydrogen ion activity, which in dilute solutions, such as Sierra Nevada lakes, is roughly equivalent to the hydrogen ion concentration. pH controls many chemical and biological lake processes. It is sensitive to change from acidic inputs and depressions in acid neutralizing capacity.

Specific conductance is the measure of a waters' ability to conduct an electrical current and provides a broad measure of the amount of ions in a water sample. More dilute lakes, those with low specific conductance measurements, are most sensitive and susceptible to effects from stressors such as atmospheric deposition and visitor use. A change detected in specific conductance, especially in the dilute lakes of the Sierra Nevada, may indicate a change in the concentration of other major ions or nutrients of interest. It is relatively quick and inexpensive to measure, continuously and discontinuously.

Dissolved oxygen sustains aquatic communities that respire aerobically, including zooplankton, algae, amphibians, and fish. Dissolved oxygen is a good indicator of eutrophication. As systems become more productive, biota consume oxygen from the water column at an increasing rate. This can lead to anaerobic conditions. Water temperature and atmospheric pressure directly affect the solubility of oxygen.

Acid neutralizing capacity (ANC) is the measure of a waters' capacity to neutralize acid. At the pH of most Sierra Nevada lakes ANC is composed primarily of the bicarbonate ion. Lakes with low ANC concentrations are more susceptible to acidification. In the Sierra Nevada, decreases in ANC are typically observed during spring snowmelt, when high streamflows dilute ANC concentrations. ANC depression also occurs during 'dirty' summer and fall storm events, when high concentrations of acids are washed into receiving waters.

Major ions (Ca, Na, Mg, K, Cl) are important in understanding the geochemical evolution of surface waters in the Sierra Nevada, lend insights into climatic variability, and are sensitive to external stressors such as atmospheric deposition and climate change.

Sulfate is a strong acid anion that readily leaches into receiving waters. It is an indicator of acidification from atmospheric deposition. Sulfur compounds, primarily originating from fossil fuel combustion, are deposited as wet and dry deposition. A decreasing trend in sulfate concentrations has been observed in Sierra Nevada lakes during the past 25 years and is attributed to the success of the Clean Air Act.

Nitrogen is an essential nutrient, and often the limiting macronutrient in aquatic ecosystems. Increases in nitrogen can lead to lake eutrophication and changes in aquatic ecosystem structure. The network has emphasized nutrient (i.e., nitrogen and phosphorus) monitoring for three reasons: 1) nutrient availability controls ecosystem productivity through its influence on microbial and phytoplankton growth, 2) changes in nutrient availability are likely to alter ecosystem structure (i.e., numbers and types of species present) and, 3) nutrient availability is likely to be sensitive to external stressors. In particular, effects of atmospheric nutrient deposition—a primary Sierra Nevada stressor—on both aquatic and terrestrial habitats, are of high interest to management and science and one of the primary reasons for selecting lakes for monitoring. To address SIEN's monitoring questions, a suite of nitrogen fractions were selected for monitoring: dissolved inorganic nitrogen (DIN: sum of NO_3^-, NH_4^+ and NO_2^- ions), total dissolved nitrogen (TDN), particulate nitrogen (PN), dissolved organic nitrogen (DON: calculated as TDN minus DIN), and total nitrogen (TN: calculated as TDN + PN).

Dissolved inorganic nitrogen includes the two major oxidized forms of aqueous nitrogen, NO_3^- and NO_2^-, and the most reduced form, ammonium (NH_4^+). In Sierra Nevada lakewater, nitrate is the predominant form of DIN; nitrite and ammonium are occasionally detected in hypolimnetic waters with low redox. Nitrate is a mobile anion and the form of N that most readily leaches into receiving waters during snowmelt runoff. In Sierra Nevada surface waters, nitrate concentrations are typically low except during spring runoff and following fires. For the monitoring program, nitrate and nitrite will be determined in all samples by ion chromatography. Ammonium ion will not be quantified owing to the relatively long transport time of the samples from the field to the laboratory and the likelihood that ambient levels are below the method detection limit.

Total dissolved nitrogen is all dissolved (i.e., material not retained by a 1.0 micron filter) organic and inorganic nitrogen.

Particulate nitrogen is described analytically as the material retained by a sub-micron glass fiber filter: Pall Gelman A/E (nominal pore size 1.0 µm) and Whatman GF/F (nominal pore size 0.7 µm). Historically, A/E filters have been most commonly used in collections from Sierra Nevada lakes and will be used in the SIEN sampling plan. Particulate nitrogen represents much of the nitrogen content in sestonic biota, primarily phytoplankton. Particulate nitrogen concentrations may be more sensitive to change than dissolved concentrations because increased nitrogen inputs to nutrient poor systems are rapidly taken up by biota—increases may initially be detected in phytoplankton N content rather than DIN.

Dissolved organic nitrogen is all dissolved (i.e. material not retained by a .45 micron filter) organic nitrogen. It is computed as the difference between TDN and DIN. For the SIEN program DIN will be the sum of nitrate and nitrite.

Total nitrogen is a common measure in monitoring programs as it is an indicator of both dissolved nutrients available to phytoplankton and algae as well as the N content of planktonic organisms. In most cases TN is relatively inexpensive and straightforward to measure—especially in waters with high N concentrations, and is a water quality standard used by most states. Monitoring trends in TN will increase comparability with other monitoring programs. Although TN may be measured directly in unfiltered water samples, SIEN will calculate it as TN = TDN + PN.

Due to the dilute nature of and small changes in concentration that can affect SIEN's aquatic ecosystems, we will be more likely to detect a change by monitoring multiple nitrogen components. It also enables SIEN to examine status and trends of nutrient ratios.

Phosphorus, like nitrogen, is an essential nutrient, and often the limiting macronutrient, in aquatic ecosystems. The network has emphasized nutrient (i.e., nitrogen and phosphorus) monitoring because of the need for ecological status and long-term trend information on SIEN lake ecosystems. We are monitoring three measures of phosphorus availability in network lakes: *total dissolved phosphorus (TDP), particulate phosphorus (PP),* and *total phosphorus (calculated TDP + PP).*

Total dissolved phosphorus is all dissolved (i.e., material not retained by a .45 micron filter) organic and inorganic phosphorus (i.e., PO_4^{3-} ion).

Particulate phosphorus is described analytically as the material retained by a sub-micron glass fiber filter. Two types of filters are commonly used for collection of particulate matter in lakes: Pall Gelman A/E (nominal pore size 1.0 µm) and Whatman GF/F (nominal pore size 0.7 µm). Historically, A/E filters have been most commonly used in collections from Sierra Nevada lakes and will be used in the SIEN sampling plan. Phosphates, which bond strongly with iron hydroxides in soil or precipitate as calcium phosphates, are typically transported to receiving waters through wind and water erosion. As a result, P is commonly found attached to colloidal material or bound in lake sediments. Much of organic PP in the water column is bound in phytoplankton. Particulate phosphorus concentrations are sensitive to change because increased P inputs to nutrient poor systems are likely to be rapidly taken up by biota—increases will initially be detected in phytoplankton P content rather than TDP.

Total phosphorus, like total nitrogen, is a common measure in water quality monitoring programs. TP is also an indicator of eutrophication and trophic status, is relatively inexpensive and straightforward to measure, especially in waters with high P concentrations, and is a water quality standard used by most states. Monitoring trends in TP will increase comparability with other monitoring programs. Although TP may be measured directly in unfiltered water samples, SIEN will calculate it as TP = TDP + PP.

The network can also examine status and trends in nutrient ratios including PN:PP and DIN:TP.

Nutrient ratios, including PN:PP, DIN:TP, and TN:TP, are useful chemical indicators in assessing lake trophic status. Sickman et al. (2003), studying shifts in limiting nutrients in Emerald Lake, detected trends in PN:PP ratios while TN trends were not significant. Elser et al. (2009) detected changes in nutrient limitations from atmospheric deposition of nitrogen at regional scales using TN:TP. The ratio of NO3:DON is a good indicator of lake chemistry change from atmospheric deposition (Williams and Tonnessen 2000).

Lake levels fluctuate based on annual precipitation and evaporative demand. Lake levels may be sensitive to climate change.

1.6. Management Decisions and Thresholds

Parks will use status and trend information from the lake monitoring protocol to make park-level management decisions, monitor compliance with state water quality standards, inform regional permitting of point-source industrial emissions, influence regional, state, and national environmental policies, meet Government Performance Results Act reporting requirements, and inform the public.

At the local park-level these data may be used to inform park planning projects, regulate visitor use, inform fire management, meet government reporting requirements, and contribute to the protection and restoration of aquatic ecosystems, including declining amphibian populations.

Yosemite, Sequoia, and Kings Canyon are in Class I Airsheds. Under the 1977 Amendment to the Clean Air Act, protection of Class I Airsheds must be considered when evaluating permits for industrial point-sources (e.g., power plants). As a result, park managers are consulted when permit renewals or proposals for new industrial plants are considered. Data from the lake monitoring protocol will assist managers in making informed decisions on the effects of emissions from industrial sources on park resources by providing scientifically credible long-term data.

Protecting park resources from external non-point sources is more challenging for park management. Despite the challenges, Rocky Mountain National Park has developed a resource management goal for nitrogen deposition. Collaboratively, the Colorado Department of Public Health and Environment, the U.S. Environmental Protection Agency Region 8 (EPA), and the National Park Service developed a Nitrogen Deposition Reduction Plan (Baker et al. 2007). Data from research and monitoring in the park were used to identify critical loads for nitrogen deposition. Although compliance is voluntary, this is seen as an important step in protecting parks from excessive nitrogen inputs. Sequoia, Kings Canyon, and Yosemite are currently working with the University of California, Riverside to apply similar techniques and develop critical nitrogen loads and nutrient criteria for Sierra Nevada lake ecosystems (Sickman et al. 2006). Once nutrient criteria and critical loads are identified, status and trend information from the lake monitoring can be compared to these ecologically meaningful thresholds. Parks can use this information to influence state and national policy decisions.

Establishing ecological thresholds and management triggers is not a trivial task. It will involve input from park staff and outside area experts and likely will require additional research. SIEN plans to identify threshold conditions and management triggers for water quality measures over the next several years. Water quality standards can and will be used as a management trigger;

however, due to the dilute nature of Sierra Nevada lakes, ecological thresholds unique to these systems will be far more successful in protecting SIEN lakes.

Parks will use the lake monitoring information to interpret the status and trends of aquatic resources to the public. Since many of the threats to park aquatic systems are from external sources, informing visitors and communities who have the power to change their own lifestyles and influence elected officials is an important management action.

1.7. Important Data Sets and Monitoring Programs

Sierra Nevada Network parks have current and historic aquatic resources data that have been instrumental in developing the lake monitoring protocol. Significant time and resources were put towards compiling and summarizing available information as part of Phase I in Vital Signs program development. In collaboration with Colorado State University and U. S. Geological Survey-Water Resources Division, the following products were created:

- Summary report of existing water resources information, including data sets, publications, current research and monitoring projects, and an overview of stressors and issues (Appendix A).
- Literature search with results compiled in an EndNote database that contains ~700 SIEN water references.
- Trend analyses on long-term water chemistry data sets (Appendix A).
- MS Access database, in which all known water quality records and some streamflow records for SIEN were compiled into one database. The database contains over 310,000 water quality records for 802 sites.

There are several key monitoring programs, within and outside parks, that have informed the development of this program. They include:

Surface Water Ambient Monitoring Program (SWAMP): SWAMP is a state-wide monitoring effort designed to assess the condition of water resources throughout California. It is administered by the State Water Board and implemented by the nine Regional Water Quality Control Boards. Funding limits monitoring to the highest priority waters where monitoring is most needed in each region. SWAMP coordinates with other monitoring efforts in order to capture additional information that will inform the program about the status of California's waters. SWAMP developed criteria, which they encourage other monitoring programs to adhere so their data may be 'SWAMP compatible'.

SIEN is coordinating with SWAMP to facilitate data sharing between programs (*refer to Section 1 for details*).

Lake Alkalinity Evaluation in the Sierra Nevada (LAKES): Project LAKES is the Pacific Southwest Region, USDA Forest Service, Air Resources Program's long-term lake monitoring program. The primary purpose is to assess water quality status and change related to air pollution effects. Monitoring is focused on lakes with low ANC concentrations---an indicator of sensitivity to acid deposition. They monitor lake chemistry for nine Class I Airsheds in the Sierra Nevada, southern Cascades, and northeastern California. Many sites are located near and between SIEN parks.

SIEN and Project Lakes collaborated throughout the protocol development process. Staff have attended each other's meetings and trainings. Project LAKES staff provided valuable input and shared data sets for power analyses during protocol development. The programs will continue to collaborate through information sharing.

Long-term Research and Monitoring in the Tokopah Watershed: Over 25 years of monitoring has been conducted at several waterbodies, in the Tokopah watershed, located in the upper Marble Fork of the Kaweah in Sequoia National Park. Emerald Lake is one of the most highly studied sub-alpine watersheds in the world. University of California, Santa Barbara leads the majority of the research including maintaining the gaging station at Emerald Lake. However, multiple agencies and universities have contributed significant research and monitoring efforts, including U.S. Geological Survey, National Park Service, UC Riverside, and others.

Hydrologic Benchmark Network (HBN): HBN is a national U. S. Geological Survey program that monitors minimally disturbed watersheds for long-term trends in streamflow and water quality. There are two HBN sites in SIEN parks. Merced River at Happy Isles, in Yosemite National Park, has a water quality record from 1964–present and streamflow record from 1915–present. Marble Fork of the Kaweah, in Sequoia in National Park was recently added to the HBN in 2003, although water quality and streamflow data have been collected there since 1993.

Visitor Experience and Resource Protection Program (VERP): Yosemite National Park monitors a suite of indicators, including water quality and hydrology, to assess visitor use impacts along the Merced and Tuolumne Wild and Scenic River corridors.

2. Sample Design

Our network, along with others working in large mountainous landscapes, struggled with the trade-offs between in-depth temporal sampling and an ability to make inferences across the landscape. SIEN lakes, for the most part, are located in the remote Wilderness areas of Yosemite, Sequoia, and Kings Canyon (**Figure 5**). Access, logistics, and safety were prominent considerations throughout the development process. An additional and equally important requirement was a sampling design that would address both trend and status objectives. Balancing these trade-offs, we settled on a design that is composed of two site types: 1) *extensive sites*, which are probabilistically selected and sampled once every 1–4 years and, 2) *index sites*, which are judgmentally selected and sampled multiple times each year. Incorporating a split-panel design for the extensive sites provided further flexibility.

The Network worked closely with statisticians at Oregon State University and the University of Idaho to develop the sample design, perform power analyses, and identify data analysis approaches. Sample design, power analysis, and data analysis components were developed simultaneously through a very iterative process. We discuss the sample design in this section. Please refer to Section 5, Data Analysis and Reporting and Appendix B: Lake Chemistry Power Analysis for the Sierra Nevada Network of the National Park Service, for detailed information on these components.



Figure 5. Lakes in Kings Canyon National Park from Mt. Goddard. (Photo: B. Meadows).

2.1. Extensive Sites

2.1.1. Target Population and Sampling Frame

> ***Target Population:*** *Sierra Nevada Network lakes that are ≥ 1.0 ha in area and ≥ 2.0 m in depth during August and September.*

The target population for inference on water chemistry in Sierra Nevada Network lakes includes all lakes in the network that are greater than or equal to 1.0 hectare in area *and* greater than or equal to 2.0 m in depth (**Figure 6** and **Figure 7**). The Network's definition of a 'lake' was reached after much discussion and was defined to ensure we were excluding ponds and small tarns, which have different physical, chemical, and biological properties. Ponds are defined by Cowardin et al. (1979) as waterbodies that are less than 2 m at their maximum depth. The minimum lake area size, 1 ha, was selected to be consistent with lake selection from the EPA's Western Lakes Survey and the U. S. Forest Service's Project LAKES (long-term lake monitoring program on the National Forests surrounding SIEN parks). Reservoirs created by damming rivers (i.e., Hetch Hetchy and Lake Eleanor), are excluded from the target population. Lakes that are natural lakes but have been hydrologically modified (i.e., contain dams or diversions) are included in the target population. Devils Postpile does not have any lakes; therefore, the target population for the network only includes lakes in Sequoia, Kings Canyon, and Yosemite.

The population is sampled during the late ice-free season—August and September. Late summer and fall sampling is a better indicator of lake trophic condition. Nutrient concentrations during the growing season are good indicators of N or P saturation and changes in limiting nutrient status. If increases in the concentrations of nutrients are observed when demand is highest, this is an indication a nutrient might no longer be limiting—due to increased inputs or changes in lake processes. The work group strongly considered spring sampling because these data would provide an early warning indicator of changes in nitrate pulses and ANC depression and would be a better indicator of changes in rates of atmospheric deposition. Although these questions are important to SIEN, addressing ecological condition of the lake system is higher priority and more consistent with the general philosophy of the Network. In addition, access to remote lakes during snowmelt is impractical and potentially hazardous.

The sampling frame is constructed from two data sets. The primary data set is the National Hydrography Dataset (NHD), which contains geospatial hydrologic data that enumerate all lakes within the parks. To select lakes that meet the greater than 2.0 m minimum depth criteria, the Network is using an extensive local data set that contains maximum lake depth measurements for nearly all (over 3,500) lentic waterbodies in the network (Knapp 2003a).

The sampling unit is 'lakes', with responses taken within lakes. Measurements are observed at the lake outlet for all panels and at both outlet and mid-lake for panel [1-0] (response design). Ideally, we would like to collect mid-lake samples at all sites. Mid-lake collection increases personnel and laboratory costs; this was not possible with current funding. For sites where both locations are sampled, differences between mid-lake and outlet samples will be compared after the 2008 field season. If additional funds become available, expanding the mid-lake sampling component is a priority. When lakes are well mixed, outlet and mid-lake measurements are

expected to be quite comparable with respect to dissolved chemical species. However, when lakes are stratified and vertical temperature gradients exist, chemistry may be less comparable. It is also likely that seston concentrations (PN, PC and PP) will not be consistent between the outflow and mid-lake stations.

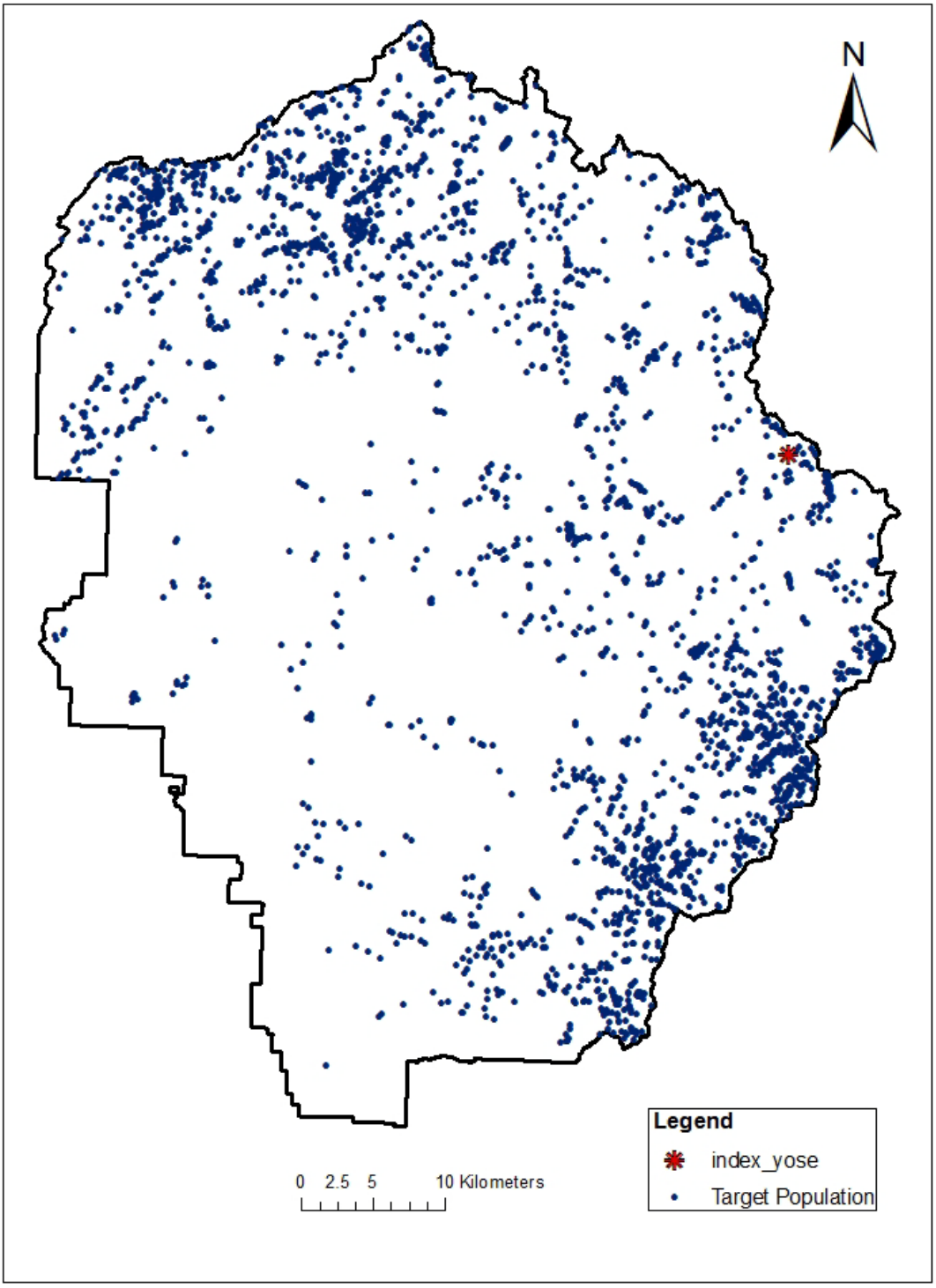


Figure 6. Target population and index sites in Yosemite.

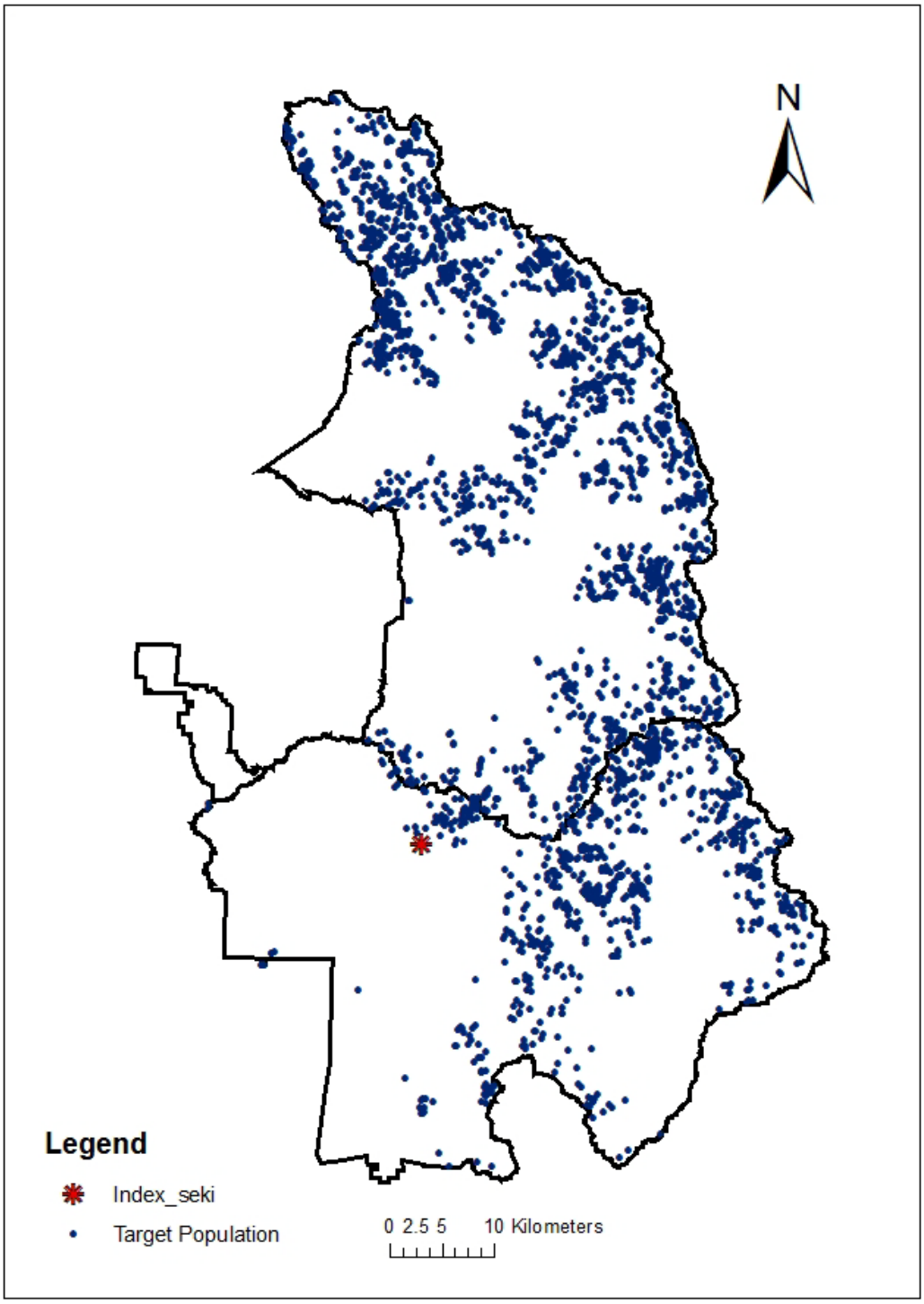


Figure 7. Target population and index sites in Sequoia and Kings Canyon.

2.1.2. Membership Design

The membership design specifies how the units in a sample are chosen (McDonald 2003). A simple random sample is a familiar example of a membership design. For lake monitoring, we elected to use a generalized random tessellation stratified design (GRTS) in conjunction with variable probability sampling based on travel time estimates from a cost-surface model. A similar design was also selected for SIEN's Wetland Ecological Integrity monitoring.

The GRTS design employs a systematic sampling approach along a randomly ordered sequence of location addresses to obtain a spatially balanced probability sample (Stevens Jr. and Olsen 2003, Stevens Jr. and Olsen 2004). The primary benefits of the GRTS design that influenced our decision are: 1) it provides spatially balanced coverage of points across the sampled population, 2) variable probability sampling may be incorporated into a GRTS design, and 3) the neighborhood variance estimator, used with GRTS designs for status estimates, is smaller than variance estimates computed assuming a simple random sample (Stevens Jr. and Olsen 2003).

A simple random sample, although the most straightforward design to implement from the sample selection and data analysis perspectives, may result in samples that are ill-distributed across the area of interest. Sampled lakes may be clustered, resulting in an inefficient sample for long-term monitoring because information is essentially repeated within the cluster (McDonald 2003). The GRTS design increases efficiency because the probabilistically selected sample points are spatially-balanced across the landscape. The result of a GRTS sample draw is an ordered list of sites that are visited in sequence. The design provides flexibility because sites may be added or subtracted from the list. For example, if funding or time elapses before the full sample can be achieved, a sequential sample of points will still be spatially balanced. Similarly, if more funds are made available or if some points could not be visited due to accessibility problems, a list of sampled points that was drawn with additional points could be sampled and still provide a spatially balanced sample. This flexibility is an important feature because of the logistical challenges associated with sampling in remote mountainous areas.

The GRTS design can incorporate variable probability sampling. SIEN inclusion probabilities are based on a cost-surface model that computes relative travel times to sites based on factors such as the presence of trails, vegetation type, and slope angle (Frakes et al. 2007). Data from GIS layers are used to compute the travel time across the park landscapes and for each site in the target population; the inclusion probability for each site is inversely proportional to this time. Lakes that are quicker to access (i.e., closer to trails and trailheads or accessed via 'easier' cross country terrain) have a higher probability of being selected. However, lakes that are further away and more difficult to access still have some nonzero probability of inclusion and are included in higher numbers as sample sizes increase.

Analysis of GRTS sample data incorporates the neighborhood variance estimator. Neighborhood variance estimates are 22% to 58% smaller than variance estimates computed assuming a simple random sample (Stevens Jr. and Olsen 2003). The result is higher confidence in status estimates. Unfortunately, this estimator may only be used for SIEN's status estimates. The ability to apply the neighborhood variance estimator, or equivalent, currently does not exist for trend estimation (Refer to Section 2.3 Sample Design Limitations).

The lakes are stratified by park boundaries for a total of two strata---Yosemite and Sequoia/Kings Canyon. This provides the ability to draw park-level inferences, when enough data are available, in addition to network-level inferences.

2.1.3. Revisit Design

The revisit design provides the temporal sampling structure for the selected sites (McDonald 2003). Sites are generally split into panels and panels may be visited annually or on an alternating schedule (e.g., once every 4 years). Panel designs provide balanced replication of sites over time so that spatial and temporal effects may be modeled and trend may be accurately estimated. Extensive sites are sampled in August and September.

We have selected a serial augmented panel design: [(1-0), (1-3)] (**Figure 8**). Notation for panel designs is defined by McDonald (2003). The first number is the number of consecutive occasions that a panel will be sampled, and the second is the number of consecutive occasions that a panel is not sampled before repeating the sequence. The total number of panels in the rotation design is normally the sum of digits in the notation. For example, using this notation the digit pair [1-3] means that members of four panels will be visited for one occasion, not visited for three occasions, then visited again for one occasion, not visited for three occasions, and so on. If a single panel is to be visited every sample occasion, its revisit design is [1-0]. The notation for a split panel design, [(1-0), (1-3)], means that units in one panel will be visited every occasion, while units in the four other panels will be visited once every four years.

	Sample Occasion									
Panel	1	2	3	4	5	6	7	8	9	10
Design [(1-0), (1-3)]										
1	X	X	X	X	X	X	X	X	X	X
2	X				X				X	
3		X				X				X
4			X				X			
5				X				X		

Figure 8. Revisit design, [(1-0), (1-3)].

We are sampling a total of 25 lakes per year across the network. Thirty-two percent of the annual resources are allocated to the annual panel (1-0) and the remaining to the (1-3) panels. This translates to 8 lakes per year in panel (1-0) and 17 lakes per year for the (1-3) panels. This translates to a total of 76 different lakes sampled after one complete rotation of the panel design. Allocations are based on recommendations by Urquhart et al. (1993)and McDonald (2003), who recommend between 10-50% of resources going to the (1-0) panel depending on the program objectives. A large oversample was drawn, enabling the possibility to easily as samples if additional funding became available.

Combinations of panel designs are seemingly unlimited. We selected four revisit designs that were appropriate for the lake protocol objectives: [1-0], [(1-0), (1-3)], [(1-0), (2-3)], and [(1-0), (2-5)]. Then to assist in selecting the optimal revisit design, we ran power simulations (i.e.,

simulations incorporating statistical tests of water quality trends) comparing the four designs (Starcevich 2010). Power differences between designs were subtle. However, the [1-0] design, for most of the analytes, exhibited lower or equal power compared to the other three designs. The three split-panel designs had very similar power results, especially between [(1-0), (1-3)] and [(1-0), (2-3)]. The [(1-0), (1-3)] design was selected for the following reasons:

1. The (1-0) panel provides year to year data connectivity and contributes to increasing power to detect trend by reducing temporal variability.
2. The (1-3) panels increase the spatial sample size, reducing spatial variability thus increasing power to detect trend and status.
3. The (1-3) design was selected over the (2-3) design because it has a higher spatial sample size (increasing power for status estimates) and rotates through one year sooner.
4. The (2-5) design was not selected because of the longer rotation time.

The majority of the measures are sampled in accordance with the rotating panel-design. However, in-site data loggers enable us to collect continuous water-level and temperature measurements throughout the year. These measures will initially be collected at the annual panel sites. As technology improves (i.e., battery life increases and costs decrease) we may extend continuous sampling to the panel 3-5 sites.

