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SEQUOIA AND KINGS CANYON NATIONAL PARKS

CALIFORNIA

WATER RESOURCES INFORMATION AND ISSUES OVERVIEW REPORT

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Sequoia and Kings Canyon National Parks

California

Water Resources Information and Issues Overview Report

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Technical Report NPS/NRWRD/NRTR- 2005/333

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EXECUTIVE SUMMARY

Water Resource Information and Issues Overview reports (WRIIOs) provide National Park Service (NPS) management with a better understanding of a park's water resources and the current water-related issues. These reports typically summarize existing hydrological, chemical and biological information, and identify and analyze major water resource issues facing a park. A Water Resources Stewardship Report typically follows a WRIIO, providing strategies that address these issues as the park works toward achieving the "desired conditions" for water resources, presented in the park's General Management Plan.

For Sequoia and Kings Canyon National Parks (SEKI), the water-related issues are numerous, time sensitive, and complex. The primary objectives of this report are to 1) provide background for SEKI's natural resources and relevant water-related legislation, 2) identify the major water-related issues, and 3) present information relevant to these issues, including management considerations that will serve as the foundation for a Water Resources Stewardship Report.

The contents of this report are limited to information acquired by the authors during the time this report was prepared. Where appropriate, issue-specific recommendation(s) previously proposed by NPS management via SEKI planning documents (e.g., RMP) are included. As a result, descriptions of the natural resources and water resource issues vary in detail, and inclusion of issue-related recommendations is inconsistent.

SEKI is a large NPS unit protecting over 865,000 acres (350,046 ha) in the southern Sierra Nevada mountain range of California. These parks contain a diverse array of habitats due to the presence of lands ranging from 1,370 feet (417 m) above mean sea level (msl) in elevation in the foothills to 14,494 feet (4,418 m) (msl) on the Sierra crest at Mount Whitney, the highest point in the contiguous 48 states. Parts of the headwaters of five major rivers originate in SEKI, including the Kaweah, Kern, Kings, San Joaquin and Tule, while extensive past glaciations helped create the presence of over 3,000 lakes and 2,000 miles (3,219 km) of stream. The parks' water resources are diverse and extensive, including river systems, lakes, ponds, wetlands, glaciers, ground water, and mineral and thermal springs.

As part of the technical assistance provided by the NPS Water Resources Division (WRD) to help produce this report, WRD staff traveled to the parks in 2003. The purposes of this travel were to 1) introduce elements of the WRIIO effort to SEKI, 2) become familiar with the water resources and high priority water-related issues at the parks, 3) obtain pertinent information from the parks' files, and 4) help facilitate a scoping workshop that included participation by SEKI staff and regional water resource professionals. The priority issues identified during this effort and discussed in this report include:

• *Contaminants, Nutrients and Atmospheric Deposition* – The effects of contaminants, nutrients and atmospheric deposition on natural resources is one of the biggest threats to

SEKI's water resources. Contaminants and nutrients have significant potential to degrade SEKI's water quality and negatively affect biota. SEKI therefore needs to continue monitoring wet and dry deposition chemistry and seek to expand the network to include deposition along an elevation gradient. Monitoring of air quality and analyzing samples for gaseous and fine particle pollutants also needs to be continued and expanded. SEKI staff should continue to support sampling efforts by NPS Air Resources Division and others to evaluate long-range transport of airborne contaminants into national parks. Research on atmospheric transport and deposition of contaminants and nutrients into watersheds needs to be facilitated and assisted. Long-term research and monitoring of water chemistry and hydrology in headwater catchments of the Marble Fork Kaweah River and research of the effects of airborne contaminant deposition on amphibians and aquatic ecosystems should also be facilitated and assisted by SEKI staff.

• *Climate Change* - The effects of climate change on natural resources is also one of the biggest threats to SEKI's water resources. Climate change is predicted to significantly reduce annual snowpack amounts in the southern Sierra Nevada during the 21st century, and has the potential to exacerbate and dominate all other stressors in importance in the coming decades. SEKI therefore needs to continue monitoring water quality and quantity to assess water resource trends in response to expected changes to climate, including assisting with design and implementation of Vital Signs water quality monitoring for the Sierra Nevada Network and collecting water samples in Marble Fork Kaweah River as part of the U.S. Geological Survey's (USGS) Hydrologic Benchmark Network. SEKI staff should support and assist the Sierra Nevada Global Change Research Program that is implemented by the USGS to help anticipate and adapt to changing environmental conditions. Investigations of climate and glacier interactions should be initiated by establishing a network of index glaciers selected from the new database of Sierra Nevada ice. SEKI staff should support and assist the University of California, Merced in establishing a research and monitoring transect through the Kaweah River to study and monitor water resources as part of the proposed Sierra Nevada Hydrologic Observatory. Collaboration with the Scripps Institute of Oceanography in installing and maintaining research gauges in several SEKI drainages is needed to evaluate trends in onset of snowmelt in the southern Sierra Nevada and complement identical investigations begun in other NPS units in California. An inventory of ground water resources and quantification of ground water amounts are also needed in SEKI.

• *Fire Management* - The effects of fire management on natural resources is also a significant issue related to SEKI's water resources. The buildup of fuels due to fire suppression has impacted surface water flows. Wildfires and prescribed burns of moderate to high severity are also known to change water quality. SEKI needs to continue supporting and assisting research of the effects of fire on ecosystem processes, including physical, chemical and biological parameters. Water quality in streams that drain areas planned for controlled burns should be monitored both before and after fire to determine how burning affects water chemistry. The effects of fires in higher productivity, low elevation areas that may contribute nutrients to lower productivity, high elevation watersheds also needs to be investigated.

• *Aquatic Biological Impacts - Invertebrates* – The biggest issues related to invertebrates in SEKI is a lack of knowledge and understanding of this diverse faunal assemblage. SEKI needs to build upon recent invertebrate sampling results to obtain funding to conduct an inventory of invertebrates throughout SEKI. Use results from 1) the inventory of karst fauna to establish a cave invertebrate monitoring program and 2) the evaluation of high elevation stream invertebrate communities to select future ecological restoration and aquatic diversity management areas. SEKI should consider biomonitoring of aquatic invertebrates to complement monitoring of water chemistry. SEKI staff should assist any utilization of 1) aquatic invertebrates in the Vital Signs water quality monitoring program and 2) meadow invertebrates in the Vital Signs monitoring plan.

• *Aquatic Biological Impacts - Amphibians* – The decline of amphibian species, especially the rapid and severe decline of the mountain yellow-legged frog (MYLF), is the major amphibian-related issue in SEKI. The recent success of introduced trout removals in the MYLF restoration project needs to be expanded to a programmatic plan that implements restoration in additional high elevation basins and improves restoration methodology. Current studies of MYLF genetics must be consulted so that all basins containing significantly unique genetic groups of MYLFs are represented. Proposed studies of any founder effects that may occur in new populations in restoration areas should be encouraged. SEKI staff must facilitate