2.1.4. Extensive Sampling Sites

We created a cost-surface model for each park following methods in Frakes et al. (2007).We drew the GRTS sample using the R workspace 'spsurvey' (Kincaid 2006). The selected sites are presented in **Figure 9** and the sites and cost surface model results are in SOP 1 (Lake Monitoring Sites). Original files, including the R code, sample frame data, input files, model output, GRTS output, etc., along with metadata are stored in the appropriate folders under the I&M directory structure.

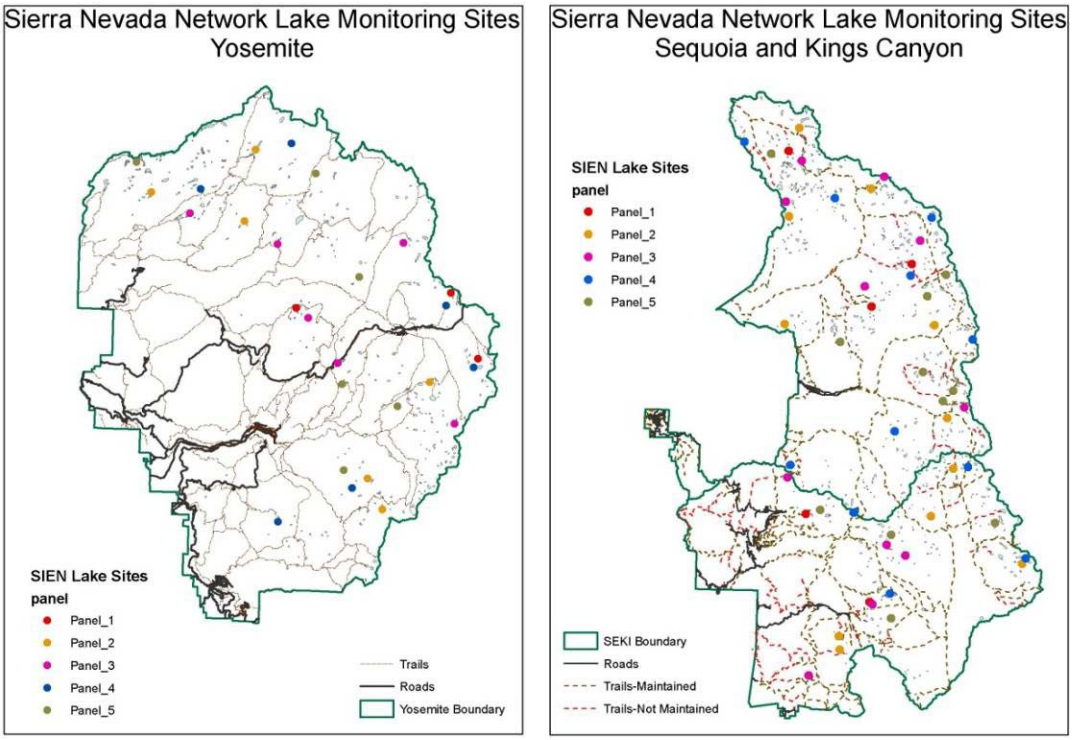


Figure 9. Sampling locations in Yosemite, Sequoia, and Kings Canyon National Parks.

2.2. Index Sites

Data collected at index sites will enable SIEN to answer objectives at a finer temporal scale and examine intra-annual patterns. Since index sites are sampled more frequently and focused on an individual site, we expect to detect trends for index sooner and with higher power than at extensive sites (i.e., network scale). Although it is not possible to make network-wide statistical inferences from these more intensively collected data, these data will inform results observed at extensive sites. This is a common design consistent with other successful long-term lake and watershed studies (Tonnessen 1991, Baron 2001).

2.2.1. Target Population

There are two index sites in the network: Upper Granite Lake located in Yosemite National Park and Emerald Lake located in Sequoia/Kings Canyon National Parks (**Figure 6** and **Figure 7**). Since these lakes were judgmentally selected, statistical inferences may only be made to the individual lake. Measurements are observed at the lake outflow and mid-lake.

The protocol includes one index site per park. However, maintaining this target population is dependent on a partnership with the University of California (UC) and their year-to-year funding. Emerald Lake sampling is conducted by UC, who share these data with SIEN. SIEN conducts sampling at the Upper Granite site. If UC ever lost funding for Emerald Lake sampling, SIEN would drop sampling at Upper Granite and shift resources to Emerald Lake. This decision was made due to the importance of maintaining the highly valuable long-term data set at Emerald Lake. If this were to happen the index site target population would drop to one lake. Please refer to Sections 7.3 for more details on the UC-SIEN partnership.

2.2.2. Revisit Design

Each Index site is sampled once a month, from approximately late-June through early October. Water-level and temperature are measured continuously.

2.2.3. Rationale Behind Index Site Selection

Index sites were selected based on the following criteria: accessibility, prior research or monitoring, and sensitivity to stressors. Index sites, with a brief description on why they were selected, are:



Emerald Basin

- *Emerald Lake*, in Sequoia National Park, is one of the more thoroughly studied sub-alpine lakes in the world, with over 25 years of research and monitoring that continues through present day. The lake is relatively easy to access—10 miles round-trip via an easy-moderate day hike. It has high exposure to pollutants from the Central Valley, and therefore, is an early warning indicator for other less-exposed lakes in the parks. The lake contains introduced trout and provides limited habitat for tree frogs.



Upper Granite Lake

- *Upper Granite Lake*, in Yosemite National Park, is located in the upper Tuolumne watershed a couple of miles from Tioga Pass. This site was sampled periodically from 1981- 2001 by the University of California, Santa Barbara. Coincidently, it is also one of our annual panel sites and therefore, has additional data from 2008-present. The geology, vegetation, and lakes size and chemistry are characteristic of many Sierra Nevada alpine/sub-alpine watersheds. This site was selected for its practical access, historic data record, and watershed and chemistry characteristics. The lake is easy to access. It is approximately a 4-mile round-trip hike from the Tioga Pass trailhead. A site visit can be accomplished in less than a day. The lake contains fish and has limited amphibian populations.

2.3. Sample Design Limitations

There are no perfect sample designs; all designs have advantages and limitations. Tools such as GRTS, panel-designs, and variable probability sampling can complicate data analysis or require the analyst to make assumptions s/he may not be entirely comfortable with. The Network, in constructing the design, has made every effort to maximize advantages and minimize limitations in the context of the lake monitoring objectives and realities of logistics and budgets.

The primary limitation with GRTS, in the context of this protocol, is the inability to incorporate the neighborhood variance estimator into a trend analysis. The estimator can be used to calculate variance for SIEN's status objectives. However, when estimating trend one must ignore the GRTS design and assume a simple random sample. Since the neighborhood variance estimator is 22% to 58% smaller than variance estimates calculated for a simple random sample (Stevens Jr. and Olsen 2003), this is a conservative assumption that we are comfortable with. If methods are ever developed to incorporate the neighborhood variance estimator into trend analyses, SIEN can apply these methods and increase the confidence with which we report trend.

We are selecting lakes using a cost-surface model to apply unequal probability inclusions. Trend analyses in the context of panel designs cannot incorporate variable probability sampling. Therefore, when testing for trend it must be assumed that sites had equal chance of being selected. This is the assumption with which we are the least comfortable because it biases the results towards lakes that are quicker to access. For Yosemite, the likely result is increased sites along the Tioga road corridor and for Sequoia/Kings Canyon sites along the eastern and western edges of the parks. We elected to accept the consequences of this assumption because the alternative, selecting sites with equal probability, would significantly increase travel times and logistical challenges thus reducing sample sizes and increasing nonresponse error. Nonresponse error is likely to increase because the more difficult a site is to reach, the greater the chance it might not be sampled due to safety, weather, unexpected terrain, etc. Note that these assumptions are only for the trend estimates. Status calculations can account for the unequal distribution of samples by weighting the data (i.e., sites with lower probability of being selected are given more weight when calculating means, proportions, and other status variables).

The primary limitation of the index site design is the inability to make network or park-wide inferences because these sites were not randomly selected. We are comfortable with this limitation because they are complemented by the extensive sites. As discussed above, it is our only realistic opportunity to collect intra-annual data.

2.4. Sources of Nonsampling Error

Several nonsampling error sources may affect the precision and accuracy of estimates from these surveys. Frame error may be generated by error in the maps used to create the sampling frame. Lakes that are close to 1 ha in area or 2 m in maximum depth may be included or excluded in the sampling frame, in error. However, this error is not expected to be large or consequential in estimation and inference.

Nonresponse error may occur for the extensive sampling if survey crews have difficulty in accessing a lake or encounter harsh environmental conditions. Obtaining spatially balanced samples with alternative sites may decrease the error due to nonresponse if alternate sites are representative of sites missed due to site inaccessibility.

Occasionally, water samples are damaged or contaminated or laboratories have problems obtaining measurements. Quality control and assurance programs are used to track why these problems occur so that the mechanism may be examined and the appropriate methods to account for nonresponse are used. Measurement errors can occur when field crews are not properly trained or instrumentation fails. Field crews may possibly misuse probes during surveys or introduce subjectivity into measurement processes when lakes are stratified and multiple samples are taken. Below-detection-limit data may be obtained during chemical analyses in which instrumentation fails to obtain a response. Measurement errors are minimized by training field crews, using labs with low minimum detection limits, and applying imputation techniques and appropriate models in the analysis phase.

2.5. Minimum Detectable Difference

After much discussion and running of preliminary power analyses, we decided that the trend analysis would test for trend versus no trend (i.e., $\beta = 0$). Testing for any trend ($\beta = 0$), versus testing for a specific change (e.g., $\beta = .20$), is more consistent with the objectives of a monitoring

program and results in higher power. It is a conservative approach, providing managers with an early warning of change and with higher confidence. Managers will know the magnitude of the trend before deciding if and when to take any management actions.

2.6. Power Analysis

Power analysis provides a 'reality check' on project goals and objectives and an *a priori* understanding of the ability and confidence with which one can detect trends and estimate status over time. Power analysis results were used to inform sampling design, sample size, and data analysis decisions. Power results at extensive sites apply to water chemistry trend tests only. SIEN's status objective, 'Determine the proportion of Sierra Nevada Network lakes above threshold values' could not be tested because thresholds have yet to be identified. Once thresholds are identified (not a trivial task), we will run power analyses for status testing. Amphibian power analyses were not performed because these data are intended to 1) be analyzed by parks and researchers with their data, and 2) simply document the presence of amphibians at sampled lakes.

Power analyses were not computed for the index sites. Power simulation methods are not readily available for the Seasonal Kendall Test for trend and we were limited by time and resources. It was beyond the scope of this protocol to develop power analysis methods for the Seasonal Kendall Test, a frequently used approach to test for long-term trends in water quality at single sampling stations. Monitoring programs typically sample a maximum of once per month (higher frequencies complicate serial correlation issues). Hirsh and Slack (1984) recommend collecting a minimum of 5-10 years of data before running the Seasonal Kendall Test for trend.

Trend may be defined in a number of ways and definitions should be clarified so that survey goals are clear. Surveys conducted over time may be used for estimation at particular points in time, to estimate average parameters over time, to measure net or annual change in a population, to measure factors contributing to individual change, or to measure durations of events (McDonald 2003). Individual change is measured at the level of the sampling unit. The measurement of net change includes all sources of change and is measured at the scale of the population. Therefore, individual change does not necessarily imply net change because trends at individual sites may vary and result in no net change. The power analysis targets net change in the population (i.e., SIEN Lakes). Net change may also be expressed in annual change so that power approximations for different time spans may be more directly compared. The detected population change is measured in linear trend; however, trend may be detected by measuring linear trend without asserting that trend is strictly linear (Urquhart and Kincaid 1999).

In this section we provide a summary of the power analysis methods and results. Please refer to Appendix B for the complete report on the power analysis methods and results.

2.6.1. Pilot Data

We were fortunate to have several high quality data sets with both temporal and spatial data that were used for the power analysis: the Western Lakes Survey (WLS), a re-survey of WLS sites in National Parks, and the Seven Lakes Study.

The Western Lake Survey, conducted in 1985 by the EPA with cooperating agencies, was a one-time regional sampling of high elevation lakes in the mountainous west. Seven hundred and

nineteen lakes, representing a target population of 10,393, were sampled throughout the west, including in Yosemite, Sequoia, Kings Canyon and the upper Middle Fork of the San Joaquin above Devils Postpile. Clow et al. (2002), in 1999, resurveyed a subset of these lakes (n=32) in Yosemite, Sequoia, and Kings Canyon.

Researchers from UC Santa Barbara measured atmospheric deposition and lake chemistry in seven alpine and subalpine watersheds in the Sierra Nevada as part of the "Seven Lakes Study" (Melack et al. 1998). The study watersheds span the Sierra Nevada and include sites in or near Lake Tahoe, Yosemite, and Sequoia. This data set contains both temporal and spatial data. The period of record for most of the lakes is approximately nine years. The exception is Emerald Lake in Sequoia National Park, which has been a long-term research and monitoring site for over 25 years.

2.6.2. Methods

To accurately estimate power to detect trend, analysis methods and tests of trend used in the power analysis should reflect future data analysis approaches as closely as possible. The approach taken here is often used for detecting trend from panel designs and will be used by SIEN for trend tests.

Briefly, an overview, power analysis was conducted using a mixed linear model, proposed by VanLeeuwen et al. (1996) and Piepho and Ogutu (2002). A mixed model allows some effects to be considered fixed and some to be considered random. 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 subjects (lakes) and over time (years). Estimates of the variance components and the fixed effects, calculated from the pilot data, were used to simulate similar populations with specific net changes (i.e., 20%, 30%, and 40% change) in the responses over time. Trend was evaluated using the linear mixed model. Benefits of the linear mixed model approach include flexibility to account for covariate data and the ability to partition variance into components that may influence in different ways the power to detect trend. For more detail on the linear mixed model for trend detection, see the power analysis report in Appendix B.

2.6.3. Results

Power analyses were run for the analytes using water samples collected in September and October (Starcevich 2010). Four revisit designs were compared and the results assisted the Network in selecting a final revisit design. Two approaches were used to calculate sample size. The first approach examined the number of lakes needed to obtain power to detect a given change over a set period of years. The second approach examined the number of consecutive years of surveys needed to obtain power to detect a population change for a fixed sample size. The results from these two approaches, in conjunction with sampling objectives, were used by the network to determine sample size, the % change we were willing to accept, and number of years to detect trend.

Once a final design was determined, we ran a power analyses for this given design. The final design is: a [(1-0), (1-3)] revisit design; sampling 25 lakes per year with 8 visited annually (Panel 1) and 17 visited per year in the alternating panels (Panels 2-5); and for the hypothesis test of no change over time ($\beta = 0$). Tests were run given 20, 30, and 40% change over 10 years and over 30 years for measures with low variance and high power (Table 2). Tests were run given 20, 40,

60, and 80% change over 10 years and over 30 years for measures with higher variance and lower power (**Table 3**).

Table 2. Power estimates for SIEN water chemistry measures. Tests were run given 20, 30, and 40% change over 10 years and over 30 years. 'δ' is the given change of a measure.

	10-year Trend			30-year Trend		
Measure	**δ=0.20**	**δ=0.30**	**δ=0.40**	**δ=0.20**	**δ=0.30**	**δ=0.40**
Spec. Cond.	0.517	0.746	0.917	0.543	0.827	0.959
ANC	0.304	0.481	0.734	0.479	0.808	0.968
SO4	0.258	0.379	0.525	0.274	0.445	0.652
PN	0.179	0.270	0.379	0.265	0.437	0.612
PP	0.158	0.239	0.234	0.218	0.330	0.441
pH	1.000	1.000	1.000	0.921	1.000	1.000
Na	0.241	0.332	0.414	0.283	0.469	0.682

Table 3. Power estimates for SIEN water chemistry measures. Tests were run given 20, 40, 60, and 80% change over 10 years and over 30 years. 'δ' is the net change of a measure.

	10-year Trend				30-year Trend			
Measure	**δ=0.20**	**δ=0.40**	**δ=0.60**	**δ=0.80**	**δ=0.20**	**δ=0.40**	**δ=0.60**	**δ=0.80**
NO3	0.152	0.161	0.212	0.244	0.138	0.192	0.307	0.403
Ca	0.210	0.407	0.645	0.788	0.131	0.169	0.281	0.341
Mg	0.168	0.293	0.485	0.596	0.118	0.140	0.198	0.231
K	0.228	0.382	0.539	0.705	0.178	0.317	0.571	0.729
Cl	0.104	0.125	0.182	0.240	0.105	0.115	0.120	0.112
Temp.	0.150	0.326	0.523	0.639	0.122	0.133	0.180	0.199
DON	0.145	0.202	0.269	0.312	0.112	0.194	0.318	0.419
PC	0.180	0.268	0.346	0.497	0.196	0.395	0.629	0.777
TDP	0.166	0.304	0.462	0.594	0.192	0.402	0.630	0.795

The net change over a 10-year period results in a larger annual change than the same net change over a 30-year period. Note also that, for many analytes, the power to detect trends is less than the desired level of 0.8. The highest power is obtained for specific conductance, ANC, and pH. Power to detect trends may be increased by examining subpopulations with similar trends and incorporating covariate information into the linear mixed model to reduce variation. While some analytes exhibit low power for trend detection under all but the most extreme trend scenarios, we feel that monitoring these analytes is warranted due to the low additional cost of collection and analysis and the high relative cost of overlooking a dramatic change over time. Other approaches for trend detection, such as nonparametric tests, will also be applied before a determination of trend is made.

3. Field and Laboratory Methods

3.1. Data and Sample Collection

Standard Operating Procedures describe field collection methods in detail, including pre-season preparation, water and hydrologic sampling methods, post-processing and shipping of samples, and end-of-season procedures (**Table 4**).

Table 4. Standard Operating Procedures pertinent to field methods.

SOP	Title and Description
SOP 1	*Lake Monitoring Sites* This SOP documents the locations, including maps and UTM's, for the extensive sites. It also includes the site selection process and cost surface analysis results.
SOP 2	*Safety* The Safety SOP provides safety information, checklists, Job Hazard Guidelines, and forms for Sierra Nevada Network and contract personnel who are involved with field activities. It covers general safety issues associated with field sampling and wilderness travel (e.g., driving hazards, lightning) and issues specific to lake sampling (e.g., high flows, boat safety). All field employees are required to complete comprehensive field safety training.
SOP 3	*Staff Training* This SOP describes the training requirements for the lake protocol. The protocol lead is responsible for providing training and ensuring these requirements are completed by all field staff. Lake monitoring training includes safety training, general NPS training requirements, and field sampling methods. The SOP includes an example agenda and links to previous presentations and handouts.
SOP 4	*Quality Assurance Project Plan* The Quality Assurance Project Plan (QAPP) describes quality assurance and quality control objectives and procedures. It covers *Project Management*, *Data Generation and Acquisition*, *Assessment and Oversight*, and *Data Validation and Usability*. The QAPP meets the State of California's Surface Water Ambient Monitoring Program (SWAMP) quality requirements so SIEN data are compatible with SWAMP.
SOP 5	*Field Season Preparation* This SOP covers pre-season field preparations including hiring, training, and equipment and trip preparations.
SOP 6	*Chain-of Custody* A chain-of-custody form is used to track samples. This SOP contains chain-of-custody procedures and the form.
SOP 7	*Equipment Disinfection* Field equipment that contacts water or organisms must be disinfected between waterbodies per the Equipment Disinfection protocol. The purpose is to prevent the introduction and spread of non-native organisms. Of particular concern in this region are chytrid fungus (*Batrachochytrium dendrobatidis*), New Zealand mudsnail (*Potamopyrgus antipodarum*), and quagga mussel (*Dreissena rostriformis bugensis*).

Table 4. Standard Operating Procedures pertinent to field methods (continued).

SOP	Title and Description
SOP 8	*Water Sampling Methods* This SOP describes field sampling methods for outlet and mid-lake water chemistry sampling. It details how to record field observations, collect in situ water quality measurements, collect and process water samples (filtered and unfiltered), and collect and process particulate filter samples. Water sampling equipment checklists and field forms are located in this SOP.
SOP 9	*Sample Handling, Storage, and Shipping* This SOP describes sample handling procedures once the samples are removed from the field. It includes storage, chain-of-custody, processing at the park water labs, and shipping information.
SOP 10	*Water-level and Continuous Temperature Sampling Methods* This SOP includes procedures for level-logger installations and downloads.
SOP 11	*Post-season Procedures* This SOP describes end-of-season protocols for cleaning, inventorying, and storing equipment. It discusses post-season debriefing.

3.1.1. Field Season Preparation

Although the field season does not begin until June, preparations should begin as early as the previous October. The protocol lead and logistics technician are responsible for winter preparations. The crews will start work in June and at this point will take on additional preparation responsibilities. Field season preparation involves coordinating shared technician positions, hiring employees, planning sampling trips and routes, submitting permits and backcountry travel plans, preparing equipment and data sheets, and training (**Table 5**). Detailed pre-season procedures are in SOP 5 (Field Season Preparation). The water sampling field equipment checklist is located at the beginning of SOP 8 (Water Sampling Methods).

In Yosemite, all NPS employees must apply for and carry a research permit. It is recommended the protocol lead submit the permitting paper work in January. Sequoia and Kings Canyon does not require NPS employees to apply for and carry research permits. However, Wilderness compliance, including the Minimum Requirement Analysis, needs to be addressed at all parks. SIEN is currently coordinating with SEKI and YOSE Wilderness managers.

Table 5. Field season preparation timeline.

Timing	Prep Activity	Responsibility
October	1. Label sample bottles for next season	Logistics Tech & Crew
December	2. Coordinate shared tech positions with protocol leads and park staff (may continue into Feb.)	Protocol Lead
	3. Announce seasonal positions.	Protocol Lead
January	4. Submit research permit.	Protocol Lead
February	5. Hire and finalize shared crews.	Protocol Lead
	6. Arrange seasonal housing.	Protocol Lead
March	7. Plan wilderness trip itineraries.	Protocol Lead & Logistics Tech
April	8. Order any final equipment needs.	Protocol Lead (sampling equip.) & Logistics Tech (backcountry equip.)
	9. Create and print site maps.	Logistics Tech
	10. Make dorm reservations.	Logistics Tech
	11. Send welcome letter to field techs.	Protocol Lead
May	12. Start coordinating food and equipment caches.	Logistics Tech
June & July	13. Conduct training.	Protocol Lead
	14. Prepare data sheets and equipment for the season.	Crew
August	15. Prepare and finalize extensive survey itineraries.	Crew
	16. Order supplies for next season.	Protocol Lead
Prior to each trip	17. Prepare equipment and logistics required for individual site visits.	Crew

3.1.2. Field Work

Crews hike to sampling locations. Couriers may be used to shuttle samples, if needed. Lightweight rafts are used to access the lake center. Wilderness travel logistics and backpacking loads are the most challenging aspect of this protocol. Crews use ultra light equipment whenever possible—much of the gear is provided by SIEN. To lighten loads further, protocol and crews should coordinate with park staff to place food drops at backcountry camps and ranger cabins via routine stock or helicopter visits.

Access routes and trailheads vary by year and depend on current backcountry conditions, suite of sites selected for the year, crews abilities, shared-crew logistics, and numerous other logistical considerations (e.g., housing locations, crew schedules). As crews visit the sites, especially

during the first four years, they document their routes via written text and in some cases GPS track logs. Detailed site location information is stored on the network (J:\sien\monitoring_projects\water\operations\backcountry_trips). The Project Lead and Logistics Tech will plan trip itineraries during the pre-season and at the beginning of each season, work with crews to revise itineraries to fit crew members' hiking abilities and skills. This is not only important for logistics, but also safety. Crews are required to become very familiar with their routes using resources such as site descriptions from prior crews, topographic maps, and local knowledge.

Crews will be collecting field observations, *in situ* water quality measurements, water samples (filtered and unfiltered), particulate filter samples, and water-level data (**Table 6**). Field methods and equipment lists for water chemistry and hydrologic sampling are covered in detail in the SOPs 8 and 10 and the QAPP. Crews conduct water chemistry sampling at both index and extensive sites. All lakes are sampled at the outlet. Index and [1-0] panel lakes are also sampled at mid-lake. A mid-lake sample is collected from the epilimnion, 1 m below the surface and if the lake is stratified, a second sample is collected from the hypolimnion. Water-level and continuous temperature monitoring is conducted at index sites and annual panels.

Table 6. Observations and measures collected at SIEN lakes.

Data Collection Type	Measure
Field observations	Weather, lake photo, fish presence
In situ water quality measures	Water temp, specific conductance, dissolved oxygen, pH
Water samples-unfiltered	pH, acid neutralizing capacity, specific conductance
Water samples-filtered	Dissolved inorganic nitrogen, dissolved organic nitrogen, total dissolved nitrogen, total dissolved phosphorus, calcium, sodium, magnesium, potassium, chloride, sulfate
Particulate filter samples	Particulate nitrogen, particulate phosphorus, particulate carbon
Hydrologic data	Lake water-level

3.1.3. Sample Handling and Shipping

All staff who handle samples are required to adhere to quality control and chain-of-custody procedures to ensure sample integrity is tracked and maintained. Samples should be kept as cool as possible while in the field—for example, store in the shade. Once samples reach the trailhead, they should be stored in a cooler with ice as soon as possible. Samples are delivered to the Yosemite or Sequoia water lab (or other designated processing facility), where they are temporarily stored in a refrigerator or freezer (refer to SOP 9 and QAPP for sample storage requirements and holding times) and prepared for shipping. Samples are over-night shipped, early in the week (Mon-Wed), in coolers with blue ice to the analytical laboratory. Chain-of-custody is tracked from the moment the sample is collected until analysis is complete and the remaining sample has been discarded.

3.1.4. Quality Assurance and Quality Control

Quality assurance and quality control procedures for field methods are documented in field sampling SOPs and the Quality Assurance Project Plan (QAPP). Procedures follow NPS-WRD (Irwin 2006) and SWAMP guidelines (Nichol et al. 2004). SIEN's QAPP follows the SWAMP

QAPP Template and will be reviewed by the State to ensure SIEN data are 'SWAMP compatible'. The QAPP and field SOPs address measurement quality objectives, sample contamination, field measurements, sample handling and custody, instrumentation testing and calibration, and field audits.

3.1.5. End-of-Season Procedures

Once sampling is complete at both extensive and index sites, crews inventory, clean, and store equipment for the winter. Broken equipment is fixed or replaced. The crew lead makes a list of equipment that requires replacing.

The protocol lead leads a post-season debriefing with all crew members. The purpose is to discuss the season and any departures from protocol (missed sites, samples, etc.) and identify successes and areas that require improvement.

3.2. Field and Laboratory Analyses

Field and laboratory instrumentation and methods were chosen based on their suitability for dilute water samples and use in previous studies of Sierra Nevada lakes. With the exception of field measurements of in-situ temperature, oxygen, and specific conductance, all other chemical analyses will be conducted by outside contract laboratories. All methods, along with method detection limits (MDLs), minimum levels of quantitation (ML) and method quantitation limits are presented in **Table 7**.

In situ measurements are made using a YSI multi-parameter sonde. Sensor specifications are as follows: 1) For field temperature and oxygen measurements a YSI polarographic oxygen sensors and thermistors will be used. Field specific conductance measurements will be made with a platinum conductivity electrode with a cell constant of K=1 cm^{-1}. In the laboratory a lab-grade conductivity meter equipped with a K=0.1 cm^{-1} cell will be used. Laboratory pH will be made with a high quality, laboratory pH meter equipped with an Orion-Ross combination electrode. This electrode works especially well in dilute waters. Acid neutralizing capacity of samples will be measured by Gran Titration using the laboratory pH meter and Ross electrode. Hydrochloric acid with a normality of 0.1 will be used to titrate the sample past the equivalence point. Four titrant-pH measurement pairs will be made between pH 4.3 and 3.7 and used in the Gran computation. Continuous lake water-level and temperature are measured at index and annual panel sites using Solinst water levelloggers. All field and laboratory instruments will be calibrated using manufacturer's direction using NIST-traceable standards, where feasible.

Major anions plus nitrate and nitrite will be measured using chemically suppressed ion chromatography on a Dionex ion chromatograph. A contract laboratory will do these analyses following EPA Method 300.1 or a modification thereof. Major cations will be measured by one of two methods by a contract laboratory: a) flame atomic absorption spectrophotometry (EPA Method 200.9) or inductively coupled plasma (EPA Method 200.7). While ion chromatographic methods exist for cations, they are not appropriate for the low cation levels expect in the lake samples and previous method-intercomparison studies indicate that ion chromatography has difficulty measuring concentrations of divalent cations such as calcium and magnesium.

Particulate carbon, nitrogen, and phosphorus will be collected on Pall A/E glass fiber filters that have been precombusted at 500°C for 3 hours. Approximately 500 mls of lake water will be

passed through each filter sample and stored at -20°C until analyzed. Particulate C and N will be measured on a high-temperature elemental analyzer. Particulate P and total dissolved P will be measured by digestion by a persulfate-NaOH-boric acid reagent (Valderrama 1981). Following digestion, all forms of nascent P will be in the form of phosphate ions which will be quantified using EPA Method 365.1. Total dissolved nitrogen (TDN) will be analyzed using the Valderrama method as well, with the nitrate produced by the digestion measured by EPA Method 353.2. Dissolved organic nitrogen will be computed as the difference between TDN and dissolved inorganic nitrogen (nitrate+nitrite). Owing to anticipated delays in returning samples from the field, and the fact that ammonium is likely to at or below the detection limit, we will not measure ammonium in the lake samples.

Table 7. Analytical methods and measurement quality objectives.

					Precision	Bias		
Measure	**Method**	**MDL**	**ML**	**AMS**	**RPD**	***Check Samples***	***Spike Recovery***	**Completeness**
Core parameters								
Temperature	Thermistor	-	-	0.1 oC	±0.15 °C	-	-	95%
Specific Conductance - field	Conductivity meter (1 cm cell)	-	-	0.1 uS/cm	±0.5 us/cm	-	-	95%
Specific Conductance - lab	Conductivity meter (0.1 cm cell)	-	-	0.01 uS/cm	±0.1 uS/cm	-	-	95%
pH - lab	pH meter w/ Ross electrode	-	-	0.01 pH unit	±0.2 ph unit	-	-	95%
Dissolved oxygen - field	YSI DO meter	-	-	0.2 mg/l	±0.5 mg/l	-	-	95%
Nitrogen								
Nitrate	Ion chromotography (EPA Method 300.1)	*0.3 umol/L*	*0.95 umol/L*	-	5%	*±10%*	*80-120%*	95%
Nitrite	Ion chromotography (EPA Method 300.1)	*0.3 umol/L*	*0.95 umol/L*	-	5%	*±10%*	*80-120%*	95%
Dissolved organic nitrogen	TDN - (nitrate+nitrite)	-	-	-	-	-	-	95%
Total dissolved nitrogen	Valderrama (1981): Persulfate digestion followed by EPA Method 353.4	0.5 umol/L	2 umol/L	-	20%	*±10% or ± 0.040 uM*	*80-120%*	95%
Particulate nitrogen	Elemental Analyzer (EPA Method 440.0)	-	-	-	-	-	-	95%
Phosphorus								
Total dissolved phosphorus	Valderrama (1981): Persulfate digestion followed by EPA Method 365.5	0.05 umol/l	0.2 umol/L	-	20%	*±10% or ± 0.040 uM*	*80-120%*	95%
Particulate phosphorus	Valderrama (1981): Persulfate digestion followed by EPA Method 365.5	-	-	-	-	-	-	95%
Carbon								
Particulate carbon	Elemental Analyzer (EPA Method 440.0)	0.1 umol/L	0.4 umol/L	-	-	-	-	95%
Major Ions								
Calcium	*Inductively coupled plasma (ICP) (EPA Method 200.7) using modifications in Dombek (2009) and Mirishige and Kimura (2008)*	0.2 umol/L	0.8 umol/L	-	5%	*±10%*	*80-120%*	95%
Sodium	*Inductively coupled plasma (ICP) (EPA Method 200.7) using modifications in Dombek (2009) and Mirishige and Kimura (2008)*	0.2 umol/L	0.8 umol/L	-	5%	*±10%*	*80-120%*	95%
Magnesium	*Inductively coupled plasma (ICP) (EPA Method 200.7) using modifications in Dombek (2009) and Mirishige and Kimura (2008)*	0.2 umol/L	0.8 umol/L	-	5%	*±10%*	*80-120%*	95%
Potassium	*Inductively coupled plasma (ICP) (EPA Method 200.7) using modifications in Dombek (2009) and Mirishige and Kimura (2008)*	0.2 umol/L	0.8 umol/L	-	5%	*±10%*	*80-120%*	95%
Chloride	Ion chromotography (EPA Method 300.1)	0.3 umol/L	0.95 umol/L	-	10%	*±10%*	*80-120%*	95%
Sulfate	Ion chromotography (EPA Method 300.1)	*0.3 umol/L*	*0.95 umol/L*	-	5%	*±10%*	*80-120%*	95%
ANC	Gran titration (Rounds et al 2006)	0.5 umol/L	2 umol/l	-	-	-	-	95%

MDL: Method detection limit; ML: Minimum level of quantitation; MQL: Method quantitation limit;
AMS: Alternative measurement sensitivity; RPD: Relative percent deviation

3.2.1. Quality Assurance and Quality Control

Detailed QA/QC procedures are described in SOP 4 (QAPP). The following is a summary of the QA/QC procedures and measurements we require for laboratory analyses:

Precision: Precision is the reproducibility of an analytical method. Each laboratory is expected to maintain records for use by analysts in monitoring the overall precision of certified reference materials and natural samples. Within each analytical run, measurements of precision will be performed at a 5% frequency (i.e., one duplicate for every 20 samples) or at least once if the run contains less than 20 samples. Both certified reference material and natural samples will be used in measurements of precision.

Laboratory Method Blank: Laboratory method blanks (also called extraction blanks, procedural blanks, or preparation blanks) are used to assess laboratory contamination and instrument background during all stages of sample preparation and analysis. An appropriate number of laboratory blanks will be done at the beginning and throughout each analytical run.

Matrix Spike Recovery: A laboratory fortified sample matrix (commonly called a matrix spike, or MS) will be used both to evaluate the effect of the sample matrix on the recovery of the compound(s) of interest and to provide an estimate of analytical precision. Recovery is the accuracy of an analytical test measured against a known analyte addition to a sample. These QA samples will be done at a 5% frequency in each analytical run.

Holding Time Tests: During each field season, duplicate samples will be collected at three index lakes. The lakes chosen will be sampled on the final day of a field trip so that they can be rushed back to the laboratory. One set of replicates will be held for the standard holding times under standard storage conditions that are specified in the QAPP. The other set of duplicates will be stored at room temperature for 7 days then held for the standard holding times under standard storage conditions before analysis. All chemical analyses will be conducted on the duplicate samples and the results will be compared statistically to determine if 7 days of storage results in significantly different analyte concentrations.

Equipment Blanks (done in lab prior to field work): To insure that equipment used during sampling does not contaminate samples, the device is filled with DI water or DI water is pumped through the device, transferred to sample bottle(s), preserved (if appropriate) and analyzed by the lab.

Field Duplicates: Duplicate samples will be collected for all parameters at an annual rate of 5% of total samples to be collected within a given year's monitoring plan. These duplicate samples will be done in addition to the duplicate used for the holding time tests. The duplicate sample will be collected in the same manner and as close in time as possible to the original sample.

Field Blanks: A field blank is designed to assess potential sample contamination levels that could occur during field sampling and sample processing. Field Blanks (DI water) are taken to the field, transferred to the appropriate container, preserved (if appropriate), and otherwise treated the same as the corresponding sample type during the course of a sampling event. Field blanks for water quality constituents should be conducted upon initiation of sampling, and if field blank

performance is acceptable, further collection and analysis of field blanks for these other media and analytes need only be performed on an as-needed basis, or during field performance audits.

3.2.2. Analytical Laboratories

Analysis of dilute lake samples from the Sierra Nevada presents many challenges for an analytical laboratory. Concentrations of many analytes will be near the detection limit for many standard methods and special procedures may be necessary to push required detection limits (**Table 7**). Another issue is the risk of cross-contamination of dilute samples by others with higher analyte concentrations. In many contract analytical laboratories, sample matrices might include wastewater, brackish water, and industrial waters – all of which pose a threat of cross contamination for Sierra Nevada waters. Thus, selection of appropriate contract laboratories is of utmost importance to the success of the SIEN Lake Monitoring Program.

SIEN is using two laboratories in order to get the full suite of measures analyzed. Water samples are analyzed by the University of Colorado, Kiowa Lab and particulate samples are analyzed by the University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory. Analytical results can vary between labs even when the same methods are followed. It is ideal in a long-term monitoring program to remain as consistent as possible with labs. However, we recognize this may not always be possible. It is a high priority for SIEN to remain with these labs, however, if a laboratory change is ever warranted a new lab will be selected in strict accordance with our measurement quality objectives. Every effort will be made to overlap a subset of samples. Kiowa and Chesapeake Bay laboratory contact information is:

Kiowa Lab
Institute of Arctic and Alpine Research, University of Colorado at Boulder, Research Lab 1, Room 206, 1560 30th Street, Boulder, Colorado 80303

Principal Investigator: Mark Williams (303) 492-8830, markw@snobear.colorado.edu

Researcher: Christine Siebold, (303) 735-6336, christine.seibold@colorado.edu

Chesapeake Biological Lab
University of Maryland Center for Environmental Science
Chesapeake Biological Laboratory
Nutrient Analytical Services Laboratory
PO Box 38
Solomons, MD 20688

Primary Contact: Carl Zimmerman, (410)-326-7252, carlz@umces.edu

3.3. Method Comparability

Comparability between projects was a primary criterion used in selecting the analytical methods and procedures used in the SIEN Program. A detailed summary of analytical methods used by the most extensive monitoring programs of Sierra Nevada lakes to date are presented in the QAPP. Overall, the projects listed used identical or very similar methodologies. For example, dissolved inorganic nitrogen, chloride and sulfate were all measured by EPA Method 300.1 – ion chromatography (IC)- with slight differences in instrumentation. The major exception to consistency was the use of IC for base cation analyses by the U.S. Forest Service. Unpublished

inter-laboratory comparisons of cations in Sierra Nevada lakes measured by IC, atomic absorption spectrophotometry (AA) and inductively coupled plasma (ICP) have demonstrated that AA and ICP produce similar divalent cation concentrations on duplicate samples. In contrast, divalent cation concentrations measured by IC are not consistent with AA and ICP values (J. Sickman, UC Riverside and D. Clow, US Geological Survey, unpublished data). Thus for the SIEN protocol, only AA or ICP methods will be used for base cation analyses.

4. Data Management

Data take on different forms during various phases of a project, and are maintained in different places as they are acquired, processed, documented, analyzed, reported, and distributed. Flow of the lake monitoring data and information can be visualized using a "data life cycle" model (**Figure 10**). Acquired raw data go through multiple steps before they are disseminated as a 'certified' data set or as information conveyed in the form of reports, maps, etc. Water chemistry and hydrologic data are stored locally in SIEN's Water Database (*refer to Section 4.1 for a description of the database*). Once certified, data are disseminated via the following national, state, and local avenues: 1) STORET, EPA's national water quality database, 2) California Environmental Data Exchange Network (CEDEN), the State's repository for aquatic data, and 3) direct request to the network. Products are also disseminated through multiple venues including SIEN websites and NatureBib.

Although information management is prevalent throughout the protocol, there are several SOPs that focus specifically on data and information management procedures (**Table 8**). SOP 12 (Data Management) is the central data management reference. It walks you through the data management steps, from acquisition to dissemination, and points to detailed procedures located in other SOPs.

Table 8. Data management SOPs.

SOP	Title and Description
SOP 4	*Quality Assurance Project Plan* The Quality Assurance Project Plan (QAPP) describes quality assurance and quality control objectives and procedures. It covers an overview of data management, documentation, records management, review, verification, validation, and reconciliation. The QAPP meets the State of California's Surface Water Ambient Monitoring Program (SWAMP) quality requirements so SIEN data are compatible with SWAMP.
SOP 12	*Data Management* This is the central data management reference. It walks you through the data management steps (i.e., data life cycle), from acquisition to dissemination, and points to detailed procedures located in other SOPs.
SOP 13	*Database Users' Manual* This is the User's Manual for the SIEN Water Database. It contains all procedures for the database including entering, verifying, committing, and exporting water chemistry and streamflow data.

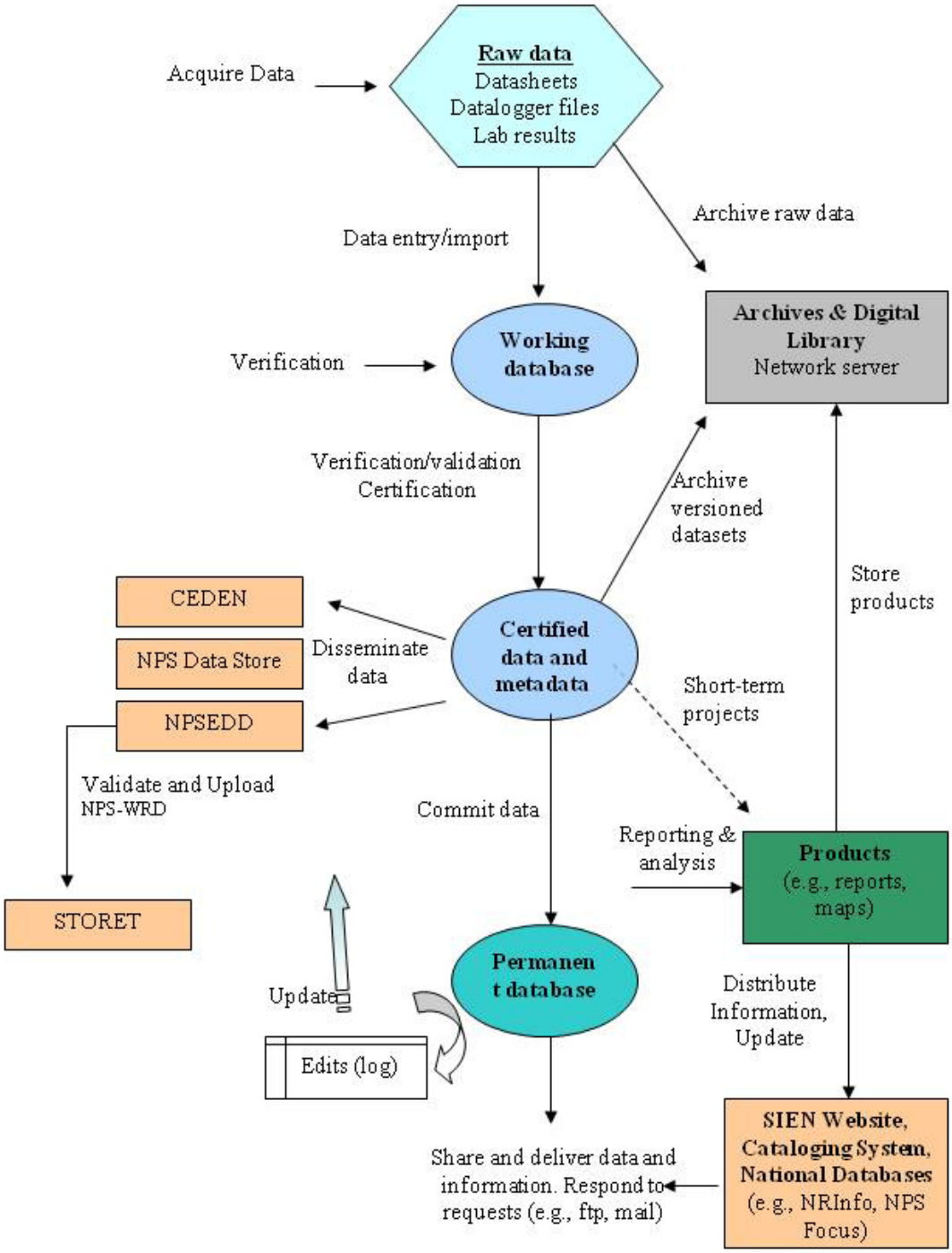


Figure 10. Lake monitoring data flow chart.

4.1. SIEN Water Database

We are working with the State of California and the Surface Water Ambient Monitoring Program (SWAMP) to improve information sharing and facilitate the flow of data between NPS and the State. The State of California maintains the California Environmental Data Exchange Center (CEDEN) which is a state-wide database through which all water quality and aquatic biota data collected by water quality programs in the state are integrated and made publicly available (http://bdat.ca.gov/Php/ceden.php). The Department of Water Resources has developed a desktop database application in MS Access that is used by the SWAMP program and their clients to store and deliver their data to CEDEN. The SWAMP database design is consistent with the Natural Resources Database Template (NRDT) and adheres to protocols established by the Environmental Protection Agency and State of California for data standardization and quality assurance.

The SIEN Water Database is a modified version of the SWAMP client database (version 2.2). We modified the SWAMP database to incorporate all metadata (required and optional) included in NPSTORET and to meet the specific requirements of our program, including the capacity to store continuous streamflow data. We provide an entity relationships diagram showing some of the core table and relationships in the database (Figure 11) more detailed information is available in the water database user's manual (SOP 13). The result is a database that interfaces with the National Park Service-Water Resources Division NPSTORET, and thus STORET, and the State of California's CEDEN. Data are uploaded, via a built-in interface module, to Excel spreadsheets that meet the National Park Service STORET Electronic Data Deliverable (NPSEDD) specifications. Data are submitted to NPS-WRD annually. The State of California will be designing the SIEN-CEDEN interface. Data are uploaded by the Data Manager to CEDEN annually.

4.2. Data Quality Assurance and Quality Control

Quality assurance and quality control procedures, like data management, are integrated into all aspects of the protocol with the overall goal of producing high quality and thoroughly documented data.

Data quality is appraised by applying verification and validation procedures as part of the quality control process. These procedures are more successful when preceded by effective quality assurance practices (i.e., planning). *Data verification* checks that the digitized data match the source data, while *data validation* insures that the data make sense.

The verification method we are using is *visual review after data entry* to verify lake chemistry and streamflow data. Upon completion of data entry, all records are printed and compared with the original values from the hard copy by field or data technicians. The protocol lead will verify 10% of the records at the end of each field season. In addition, s/he will calculate summary statistics and identify duplicate or omitted records.

We use the following three validation methods:

1. *Data Entry Application Programming.* Certain components of data validation are built into data entry forms. This method is essentially part of the database design.

2. *Outlier Detection.* Data quality assurance procedures should not try to eliminate outliers. Extreme values naturally occur in many ecological phenomena; eliminating these values simply because they are extreme is equivalent to pretending the phenomenon is 'well-behaved' when it is not. Eliminating data contamination is perhaps a better way to explain this quality assurance goal. When an outlier is detected (via GIS, database, graphic, and statistical tools for ad-hoc queries and displays), the possibility of contamination will be evaluated and flagged.
3. *Other Exploratory Data Analyses.* Palmer and Landis (2002) suggest calculations for assessments of precision, bias, representativeness, completeness, and comparability may be applicable and, for certain types of measurements, evaluation of detection limits may also be warranted. Normal probability plots, Grubb's test, and simple and multiple linear regression techniques may also be used (Edwards 2000).

Fields for QA/QC documentation (e.g., metadata, water quality QA/QC result codes, QA/QC samples) are built into the database so QA/QC information "travels" with the data. This enables end-users to assess data quality in the context of their specific uses.

Please refer to SOP 4 (QAPP) for detailed verification and validation methods and roles and responsibilities.

4.3. Metadata and Archiving Procedures

Metadata are stored in the SIEN water database and Metadata Tools and Editor and are uploaded to the NPS Data Store. General project and station metadata should be entered into the database prior to field sampling and updated as needed.

The primary depository for paper records is the Inventory and Monitoring office at Ash Mountain, Sequoia National Park. The primary depository for electronic files is on the Sequoia and Kings Canyon National Parks network in the Inventory and Monitoring file directory structure. Electronic copies of documents, records, etc. are made available to staff stationed in other parks via the SIEN I&M Internet and Intranet sites and local park networks. Copies of paper documents are also stored as needed in satellite offices or scanned and stored on the network. Electronic records are backed-up in accordance with procedures outlined in the SIEN Data Management Plan (Cook and Lineback 2007).

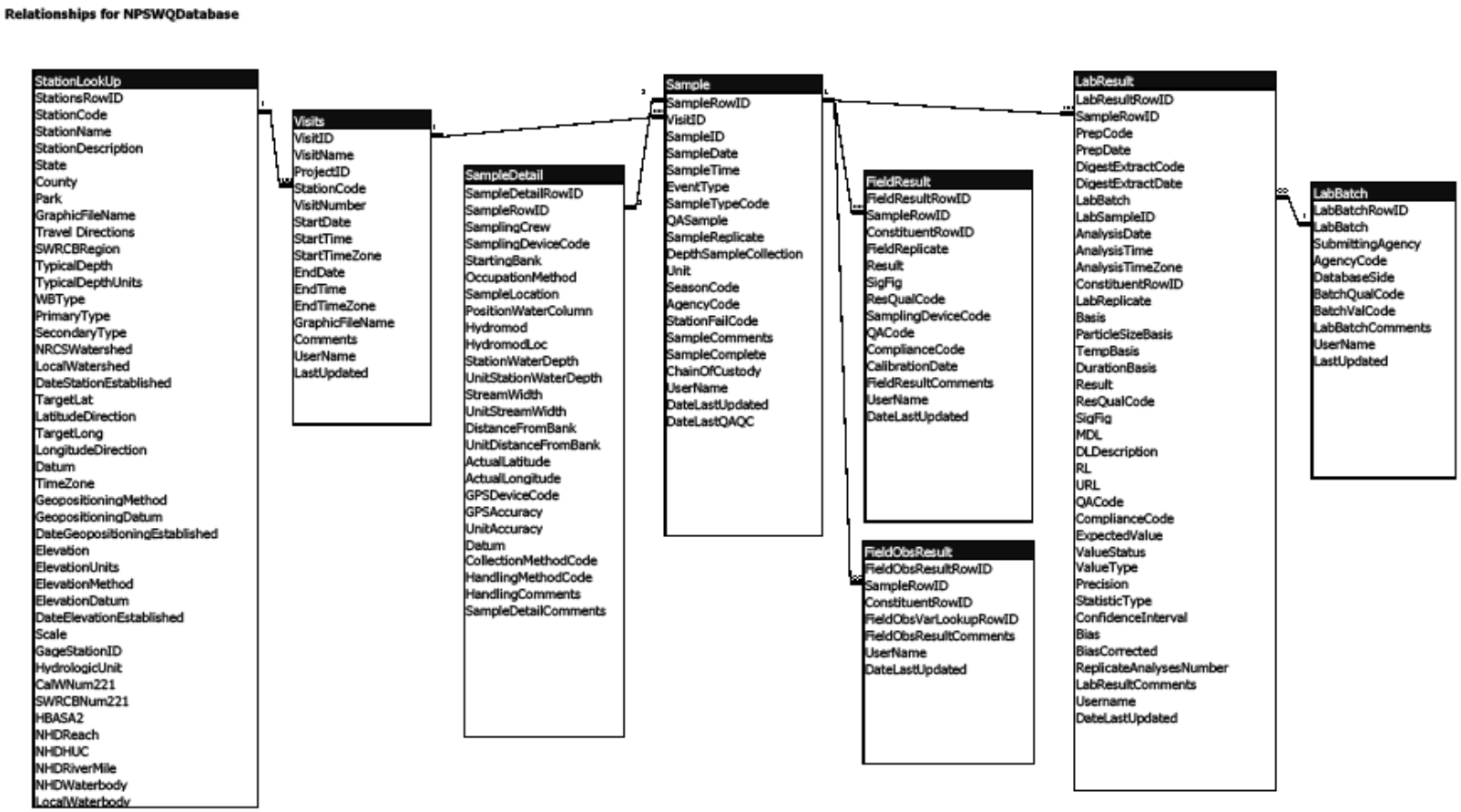


Figure 11. The entity relationships diagram illustrates the logical data model that is the basis for the Lake Monitoring project database, NPSWQdatabase.mdb. The database adheres to NPS NRDT version 3.2 standards. The tables, StationLookup, Visits, and Samples, correspond to the “mandatory tables” in the NRDT, tblLocations, tblEvents, and tblFieldData, respectively. StationLookup provides information about where the sampling was conducted. Visits holds information about the time and date of the sampling event, and Samples records information about the water samples. Each of these tables contains a primary key which prevents the creation of duplicate records. The table relationships are based on common fields within tables which may either be primary or foreign keys. The tables, SampleDetail, FieldResult, FieldObsResult, LabResult, and LabBatch store results and are shown here to provide context for the disposition of data collected in the field.

5. Data Analysis and Reporting

5.1. Data Analysis Approaches: Overview

Please refer to SOP 14 for a detailed description of the data analysis procedures.

Data analysis approaches were developed in concert with sample design development and power analysis simulations. The protocol lead is responsible for performing the following pre-determined data analyses: descriptive statistics, time series, threshold conditions, trend analysis, and streamflow for the index and extensive sites (**Table 9**). All analyses, with the potential exception of trend, are performed annually. Trend analyses are calculated at least every four years, once there is a minimum of five years of data. We anticipate these analyses will be supplemented by additional analyses as the program matures.

Index sites and extensive sites may not be quantitatively compared. However, these data are used to qualitatively inform each other and inform the interpretation and discussion of results.

Table 9. Data analysis procedures with corresponding monitoring objectives.

Inference Goal	Data Analysis Procedure	Monitoring Objective
Status	Descriptive statistics	– Characterize Sierra Nevada Network lakes – Quality control
Status	Threshold conditions	– Determine the proportion of Sierra Nevada Network lakes and index sites above threshold values for selected constituents
Trend	Time series plots	– Characterize Sierra Nevada Network lakes – Visually detect long-term trends in lake water chemistry for Sierra Nevada Network lakes – Visually detect intra- and inter-annual trends in lake water chemistry for Sierra Nevada Network index lakes – Visually detect intra- and inter-annual trends in lake level for Sierra Nevada Network lakes and index sites – Quality control
Trend	Mixed linear model	Statistically detect long-term trends in lake water chemistry for Sierra Nevada Network lakes
Trend	Seasonal Kendall test	Statistically detect intra- and inter-annual trends in lake water chemistry for Sierra Nevada Network index lakes

5.1.1. Index Sites

Status estimates for water chemistry at the index sites are computed using standard descriptive statistics and time series plots for each lake. Data may be analyzed by year and season.

Trend at individual index sites is computed using the Seasonal Kendall Test (SKT) modified to account for serial correlation ($\alpha = 0.10$) (Hirsch and Slack 1984). The SKT is commonly used to test for long-term water quality trends at single sampling stations. The Sen Slope method is used to estimate magnitude of the trends. Raw concentrations and flow-adjusted concentrations are both tested. Flow-adjusted concentrations are tested by modeling the variation due to discharge using a loess routine and conducting trend analyses on the residuals.

5.1.2. Extensive Sites

Status estimates for network-wide water chemistry are estimated using 1) descriptive statistics, 2) time series graphs, and 3) threshold conditions. In addition to providing a summary of the data, the descriptive statistics and time series graphs are used to verify and validate data for quality control purposes. Threshold conditions are computed by estimating the proportion of lakes that exceed a given threshold condition. Before proportions can be computed, the Network must identify the threshold conditions to which the data are compared. Status estimates are computed annually for index and extensive sites. Methods incorporate the GRTS neighborhood variance estimator (Stevens Jr. and Olsen 2003) and censored data approaches (Helsel 2005).

A mixed linear model is used to test for trend at the network scale (i.e., extensive sites) ($\alpha = 0.10$). van Leeuwen et al. (1996) and Piepho and Ogutu (2002) developed this method specifically to address trend estimation for correlated data. A mixed model allows some effects to be considered fixed and some to be considered random. 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 subjects (lakes) and over time (years).

We describe two estimates of trend using the mixed linear model approach: 1) Estimating annual trend on the original scale, and 2) Estimating multiplicative trend on the original scale. Mean annual trend estimates the proportion by which the population changes from year to year. Multiplicative trend estimates the net change over a specific span of time. Analyzing the annual trend may be helpful when comparing two trend estimates taken over differing spans of time. Net trend estimates are helpful in interpreting overall changes in the population over time.

Once a minimum of 5-10 years of data points are collected for an individual extensive site, the SKT may be used to estimate trend at the individual lakes. These results will provide a comparison to the population-level estimates and provide managers with additional site specific data.

5.2. Reporting

The program will consistently produce two types of reports, (1) annual summary reports and (2) comprehensive status and trend reports. Annual reports are produced once a year following the field season. Comprehensive reports are produced once every four years after a complete rotation of the panels. Comprehensive reports will provide an in-depth analysis of program results. In addition to the reports, the network will produce an annual lakes protocol resource brief. The protocol lead works with the network Program Manager to integrate reporting with the larger Vital Signs Monitoring Program reports and the Annual Administrative Report and Work Plan. Reports will be distributed to NPS-WRD, Network staff, Resource Chiefs, Science Committee, and Water Resources Work Group. Reports will also be made available to interested park staff and the public via the SIEN I&M web pages.

Annual reports will include the following information:

- Description of field season highlighting accomplishments
- Documentation of any deviations from the protocol, such as missed sites or samples
- Results from the current field season presented as follows: summary statistics, boxplots, GIS maps depicting concentrations at sampled sites, and proportion of lakes exceeding thresholds (refer to Table 9 and SOP 14).
- Status and trend estimates for complete data set (optional)
- Quality assurance and quality control analyses
- Discussion of results, which may include management implications
- Recommendations for future improvements.

Comprehensive reports will include the following information:

- Overview of the protocol status and major accomplishments
- In-depth status results for multiple years presented as summary statistics, box plots, GIS maps depicting concentrations at sampled sites, and proportion of lakes exceeding thresholds.
- In-depth trend analysis presented as time series plots, linear mixed model results (extensive sites), and Seasonal-Kendall test results (index sites) (Refer to Table 9 and SOP 14).
- In depth, quality assurance and quality control analysis and discussion.
- In-depth discussion of results, including management implications.
- Recommendations for future improvements.

Protocol implementation success will be thoroughly reviewed by Network staff, the Water Work Group, and Science Committee following the first field season. Thereafter, the program will be formally reviewed and evaluated every 4 years, starting in FY13.

6. Personnel Requirements and Training

The Lake Monitoring Protocol Lead is the Network Physical Scientist, supervised by the Network Program Manager. Field monitoring is conducted by GS-5 field technicians (biological, physical, or hydrological science technicians). Student Conservation Associates (SCAs), student hires, or other interns may also be considered.

Sampling is conducted primarily by two crews—a Yosemite based crew and Sequoia based crew. SIEN and park staff provide additional support. It is strongly recommended that the more remote annual panel sites are sampled using a crew of three because these sites require additional gear (i.e., heavier packs) in order to conduct the mid-lake sampling. Yosemite and Sequoia based crews can be combined or crews can be supplemented with SIEN or park staff.

Since field work is not full-time for a full season, technicians are shared with other I&M protocols and/or park projects. The Network Data/Logistics Technician provides logistical support for field sampling.

The Water Work Group, which was instrumental in the development of this protocol, will continue to be involved in advisory and support roles. The network will continue to consult and work with area experts from universities and federal and state agencies.

6.1. Roles and Responsibilities

Table 10 summarizes the personnel roles and corresponding responsibilities.

Table 10. Summary of roles and responsibilities.

Role	Responsibilities
Protocol Lead	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/ Program Manager 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 and data analysis procedures; upload data to NPS-WRD and CEDEN; provide GIS technical support.
Program Manager	Coordinate with protocol lead to meet I&M Program requirements (e.g., budget, reporting, education/outreach); integrate lake monitoring with Vital Signs program.
NPS-Water Resource Division	Review protocol; quality check data and upload to STORET; review annual and comprehensive reports; advise and provide technical assistance, as needed.
Logistics Tech	Provide logistical support for field sampling; order and track supplies; assist with pre-field season prep; shuttle samples from wilderness or trailheads to local park labs.
Crew Members	Prep for field sampling and wilderness travel; collect water samples and monitoring data following protocol and QAPP procedures; fully document procedures and anomalies; submit wilderness travel plans, ship samples, enter field data into database; perform end-of-season procedures; ensure safety of self and crew members.
Water Work Group	Provide technical guidance; coordinate with protocol lead on park-level logistics (e.g., wilderness MRA, research permitting, housing); assist in disseminating information as appropriate; provide review and evaluation.
Area Experts	Provide guidance and technical assistance as needed.

6.2. Qualifications and Training

Positions performing primary lake protocol roles (i.e., protocol lead and crew member) are required to meet the general qualifications for these roles (**Table 11**). The protocol lead should have experience with water chemistry and hydrologic sampling and analysis. Field technicians should be comfortable traveling and working in remote wilderness areas for extended periods of time. They must have a high level of physical fitness and be proficient swimmers.

Table 11. Qualifications for lake protocol roles.

Role	Qualifications
Protocol Lead	Meets basic requirements for a GS-11 Physical Scientist, Hydrologist, or Aquatic Ecologist. Education and/or experience in water quality required.
Crew Member	Meets basic requirements for a GS-5 bio/phys/hydro tech. Has strong wilderness travel, leadership, and field sampling experience. Water sampling education and/or experience desirable. Knowledge of the Sierra Nevada wilderness highly desirable. High level of physical fitness. Proficient swimmer.

Once hired, staff will receive detailed training on protocol methods, safety, and park specific training requirements. Detailed training requirements are in SOP 3.

7. Operational Requirements

7.1. Annual Workload and Field Schedule

The field sampling season is from approximately late June through early October (**Table 12**). Index sites are sampled once per month through the sampling season. Extensive sites are sampled late in the season--August and September. Field data entry is completed by the end of October. Data analysis and reporting occurs during winter months. Annual and comprehensive reports (produced every four years) are submitted to the Program Manager and NPS-WRD by the end of April.

Table 12. Annual schedule.

Event	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
End of season wrap-up												
Field data entry												
Hiring												
Lab results received												
Data analysis/reporting												
Pre-season field prep												
Index site sampling												
Extensive site sampling												

7.2. Facility and Equipment Requirements

Lake protocol personnel use office and laboratory space in both Sequoia (Ash Mountain) and Yosemite (El Portal and Tuolumne Meadows – Bug Camp). Parks provide office space at both Yosemite and Sequoia so crews may organize field gear, access email and phones, and complete data entry tasks. Staff also require use of the water laboratories located in both parks to process, store, and ship samples. The Physical Scientist's primary office is located in Sequoia; temporary office space is available when working in Yosemite. Facilities are provided by the parks.

Crews, since they will be primarily in the wilderness, 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, Tuolumne Meadows-Bug Camp, El Portal, or potentially other seasonal housing, if available. The White Mountain Research Station located in Bishop may be used for temporary East side housing.

Equipment inventory and checklists are located in field SOPs. A seasonal government vehicle or rental vehicle is provided to each of the field crews. Depending on the unique logistics of each field season, the vehicles may be shared with other projects.

7.3. Partnerships

We are collaborating with several partners, including the State of California Surface Water Ambient Monitoring Program, University of California (Santa Barbara and Riverside), USDA Forest Service, and the U.S. Geological Survey. Partnerships are not through formal CESU, inter-agency, or other agreements as they focus primarily on data and information sharing (i.e., no funds exchanged).

SIEN is working closely with the University of California to incorporate their long-term sampling at Emerald into our reporting as Emerald Lake is one of our two index sites. UC will provide Emerald Lake water chemistry data to SIEN and SEKI on an annual basis. SIEN will incorporate these results into their annual reports, although it is possible that Emerald Lake data may lag by one year compared to SIEN data due to differences between UC and SIEN in timing of reporting laboratory results. If UC ever lost funding for Emerald Lake sampling, SIEN would drop sampling at the Upper Granite index site and pick-up the sampling at Emerald Lake. This decision was made due to the importance of maintaining the highly valuable long-term data set at Emerald Lake.

SIEN also works closely with several other agencies. We will be uploading data to the State of California's water quality database through collaboration with SWAMP. We collaborated with the USDA Forest Service long-term lake monitoring program during the development phase. We greatly benefitted from their expertise and considered compatibility with their protocol when making decisions. However, due to differing objectives our data are not directly compatible and at this time we do not have any plans for joint analyses. Cooperators at the University of California and U.S. Geological Survey provided their expertise during protocol development.

7.4. Budget

The Lake Monitoring Protocol annual budget is $96,119 (**Table 13**) and includes permanent, term, and seasonal staff salaries, field supplies, vehicle, travel, and lab costs. Significant portions of the lake protocol resources are put towards data management, primarily time from the Physical Scientist, Data Manager, and crew members. As a consequence, approximately 39% of the total annual budget is dedicated to data management, analysis, and reporting. The annual cost to run the lakes project, minus salaries for permanent and term staff (who work on multiple projects and whose salaries are accounted for at the program level), is $38,909. Other costs that are absorbed at the program level include computers, meeting-related travel, office supplies, and administrative support. The general SIEN I&M program budget is outlined in the Sierra Nevada Network Vital Signs Monitoring Plan (Mutch et al. 2007). This project is supported by a combination of NPS-Water Resources Division (WRD) Water Quality Monitoring funds and Inventory and Monitoring Program Vital Signs funds.

Table 13. Lake Monitoring Protocol Annual Budget.

Program Item	Allotted Time	Estimated Expense	Data Management	
			% time	Cost ($)
Personnel*				
Physical Scientist (GS-11)	14 Pay Periods: prepare and conduct field season, data management, and analysis and reporting (annual, status & trends)	$43,750**	50	$21,875
Data Manager (GS-11)	2 Pay Periods	$7,060**	100	$7,060
Data/Logistics Tech (GS-7)	3 Pay Periods	$6,400**	25	$1,600
(4) Biotechs (GS-5)	4 Pay Periods	$25,933	25	$6,484
Operations, Equipment, and Lab Analyses				
Travel		$3,000	-	-
Supplies		$1,200	-	-
Vehicle		$2,400	-	-
Shipping		$300	-	-
Laboratory analyses		$6,076	-	-
Total		**$96,119**	**-**	**$37,018**

* Salary costs are based on 2011 wages. For field crews, this estimate includes regular pay plus Sunday differential and holiday pay, when applicable.

** Permanent or term staff

7.4.1. Park Contributions

Park and Network staff agree that 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 are currently unable to commit significant amounts of their time towards implementing the protocol. Park staff contributions will primarily be through participation in the Water Work Group, assisting with park-level logistical support as their time permits, and coordinating with Network staff to cost-share seasonal crews. Parks also provide significant resource support by providing office and laboratory facilities. The Work Group hopes that as the program continues to develop, park contributions will increase through time.

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Sierra Nevada Network Lake Monitoring Protocol

Appendix A. Evaluating Existing Water Resources Information in the Sierra Nevada Network for the Vital Signs Water Quality Monitoring Plan

Version 1.00, September 2005

Prepared by Andi Heard and John D. Stednick, Colorado State University

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Acknowledgements

The Sequoia and Kings Canyon History section was written and map templates were developed by Curtis Stumpf, Student Conservation Associate

.

Introduction

The Sierra Nevada Network (SIEN) of the U. S. National Park Service's Inventory and Monitoring Program is developing a Vital Signs monitoring plan. Water quality monitoring is one component of the plan. The initial steps in developing a comprehensive water quality monitoring plan include identifying, summarizing and evaluating existing water resources (National Park Service-Water Resources Division 2003).

The Sierra Nevada Network parks include Devils Postpile National Monument and Sequoia, Kings Canyon and Yosemite National Parks (Figure 1). Network parks are located on the western slope of the Pacific Crest in the Sierra Nevada Mountains and span seven major watersheds. These watersheds, from north to south, are the Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule and Kern. Runoff from these watersheds drains into the San Francisco Bay/ Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south. The Sierra Nevada parks protect a diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs and karst springs.

Water dynamics in the Sierra Nevada are a critical component of both the parks' ecosystems and the larger California water infrastructure. The region has a Mediterranean climate characterized by cool, wet winters and hot, dry summers. Most of the precipitation falls as snow in the mid and high elevations. The snowpack acts as a temporary reservoir, storing water that will be released during the warmer and drier months. Peak runoff typically occurs in May or June (Figure 2). Water is captured and stored for summer use in a series of reservoirs that line the Sierra foothills.

Water is the most valuable resource commodity in the Sierra Nevada. Sierra Nevada ecosystems produce approximately 2.2 billion dollars worth of ecosystem based revenues annually and water accounts for more than 60% of these revenues (SNEP 1996). Primary uses include irrigated agriculture, domestic water supplies, hydroelectric power, recreation and tourism. Water resources and associated aquatic and riparian habitats also have high ecological value. Approximately 21% of the vertebrates and 17% of plants in the Sierra Nevada are associated with riparian habitats (SNEP 1996).

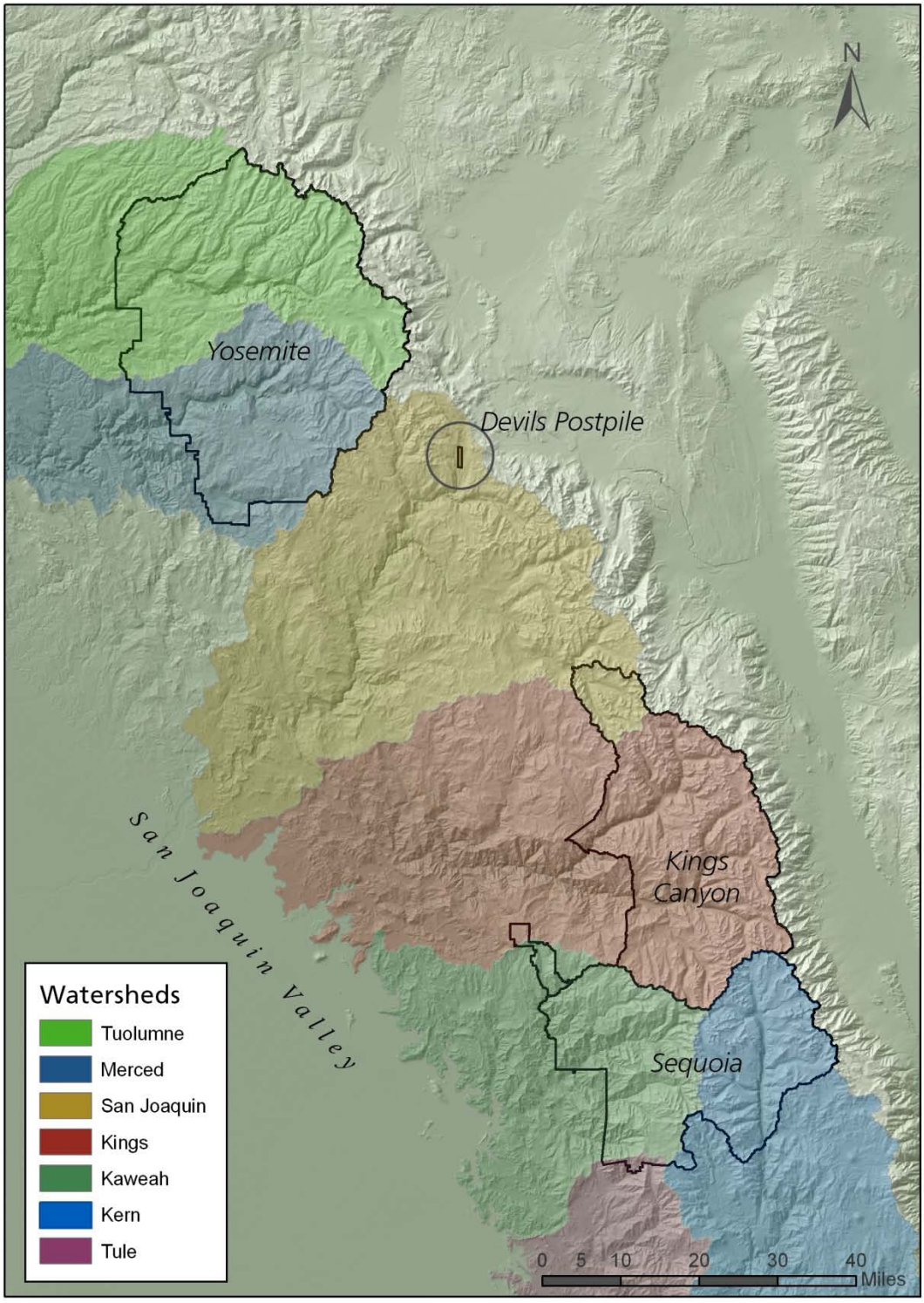


Figure APP A.1. Sierra Nevada Network parks and watersheds.

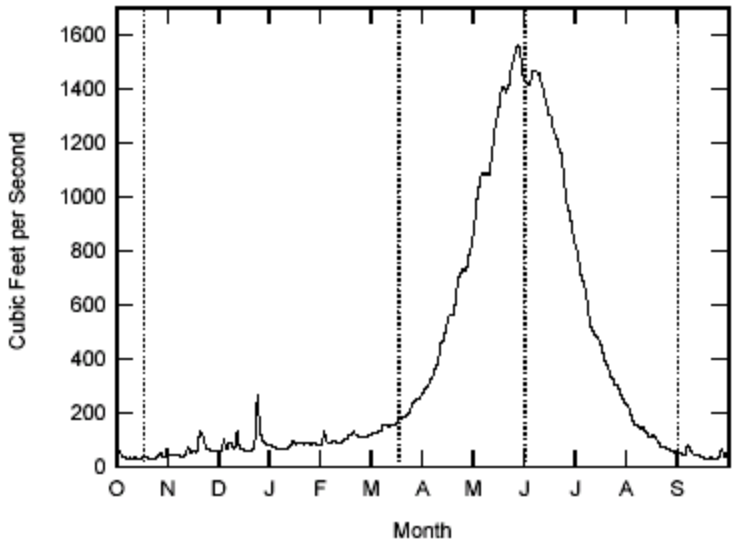


Figure APP A.2. Representative mean annual hydrograph from the Merced River at Happy Isles in Yosemite National Park. National Park Service- Water Resources Division plotted the hydrograph using a 72 year record (National Park Service 1998). Vertical lines divide the hydrograph into four seasons.

Purpose and Scope

The purpose of this report is to evaluate existing water quality information, including data sets, publications and current research and monitoring projects, for water resources in the Sierra Nevada Network parks. The network is developing a vital signs water quality monitoring plan using a three phase approach (Fancy and Gross 2004). Phase I entails synthesizing existing information, identifying key management issues, and developing conceptual models to support planning efforts. Phase II entails prioritizing vital signs indicators. Phase III is developing the monitoring design.

This report provides background information needed to develop a long-term monitoring plan. There are six objectives:

1. Describe the water resources in the parks.
2. Identify historic water resources research and monitoring projects. Document existing data sets.
3. Identify current water resources research and monitoring projects.
4. Identify local water resource issues including 303(d) waters, Wild and Scenic Rivers, and issues identified in 305(b) reports and by local managers.
5. Identify current and emerging threats to aquatic ecosystems.
6. Identify long-term data sets and analyze for temporal trends.

Current and Emerging Aquatic Ecosystem Threats

The State Water Resources Control Board and nine Regional Water Quality Control Boards, under the Porter-Cologne Water Quality Control Act, are responsible for the protection and enhancement of California's water resources. Each Regional Water Quality Control Board adopts Basin Plans, which contain beneficial use designations, water quality objectives and implementation programs. Sierra Nevada network parks fall under the jurisdiction of the Central Valley Regional Water Quality Control Board and have waters contained in both the Sacramento-San Joaquin and Tulare Lake Basins. Under sections 305(b) and 303(d) of the Clean Water Act, California is required to assess the overall health of the state's waters and identify waters that are not attaining water quality standards. The State must compile water quality limited waters in a 303(d) list and initiate the process to bring listed waters back into compliance. The Sierra Nevada Network parks do not contain any 303(d) listed waters (State Water Resources Control Board 2002). The State also has the authority to designate waters as Outstanding Natural Resource Waters. This designation is the highest level of protection that may be afforded to a water body. The Sierra Nevada Network parks do not have any Outstanding Natural Resource Waters; however, national park waters are strong candidates for this designation

The Sierra Nevada Ecosystem Project (SNEP) concluded that aquatic and riparian systems are the most altered and disturbed habitats in the Sierra Nevada (SNEP 1996). The primary reasons for the deterioration are changes in flow regimes, disturbances from land use practices, and the introduction of non-native organisms. Despite the impacts on aquatic and riparian habitats, basic hydrologic processes and water quality remain in relatively good condition (Kattelmann 1996). Hydrologic modifications and degraded water quality are of greatest concern in foothill reservoirs and downstream areas in the Central Valley.

The Sierra Nevada national parks protect many lakes, streams and rivers with unaltered flow regimes and good to high water quality. However, the parks water resources are subjected to natural and anthropogenic disturbances that have the potential to modify the systems and degrade water resources. Some of these stressors are localized, threatening relatively small areas or specific water bodies, and may include visitor use impacts, small dams and diversions, or mines. Local stressors, which vary between parks, are discussed in the individual park sections of this report. Water resources in the Sierra Nevada Network parks are also affected by systemic stressors, which occur at regional and ecosystem scales. Managers and researchers, using the findings from the Sierra Nevada Ecosystem Project (SNEP 1996), identified five important systemic stressors to Sierra Nevada systems: 1) loss of pre-Euroamerican fire regimes, 2) non-native invasive species, 3) air pollution, 4) habitat fragmentation, and 5) rapid anthropogenic climatic change (Sequoia and Kings Canyon National Parks 1999). The stressors with the greatest impact on the parks' flow regimes and water quality are altered fire regimes, air pollution and climate change.

Over 100 years of fire suppression polices have altered fire regimes in the Sierra Nevada Network parks. In general, fire frequencies have decreased and the potential for higher severity wildfires has increased (Swetnam 1993, Caprio and Lineback 1997). Potential effects on water resources from a lack of fire are reduced stream flows, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires have the

potential to impair water resources. Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003). Deposition of ash particles in the surrounding landscape may contribute to increasing nutrient inputs to oligotrophic waters (Spencer et al. 2003).

Since 1968 and 1970, Sequoia and Kings Canyon, and Yosemite National Parks have used fire extensively as a tool to reduce fuel loads and restore the natural processes of fire to park ecosystems (Caprio 1999). Although the parks' fire management programs made significant progress in the last 35 years, altered fire regimes are still considered one of the largest threats to the parks' ecosystems (Sequoia and Kings Canyon National Parks 1999). Water quality research in the parks has focused on the effects of prescribed burning on hydrology, stream chemistry and nutrient cycles. Increases in stream flows and solute concentrations were detected following prescribed fires in headwater streams of Sequoia National Park (Williams and Melack 1997b, Heard 2005). However, solute concentrations were still well below levels that would threaten aquatic ecosystems. Long-term monitoring with repeated prescribed burning are needed to determine if these increases were within the natural range of variability. Effects of prescribed burning on stream flows or water quality have not been detected at the landscape scale (Heard 2005). The effects of a large, high-severity wildfire are likely to be more pronounced and detectable at larger scales.

The western slope of the central and southern Sierra Nevada is impacted by some of the worst air pollution in the United States (Cahill et al. 1996). Contaminants and nutrients, produced from agricultural, urban, and industrial sources in the San Francisco Bay Area and the Central Valley, are transported by air currents into the Sierra Nevada where they are deposited as wet or dry deposition. High elevation lakes and streams in the Sierra Nevada are oligotrophic, have a low buffering capacity, and sensitive to change from atmospheric deposition of nutrients, toxic substances, and acids. Increased nitrogen and phosphorous inputs are contributing to eutrophication, changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes (Goldman et al. 1993, Sickman et al. 2003). Pesticides from the adjacent Central Valley (LeNoir et al. 1999) and global sources (National Park Service Air Resources Division 2003) have been detected in Sierra Nevada streams and lakes at all elevations. The extent of the effects on aquatic ecosystems is largely unknown; however, current research suggests that pesticides may be a threat to aquatic species, including declining amphibian populations (Sparling et al. 2001, Davidson and Shaffer 2002). At a recent water resources scoping meeting in Sequoia and Kings Canyon, participants identified atmospheric transport of contaminants into the parks as one of the top threats to aquatic resources. Episodic acidification from acid neutralizing capacity (ANC) depression during snowmelt and increased nitrate deposition is also a potential threat, although Sierra Nevada waters appear to be fairly resilient and able to buffer current and potentially increased inputs (Leydecker et al. 1999).

Global temperatures have increased over the last century. Climatologists and atmospheric scientists have attributed at least part of this increase to anthropogenic inputs of greenhouse gases (Houghton et al. 1996). Greenhouse gas concentrations and global temperatures are expected to continue to rise. It is predicted that even a modest temperature increase (2.5 °C) will significantly alter hydrologic processes. The most pronounced changes are earlier snowmelt runoff, reduced summer base flows and soil moisture, (Dettinger et al. 2004), a lower snowpack

volume at mid-elevations (Knowles and Cayan 2001), and increased flooding, including rain-on-snow events. The water infrastructure in California was built under the assumption that the Sierra Nevada snowpack would act as a temporary reservoir for the State's water and release it slowly during the spring and early summer months. Changes in precipitation type and timing will result in longer and drier summers with less water available during the months it is most needed. Water quality would be threatened by increased flooding and erosion and lower summer flows. Prolonged summer drought would increase the potential for high severity wildfires, further threatening water quality.

Methods and Approach

We used the following approach to evaluate existing water resources information for the network parks: 1) perform an extensive literature search and compilation, 2) identify and retrieve existing data sets, 3) identify long-term records for trend analyses, and 4) use the existing information to identify specific water resource issues and current and emerging threats to aquatic ecosystems.

Since water resources information is a broad topic that spans multiple disciplines, we established guidelines to focus the literature search and data retrieval efforts on water quantity and water quality information in the network parks. The guidelines were as follows:

- Include references and data sets for air, geological and biological resources research and monitoring projects only if stream flow or water quality parameters were also measured.
- Include a list with brief descriptions of active meteorological and air quality monitoring sites.
- Do not include fish, macroinvertebrates, and aquatic plants unless 1) water quality or quantity issues were also addressed (i.e. temperature, nutrients), 2) the water body was somehow altered (i.e. dams and holding ponds), or 3) bio-monitoring as an indicator of water quality was specifically addressed.

Sequoia, Kings Canyon, and Yosemite National Park boundaries include most of the headwater streams for the park watersheds. Therefore, we focused on information within the park boundaries. Devils Postpile National Monument does not include the headwaters of the Middle Fork of the San Joaquin River; upstream waterbodies are managed by the Inyo National Forest. For this park, we captured information for waterbodies both within the monument and upstream. We included downstream information for all the parks if it was located near the park boundary, was of especially high value, or was the best available information for the watershed.

Literature Review

We conducted an extensive literature search for the Sierra Nevada Network parks by querying existing databases, websites, park managers and researchers. The results are stored in an EndNote 5.0 library titled *SIEN Water* and include references from the following databases: NRBIB, USGS/ Sequoia and Kings Canyon Field Station Procite database, ISI Web of Science, Water Resources Abstracts (Cambridge Scientific Abstracts), GeoRef (Cambridge Scientific Abstracts), and Ecology Abstracts (Cambridge Scientific Abstracts). Additional sources include the Environmental Protection Agency and State of California websites, I&M project database and results from water quality scoping meetings.

Data Retrieval

The Water Resources Division of the National Park Service did a thorough search for existing water quality data in all four network parks during the 1990s and results are available in the Baseline Water Quality Data Inventory and Analysis reports (National Park Service 1994, National Park Service 1997, National Park Service 1998). As part of this effort, they organized all the raw data in Visual dBase databases. The Water Resource Division also summarized the presence/absence and distribution of Servicewide Inventory and Monitoring Program “Level 1” water quality parameter groups. Four of these parameters (temperature, specific conductance, pH

and dissolved oxygen) are considered 'core parameters' and will be monitored servicewide (National Park Service- Freshwater Workgroup Subcommittee 2002) (Table APP A.1). Gaging station locations with available metadata were identified. However, flow data associated with these sites were not included; only flow data associated with water quality samples were reported. The Baseline Water Quality Reports and associated databases were used as a starting point for identifying historic water data sets.

Table APP A.1. Level 1 water quality parameter groups. Bolded parameters are the core parameters that all the networks are required to monitor.

- **Temperature**
- **pH**
- **Conductivity**
- **Dissolved Oxygen**
- Alkalinity
- Flow
- Bacteria
- Toxic Elements
- Clarity/Turbidity
- Nitrate/Nitrogen
- Phosphate/Phosphorous
- Chlorophyll
- Sulfates

We then conducted extensive searches in each park to identify and retrieve additional water quantity and water quality data sets. Searches included national water quality databases, local park databases, computer files, the *SIEN Water* digital library, and the results of water quality scoping meetings. We also contacted park managers, outside researchers and state agencies for additional information and data sets.

We queried national databases that included STORET Legacy and Modernized STORET, maintained by the Environmental Protection Agency (Environmental Protection Agency 2003), and the National Water Information System database (NWIS Web), maintained by the U. S. Geological Survey (U. S. Geological Survey 2003). The Baseline Water Quality Reports captured the STORET Legacy data through the period of record identified in each report. As a result, STORET queries were restricted to post Baseline Water Quality report dates. STORET Legacy and Modernized STORET were queried by Hydrologic Unit Code (HUC), county and latitude and longitude polygons. NWIS Web was queried by HUC and latitude and longitude polygons. All data including the Baseline Water Quality Reports and NWIS data sets are in MS Access databases.

Concurrently, an interagency agreement with the USGS-WRD was initiated to develop and populate a water quality geodatabase for the Sierra Nevada Network. USGS uploaded STORET and NWIS data to the SIEN geodatabase. Additional data compiled as part of this report was also uploaded. The Sierra Nevada Network water quality geodatabase contains existing water quality data in one MS Access database.

Trend Analyses

We selected long-term data sets that met specific criteria for temporal trend analyses. The data sets had to have a period of record greater than five years and a sample size greater than 50.

Protocols, metadata and QA/QC reports needed to be well documented. Time series and box plots were used to further evaluate the quality of data and to identify any erroneous data points.

Stream chemistry data were tested for temporal trends using the Seasonal Kendall Test modified to account for serial correlation ($\alpha = 0.05$) (Hirsch and Slack 1984). The Sen Slope method was used to estimate magnitude of the trends. Three to four seasons were defined for each site based on the hydrology and seasonal variability of solute concentrations. Selected seasons had to meet the requirement that a minimum of 50% of the possible comparisons needed to be made for 80% of the seasons. Raw and flow-adjusted concentrations were both tested. Flow-adjusted concentrations were tested by modeling the variation due to discharge using a loess routine and conducting trend analyses on the residuals. Statistical analyses were performed using S-Plus 6.1 with the USGS S-ESTREND library (Slack et al. 2003).

Devils Postpile National Monument

Devils Postpile National Monument encompasses 320 hectares in the upper Middle Fork of the San Joaquin watershed in the central Sierra Nevada. The monument was established in 1911 to protect two prominent geologic features, the Devils Postpile formation and Rainbow Falls (Huber and Eckhardt 2002). The Postpile is a mass of 18 m high polygonal basalt columns that were formed from a cooling lava flow over 100,000 years ago. Rainbow Falls is a 31 m water fall along the Middle Fork of the San Joaquin River. Elevations in the monument range from 2,200 to 2,500 meters. The vegetation type is montane forest dominated by red fir (A*bies magnifica*) and lodgepole pine (*Pinus contorta*). Three-quarters of the monument lands are included in the Ansel Adams Wilderness and surrounding lands are managed by the Inyo National Forest, under the USDA Forest Service.

Water Resources

Devils Postpile National Monument is located entirely in the upper Middle Fork of the San Joaquin watershed. It is the only park in the network where the headwater streams are not included in the park boundary. The headwaters of the Middle Fork of the San Joaquin begin 14.1 km upstream of the monument at Thousand Island Lake. The watershed area above the monument is managed by Inyo National Forest.

The monument has 5.9 km of rivers and streams including the Middle Fork of the San Joaquin River, and short sections of King Creek and an un-named creek, both tributaries to the San Joaquin (Figure APP A.3). The Middle Fork of the San Joaquin River travels the length of the monument and plunges 31 m over Rainbow Falls before crossing the southern boundary. Carbonated mineral springs are located in Soda Springs Meadow, near the ranger station and campground facilities.

There are no impoundments or diversions within the monument boundary. The public water supply is pumped from a well near the Middle Fork of the San Joaquin (Appendix 1). Small water diversions or active wells exist upstream near U. S. Forest Service campgrounds.

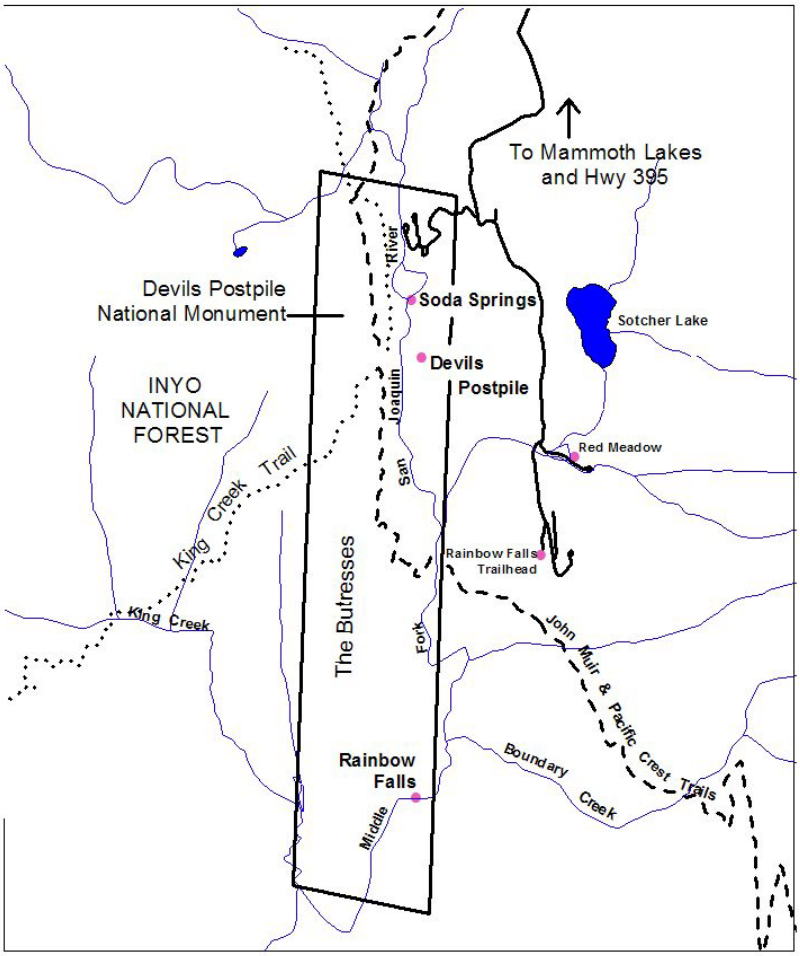


Figure APP A.3. Lakes, rivers, and streams in and near Devils Postpile National Monument.

Hydrologic and Water Quality Data Sets

Water Quantity

Water quantity data for Devils Postpile National Monument are limited. Historically, stream flow was not continuously monitored within or near the monument boundary (Rowan et al. 1996, National Park Service 1998). The nearest historic gaging station was located on the Middle Fork of the San Joaquin River at Millers Crossing, approximately 15 km downstream from the boundary. Flow data from 1921-1991 are available from NWIS Web (Appendix 2).

The first collection of stream flow data in the monument began in 1994. A staff gage was installed along the Middle Fork of the San Joaquin River near the Devils Postpile formation and

a stage-discharge relationship developed. National Park Service rangers recorded staff gage measurements during routine patrols (Rowan et al. 1996).

Queries in NWIS Web also identified one well just outside the northeast corner of the park boundary. No monitoring data were available through the NWIS Web site.

Water Quality

Existing water quality data for Devils Postpile and all upstream waterbodies are located in four main data sets: the Baseline Water Quality Report, STORET Legacy, Fishery and Riparian Resources of Devils Postpile National Monument and Surrounding Waters report, and the Non-point Source Water Quality Monitoring, Inyo National Forest, 1975 report (Table APP A.2).

Table APP A.2. Historical water quality data sets for Devils Postpile National Monument and upstream waters.

Data Set	Agency	Beg. Year	End Year	No. Records
Horizon Report	NPS	1980	1997	358
STORET: Upper San Joaquin	EPA	1980	1985	38
Fishery and Riparion Resources Assessment	Fish and Game	1994	199	
Water quality monitoring, Inyo National Forest	UCLA/UCD	1975	1975	

The Baseline Water Quality Report includes 358 water quality records from 1980 -1997. Sixty-seven of these records are from samples taken within the monument boundary. The remaining 291 records are within the larger study area, which was defined as 3 miles upstream and 1 mile downstream of the park boundary. Water quality records exist for 9 of the 13 Inventory and Monitoring Level 1 parameters. Data do not exist for the dissolved oxygen, flow, chlorophyll, and bacteria parameter groups. The data captured in the Baseline Water Quality Reports are from 19 different sites and are associated with four specific monitoring projects.

- California Department of Fish and Game monitored eight of the sites as part of a statewide monitoring program to assess fish populations. They measured pH, conductivity, temperature, and alkalinity during the 1980s and 1990s.
- The Environmental Protection Agency measured 26 water quality parameters in Iceburg Lake and Nydiver Lakes (middle) as part of the 1985 Western Lake Survey. The project objectives were to 1) identify lakes in potentially sensitive areas that were acidic, 2) identify lakes in potentially sensitive areas that had low acid neutralizing capacity (ANC), and 3) determine the chemical characteristics of lake populations (Blick et al. 1987a).
- The Department of Energy sampled four sites during August of 1980 as part of the National Uranium Resource Evaluation (U. S. Geological Survey 2001). This was a national project initiated in 1973 to identify uranium resources in the United States. They sampled 15-24 water quality parameters, including metal concentrations.
- Four springs were monitored in the 1980’s and 1990’s for multiple water quality parameters. Associated projects and monitoring agencies are not known.

STORET Legacy contains water quality data for two additional sites in the upper San Joaquin that were not captured in the Baseline Water Quality Report. These sites were part of the

National Uranium Resource Evaluation and are located upstream of the monument and the Baseline Water Quality Report study area. There are 38 additional records associated with these sites. Modernized STORET does not contain any records for the upper watershed.

The Fishery and Riparian Resources of Devils Postpile National Monument and Surrounding Waters report (Rowan et al. 1996) summarizes and augments existing fishery and riparian information for the Devils Postpile area. This survey led to the designation of the Middle Fork of the San Joaquin River within Devils Postpile as a Wild Trout Water by the California Department of Fish and Game. As part of this project, researchers installed the Middle Fork of the San Joaquin River staff gage and collected additional water quality data for 12 sites. Parameters included stream flow, water temperature (hourly), pH, sediment observations and substrate quality. Researchers measured aquatic macroinvertebrate taxon composition and diversity to assess current and future impacts from anthropogenic disturbances. One component of this study was to assess benthic macroinvertebrate communities. They collected samples using The California Stream Bioassessment Procedure, a biological monitoring tool used to detect change in aquatic systems (Schroeter and Harrington 1995).

The University of California, Davis and the University of California, Los Angeles measured water quality parameters for 34 waterbodies on the Inyo National Forest in 1975 (Baas et al. 1976). The focus of the study was to assess the impact of non-point sources on water quality in wilderness and recreational areas. Four of the study lakes (Shadow, Ediza, Garnet, and Thousand Island) are located in the upper San Joaquin watershed.

Water Resources Monitoring

In the summer of 2004, Scripps Institute of Oceanography installed a gaging station on the Middle Fork of the San Joaquin River near the pump house. Scripps is currently monitoring stream flows at 39 sites in the upper Merced and Tuolumne watersheds as part of a hydroclimate monitoring network (DiLeo et al. 2003). Installation of the Devils Postpile gaging station is an expansion of this program into the upper San Joaquin watershed.

The next nearest gaging station is downstream from the monument on the San Joaquin River below the Mammoth Pool Reservoir.

Currently, there are no water quality research and monitoring projects in the monument.

Local Water Resource Status and Issues

In the Baseline Water Quality Report data were compared to EPA water quality criteria and instantaneous concentration values selected by the Water Resources Division (National Park Service 1998). Alkalinity exceeded the criterion (100% exceeding) more than any other constituent. Concentrations were below the threshold used by the NPS Air Resources Division to determine potential sensitivity to acid deposition. Consistent with the alkalinity findings, pH values also exceeded (50% exceeding) the lower limit criterion. Dissolved arsenic exceeded (25%) the freshwater acute criterion. The following constituents exceeded the EPA drinking water criteria: total chloride (14%), fluoride (33%), and arsenic (50%). The Water Resources Division had difficulty evaluating current water quality in the monument due to the absence of long-term monitoring data and dissolved oxygen and bacteria data. However, using the limited available data they concluded that water quality generally appears to be good.

The Central Valley Regional Water Quality Control Board considers water quality in Sierra Nevada headwater streams to be good to excellent and suitable for all beneficial uses (California Regional Water Quality Control Board Central Valley Region 1998). Devils Postpile National Monument and the upstream watershed do not contain any 303(d) listed waters (State Water Resources Control Board 2002).

The town of Mammoth Lakes is proposing to pump groundwater from the San Joaquin Ridge. This action could reduce annual flows in the Middle Fork of the San Joaquin River in Devils Postpile, although impacts are unknown (National Park Service 2002a).

Visitor use impacts in the monument and upstream at U. S. Forest Service campgrounds are a potential threat to water quantity and quality. Specific concerns identified during scoping meetings and by park managers include upstream diversions, stream bottom litter, human waste, stream bank degradation and increased runoff where vegetation is sparse (National Park Service 2003b).

Managers identified arsenic, from volcanic sources, as a potential threat to the Devils Postpile drinking water supply. Dissolved arsenic concentrations in park waters have exceeded EPA freshwater acute and drinking water criteria (National Park Service 1998).

Abandoned mines are located throughout the upper San Joaquin watershed. Managers identified acid rock drainage as a potential threat to water quality in Devils Postpile.

Although quantitative fire history studies were just initiated in the Devils Postpile area, managers believe that fire suppression policies have altered fire regimes in the monument forests (Caprio 2004). In 1992, a moderate to high severity wildfire, The Rainbow Fire, burned through 85% of the monument. Ecological effects following this fire were more pronounced and outside the natural range of variability, especially at the lower elevations (Caprio 2004). Effects on water resources appeared to be minimal, but post-fire monitoring of pH, substrate and macroinvertebrates was limited to one year (1994) (Rowan et al. 1996). Long-term effects and effects on other water quality parameters including nutrients and temperature are not known. Due to the high severity of the fire and losses in seed banks, recovery of the vegetation is slow and the long-term effects on stream flow and water quality are uncertain.

Sequoia and Kings Canyon National Parks

Sequoia and Kings Canyon National Parks encompass 350,169 ha in the southern Sierra Nevada. Eighty-four percent of the parks are designated wilderness. The parks are primarily bordered by Inyo National Forest on the east, Sequoia National Forest on the south, Giant Sequoia National Monument on the south and west and Sierra National Forest on the west and north. Smaller sections of the boundaries are also shared with the Bureau of Land Management and private landowners. Elevations in the park range from 418-4417 m and include a variety of vegetation types that range from chaparral and oak-woodland in the lower elevations to the higher elevation sub-alpine and alpine vegetation. The giant sequoia mixed conifer forests are located in the mid-elevations, 1650-2000 m, along the western slope.

History

Much like the rest of the West, the Southern Sierra Nevada was first valued for its natural resources, and activities including logging, grazing, and mining. After several years of resource extraction and exploration of the area, word of the spectacular beauty of the landscape and the giant sequoia groves spread across California. As tourism and recreation increased, concern began to be voiced regarding protection. Editorials in local newspapers and talk in San Francisco began to fuel a growing conservation ethic centered on preservation of these mountain landscapes and resources (Strong 1996).

Also during this time, people in the valley dependent on agriculture, were becoming concerned with deterioration of the mountain ecosystem. They especially began to notice the impacts of logging on water resources, which were of vital interest for irrigation (Dilsaver and Tweed 1991). Led by well-known journalist George W. Stewart, and politician John F. Miller, a campaign for protection of the southern Sierra Nevada. Eventually, "…. a bill to provide for setting apart a certain tract of land in the State of California as a public park," was proposed (Dilsaver and Tweed 1991). On September 25, 1890, President Benjamin Harrison signed the bill enabling the protection of two townships and four sections be set aside for "enjoyment of the people," and Sequoia became the second national park to be established (Strong 1996).

One week after creation of Sequoia was finalized, a second Act was passed, increasing the size of the park by three times. There is speculation that the Southern Pacific Railroad, which acknowledged that the National Park would increase tourism and their own business, wanted further protection of water resources of the San Joaquin Valley (Strong 1996).

Kings Canyon National Park was championed as an addition to Sequoia for many years by the Sierra Club, conservationists, and others. Under control of the Forest Service, there was a conflict of interest between park advocates, and those wanting to augment the water resources with dams for hydroelectric power (Strong 1996). The Kings River remained a valuable resource for valley residents for irrigation, while the city of Los Angeles wanted to harness the potential for hydropower, and others, including the Forest Service, saw the area as a possible tourism destination (Dilsaver and Tweed 1991)

In 1935, the Secretary of the Interior, Harold Ickes, proposed a bill to establish Kings Canyon National Park. He designated the park as one of backcountry and wilderness uses, intending to maintain the park in its natural state. Though this proposal was met with a great deal of initial

opposition, Ickes promoted the potential of a tourist magnet, and promised valley residents the necessary water allocation. Appeasing the dissidents of the powerful Kings River Water Association with water projects outside of the park, and with the withdrawal of Los Angeles's need for water due to the recently completed Boulder Dam on the Colorado River, Ickes was able to create legislation for the creation of the park. On March 4, 1940, Kings Canyon National Park was established when Franklin D Roosevelt signed the bill, adding 450,000 acres of the Sierras to the National Park Service (Strong 1996).

Water Resources

Sequoia and Kings Canyon National Parks consist of four major watersheds: the Kaweah, Kern, Kings, and San Joaquin. A very small portion of the park is also located in the upper Tule watershed. These watersheds all drain to the west of the Pacific Crest and into California's Central Valley.

Mean annual precipitation is 92 cm at the middle elevations (National Atmospheric Deposition Program (NRSP-3)/National Trends Network 2004). Most of the precipitation falls during the winter months (Figure APP A.4). The dominant precipitation types are rain at the low elevations and snow at the middle and high elevations.

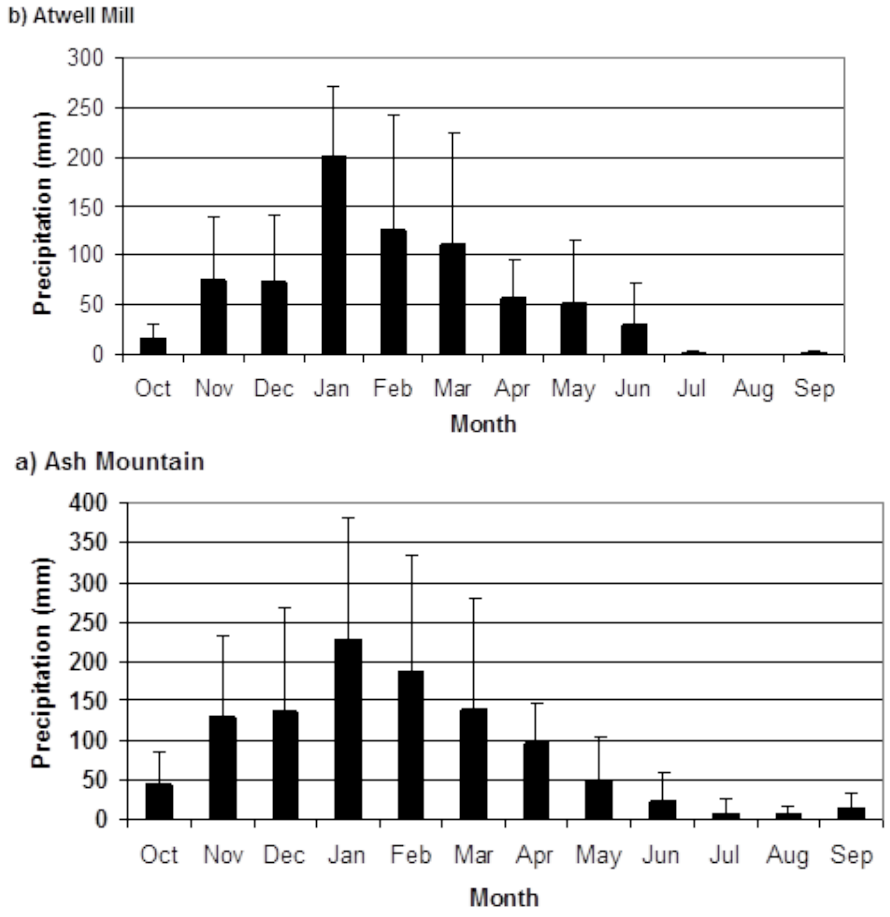


Figure APP A.4. Mean monthly precipitation at a) low (Ash Mountain: 535 m) and b) middle (Atwell Mill: 1,975 m) elevations (Sequoia and Kings Canyon National Parks 2002a, U. S. Army Corps of Engineers 2002).

There are approximately 2,650 lakes and ponds and thousands of kilometers of streams and rivers within the parks' boundaries (Sequoia and Kings Canyon National Parks 2002b) (Figure APP A.5). Sequoia and Kings Canyon are also known for their unique cave resources that include underground streams and lakes and karst springs. The parks contain more than 200 caves formed in mesozoic limestone. Additional water resources include cold and hot springs, wet meadows, seeps and ephemeral pools.

Sequoia and Kings Canyon National Parks contain three Wild and Scenic River segments, which include the Middle and South Forks of the Kings River (98.5 km) and the North Fork of the Kern River (46.5 km). Under the Wild and Scenic Rivers Act, the park is required to develop a Comprehensive Management Plan to ensure protection of the river's free flowing status and to protect and enhance the river corridor's outstandingly remarkable values (ORVs). To date, a draft Wild and Scenic River Plan and Study has been developed and incorporated into the draft General Management Plan. After these plans are complete, the park is required to develop user carrying capacities with associated monitoring strategies. Five other rivers within the park, the South Fork of the San Joaquin, and the Marble, Middle, East and South Forks of the Kaweah, were determined to be eligible for the Wild and Scenic River designation (National Park Service 2002b). Proposals to designate these rivers are still in the draft phase.

There are four large impoundments within the park boundary. All four were built on existing lakes in the upper East Fork of the Kaweah in the early 1900s and are currently operated by Southern California Edison. Numerous small impoundments also exist in small creeks primarily used for water supplies. There are at least 18 water diversions and seven wells within the park boundary. Most are small diversions for local water supplies, particularly in the Mineral King area. There are likely additional diversions and wells within the park associated with private in-holdings. Southern California Edison holds the water rights for the two largest diversions, located on the Middle Fork and Marble Fork of the Kaweah near Potwisha Campground.

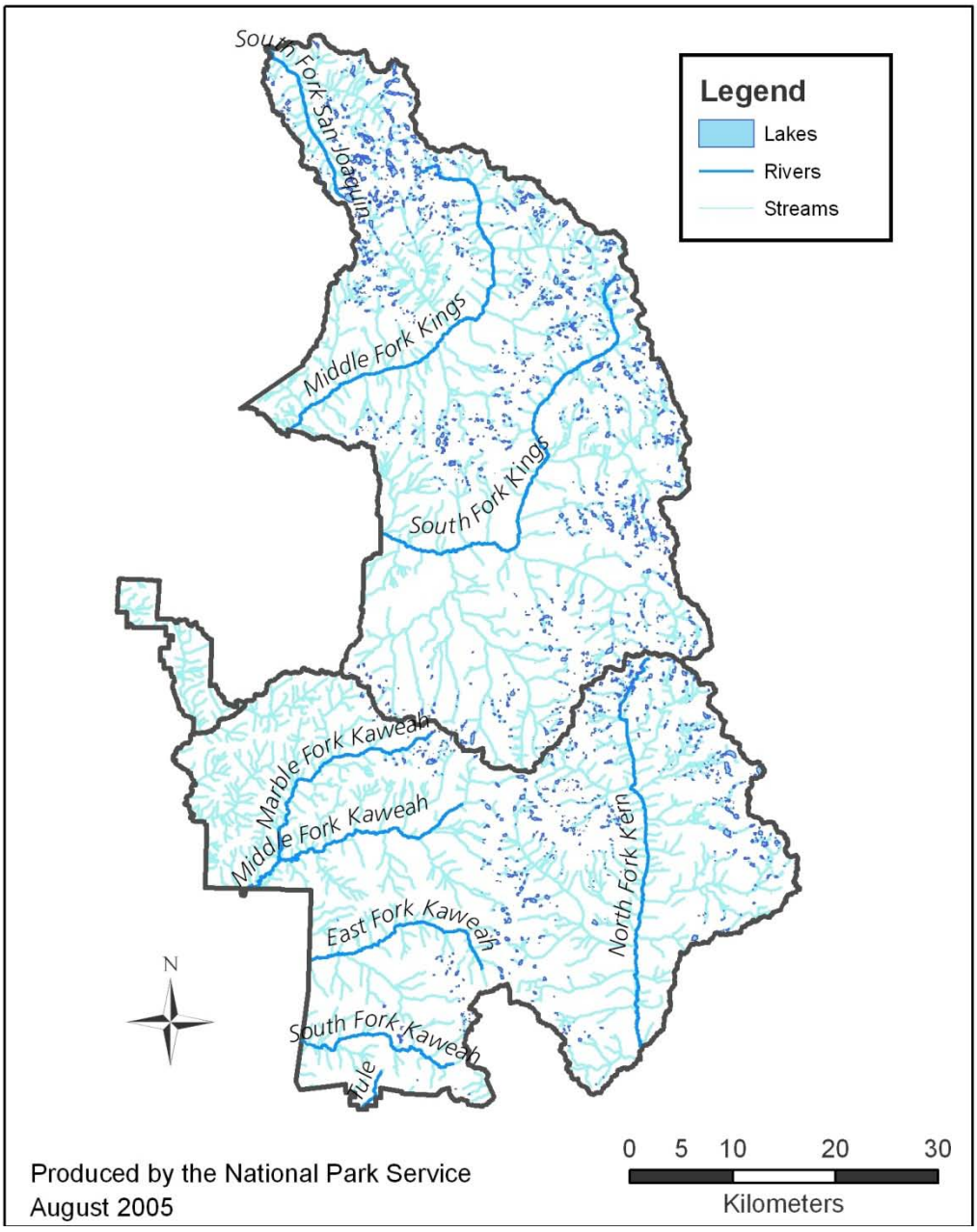


Figure APP A.5. Lakes, rivers, and streams in Sequoia and Kings Canyon National Parks.

Hydrologic and Water Quality Datasets

The Water Resources Division of the National Park Service conducted a search for existing water resources data in and near Sequoia and Kings Canyon National Parks during the 1990s. The results are summarized in the Baseline Water Quality Data Inventory and Analysis report (National Park Service 1997). Thirty-one gaging stations were documented, with 19 inside the park boundary. NPS-WRD retrieved 66,040 water quality records that date from 1951-1994. 56,665 of these records are located within the parks boundaries. Water quality records exist for 13 of the 14 Inventory and Monitoring Level 1 parameters. Data were not identified for the chlorophyll parameter group.

Historic flow data are available from 24 gaging stations in or near the parks (Appendix 2). Twenty-three of the stations were located in the Kaweah River drainage, and one historic site was located on the South Fork of the Kings River near Cedar Grove.

Queries in the Environmental Protection Agency's STORET Legacy database revealed many water quality records for Sequoia and Kings Canyon National Parks; however, all of these records were already captured by NPS-WRD in the Baseline Water Quality Report. Queries in EPA's Modernized STORET determined that no Sequoia and Kings Canyon records are currently stored in the database. The USGS National Water Information System (NWIS Web) database was also queried and an additional 10,724 water quality records were retrieved. A comparison between NWIS and Baseline Water Quality Report data determined there was overlap between the two databases. Of the 10,724 records in NWIS Web, 2,241 are unique records that were not captured in the Baseline Water Quality Report. There are nine additional water quality data sets identified during local searches in the park and with co-operating agencies (Table APP A.3).

Table APP A.3. Water quality data sets compiled for Sequoia and Kings Canyon National Parks.

Data Set	Agency	Beg. Year	End Year	No. Records
Horizon Report	NPS	1951	1994	66040*
NWIS	USGS	1960	1980	10724*
SEKI Watershed Program	NPS/ USGS	1983	2003	6,650
Western Lakes Survey	USGS/ EPA	1999	1999	
Lake inflow chemistry (7 lakes study)	UCSB	1983	2000	935
Lake outflow chemistry (7 lakes study)	UCSB	1986	2001	1,517
Lake chemistry (7 lakes study)	UCSB	1982	1995	1,144
Marble Fork Kaweah (Tokopah and Potwisha)	UCSB	1993	2000	890
Emerald Lake Outflow	UCSB	1983	2001	199
Sierra Episodes Study	UCSB	1993	1994	340
Amphibian/high elevation lake Inventory	UCSB SNARL	1999	2001	
SWAMP	RWQCB	2002	2003	55

* A record in the marked data sets (*) contains one paramter for one sample. For the other data sets, one record contains one sample that may have multiple parameters.

Water Resources Monitoring

Numerous water quantity and water quality studies have been conducted at Sequoia and Kings Canyon National Parks. The literature search for these parks captured 317 references that included 91 journal publications. I identified 12 long-term studies and several additional studies that may be of particular value to the Inventory and Monitoring Program (Table APP A.4).

Table APP A.4. Long-term monitoring sites in Sequoia and Kings Canyon National Parks.

Site Name	Period of Record	Water Quality	Flow
Chamise Creek	1985-2000, 2002-present	x	x
Tharp's Creek	1984-2000, 2003-present	x	x
Log Creek	1984-2000, 2003-present	x	x
Emerald Lake outflow	1984-present	x	x
Marble Fork Kaweah- above Tokopah	1993-present	x	x
Topaz Lake outflow	1987-present	x	x
East Fork Kaweah- nr Look Out Pt	1995-present	x	
Trauger's Creek	1995-present	x	x
Deadwood Creek	1995-present	x	x
Middle Fork Kaweah - at Potwisha	1949-present		x
Marble Fork Kaweah- at Potwisha	1950-present		x
East Fork Kaweah - nr 3 Rivers	1952-present		x

Long-term Monitoring in the Middle Fork of the Kaweah Watershed

As part of the Sequoia and Kings Canyon Watershed Research Program, which was a cooperative effort between the National Park Service, U. S. Geological Survey and UC Santa Barbara, four long-term watershed study sites were established along an elevational gradient in the Middle Fork of the Kaweah watershed (U. S. Geological Survey - Biological Resources Division 2000). The sites, which include Chamise Creek (750m) in the chaparral vegetation zone, Tharp's Creek (2067m) and Log Creek (2067m), both in the mixed conifer zone, and Emerald Lake Outflow (2807m) in the subalpine zone, were established between 1983 and 1985. Although there were some gaps in data collection, the records remain relatively continuous through present day. Stream flow and stream chemistry (pH, ANC, conductivity, nutrients and major anions and cations) were collected as part of air pollution, climate change and fire research studies.

Research in the sub-alpine zone, near the Emerald Lake watershed site was expanded to include two other sites in the larger Tokopah watershed, the Marble Fork of the Kaweah and Topaz Lake. The Emerald Lake basin is one of the most thoroughly studied subalpine watersheds in the world. The literature search captured 87 publications and reports resulting from research in the Tokopah watershed.

In 2003, the US Geological Survey-Water Resources Division established a Hydrologic Benchmark Network (HBN) site on the Marble Fork of the Kaweah River above Tokopah Falls. The HBN is a national program that monitors minimally disturbed watersheds for long-term trends in streamflow and water quality (U. S. Geological Survey 2000). This site is co-located with UC Santa Barbara's study site.

East Fork of the Kaweah Watershed

In the East Fork of the Kaweah, Colorado State University and the Sequoia and Kings Canyon Watershed Research Program investigated the individual and cumulative effects of landscape scale prescribed fire on hydrology and stream chemistry at different spatial and temporal scales. To investigate the potential effects of prescribed fire at different scales, water quality parameters were measured in the large (i.e. 20,000 ha East Fork Kaweah) watershed and in two small (i.e. 100 ha Deadwood and Trauger's) watersheds nested in the larger watershed.

Deadwood, the 100 ha watershed, was treated with a single prescribed fire that burned 60% of the watershed area. Water yield was not affected by the burn. Changes in stream chemistry were detected for specific conductance, ANC, chloride, sulfate, calcium, sodium, potassium nitrate, and phosphate. The East Fork, the 20,000 ha watershed, was treated with eight prescribed fires staggered over seven years that burned 11% of the watershed area. Changes in hydrology and stream chemistry were not detected at the landscape scale. Effects of large scale prescribed burning are more pronounced in headwater streams than at the landscape scale. Differences were attributed to smaller percent watershed and riparian areas burned in the 20,000 ha watershed. Results from this study indicate that treatments must be larger or more frequent than burning 11% of the watershed area over seven years before detectable changes in water yield and stream chemistry at landscape scales occur (Heard 2005).

South Fork of the Kings River

The Central Valley Regional Water Quality Control Board is monitoring the South Fork of the Kings River for nutrients and pathogens as part of the State's Surface Water Ambient Monitoring Program (SWAMP) (Bufort in progress). Data will eventually be uploaded to STORET.

Drinking Water Monitoring

The Sequoia and Kings Canyon Branch of Public Health monitors water quality for drinking water sources and wastewater discharge effluent. Currently, source water monitoring is conducted at approximately thirteen sites in the parks. Detailed source location data are not widely published for security reasons; however, more information can be obtained from the parks' Public Health Sanitarian. Front country drinking water sources are monitored for total coliform, escherichia coli (most probable number/100ml), general minerals, general physical and inorganic chemical parameters. Monitoring frequency is dependent on the classification of the water system and the source (National Park Service 1999, Scharz personal communication). Results are stored in an Access database and summarized in annual Consumer Confidence Reports. There are at least seven spray and leach fields in the parks. Discharge effluent is monitored weekly for total coliform, fecal coliform, settleable solids, suspended solids, and biochemical oxygen demand. Wells located at the Clover Creek disposal area are sampled twice a year for total coliform and escherichia coli (Schwarz 2004).

Long-term USGS Gaging Stations

Three USGS gaging stations, operated in conjunction with Southern California Edison, have over 50 years of discharge data for the Marble, Middle and East Forks of the Kaweah.

Currently, there are ten active gaging stations in the Sequoia and Kings Canyon National Parks (Appendix 2) and fourteen research and monitoring projects addressing water quantity and water quality issues (Appendix 3).

The US Geological Survey in conjunction with Southern California Edison operates two gaging stations, located on the lower Middle and Marble Forks of the Kaweah River. The National Park Service and UC Santa Barbara maintain the eight other stations which are used to gage smaller watersheds (13-1900 ha) associated with research studies. These sites include Chamise, Tharp's, Log, Emerald Outflow, Topaz Outflow, Marble Fork Kaweah above Tokopah, Trauger's, and Deadwood. Continued operation of these eight research watersheds is dependent on research needs and funding.

The US Geological Survey in conjunction with Southern California Edison also operates two gaging stations located just outside of the park. The East Fork of the Kaweah and the Main Fork of the Kaweah are gaged just downstream from the park boundary.

The Kern and Kings Rivers are not gaged near the park boundary. The nearest station on the South Fork of the San Joaquin is below the Florence Lake reservoir, approximately 12 km downstream. Specific station information and metadata were not compiled for these sites; however, data are available from NWIS Web.

Currently, the parks have 14 meteorological stations, five air quality monitoring sites, and 29 snow sensor and survey courses (Appendix 5). Detailed information regarding these sites is available from the Inventory and Monitoring Program's Project database or directly from the Sequoia and Kings Canyon Air Resources Branch.

Current Research Projects

Four research projects are investigating the effects of prescribed fire on aquatic systems (Additional information is listed in Appendix 3):

- Park staff members are continuing to monitor hydrology and stream chemistry in Tharp's and Log Creeks in order to study the effects of a prescribed fire re-burn in the Tharp's watershed.
- The park staff is also working with US Geological Survey- Biological Resources Division and UC Santa Barbara to summarize existing data and produce several publications addressing long-term research in the Tharp's and Log watersheds (Engle and Melack in prep).
- Colorado State University is investigating the effects of landscape scale prescribed burning on hydrology and stream chemistry in the East Fork of the Kaweah (Heard in prep).
- UC Berkley has a project in the East Fork of the Kaweah studying the effects of prescribed fire on aquatic macroinvertebrates, periphyton, channel morphology, hydrology, large woody debris, and riparian vegetation in headwater streams (Rogers in progress).

Four projects are studying the effects of air pollution (pesticide and nitrogen deposition) on aquatic resources:

- The Environmental Protection Agency is studying the distribution of agricultural contaminants in relation to the decline of the mountain yellow legged frog (*Rana muscosa*) in Sequoia and Kings Canyon National Parks and the Sierra National Forest (Bradford in progress).

- Texas A&M University and the U. S. Geological Survey are investigating the effects of pesticides on Pacific treefrog tadpoles along a north-south transect in the Sierra Nevada. Researchers translocated and placed tadpoles in chambers among sites located in Sequoia, Yosemite and Lassen National Parks (Sparling and Cowman 2003).
- The Western Airborne Contaminants Assessment Project (WACAP) is a cooperative effort between multiple agencies and universities to study persistent organic pollutants in western National Parks. Pear and Emerald lakes, in Sequoia National Park, were chosen as two of the WACAP sites (Landers in progress).
- UC Santa Barbara is investigating biogeochemical and hydrological mechanisms that influence the extent of nitrogen-limitation in alpine and chaparral ecosystems. Their study will further our understanding of how increased nitrogen deposition and climate change will affect nitrogen cycling in these ecosystems (Melack et al. 2002).

Portland State University is inventorying and mapping glaciers in Sequoia and Kings Canyon, Yosemite and the surrounding national forests (Basagic in progress). Information from this study will help managers understand how climate affects hydrologic processes in the Sierra Nevada.

University of California, Davis is investigating the prevalence and concentration of coliform bacteria in Sierra Nevada wilderness area lakes and streams. Researchers will collect water samples from over 120 lakes and streams, including waterbodies in Sequoia and Kings Canyon National Parks (Derlet 2004).

Western Kentucky University and the National Park Service are measuring stream stage, conductivity, pH, and temperature in Tufa Falls Creek, located in the East Fork of the Kaweah watershed. This research will contribute to the overall understanding of the role of karst systems in global carbon budgets (Despain in progress).

Local Water Resource Issues

In the Baseline Water Quality Report water quality data were compared to EPA water quality criteria and instantaneous concentration values selected by the Water Resources Division (National Park Service 1997). Alkalinity exceeded the criteria (99% exceeding) more than any other constituent. Concentrations were below the threshold used by the NPS Air Resources Division to determine potential sensitivity to acid deposition. Consistent with the alkalinity findings, pH values also exceeded (49% exceeding) the lower limit criterion. The following constituents were found to exceed criteria for freshwater aquatic life: dissolved oxygen (9%), turbidity (1%), cadmium (7%), mercury (3%), and zinc (1%). The following constituents exceeded EPA drinking water criteria: chloride (<1%), cadmium (4%), lead (18%), and mercury (11%). Total coliform (14%) and fecal coliform (21%) values exceeded criteria for freshwater bathing. The Water Resources Division had difficulty evaluating current water quality in the parks due to a lack of data after 1985. However, using limited available data they concluded that water quality generally appears to be good.

The State initiated the Surface Water Ambient Monitoring Program (SWAMP) in 1999 to assess California's waters. As part of this program, Regional Water Quality Control Boards (RWQCBs) are monitoring water quality to determine if waters should be listed as 303(d) waters. Due to the outstanding water quality, Sequoia and Kings Canyon National Parks do not have any water

bodies that are listed (State Water Resources Control Board 2002). However, the South Fork of the Kings River near the park boundary was selected for preliminary monitoring of nutrients and pathogens. Preliminary results from SWAMP indicate that concentrations are low and the South Fork of the Kings will not be considered for 303(d) listing (P. Bufort, oral comm., 2003). The Central Valley RWQCB considers water quality in the parks to be good to excellent and suitable for all beneficial uses (California Regional Water Quality Control Board Central Valley Region 1995). In general, the Basin Plans and 305(b) report are primarily concerned with river segments below the foothill dams and groundwater in the Central Valley.

Other local issues of concern for SEKI identified during recent water resources scoping meetings include:

- Water quantity can be a problem for the Grant Grove water supply, which consists of two wells and two springs. In addition, water rights for these sources may not be secured by the park.
- Potential acid rock drainage from abandoned mines in the Mineral King area of Sequoia National Park could degrade water quality in the East Fork of the Kaweah. Impacts on water quality have been observed from one mine in the park. Impacts from other mines and cumulative impacts at a larger scale have not been quantified.
- High concentrations of nutrients and bacteria from spray fields can move into receiving stream waters. Monitoring in streams near the Red Fir and former Giant Forest spray fields detected increased nutrient concentrations up to 3 km downstream of the sites (Sequoia and Kings Canyon National Parks 1999). There are a minimum of seven spray fields in the park.
- There was expressed concern about the effects of pharmaceuticals on park waters. While effects maybe more pronounced in urban areas well downstream of the park boundaries, there is currently no information on whether pharmaceuticals occur in the parks in sufficient concentrations to have chemical or biological effects on humans or ecosystems.
- There are little data available on the impacts of the impoundments and diversions within the park. Since these structures alter flow regimes and have the potential to degrade water quality, park managers identified this as an area of high concern (see earlier *Water Resources* section and Appendix 1 for descriptions of the impoundments, diversions, and wells).

Yosemite National Park

Water Resources

Yosemite National Park consists of two major watersheds: the Tuolumne and Merced. It also contains a small portion (130 ha) of the Fresno River watershed. These rivers drain to the west into the Central Valley and eventually the Sacramento-San Joaquin Delta (Figure 6).

Mean annual precipitation is 914 mm in Yosemite Valley (1,220 m) and 1270 mm in Tuolumne Meadows (2650 m). Most of the precipitation falls during the winter months. Dominant precipitation types are rain at low elevations and snow at middle and high elevations.

There are approximately 1,600 lakes (surface area greater than 0.0073 ha) and thousands of kilometers of streams and rivers within the park boundaries. Yosemite Valley is known for some of the most scenic and tallest waterfalls in the world; Yosemite falls drops 739 m before it hits the valley floor and flows into the Merced River. Additional water resources include springs, wet meadows, including peat meadows, seeps and ephemeral pools.

There are two Wild and Scenic Rivers, the Merced (130.0 km) and Tuolumne (87.0 km) Rivers, in Yosemite. Under the Wild and Scenic Rivers Act, the park is required to develop a Comprehensive Management Plan to ensure protection of the river's free flowing status and to protect and enhance the river corridor's outstandingly remarkable values (ORVs). The management plan for the Merced Wild and Scenic River—the Merced River Plan— is near completion. Monitoring along the Yosemite Valley segments was initiated in 2004. The park is in the early stages of planning for the Tuolumne River Plan; this management plan is scheduled to be complete in 2008.

The park contains two major impoundments: Hetch Hetchy (4.45×10^8 m^3) and Lake Eleanor (3.34×10^7 m^3). Hetch Hetchy, which impounds the Tuolumne River, was created in 1938 with the completion of O'Shaughnessy Dam. Hetch Hetchy Reservoir is part of the larger Hetch Hetchy Regional Water System that supplies drinking water to the City of San Francisco and irrigation water to the Central Valley. Lake Eleanor was created in 1918 and the water is used primarily for hydroelectric power. Cascades Dam, located on the Merced River downstream of Yosemite Valley since 1918, was recently removed and the river corridor restored. Numerous small dams and diversion are located throughout the park; most of these are associated with the High Sierra Camps.

The park also has numerous wells for drinking water sources. Most of the larger wells are located in the El Portal, Yosemite Valley, Crane Flat, White Wolf, Wawona, and Tuolumne Meadows areas. There are additional research and monitoring wells located throughout the park, many associated with restoration projects.

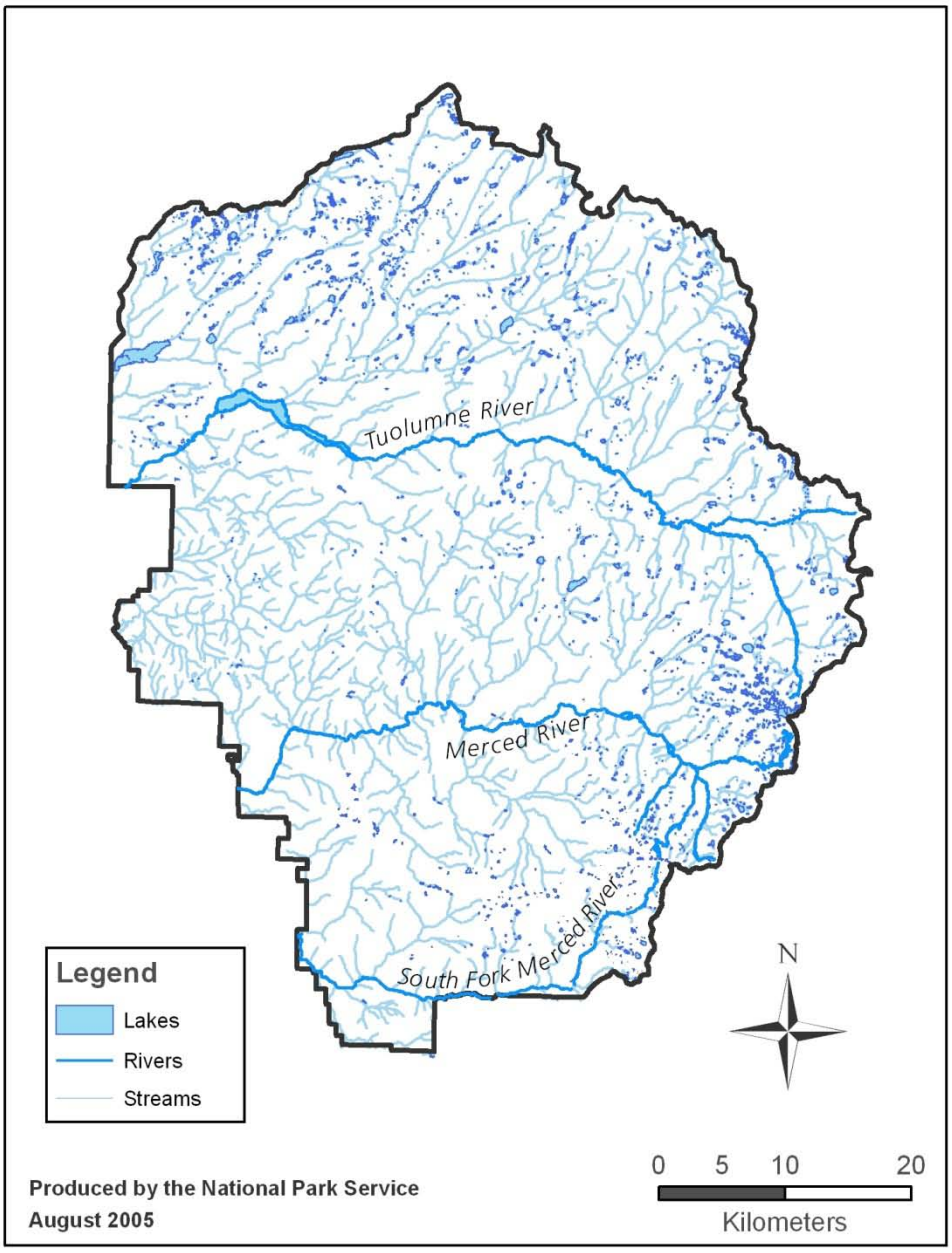


Figure APP A.6. Lakes, rivers, and streams in Yosemite National Park.

Hydrologic and Water Quality Datasets

The Water Resources Division of the National Park Service conducted a search for existing water resources data in and near Yosemite National Park during the 1990s. The results are summarized in the Baseline Water Quality Data Inventory and Analysis report (National Park Service 1994). Twenty-four gaging stations were documented, with 18 inside the park boundary. NPS-WRD retrieved 21,651 water quality records that date from 1967–1993. Water quality records exist for the 14 Inventory and Monitoring Level 1 parameters.

Historic flow data are available from 39 gaging stations in or near the park. Currently, Yosemite has 48 active gaging stations with periods of record ranging from one to 96 years. Thirty-five of these stations were installed in the last four years (Appendix 2).

The USGS-WRD queried Legacy and Modernized STORET and NWIS as part of the water quality database project. After the data were compared for duplicates and checked for data quality, 3,692 records from Legacy STORET and 40,107 records from NWIS were imported to the main water quality database. There were zero records in Modernized STORET. Additional water quality datasets identified by the USGS and park staff include the US Geological Survey's Alpine Hydro Research Group data and UC Santa Barbara's seven lakes study.

Water Resources Monitoring

Numerous water quantity and water quality studies have been conducted in Yosemite National Park. The literature search captured 242 references which included 64 journal publications. I identified 18 sites with long-term streamflow records and four sites with long-term water quality records that may be of particular value to vital signs monitoring (Table 5).

Table APP A.5. Long-term monitoring sites in Yosemite.

Site Name	Period of Record	Water Quality	Flow
Big Creek Diversion nr Fish Camp	1969-present		x
Eleanor Cr nr Hetch Hetchy	1909-present		x
Falls Cr nr Hetch Hetchy	1915-1983		x
Hetch Hetchy Reservoir	1950s-present	x	
Lake Eleanor diversion tunnel	1997-present		x
Lk Eleantor Div to Cherry Lk nr Hetch Hetchy	1996-present		x
M Tuolumne River a Oakland Rec Camp	1916-2002		x
Merced R a Happy Isles Bridge nr Yosemite	1915-present		x
Merced R a Pohono Bridge nr Yosemite	1916-present		x
Merced River at Happy Isles	1967-present	x	
Merced River at Happy Isles	1915-present		x
Merced River nr Briceburg	1966-1984	x	
Merced River nr Briceburg	1965-1974,1999-present		x
SF Merced R a Wawona	1955-1975		x
SF Merced R nr El Portal	1950-1975		x
SF Tuolumne R nr Oakland Rec Camp	1923-2002		x
Smoky Jack Cr trib nr Yosemite Village	1963-present		x
Tenaya Cr nr Yosemite Village	1912-1958		x
Tuolumne R ab Early Intake nr Mather	1943-present		x
Tuolumne R bl early intake nr Mather	1966-2004		x
Tuolumne R nr Hetch Hetchy	1910-2004		x
Tuolumne River a Tuolumne Meadows	1973-1986	x	

The site with the longest period of water quality monitoring (1967-present) in the Sierra Nevada Network is the Merced River at Happy Isles, located in upper Yosemite Valley. Happy Isles is maintained by the US Geological Survey as part of the Hydrologic Benchmark Network. Recently, the USGS installed a chemical analyzer that records continuous nitrate plus nitrite concentrations (Peterson et al. 2005). The Happy Isles watershed area is 46,900 ha and the

elevation ranges from 1,224 to 3,997 m. Like most Sierra streams, stream water at Happy Isles is dilute with a low buffering capacity; sp. conductance ranges from 3.0 to 65 uS/cm and alkalinity ranges from 20 to 360 meq/L (Mast and Clow 2000). Mast and Clow (2000) analyzed Happy Isles data set for long-term trends using water quality data from 1968-1995 (*refer to Trend Analyses section, below*). In addition to long-term monitoring data, there have been numerous additional research studies associated with Happy Isles (Hoffman et al. 1976, Clow et al. 1996, Brown and Short 1999).

The San Francisco Public Utilities Commision (SFPUC) has collected monthly surface water samples from Hetch Hetchy Reservoir since the 1950s. Currently the reservoir is sampled for alkalinity, hardness, pH, turbidity, temperature, specific conductance, chloride, and coliform bacteria (total and fecal). Limnology profiles are collected approximately once per month near O'Shaughnessy Dam. On occasion, SFPUC conducts additional sampling in the upper watershed. Water quality data are summarized in Sanitary Surveys approximately every five years and annually in Sanitary Survey Update Reports. Results indicate that water quality in Hetch Hetchy is of high quality and in full compliance with state and federal standards (San Francisco Water Team and CH2M HILL Inc. 1995, San Francisco Public Utilities Commission 1999).

The California Water Resources Control Board collected water quality data from 1973 to 1986 on the Tuolumne River near Tuolumne Meadows and from 1966 through 1989 on the Merced River near Briceburg.

The Yosemite Facilities Management Division monitors water quality for drinking water sources and wastewater discharge effluent. Detailed source location data are not widely published for security reasons; however, more information can be obtained from this division. In general, front country drinking water sources are monitored for total coliform, escherichia coli (most probable number/100ml), general minerals, general physical and inorganic chemical parameters. Monitoring frequency is dependent on the classification of the water system and the source (National Park Service 1999).

A Yosemite hydroclimate network was developed as an inter-agency effort over the last four years to further our understanding of meteorological, hydrological, and biogeochemical processes (DiLeo et al. 2003). Thirty-five new gaging stations were installed in the upper Merced and Tuolumne watersheds along with numerous water quality sampling locations.

The National Park Service monitors water quality (2004-present) as part of the Visitor Experience and Resource Protection Program (VERP) (Yosemite National Park 2004). Water quality is one of eleven indicators used to monitor the impacts of visitor use along the Merced Wild and Scenic River corridor. Parameters include fecal coliform, total nitrogen, total phosphorus, and petroleum hydrocarbons.

Current Research Projects

The US Geological Survey-Water Resources Division is investigating the sensitivity of high-elevation lakes to nitrogen deposition. Aspects of this project will specifically provide I&M with information that will help with indicator selection and sample design/protocol development.

Colorado State University is investigating the hydrological and ecological effects of groundwater pumping on water levels, fen carbon budget, and vegetation in Doghouse Meadow at Crane Flat (Cooper et al. 2005).

Texas A&M University and the U. S. Geological Survey are investigating the effects of pesticides on Pacific treefrog tadpoles along a north-south transect in the Sierra Nevada. Researchers trans-located tadpoles, placing them in chambers among sites located in Sequoia, Yosemite and Lassen National Parks (Sparling and Cowman 2003).

Portland State University is inventorying and mapping glaciers in Sequoia and Kings Canyon, Yosemite and the surrounding national forests (Basagic in progress). Information from this study will help managers understand how climate affects hydrologic processes in the Sierra Nevada.

University of California, Davis is investigating the prevalence and concentration of coliform bacteria in Sierra Nevada wilderness area lakes and streams. Researchers will collect water samples from over 120 lakes and streams, including waterbodies in Yosemite National Park (Derlet 2004).

Local Water Resource Issues

In the Baseline Water Quality Report, water quality data were compared to EPA water quality criteria and instantaneous concentration values selected by the Water Resources Division (National Park Service 1994). Alkalinity exceeded the criteria (100% exceeding) more than any other constituent. Concentrations were below the threshold (200 ueq/l) used by the NPS Air Resources Division to determine potential sensitivity to acid deposition. The following constituents were found to exceed criteria for freshwater aquatic life: dissolved oxygen (2%), pH (26%), cyanide (13%), cadmium (50%), copper (6%), lead (46%), selenium (5%), mercury (5%), and zinc (5%). The following constituents exceeded EPA drinking water criteria: nitrite (4%), nitrate (3%), cadmium (50%), lead (86%), and mercury (8%). From data in the Baseline Water Quality Reports, NPS-WRD determined surface waters to be of good quality, with indications of some impact from human activities. Potential sources identified in the report are road networks, parking lots, bridges, campsites, fuel storage facilities, and wastewater discharges. Additionally, lower pH levels, which may be natural or anthropogenic, may mobilize trace elements in the larger rivers.

Groundwater pumping from wells located in Doghouse meadow and potentially other park fens are changing the soil and vegetation type in sections of these meadows. Fens require nearly year round saturation to maintain the peat soils; lowering of the water table will oxidize soil. Peat soils accumulate at an approximate rate of 20 cm/1000 yrs.

Altered hydrology (from roads and other infrastructure) and subsequent conifer encroachment is an issue in Tuolumne and Dana meadows. Conifer encroachment has also been observed on a larger scale, throughout the Sierra; this pattern is likely attributed to climatic forces.

Development in Yosemite Valley has altered the natural hydrologic processes in the Merced River. Areas of specific concern are the Sugar Pine, Stoneman, and Ahwahnee bridges, which are diverting flow and creating alternate river channels (National Park Service 2000).

Yosemite National Park receives over 3, 350, 000 visitor's per year, with the highest visitation concentrated during the summer months in Yosemite Valley. As a result, visitor use impacts are of high concern. These include increased inputs of nutrients, pathogens, metals, and pharmaceuticals, stream bottom litter, and water withdrawals. Stream bank degradation and disruption of natural sediment regimes are issues, especially along the Merced River corridor in Yosemite Valley.

Broad-scale Spatial Surveys

There are several broad spatial studies that span Sierra Nevada parks and are of value to the vital signs monitoring program. These include the Western Lake Survey (Blick et al. 1987a, Clow et al. 2003), Amphibian and High Elevation Lakes Survey (Knapp et al. 2003), Comparative Analyses of High-Altitude Lakes and Catchments in the Sierra Nevada: Susceptibility to Acidification (Melack et al. 1998b), Distribution of Aquatic Animals Relative to Naturally Acidic Waters in the Sierra Nevada (Bradford et al. 1994).

The Western Lake Survey, conducted in 1985 by the EPA with cooperating agencies, was a one-time regional sampling of high elevation lakes in the mountainous west. The primary objectives were to determine the percentage and location of lakes that are acidic, determine the percentage and location of lakes that have low acid neutralizing capacity, determine the chemical characteristics of lake populations, and provide baseline data for future studies. Seven hundred and nineteen lakes, representing a target population of 10,393, were sampled throughout the west, including Yosemite, Sequoia and Kings Canyon and the upper Middle Fork of the San Joaquin above Devils Postpile. Clow et al. (2002) resurveyed a subset of these lakes (n=69) located in seven National Parks (Lassan, Yosemite, Sequoia, Kings Canyon, Grand Teton, Yellowstone, and Glacier). Results from both years indicate that lakes in the Sierra Nevada are some of the most dilute in the western US (Blick et al. 1987b, Eilers et al. 1989, Clow et al. 2002). Berg et al. (2005) used the lake survey data to develop a screening procedure of Wilderness lakes to identify a subset of acid sensitive (i.e. low ANC) lakes for long-term monitoring. This model was applied to lakes in Sierra Nevada Wilderness areas by the Pacific Southwest Region, USDA Forest Service Air Resources Program to select long-term monitoring sites as part of the Sierra Nevada Forest Plan Amendment. This program has resulted in several protocols and reports specific to long-term lake monitoring in USFS lands adjacent to the Sierra Nevada Network (Berg and Grant 2004b, a, Berg 2005).

Researchers from UC Santa Barbara measured atmospheric deposition and surface-water chemistry in eight alpine and subalpine watersheds in the Sierra Nevada as part of the Comparative Analyses of High-Altitude Lakes and Catchments in the Sierra Nevada study (Melack et al. 1998a). The study watersheds span the Sierra Nevada and include sites in or near Lassen, Yosemite, and Sequoia. The purpose of the study was to assess the annual and long-term susceptibility of the Sierra Nevada lakes to acid deposition. The report includes spatial and temporal analyses of solutes during snowmelt runoff, volume-weighted mean chemistry, water balances, and solute mass balances for the seven watersheds. General patterns of surface water chemistry were detected; however, there was considerable variability between watersheds. The quantity and timing of snowmelt affected the temporal variability (annual and inter-annual) of water chemistry.

Time Series Plots and Trend Analyses

Four streams with long-term water quality records were identified for trend analyses using the Seasonal Kendall test. Three of the sites are located along an elevational gradient in the Middle Fork of the Kaweah in Sequoia National Park. These sites are Chamise Creek (750m) in the chaparral vegetation zone, Log Creek (2067m), both in the mixed conifer zone, and Emerald Lake Outflow (2807m) in the subalpine zone. The National Park Service, UC Santa Barbara, and US Geological Survey-Biological Resources Division have monitored these sites since the early 1980s. The fourth site is the Merced River at Happy Isles, which is located in the upper reaches of Yosemite Valley. Happy Isles is Hydrologic Benchmark Network since, maintained by the US Geological Survey-Water Resources Division since 1964.

Temporal analyses for Happy Isles were previously conducted for the period of 1968-1995. Using the seasonal Kendall test for trend, Mast and Clow (2000) detected statistically significant trends ($\alpha = .01$) for pH and sulfate concentrations. They attributed the increasing trend in pH to inconsistencies between instruments or personnel through time as opposed to environmental factors. The decrease in sulfate was partially explained by variations in streamflow; however, interpretation was complicated by coinciding changes in analytical methods during the study period.

Long-term trends were analyzed in previous studies (Melack et al. 1998a, Clow et al. 2003) for Emerald Lake outflow. The analyses were computed again as part of this report to capture additional solutes and a longer time period and to better compare Emerald to Log and Chamise Creeks. One of the objectives of this report is to bring together these long-term data sets to assist the I&M program in developing the long-term monitoring plan. Trend test results and time series plots are presented together with some limited discussion. However, staff also should refer to previous publications and reports for in depth analyses and discussions on the hydrology and water chemistry of the individual watersheds.

Trend analyses for Chamise, Log, and Emerald were performed on raw and flow-adjusted concentrations (Table APP A.6). Seasons were selected based on patterns in hydrology and solute concentrations. Log and Emerald, both snow-dominated watersheds, had similar seasonal patterns. Four seasons were selected for Log and Emerald: October-December, January-April, May-July, and August-September. Chamise Creek flows only during large storm events from fall to spring; chemistry data are not existent for the months of July-October. As a result, only three seasons were selected for Chamise: November-December, January-April, and May-June. Analyses were not computed for ammonium in Chamise, Log, or Emerald and nitrate in Chamise and Log. These data sets contained a high percentage (between 32% and 92%) of concentrations below detection levels.

Downward trends were detected for ANC in raw (p=.015) and flow-adjusted (p=.043) concentrations in Emerald outflow (Table APP A.6 and Figure 7). Previous analyses of Emerald outflow data that covered the period of 1983-1994 did not detect long-term trends in ANC (Melack et al. 1998a). Differences may be attributed to a longer time period in our analyses or it may be attributed to differences in methodology (Melack et al. analyzed volume-weighted means using time series plots). In addition, the detected trends using the seasonal Kendall test were not very strong. Long-term trends in ANC were not detected for Log and Chamise.

Consistent with results from Clow et al. (2003), downward trends were detected for raw (p=.021) and flow-adjusted (p=.027) sulfate concentrations in Emerald outflow (Table APP A.6 and Figure 7). Results are consistent with decreases in sulfate concentrations observed in the Western lakes survey follow-up, declining sulfate deposition, and declining sulfur dioxide emissions (Clow et al. 2002, Clow et al. 2003). A downward trend was detected in Log Creek for raw sulfate concentrations (p=0.050). A trend was not detected for flow-adjusted concentrations, suggesting that precipitation patterns may partially explain the sulfate decline. Trends were not detected in Chamise.

A weak, but decreasing trend in raw calcium concentrations was detected for Emerald (p=.046). Calcium trends were not detected in Log or Chamise (Table APP A.6 and Figure 9). Trends were not detected at any of the sites for pH, specific conductance, temperature, nitrate, magnesium, sodium, potassium, and chloride (Table APP A.6 and Figures 8-11). A decreasing trend in nitrate concentrations has been observed in Emerald outflow and Log Creek (Williams and Melack 1997a, Melack et al. 1998a). Again, differences are likely explained by time periods and methodologies and the changes are small.

Table APP A.6. Seasonal Kendall test results for Chamise Creek, Log Creek and Emerald Lake outflow. P-values are bolded where a trend was detected (α = 0.05).

		Raw Concentrations			Flow-adjusted Concentrations		
		n	**p-value**	**trend**	**n**	**p-value**	**trend**
pH	Chamise	22	0.063	none	21	**0.013**	**up**
	Log	60	0.090	none	60	0.076	none
	Emerald	57	0.762	none	57	0.558	none
Sp. Cond	Chamise	22	0.568	none	21	0.960	none
	Log	60	0.305	none	60	0.173	none
	Emerald	57	0.812	none	57	0.629	none
Temp	Chamise	19	0.903	none	-	-	-
	Log	56	0.170	none	-	-	-
	Emerald	53	0.121	none	-	-	-
ANC	Chamise	22	0.455	none	21	0.706	none
	Log	60	0.248	none	60	0.869	none
	Emerald	57	**0.015**	**down**	57	**0.043**	**down**
NH4	Chamise	-	-	-	-	-	-
	Log	-	-	-	-	-	-
	Emerald	-	-	-	-	-	-
NO3	Chamise	-	-	-	-	-	-
	Log	-	-	-	-	-	-
	Emerald	57	0.720	none	57	0.585	none
Ca	Chamise	22	0.822	none	21	1.000	none
	Log	60	0.243	none	60	0.687	none
	Emerald	57	**0.046**	**down**	57	0.065	none
Mg	Chamise	22	0.834	none	21	0.876	none
	Log	60	0.685	none	60	0.209	none
	Emerald	57	0.230	none	57	0.299	none
Na	Chamise	22	0.916	none	21	0.626	none
	Log	60	0.844	none	60	0.053	none
	Emerald	57	0.526	none	57	1.000	none
K	Chamise	22	0.665	none	21	0.624	none
	Log	60	0.119	none	60	0.214	none
	Emerald	57	0.068	none	57	0.092	none
SO4	Chamise	22	0.230	none	21	0.236	none
	Log	60	**0.050**	**down**	60	0.082	none
	Emerald	57	**0.021**	**down**	57	**0.027**	**down**
Cl	Chamise	22	0.076	none	21	0.073	none
	Log	60	0.108	none	60	0.241	none
	Emerald	57	0.060	none	57	0.084	none

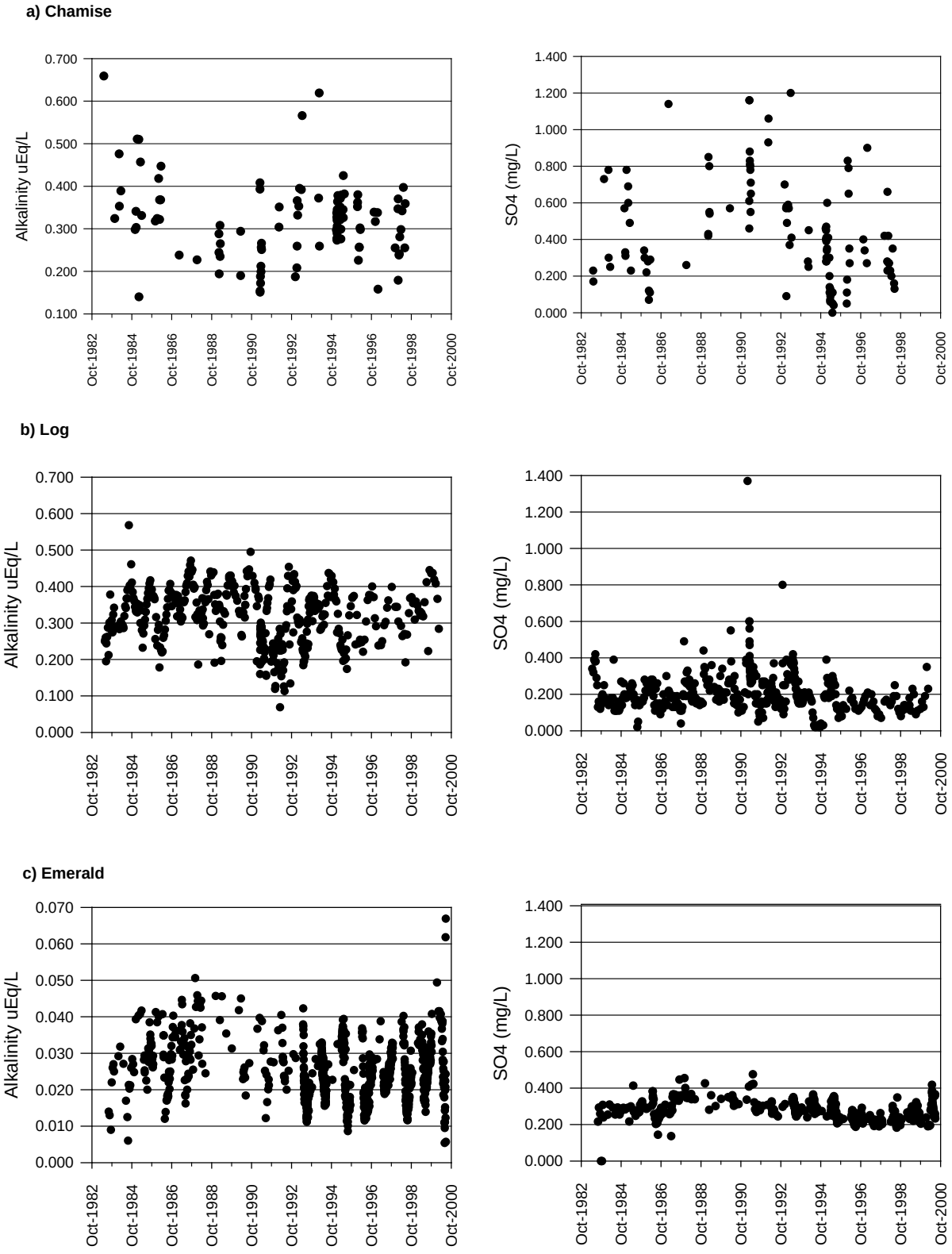


Figure APP A.7. ANC and sulfate time series plots for a) Chamise, b) Log, and, c) Emerald.

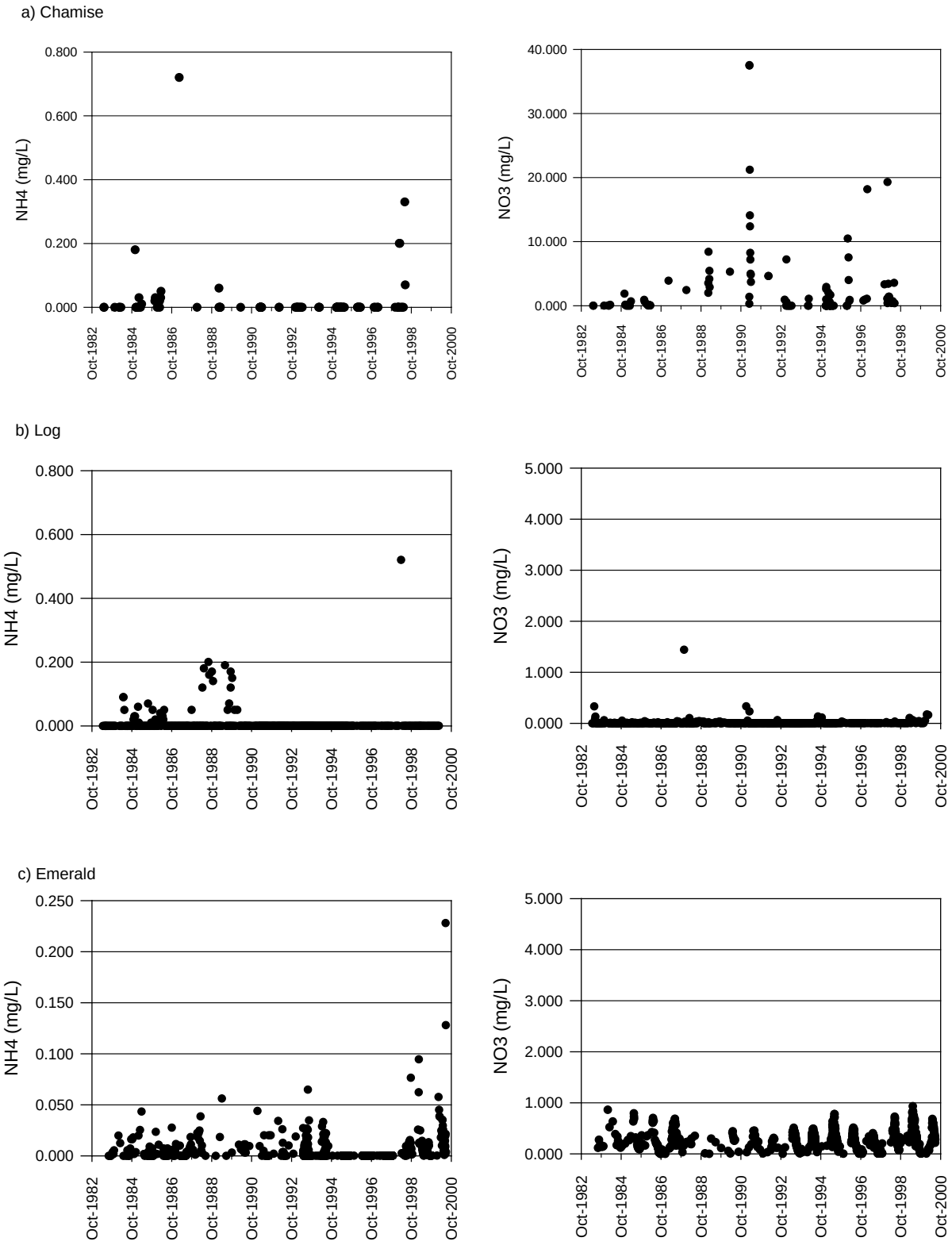


Figure APP A.8. Ammonium and nitrate time series plots for a) Chamise, b) Log, and c) Emerald.

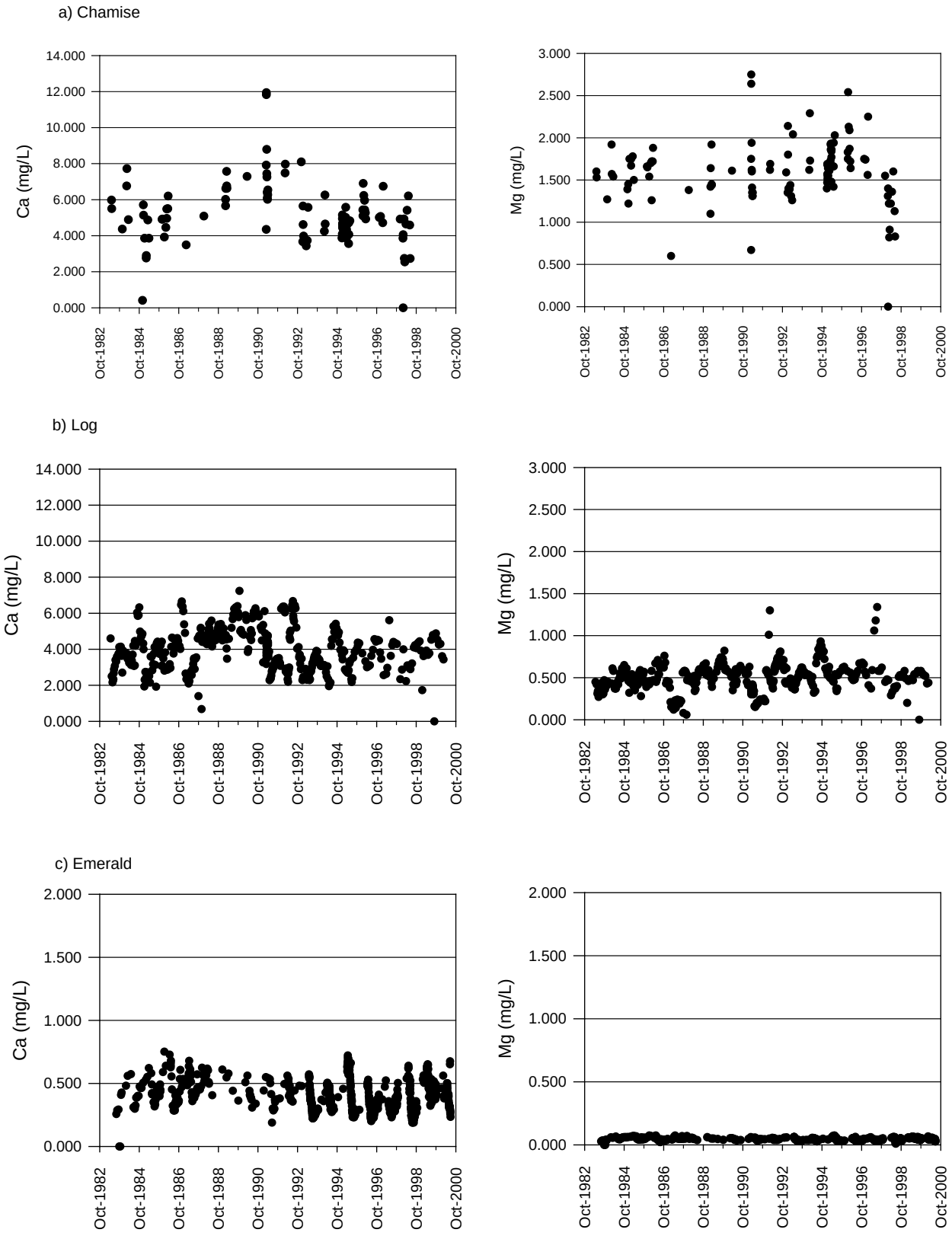


Figure APP A.9. Calcium and magnesium time series plots for a) Chamise, b) Log, and c) Emerald.

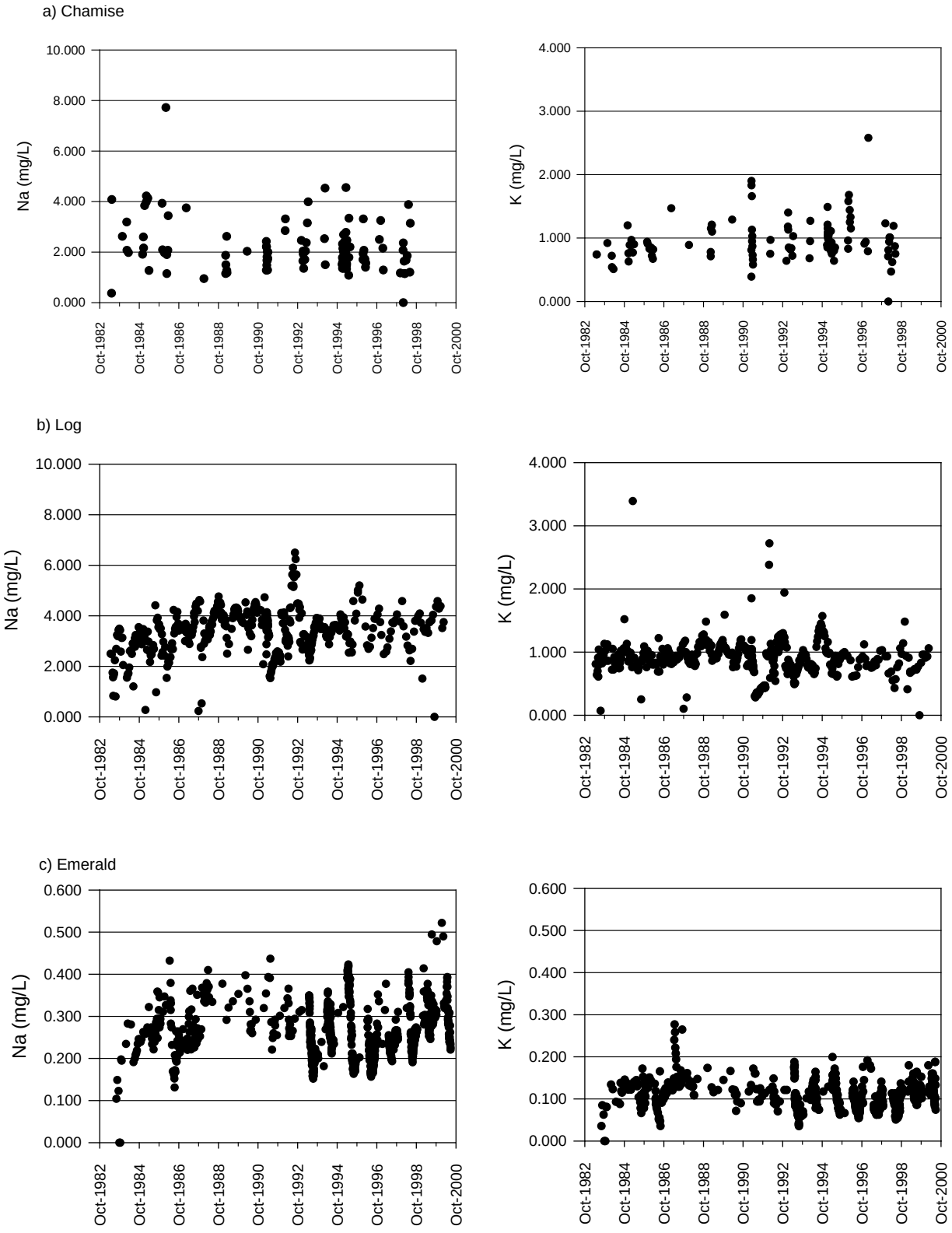


Figure APP A.10. Sodium and potassium time series plots for a) Chamise, b) Log, and c) Emerald.

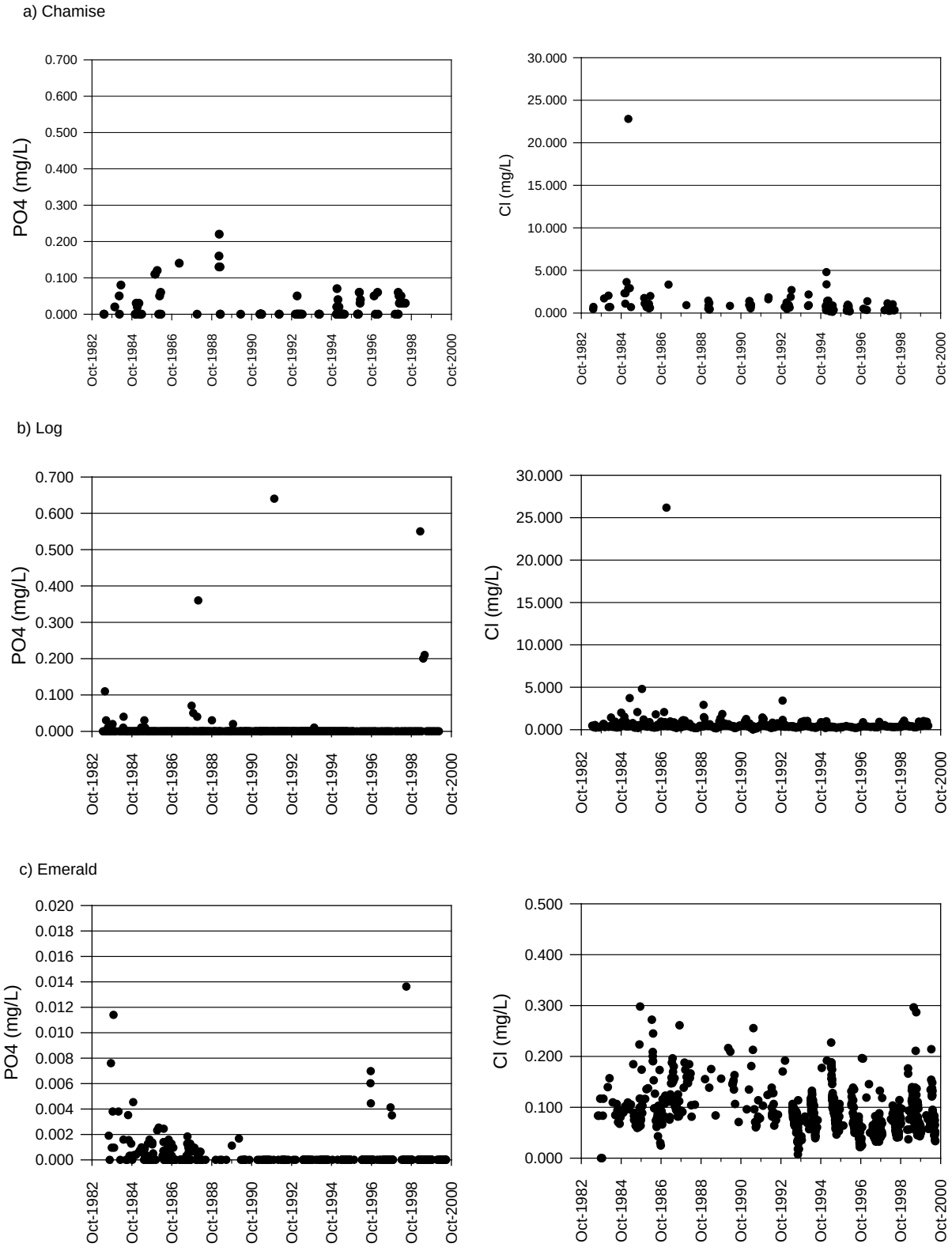


Figure APP A.11. Phosphate and chloride time series plots for a) Chamise, b) Log, and c) Emerald.

Summary

There are a substantial amount of water resource research and monitoring projects in the Sierra Nevada Network parks that the I&M program can use as a baseline for developing the Vital Signs monitoring plan. In summary, over 560 references were captured in the literature search, 802 water quality sites and 310,639 water quality records identified and uploaded to the water quality geodatabase, and 34 long-term monitoring sites identified. Most of the existing information is concentrated in the Merced, Kaweah, and Tuolumne watersheds. The watersheds with the least amount of baseline data are the Kings and Kern.

Time series plots and trend analyses data were presented for sites with long-term water quality monitoring data (Emerald outflow, Log Creek, and Chamise Creek and Merced River at Happy Isles). These sites have been well studied over the last 20-50 years; as a result, there are numerous publications investigating spatial and temporal trends specific to SIEN parks (refer to *SIEN Water* library). This information will provide network staff with a greater understanding of the temporal and spatial patterns and variability of water chemistry in SIEN parks. The new water geodatabase will enable to staff to further investigate spatial variability and patterns using existing water quality data.

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Appendices

Appendix APP A.1. Diversions, Wells, and Impoundments in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI) (National Park Service 1997, National Park Service 1998, 2003a, Meadows and Werner 2004, *personal communication*).

Park	Location	Type	Purpose	Responsible Agency
DEPO	Devils Postpile Well	Well	Drinking Water	DEPO
SEKI	400' Well, Grant Grove	Well	Drinking Water	SEKI
	Alder Creek	Diversion	Drinking Water	SEKI
	Artesion Well, Grant Grove	Well	Drinking Water	SEKI
	Ash Mountain Well	Well	Drinking Water	SEKI
	Atwell Creek	Diversion	Drinking Water	SEKI
	Bear Paw	Diversion	Drinking Water	SEKI
	Buckeye Campground Well	Well	Drinking Water	SEKI
	Cabin Creek	Diversion	Drinking Water	SEKI
	Cold Springs	Diversion	Drinking Water	SEKI
	Coyote Creek	Diversion	Drinking Water	SEKI
	Crescent Creek	Diversion	Drinking Water	SEKI
	Crystal Lake	Impoundment	Power	SCE
	Eagle Lake	Impoundment	Power	SCE
	Hocket Meadow	Well	Drinking Water	SEKI
	Lower Franklin Lake	Impoundment	Power	SCE
	Marble Fork Kaweah near Potwisha	Diversion	Power	SEKI
	Merrit Springs	Diversion	Drinking Water	SEKI
	Middle Fork Kaweah nr Potwisha	Diversion	Power	SEKI
	Potwisha Campground Well	Well	Drinking Water	SEKI
	Redwood Meadow Spring	Diversion	Drinking Water	SEKI
	Roaring River	Diversion	Drinking Water	SEKI
	Rona Springs	Diversion	Drinking Water	SEKI
	Sheep Creek, Cedar Grove	Diversion	Drinking Water	SEKI
	Silliman Creek	Diversion	Drinking Water	SEKI
	Turkey Creek, Dorst	Diversion	Drinking Water	SEKI
	Un-named Creek nr Crystal Cave	Diversion	Drinking Water	SEKI
	Upper Monarch Lake	Impoundment	Power	SCE
	Wolverton Creek	Diversion	Drinking Water	SEKI
	Wolverton Meadow Well	Well	Drinking Water	SEKI

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
DEPO									
Middle Fork San Joaquin- in DEPO	2004-present		Yes	Raw	Scripps				
Middle Fork San Joaquin- at Miller Crossing	1921-1991	11226500	No	DM, PQ	NWIS Web	47,600	2110	37.51049694	-119.1973475
SEKI									
Chamise Creek	1985-2000, 2002-present	1	Yes	DM, Raw	SEKI	4	750	36.51333565	-118.809242
Log Creek	1983-2000, 2003-present	4	Yes	DM, Raw	SEKI	49	2067	36.56108429	-118.739121
Tharps Creek	1983-2000, 2003-present	6	Yes	DM, Raw	SEKI	13	2067	36.56225693	-118.7398502
Trauger's Creek	1996-present	22	Yes	DM, Raw	SEKI	104	1400	36.44	-118.73
Deadwood Creek	1996-present	28	Yes	DM, Raw	SEKI	100	2000	36.47	-118.66
Emerald Outflow	1983-present	8	Yes	DT	UCSB/SEKI	120	2807	36.59694444	-117.3252778
Marble Fork Kaweah above falls	1992-present	11206800	Yes	DT	UCSB/SEKI	1,900	2621	36.60611111	-117.3169444

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Topaz Outflow	1986-present	363730118381701	Yes	DT	UCSB/SEKI	178	3218	36.625	-117.3636111
Pear Lake	1984-1994	363612118404001	Yes	DT	UCSB/SEKI	136	2904	36.6	-118.67
Middle Fork Kaweah - at Potwisha*	1949-present	11206501	Yes	DM, PQ	NWIS Web	26,400		36.5132786	-118.7917647
Marble Fork Kaweah- at Potwisha*	1950-present	11208001	Yes	DM, PQ	NWIS Web	13,300		36.51883444	-118.8017653
East Fork Kaweah - nr 3 Rivers*	1952-present	11208731	No	DM, PQ	NWIS Web	22,200	790	36.4516125	-118.7892639
Kaweah River nr Hammond*	1993-present	11208601	No	DM, PQ	NWIS Web	88,500	421	36.4860572	-118.8367656
South Fork Kaweah- nr Three Rivers	1911-1924	11210000	No	DM, PQ	NWIS Web	17,200	490	36.3749472	-118.8564869
South Fork Kings- nr Cedar Grove	1950-1957	11212500	Yes	DM, PQ	NWIS Web	10,500		36.8068872	-118.7495458
Kaweah R- nr Three Rivers	1903-1961	11210500	No	DM, PQ	NWIS Web	134,000	186	36.406615	-118.9542678
East Fork Kaweah- at Seq Natl P Bndry	1968-1971	11208625	Yes	DM, PQ	NWIS Web	6,130		36.4582761	-118.6539833
Middle Fork Kaweah Trib- near Mather	1967-1973	11208500	Yes	DM, PQ	NWIS Web	490		36.49300167	-118.8259319
East Fork Kaweah- Bl Mosquito Cr	1968-1973	11208620	Yes	DM, PQ	NWIS Web	4,100		36.4513308	-118.6187047
Monarch Creek	1968-1973	11208610	Yes	DM, PQ	NWIS Web	490		36.45244139	-118.5945378
North Fork Kaweah- at Kaweah	1910-1981	11209500	No	DM, PQ	NWIS Web	33,400	313	36.49022528	-118.9209344

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Kaweah R- at Three Rivers	1958-1990	11209900	No	DM, PQ	NWIS Web	108,000	247	36.44383639	-118.9034333
Sf Kaweah R A Three Rivers Ca	1958-1990	11210100	No	DM, PQ	NWIS Web	22,400	246	36.41661444	-118.9142667
Dorst Creek- nr Kaweah Camp	1960-1973	11209000	Yes	PQ	NWIS Web	1,580		36.6457783	-118.8051008
Atwell Creek	1971-1977	11208630	Yes	PQ	NWIS Web	170		36.46577667	-118.6759283
YOSE									
Bell Creek nr Pinecrest	1963-1973	11283200		DM, PQ	NWISWeb	2,359		38.16269482	-119.9432376
Big Creek Diversion nr Fish Camp	1969-present	11267350	No	DM, PQ	NWISWeb			37.46938349	-119.6151512
Big Creek nr Wawona CA		11267400							
Budd Ck	2001-present	H01	Yes	Raw	Scripps		2593	37.87333	-119.38150
Budd Creek nr Tuolumne	1963-1973	11274730	Yes	PQ	NWISWeb	76,146		37.87353595	-119.3829353
Cherry Cr bl Dion R Holm ph, nr Mather	1963-present	11278400		DM, PQ	NWISWeb/cdec	60,606		37.89020173	-119.9699046
Cherry Cr bl Valley Dam nr Hetch Hetchy	1956-present	11277300		DM, PQ	NWISWeb/cdec	30,562		37.96769944	-119.9174029
Cherry Cr cn nr Early Intake	1956-1996	11278200		DM	NWISWeb			37.8932571	-119.9557374
Cherry Cr nr Early Intake	1956-present	11278300		DM, PQ	NWISWeb/cdec	58,534	79.0656	37.89436824	-119.9626821
Cherry Cr nr Hetch Hetchy	1910-1955	11277000		DM, PQ	NWISWeb	28,749	156.6	37.99825414	-119.9010136

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Clavey R nr Long Barn	1986-1994	11283250		DM, PQ	NWISWeb	12,665	179.568	38.07658641	-120.0112948
Conness Ck (at Glen Aulin)	2001-present	H07	Yes	Raw	Scripps		2399	37.91017	-119.41867
Dana abv Gaylor	2001-present	H30	Yes	Raw	Scripps		2930	37.87917	-119.30150
Dana blw Gaylor	2001-present	H28	Yes	Raw	Scripps		2930	37.87917	-119.30150
Dana Ck	2001-present	H02	Yes	Raw	Scripps		2919	37.87630	-119.33250
Eleanor Cr nr Hetch Hetchy	1909-present	11278000		DM, PQ	NWISWeb/cdec	20,306	156.6	37.96908803	-119.8821241
Falls Cr nr Hetch Hetchy	1915-1983	11275000		DM, PQ	NWISWeb	11,914	186.18	37.97075376	-119.764343
Fletcher Creek	2005-present	H31	Yes	Raw	Scripps				
Gaylor Ck	2001-present	H10	Yes	Raw	Scripps		2930	37.87917	-119.30150
Hetch Hetchy Reservoir	?-present	11275500	Yes	Real-time	NWISWeb	117,850		37.94769893	-119.7879546
Illillouette Ck	2001-present	H14	Yes	Raw	Scripps		1676	37.72300	-119.55800
Illilouette Cr ne		11264000				1,566,950			
Ireland Creek	2002-present	H33	Yes	Raw	Scripps		2704	37.82569	-119.27711
Jawbone Cr nr Tuolume	1910-1911	11278500		DM	NWISWeb	4,947		37.89159079	-119.9954609
Lake Eleanor diversion tunnel	1997-present	ECK		DM, PQ	cdec		156.6	37.969	-119.881

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Lake Eleanor nr Hetch Hetchy	?-present	11277500	Yes	Real-time	NWISWeb	20,230		37.9740879	-119.881013
Lewis Creek	2005-present	H60	Yes	Raw	Scripps				
Lily Cr nr Pinecrest	1964-1974	11283100		DM, PQ	NWISWeb	3,082		38.14463936	-119.9007361
Lk Eleantor Div to Cherry Lk nr Hetch Hetchy	1996-present	11277100		DM	NWISWeb		162.516	37.97964333	-119.8818464
Lower Gaylor Lake	2003-present	H35	Yes	Raw	Scripps		3155	37.91333	119.26991
Lower Granite Lake	2003-present	H38	Yes	Raw	Scripps		3066	37.90788	119.28597
Lyell abv Ireland	2002-present	H32	Yes	Raw	Scripps		2704	37.82569	-119.27711
Lyell at Maclure Bridge	2003-present	H34	Yes	Raw	Scripps		2947	37.77748	119.26213
Lyell Fk abv Merced	2001-present	H11	Yes	Raw	Scripps		2438	37.70200	-119.34700
Lyell Fork (Blw Twin Br)	2001-present	H03	Yes	Raw	Scripps		2671	37.86900	-119.33367
M Tuolumne River a Oakland Rec Camp	1916-2002	11282000		DM, PQ	NWISWeb	19,037	97.44	37.82825915	-120.0115727
M Tuolumne River nr Mather	1924-1933	11281500		DM, PQ	NWISWeb	13,572		37.8499241	-119.8676789
Maclure Cr bl Maclure glcr nr Toulumne Mdw	1967-1972	11274710		DM, PQ	NWISWeb	96	400.896	37.75242991	-119.2820929
Merced abv Lyell Fk	2001-present	H12	Yes	Raw	Scripps		2438	37.69700	-119.34800

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Merced abv Merced Lk HSC (DC)	2001-present	H19	Yes	Raw	Scripps		2207	37.7383	-119.403
Merced at Ranger Cabin		H21	Yes	Raw	Scripps		2207	37.72949	119.39304
Merced blw Echo	2001-present	H15	Yes	Raw	Scripps		2134	37.73800	-119.44900
Merced blw Lyell Fk	2001-present	H13	Yes	Raw	Scripps		2377	37.70200	-119.34900
Merced Lk outlet	2002-present	H20	Yes	Raw	Scripps		2207	37.73814	119.41923
Merced Pk Fk Footbridge (DC)	2001-present	H18	Yes	Raw	Scripps		2486	37.69278	-119.3497
Merced R a Happy Isles Bridge nr Yosemite	1915-present	11264500	Yes	DM, PQ	NWISWeb/cdec	46,879	139.777	37.73159272	-119.5587736
Merced R a Pohono Bridge nr Yosemite	1916-present	11266500	Yes	DM, PQ	NWISWeb/cdec	83,139	134.3858	37.71687138	-119.6662788
Merced R a Yosemite	1912-1917	11265500	Yes	DM, PQ	NWISWeb	61,124		37.74381435	-119.590165
Merced R ab Illilouette		11263500	Yes			492,100			
Merced R nr Briceburg	1965-1974, 1999-present	11268200	No	DM, PQ	NWISWeb	178,969		37.63576505	-119.9332325
Middle Granite Lake	2003-present	H36	Yes	Raw	Scripps		3173	37.91749	119.27557
Parker Pass Ck	2001-present	H09	Yes	Raw	Scripps		2928	37.87820	-119.24695

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Rafferty Ck	2001-present	H04	Yes	Raw	Scripps		2665	37.86667	-119.32220
Reed Cr nr Long Barn	1986-1994	11283350		DM, PQ	NWISWeb	7,045	159.21	38.00464384	-120.022128
SF Merced R a Wawona	1955-1975	11267300		DM, PQ	NWISWeb	25,900		37.53882469	-119.6621022
SF Merced R nr El Portal	1950-1975	11268000		DM, PQ	NWISWeb	62,419		37.65131973	-119.8854532
SF Merced R nr Wawona	1911-1921	11267500		DM, PQ	NWISWeb	34,188		37.54160229	-119.6732143
SF Tuolumne R at Italian F nr Sequoia	1924-1933	11279500		DM, PQ	NWISWeb	16,809		37.82325848	-119.9176806
SF Tuolumne R nr Oakland Rec Camp	1923-2002	11281000		DM, PQ	NWISWeb	22,533	97.44	37.82159266	-120.0129616
SF Tuolumne R nr Sequoia	1914-1917	11280000		DM, PQ	NWISWeb	17,690		37.81159223	-119.9326811
Smoky Jack Cr trib nr Yosemite Village	1963-present	11279300	Yes	PQ	NWISWeb	17,610		37.81936827	-119.7135061
South Fork Tuolumne	2002-present	H50	Yes	Raw	Scripps		2759	37.79226	119.72264
Strawberry Creek nr Wawona	1963-1973	11267700	Yes	PQ	NWISWeb	27,195		37.63604205	-119.6829422
Tenaya Cr nr Yosemite Village	1912-1958	11265000	Yes	DM, PQ	NWISWeb	12,147	139.2	37.74214772	-119.5579409
Tuolumne R (Abv Glen Aulin)	2001-present	H06	Yes	Raw	Scripps		2548	37.89950	-119.40983
Tuolumne R (Blw Glen Aulin)	2001-present	H08	Yes	Raw	Scripps		2399	37.90983	-119.42033

Appendix APP A.2. Current and Historic Gaging Stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE) (continued).

Station Name	Period of Record	Station ID	In Park?	Data Type	Data Location	Drainage Area (ha)	Eleva. (m)	Lat	Long
Tuolumne R (Hwy120 Bridge)	2001-present	H05	Yes	Raw	Scripps		2651	37.87550	-119.35450
Tuolumne R ab Early Intake nr Mather	1943-present	11276600		DM, PQ	NWISWeb/cdec	125,356		37.87936848	-119.9471261
Tuolumne R at Hetch Hetch nr Sequoia	1910-1916	11274800		DM, PQ	NWISWeb	104,636		37.9554763	-119.7593427
Tuolumne R bl early intake nr Mather	1966-2004	11276900		DM, PQ	NWISWeb/cdec	126,133		37.88159083	-119.9701824
Tuolumne R nr Hetch Hetchy	1910-2004	11276500		DM, PQ	NWISWeb/cdec	118,363	119.364	37.93742147	-119.7982326
Upper Gaylor Lake	2003-present	H37	Yes	Raw	Scripps		3155	37.92122	119.26842
Upper Granite Lake	2003-present	H39	Yes	Raw	Scripps		3181	37.93488	119.27739
Vogelsang (Fletcher Lk inlet)	2002-present	H31	Yes	Raw	Scripps		3109	37.79657	119.33913
Warren Creek	2002-present	H40	Yes	Raw	Scripps		2759	37.95251	-119.226
Yosemite Cr a Yosemite	1912-1918	11266000		DM, PQ	NWISWeb	11,059		37.74548095	-119.5954432
Yosemite Creek	2002-present	H60	Yes	Raw	Scripps		2276	37.85159	119.57496

DM= daily mean flow; DT= daily total flow; PQ= peak flow; Raw= original data as collected

*Combined totals of river (below conduit diversion) and conduit flows

Appendix APP A.3. Current Research Projects in Sequoia and Kings Canyon National Parks.

Project	Site(s)	Investigator(s)	Agency	Park Contact
Distribution of Airborne Agricultural Contaminants Relative to Amphibian Populations in the Southern Sierra Nevada	30+ lakes in the high Sierra	David Bradford	EPA	Danny Boiano
Water Chemistry of Tufa Falls	Tufa Falls Creek	Joel Despain Chris Groves	SEKI and Western Kentucky University	Joel Despain
Microbial And Hydrological Controls Of Nitrogen Losses From Alpine And Chaparral Ecosystems During Seasonal Transitions	Chamise, Emerald, Topaz and Marble Fork Kaweah	John Melack Jim Sickman	UC Santa Barbara	Annie Esperanza
Summary and publication of Tharp's and Log data	Tharp's and Log	John Melack Diana Engle	UC Santa Barbara	Annie Esperanza
Prescribed Fire Re-burn in Tharp's Watershed	Tharp's and Log	Annie Esperanza Tony Caprio	SEKI	Annie Esperanza
Effects of Landscape Scale Prescribed Fire on Hydrology and Stream Chemistry	East Fork Kaweah, Deadwood, Trauger's	Andi Heard John Stednick	Colorado State and SEKI	Tony Caprio
Western Airborne Contaminants Assessment Project	Pear and Emerald	Dixon Landers	Oregon State?, NPS, USGS	Annie Esperanza
Frogs and Pesticides in the Sierra Nevada Mountains, CA	SEKI, YOSE, Lassen	Deborah Cowman	Texas A&M University	Annie Esperanza
Sierra glacier inventory and monitoring project	SEKI,YOSE and USFS glaciers	Hassan Basagic	Portland State University	Danny Boiano
Surface Water Ambient Monitoring Program	South Fork Kings River	Pam Bufort	RWQCB	Danny Boiano
Effects of Prescribed Fire on Stream and Riparian Ecosystems in Sequoia National Park and Blodgett Forest Research Station	East Fork Kaweah tributaries	Leah Rogers Vincent Resh	UC Berkely	Tony Caprio
Hydrologic Benchmark Network	Marble Fork Kaweah	Dave Clow	USGS-WRD	Danny Boiano
Prevalence of Coliform and Other Pathogenic Bacteria in Sierra Nevada National Parks and Wilderness Area Lakes and Streams	120+ wilderness lakes and streams	Robert Derlet	UC Davis	Danny Boiano
National Park Service Monitoring of Local Drinking Water Sources and Wastewater Discharge Effluent	At least 13 drinking water sources and 7 spray fields	Paul Schwarz	SEKI	Paul Schwarz

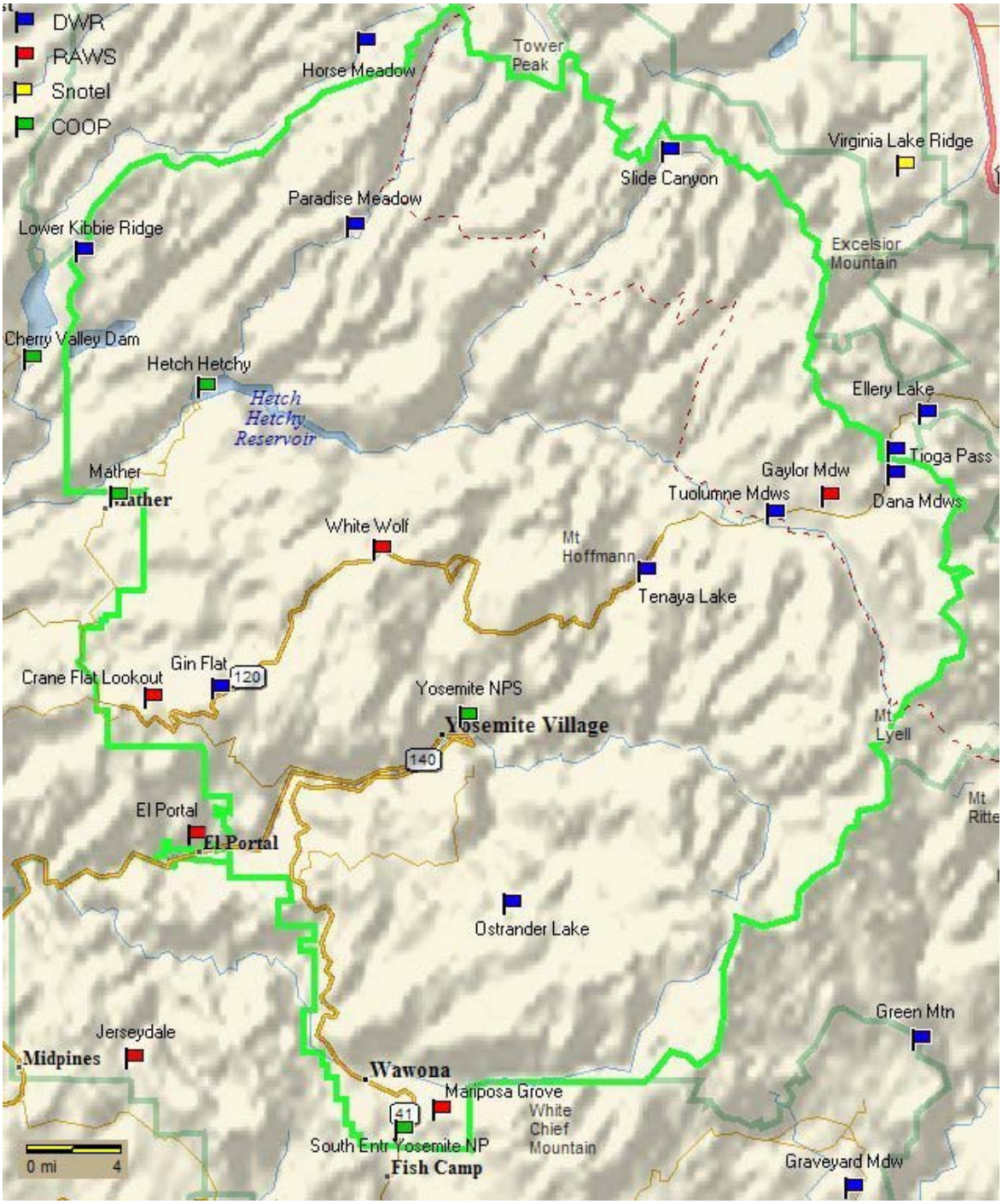
Appendix APP A.4. Current research projects in Yosemite National Park.

Project	Site(s)	Principle Investigator(s)	Agency	Park Contact
Hydroclimate Monitoring Network	Upper Merced and Tuolumne	Dan Cayan Mike Dettinger	USGS and Scripps	Joe Meyer
Nitrogen Deposition and Risk Assessment	Upper Merced and Tuolumne	Dave Clow	USGS	Lee Tarnay
Hydrological and ecological effects of groundwater pumping on water levels, fen carbon budget, and vegetation in Doghouse Meadow	Doghouse Meadows	David Cooper	Colorado State	Jim Roche
Frogs and Pesticides in the Sierra Nevada Mountains, CA	SEKI, YOSE, Lassen	Deborah Cowman	Texas A&M University	
Sierra glacier inventory and monitoring project	SEKI,YOSE and USFS glaciers	Hassan Basagic	Portland State University	Joe Meyer
Prevalence of Coliform and Other Pathogenic Bacteria in Sierra Nevada National Parks and Wilderness Area Lakes and Streams	120+ wilderness lakes and streams	Robert Derlet	UC Davis	Joe Meyer

Appendix APP A.5. Current Meteorology, Air Quality and Snow Pack Monitoring Sites in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI).

Park	Site Location	Program	Available Data	Beg.Record
			METEOROLOGY	
DEPO	Ranger Station	NPS RAWS	weather and fuel sticks	1994
SEKI	Lookout Point	NPS/ CASTNet	hourly met station	1997
	Emerald Lake	EOS/ UCSB	hourly met station	1984
	Topaz Lake	EOS/ UCSB	hourly met station	1996
	Atwell Mill	Army Corps. Eng.	daily precip totals	1975
	Ash Mountain	NPS/ NOAA	temp and precip	1928
	Giant Forest	NPS/ NOAA	temp and precip	1928
	Lodgepole	NPS/ NOAA	temp and precip	1928
	Grant Gorve	NPS/ NOAA	temp and precip	1928
	Cedar Grove	NPS RAWS	weather and fuel sticks	1992
	Sugar Loaf	NPS RAWS	weather and fuel sticks	1993
	Rattlesnake	NPS RAWS	weather and fuel sticks	1994
	Wolverton helispot	NPS RAWS	weather and fuel sticks	1995
	Ash Mountain	NPS Air	hourly met station	
	Lower Kaweah	NPS Air	hourly met station	
			AIR QUALITY	
SEKI	Lower Kaweah	NADP	precipitation chemistry	1980
	Lower Kaweah	NPS	visibility w/ repeat photography	1983
	Lookout Point	CASTNet	dry deposition	1997
	Ash Mountain	IMPROVE	fine particulate matter	1992
	Ash Mountain	PRIMENet	UV	1998
			SNOW	
SEKI	29 sites throughout SEKI	CA Water Resources	depth and SWE (some include precip)	

Appendix APP A.6. Current Meteorology Stations in Yosemite National Park.



Appendix APP A.7. Beneficial Uses for the State of California with Associated Codes and Descriptions (Information Center for the Environment 2003).

Code	Beneficial Use Name	Beneficial Use Description
AGR	Agricultural Supply	Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing.
ALL	All Beneficial Uses	All beneficial uses
AQUA	Aquaculture	Uses of water for aquaculture or mariculture operations including, but not limited to, propagation, cultivation, maintenance, or harvesting of aquatic plants and animals for human consumption or bait purposes.
BIOL	Preservation of Biological Habitats	Uses of water that support designated areas or habitats, such as Areas of Special Biological Significance (ASBS), established refuges, parks sanctuaries, ecological reserves, or other areas where the preservation or enhancement of natural resources required special protection.
COLD	Cold Freshwater Habitat	Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
COMM	Commercial and Sport Fishing	Uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes.
EST	Estuarine Habitat	Uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish shellfish, or wildlife (e.g, estuarine mammals. waterfowl, shorebirds).
FLD	Flooding	Beneficial uses of riparian wetlands in flood plain areas and other wetlands that receive natural surface drainage and buffer its passage to receiving waters.
FRSH	Freshwater Replenishment	Uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered.
GWR	Ground Water Recharge	Uses of water for natural or artificial recharge of ground water for purposes of future extraction, maintenance of water quality, or halting salt water intrusion into fresh water aquifers.

Appendix APP A.7. Beneficial Uses for the State of California with Associated Codes and Descriptions (continued).

Code	Beneficial Use Name	Beneficial Use Description
IND	Industrial Service Supply	Uses of water for industrial activities that do not depend primarily on water quality including, but not limited to, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization.
MAR	Marine Habitat	Uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shore birds).
MIGR	Migration of Aquatic Organisms	Uses of water that support habitats necessary for migration, acclimatization between fresh and salt water, or other temporary activities by aquatic organisms, such as anadromous fish.
MUN	Municipal and Domestic Supply	Uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply.
NAV	Navigation	Uses of water for shipping, travel, or other transportation by private, military, or commercial Vessels.
NONE		No designated beneficial uses
POW	Hydropower Generation	Uses of water for hydropower generation.
PROC	Industrial Process Supply	Uses of water for industrial activities that depend primarily on water quality.
RARE	Rare, Threatened or Endangered Species	Preservation of Rare, Threatened, or Endangered Species.
REC1	Water Contact Recreation	Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white water activities, fishing, or use of natural hot springs.
REC2	Non-Contact Water Recreation	Uses of water for recreational activities involving proximity to water, but not normally involving contact with water where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing.
SAL	Inland Saline Water Habitat	Uses of water that support inland saline water ecosystems including, but not limited to, preservation or enhancement of aquatic saline habitats, vegetation, fish or wildlife, including invertebrates.
SHELL	Shellfish Harvesting	Uses of water that support habitats suitable for the collection of filter-feeding shellfish (e.g., clams, oysters, and mussels) for human consumption, commercial, or sports purposes.

Appendix APP A.7. Beneficial Uses for the State of California with Associated Codes and Descriptions (continued).

Code	Beneficial Use Name	Beneficial Use Description
SPWN	Spawning, Reproduction, and/or Early Development	Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.
WARM	Warm Freshwater Habitat	Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
WET	Wetland Habitat	Uses of water that support wetland ecosystems, including, but not limited to, preservation or enhancement of wetland habitats, vegetation, fish shellfish, or wildlife, and other unique wetland functions which enhance water quality, such as providing flood and erosion control, stream bank stabilization, and filtration and purification of naturally occurring contaminants.
WILD	Wildlife Habitat	Uses of water that support terrestrial ecosystems including, but not limited to, the preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources
WQE	Environmental Water Quality	Beneficial uses of waters that support natural enhancement or improvement of water quality in or downstream of a water body including, but not limited to, erosion control filtration and purification of naturally occurring water pollutants, streambank stabilization, maintenance of channel integrity, and siltation control.

Appendix APP A.8. Beneficial Uses for Stream Segments in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI) (California Regional Water Quality Control Board Central Valley Region 1995). Beneficial use codes and descriptions are listed in Appendix APP A.7.

			Beneficial Uses													
Park	**Watershed**	**Stream Segment**	**MUN**	**AGR**	**IND**	**PROC**	**POW**	**REC1**	**REC2**	**WARM**	**COLD**	**WILD**	**RARE**	**SPWN**	**GWR**	**FRSH**
DEPO	San Joaquin	Sources to Millerton Lake	X	X			X	X	X	X	X	X				
SEKI	San Joaquin	Sources to Millerton Lake	X	X			X	X	X	X	X	X				
	Kings	Main Fork, Above Kirch Flat	X					X	X	X	X	X	X	X		X
	Kaweah	Above Lake Kaweah	X				X	X	X	X	X	X	X	X		X
	Tule	Above Lake Success	X	X			X	X	X	X	X	X	X	X		X
	Kern	Above Lake Isabella	X				X	X	X	X	X	X	X	X		X
YOSE	Merced	Source to McClure Lake		X			X	X	X	X	X	X				
	Tuolumne	Source to (new) Don Pedro	X	X			X	X	X	X	X	X				

Sierra Nevada Network Lake Monitoring Protocol

Appendix B. Lake Chemistry Power Analysis for the Sierra Nevada Network, National Park Service

Version 1.00, October 2010

Prepared by Leigh Ann Harrod Starcevich

Lake Chemistry Power Analysis

In order to assist the network in setting realistic long-term monitoring goals, the network worked with a consulting statistician through an agreement with the University of Idaho at Moscow to conduct a power analysis focused on trend detection in lake chemistry analytes over time. Power analyses are helpful in determining sample sizes that will provide information to detect changes in the population of interest over time at the desired level of change. Factors such as sample membership design, revisit designs over time, detection limits, and components of variation were considered when conducting this power analysis. SIEN used the results to guide protocol development decisions, especially related to sample design.

The report is being published separately through the Natural Resource Technical Report series. The citation for the unpublished NRTR report is:

Starcevich, L. A. H. 2012. Lake chemistry power analysis for the Sierra Nevada Network. National Park Service. Unpublished Report. National Park Service.

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Sierra Nevada Network Lake Monitoring Protocol

Appendix C. Administrative Record

Version 1.00, January 2012
Prepared by Andrea M. Heard

The purpose of the Administrative Record is to provide a history of protocol development and refinement. A timeline of events is presented in Table APP C.1. The protocol lead should update the record as major changes are made or milestones are achieved. The original protocol development summary follows the timeline of events.

Table APP C.1. Timeline of protocol development events.

Date	Event
Dec 2005	First meeting of the water resources work group. Lake protocol concept was formed and general objectives discussed.
Mar 2006	Identified specific monitoring objectives and development approach
May 2006	Work group meeting with Neil Berg, Trent Procter, and Dave Clow
Jun 2006	Physical Scientist attends USFS long-term lake monitoring training
Jul 2006	Initiated CESU agreement with UC Riverside
Oct 2006	Protocol development summary finalized
Dec 2006	Statistician begins working on lake protocol
Jan-Oct 2007	Main protocol development period
Mar 2007	Sample design meeting with water work group and cooperators
Jun 2007	Contract with Rose Cook for database development completed
Jul 2007	Draft database submitted to SIEN
Aug 2007	Draft power report complete
Sep 2007	First draft complete and 'internally' reviewed by Jim Sickman, per CESU agreement
Oct 2007	Final power analysis report submitted to SIEN
	Final database user's manual submitted to SIEN
	Draft protocol submitted to WRD for their initial review
Apr 2008	Protocol submitted to peer-review
Aug 2010	Peer-review comments received by SIEN
Oct 2010	Steering Committee (SC) requests high priority protocol costs, including Lakes, reduced to free funds for additional monitoring
Jan 2011	Water work group recommends reducing index sampling to reduce costs
Feb 2011	Protocol is revised according to peer review comments. SIEN submits revised protocol to Peer-Review Coordinator (PRC)
Feb 2011	Preliminary approval by SC to implement reduced version of Lakes
May 2011	On 5/11, SIEN corresponds with PRC regarding cost reduction-related changes to protocol. On 5/19, PRC responds with conditional approval, pending incorporation of recent changes and correction of formatting issues identified in 5/19 letter.
Sep 2011	Protocol revised to incorporate recent changes and re-submitted to PRC.
Oct 2011	Final approval received from PRC, with caveat that SIEN fix a few small issues and respond by email before receiving Final Protocol Approval Form.
Jan 2012	Final corrections made to protocol, and PRC was informed via email.

Protocol Development Summary: Lakes (Original Version)

Parks Where Protocol Will be Implemented
Sequoia & Kings Canyon **(**SEKI) and Yosemite (YOSE)

Vital Signs Addressed by Protocol
Water chemistry
Surface water dynamics
Amphibians

Justification
Sierra Nevada network parks protect over 4,500 lakes and ponds, numerous other ephemeral waterbodies, and thousands of kilometers of rivers and streams that have some of the highest water quality in the Sierra Nevada. High-elevation lakes are critical components of the parks' ecosystems, popular visitor destinations, and habitat for aquatic and terrestrial organisms including declining amphibian species. Lake ecosystems were selected for monitoring because they are valued for their ecological importance, recreational opportunities, and importance to regional water supplies, are threatened by multiple stressors, and are sensitive to change. Lakes are habitat for three amphibian species that are candidates for listing as endangered under the federal Endangered Species Act— mountain yellow-legged frog (*Rana muscosa* and *Rana sierrae)* and Yosemite toad (*Bufo canorus*).

Additional Information
The majority of Sierra Nevada Network lakes are located in the higher elevations (i.e., above 2500 m). Though a few lakes exceed 28 ha, most are only a few hectares in size and vary in depth from less than a meter to over 30 m. Water dynamics in the Sierra Nevada are a critical component of both the parks' ecosystems and the larger California water infrastructure. The snow pack acts as a temporary reservoir, storing water that will be released during the warmer and drier months. Peak runoff typically occurs late May to early June. Water is captured and stored for summer use in a series of reservoirs that line the Sierra foothills. With a few exceptions, reservoirs are primarily located downstream of park boundaries. Primary downstream water uses include irrigated agriculture, domestic water supplies, hydroelectric power, recreation and tourism.

Sierra Nevada lakes are very dilute and characterized as oligotrophic, especially in the sub-alpine and alpine basins where there is sparse vegetative cover, shallow soils, and small contributing area. Despite the low nutrient concentrations, these lakes still support a variety of aquatic fauna including zooplankton assemblages, micro-crustaceans, macro-invertebrates, fish (primarily non-native), and amphibians (Boiano et al. 2005). Two amphibian species, mountain yellow-legged frog (*Rana muscosa* and *Rana sierrae)* and Yosemite toad (*Bufo canorus*), are candidates for listing as 'endangered'.

The parks' aquatic ecosystems are subjected to natural and anthropogenic disturbances that have the potential to modify the systems and degrade water resources. Some of the biggest threats to Sierra Nevada lakes are the systemic stressors, which occur at regional and ecosystem scales. These include loss of pre-Euroamerican fire regimes, non-native

invasive species, air pollution, habitat fragmentation, and rapid anthropogenic climatic change (SNEP 1996a, Sequoia and Kings Canyon National Parks 1999). Aquatic systems are also impacted by localized stressors that threaten relatively small areas or specific water bodies; these include visitor use impacts, small dams and diversions, or abandoned mines.

Water resources are critical components of the parks' ecosystems and indicators of aquatic and terrestrial ecosystem condition. Hydrological and water chemistry measures are good indicators of aquatic and terrestrial ecosystem condition and trend because they reflect changes within the larger watershed. High-elevation lakes of the western United States are especially sensitive to change because the waters are oligotrophic and have a low buffering capacity. Sierra Nevada lakes have some of the lowest acid neutralizing capacity (ANC) concentrations in the western U.S. (Eilers et al. 1989). Changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes have been previously detected and attributed to increased nitrogen and phosphorous inputs (Goldman et al. 1993, Sickman et al. 2003).

It is well documented that amphibians are sensitive to ecosystem changes, are easy and relatively inexpensive to monitor, and measures are highly repeatable. Amphibians are sensitive to changes in ecosystem conditions, including: introduction of non-native species and pathogens (i.e., trout, chytrid fungus), habitat fragmentation and degradation (e.g., from pack-stock grazing), water quality (e.g., from toxics such as airborne pesticides), and climate (e.g., global warming, changes in hydrology). The Network would focus on three high elevation anurans: two declining species, namely mountain yellow-legged frog (*Rana muscosa)* and Yosemite toad (*Bufo canorus*); and Pacific treefrog (*Hyla regilla*).

The Network is especially interested in monitoring the Sierran yellow-legged frog (*Rana sierrae*) and Yosemite toad (*Bufo canorus*) because of their precipitous decline over the last few decades and potential listing as 'endangered' under the Federal Endangered Species Act. The Sierran yellow-legged frog, once the most common vertebrate in the high elevation Sierra Nevada, is a keystone species in high-elevation lakes. They are a major predator of aquatic and terrestrial invertebrates and a food source for alpine predators such as western terrestrial garter snake (*Thamnophis elegans*).

As of 2005, there has been continued decline in mountain yellow-legged frog populations, ranging from 91–98% across the entire range (R. Knapp and V. Vredenberg 2005, unpublished data). Recent research has shown that chytridiomycosis (*Batrachochytrium dendrobatidis*) is a proximate cause of mountain yellow-legged frog mass mortality (Rachowicz et al. 2006). The loss of mountain yellow-legged frogs is likely to have measureable impact on the natural functioning of lakes and streams within their historic range.

The Yosemite toad is endemic to the high Sierra Nevada. It has disappeared from more than 50% of the sites where it was known to occur historically. Overall status for Pacific tree frogs is undetermined, but data suggests decline in certain areas. Although research is still ongoing to fully explain the species' decline, it is well-documented that introduced

fish, which predate on tadpoles, and the disease chytridiomycosis are two of the primary causes. Other evidence suggests that pesticides and climate change may also be contributing factors.

Change detected in high-elevation lakes can be an early warning indication of change that may eventually occur at other elevations and ecosystem types. For example, elevated nitrate concentrations in surface waters are a primary symptom of N-saturated ecosystems (Fenn et al. 1998). Watersheds located near the elevational extremes (e.g., chaparral and alpine) are less effective at retaining nitrogen than mid-elevation ecosystems (Stohlgren 1988, Melack et al. 2002, Fenn et al. 2003). Alpine and sub-alpine watersheds have been shown to have a low capacity to retain nitrogen primarily due to steep talus slopes, shallow soils, and sparse vegetation (Clow and Sueker 2000). Increased nitrogen deposition in the Transverse Ranges of southern California, low elevations in the southern Sierra Nevada, and high-elevations in the Colorado Rocky Mountains has already led to excessive leaching of nitrate into receiving waters (Fenn et al. 2003).

Specific Monitoring Questions and Objectives

Monitoring Questions: The Sierra Nevada Network identified a set of broad monitoring objectives and questions for the Phase I and Phase II Monitoring Plans (Mutch et al. 2005). We used these to guide us in defining the specific monitoring objectives. Lake monitoring, in conjunction with the other indicators, will provide information that will help the network answer these questions. SIEN's broad monitoring questions that pertain to the lake monitoring protocol include:

- How are climatic trends affecting regional hydrologic regimes (snowpack depth, snow water equivalent, snowmelt, glacial extent, frequency and intensity of flood events and volume and timing of river and stream flows)?

- How do depositional patterns of nutrients (principally nitrogen and phosphorus compounds) and other major cations/anions vary along elevation gradients, in aquatic and terrestrial systems, and through time?

- How are patterns of nitrogen cycling changing?

- Are episodic acidification events increasing and are these events altering aquatic communities?

- How are water dynamics changing in response to climate and fire regimes?

- How are surface water volumes changing in lakes and wetlands?

- How does water chemistry (concentrations and fluxes) vary spatially and temporally across network parks?

- How is water quality changing with respect to water quality standards?

- 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?

Monitoring Objectives: The specific monitoring objectives are divided into three categories: (1) broad spatial scales sites or survey sites, (2) intensive index sites, and (3) landscape.

Survey Sites:

- Detect long-term trends in lake water chemistry for Sierra Nevada Network lakes.
  - Temp, pH, sp. conductance, dissolved oxygen, acid neutralizing capacity
  - Major ions: Ca, Na, Mg, K, Cl, SO4
  - Nitrate, dissolved organic nitrogen, total dissolved nitrogen
  - Total dissolved phosphorus
  - Particulate nitrogen, particulate phosphorus, particulate carbon
- Characterize Sierra Nevada Network lakes.
- Determine the proportion of Sierra Nevada Network lakes above threshold values for selected constituents.
- Detect long-term trends and abundance of high-elevation anurans, particularly mountain yellow-legged frog, Yosemite toad, and Pacific treefrog for Sierra Nevada Network lakes.

Index Sites:

- Detect intra- and inter-annual trends in lake water chemistry for Sierra Nevada Network index lakes.
  - Temp, pH, sp. conductance, dissolved oxygen, acid neutralizing capacity
  - Major ions: Ca, Na, Mg, K, Cl, SO4
  - Nitrate, dissolved organic nitrogen, total dissolved nitrogen
  - Particulate nitrogen, phosphorus, carbon
  - Total dissolved phosphorus
- Detect intra- and inter-annual trends in lake level and outflow for Sierra Nevada Network index sites.
- Detect inter-annual trends and abundance of high-elevation anurans, particularly mountain yellow-legged frog, Yosemite toad, and Pacific treefrog for Sierra Nevada Network index sites.

Potential Measures

Water Chemistry: pH, dissolved oxygen, specific conductance, temperature, major ions, acid neutralizing capacity, nitrate, dissolved organic nitrogen, total dissolved nitrogen, total dissolved phosphorus, particulate nitrogen, particulate carbon, particulate phosphorus.

Surface-water Dynamics: Lake outlet discharge lake elevation, lake volume,

Note: timing and duration of ice-out and ice-up may be included as part of the Landscape Dynamics protocol, if possible.

Amphibians: Relative anuran abundance (adults, tadpoles, egg masses), species distribution of selected anuran taxa.

Protocol Development and Status

We assembled a small work group, consisting of network and park resources staffs, to identify objectives and outline protocol development strategies for the two water resource vital signs—*surface water dynamics* and *water chemistry*. In December 2005, the work group decided that a good strategy would be to separate water resources monitoring into two protocols: (1) Lakes and (2) Rivers and Streams. We will be co-locating amphibian monitoring with the high-elevation lakes monitoring, if feasible. The lake monitoring protocol is being developed in 2006 and 2007. Protocol development for rivers and streams will begin in winter 2007.

The water and amphibian work groups, with input from Drs. James Sickman and David Clow, developed seven primary objectives and one landscape objective. The primary objectives are broken into two groups: (1) extensive sites: low intensity monitoring sites sampled at a broad spatial scale and (2) index sites that will be sampled more intensively.

Field and analytical methods for lake and water sampling are well developed. We will need to determine which methods are best suited for our purposes. We established a Cooperative Ecosystem Unit (CESU) agreement with Dr. James Sickman at the University California, Riverside. Dr. Sickman will be advising us and authoring sections of field and laboratory analytical methods and the Quality Assurance Project Plan (QAPP). The QAPP will be comparable with and meet standards set by the State of California's water quality monitoring program—Surface Water Ambient Monitoring Program (SWAMP). Dr. Sickman will also internally review and provide input on the larger protocol.

The USDA Forest Service has developed a peer-reviewed protocol for mountain yellow-legged frog and Yosemite toad monitoring in adjacent Forest Service lands (Brown 2001). We will use methods from this protocol, with some modifications, for amphibian monitoring in park lakes. This may allow combining of datasets to provide *Sierra-wide* inference for some species.

Data management components are under development (2007). We are working with the State of California and SWAMP to facilitate information sharing between our programs. We will be using a modified version of the database used by SWAMP. This is an MS Access database consistent with the Natural Resources Database Template (NRDT) with an interface module that will upload data to NPSTORET. The database will also interface with the California Environmental Data Exchange Center (CEDEN) through which all water quality data collected by SWAMP other water quality programs in the state are integrated and made available to the public.

To complement long-term monitoring data, we would like to collect sediment cores for diatom analyses. This would provide information on historical nitrogen loading to SIEN

lakes and help us identify threshold conditions. After the core protocol is developed we will be discussing how to best accomplish this component—it is likely we will need to seek additional funding.

Tentative Sampling Methods & Design

A map showing waterbody locations will be provided in the protocol (which is under development). Such map will show the location of index sites, and include the larger "sampled population" (i.e., extensive sites that are part of our sampling frame). Until peer review of the protocol is completed, the generation of random sample sites is premature.

Water chemistry will be measured in Sierra Nevada Network lakes, rivers, and streams. We are currently developing the sample design for lake water chemistry monitoring. We are integrating sampling with surface water dynamics and amphibian vital signs. The approach for river and stream monitoring will not be developed until late 2007-2008.

The Network and others working in large mountainous landscapes have struggled with the trade-offs between in-depth temporal sampling and the ability to make inferences across the landscape. We hope to achieve a balance by applying different sampling frequencies to different sites—survey sites and index sites. We still have many details to consider for a sample design, but an example of the type of design we will likely implement is a spatially-balanced probabilistic design using a rotating panel. Index sites, which will be sampled more frequently, may be selected using criteria such as accessibility, existing monitoring or research, and specific management concerns.

The target population for inference on water chemistry in Sierra Nevada Network lakes includes all lakes in the network that are greater than or equal to 1 hectare in area and greater than or equal to 2 m in depth. Since no lakes occur in Devils Postpile, the target population for the network only includes lakes in Sequoia, Kings Canyon, and Yosemite. The sampling frame will be a GIS coverage from the National Hydrography Dataset which enumerates all lakes within the park. Unequal inclusion probabilities may be formed based on a cost surface model.. Inference at the park and network level is desired, so if budgets allow, the survey design may treat the parks as strata so that inference at the park level is possible. The sampling unit for this survey will be lakes.

Surveys will be conducted to obtain estimates of status and trend. Status measurements will include measures of lake characteristics and the proportion of lakes above a certain threshold value (to be determined). Trends of chemical concentrations and ratios of constituents are also of interest. Because status is of interest and trend at the landscape level, random samples will be selected using a GRTS design to ensure spatial coverage of lakes within parks. A rotating panel design may be used so that trend may be estimated over time. Tradeoffs between replication in space at a given time for status and replication over time for trend will be explored.

Index sites will be used to monitor sites of particular interest, based on existing research and monitoring, accessibility or demonstrated sensitivity to certain stressors.. These index sites will be visited more frequently, for instance once or twice a month, from spring

through fall. Additional instrumentation will be used at index sites so that continuous data collection is possible.

A wealth of data is available for sample size approximation and power analysis. Fall lake chemistry data is available from the EPA's 1985 Western Lake Survey (Eilers et al. 1987) and a 1999 resurvey (Clow et al. 2003). The Seven Lakes Study data set has approximately five years of chemistry and flow data for seven lakes in and near network parks. Over 20 years of data are available from research and monitoring conducted at Emerald Lake. Ultimately, managers need temporal data over a broader spatial scale for trend analysis at a wider scale.

Amphibians: SIEN's science committee has decided that fiscal and logistical limitations necessitate the exploration of integration of amphibian monitoring with lake chemistry monitoring. We do not know if this will meet our amphibian monitoring or sampling objectives. We are also working with our statistician to see if–and at what level–integration can be achieved. Most lake measures will be collected in the late summer into fall; this precludes some amphibian sampling, as tadpoles and adults may be less abundant and detectable (e.g., *Hyla*). However, we have not yet conducted data analyses to assess the practicality of integration. For example, if feasible we will include lakes with a history of long-term amphibian monitoring in the lake index sites, which will be sampled throughout the season.
Our current target population includes populations (historic and extant) of mountain yellow-legged frog (*Rana muscosa*), Yosemite toad (*Bufo canorus*); and Pacific treefrog (*Hyla regilla*) in SEKI and YOSE. Decisions for sampling amphibians in DEPO have not been made; only one of our target species (Pacific treefrog) occurs there.

Details regarding sample design and probability of inclusion for amphibian populations have not been worked out yet: discussions continue between the two workgroups at this time. Detailed GIS coverages encompassing a wealth of recent amphibian data exist for both SEKI and YOSE. Large and extensive GIS coverages and datasets are available for amphibians, both from the parks themselves (e.g., comprehensive inventories; ten+ years of data at one site in Yosemite), and from surrounding USFS long-term monitoring. Under a best-case scenario, amphibian measures (e.g., abundance of anurans) would be collected at both index and extensive sampling sites, for park-level inference on trends and abundance.

The USFS within the Sierra Nevada has developed a GRTS-based, peer-reviewed monitoring protocol for mountain yellow-legged frogs and Yosemite toads that has implemented over the past five years across all Sierra Nevada national forest lands (Brown 2001). Full collaboration between NPS and USFS would be cost-effective, and would provide a complete regional picture of the status and population trends of these declining amphibians across lands with varying management practices; however, current level of SIEN monitoring funds preclude such collaboration. Regardless, we are working with our statistician to explore opportunities for data sharing with USFS.

Principal Investigators

The Sierra Nevada Network Physical Scientist will coordinate and complete the Lake protocol development with significant contributions and guidance from the Sierra Nevada Network Water Resources Work Group, National Park Service-Water Resources Division, and cooperators.

NPS Leads

Andi Heard, Physical Scientist
Sierra Nevada Network
209-379-1993
Andi_Heard@nps.gov

Meryl Rose, Ecologist (amphibian portion)
Sierra Nevada Network
209-379-3268
Meryl_Rose@nps.gov

Sierra Nevada Network Water Resources and Amphibian Work Groups

Danny Boiano, Aquatic Ecologist
Sequoia and Kings Canyon National Parks
Danny_Boiano@nps.gov

Annie Esperanza, Air Quality Specialist
Sequoia and Kings Canyon National Parks
Annie_Esperanza@nps.gov

Jim Roche, Hydrologist
Yosemite National Park
Jim_Roche@nps.gov

Steve Thompson, Wildlife Biologist
Yosemite National Park
Steve_Thompson@nps.gov

Harold Werner, Wildlife Ecologist
Sequoia and Kings Canyon National Parks
Harold_Werner@nps.gov

NPS-WRD Contacts

Barry Long, Hydrologist
National Park Service-Water Resources Division
Barry_Long@nps.gov

Gary Rosenlieb, Hydrologist
National Park Service-Water Resources Division
Gary_Rosenlieb@nps.gov

*Cooperators**
Dr. Cathy Brown, Amphibian Monitoring Team Leader
U.S. Forest Service, PSW Research Station
cathybrown@fs.fed.us

Dr. Rosamonde Cook (database development)
RosamondeCook@aol.com

Dr. David Clow
US Geological Survey
dwclow@usgs.gov

Dr. Gary Fellers
USGS Western Ecological Research Center
Point Reyes National Seashore
gary_fellers@usgs.gov

Dr. Roland Knapp
Sierra Nevada Aquatic Research Laboratory
University of California
knapp@lifesci.ucsb.edu

Dr. James Sickman
University of California, Riverside
jsickman@ufl.edu

*Other cooperators may be identified.

Development Schedule, Budget, and Expected Interim Products
The Sierra Nevada Network initiated development of the lake monitoring protocol in December of 2005 (APP C.2.). The protocol will be submitted for peer-review in fall 2007. In FY06, $10,000 were allocated to University California, Riverside (Dr. Sickman) for assistance with analytical methods and internal review of the larger protocol. In FY07, $19,000 was allocated for database modifications and training. Additional resources included statistical consulting (costs shared with other vital signs), time from park staff (from park base funds), time from the network Data Manager, and significant time from the Network Physical Scientist.

Table APP C.2. Lake Protocol development schedule.

December 2005	Identify objectives and approach
2006-2007	Develop protocol
Fall 2007	Submit for peer-review
Summer 2008	Implement

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NPS 963/115636, July 2012

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Natural Resource Stewardship and Science
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Fort Collins, CO 80525

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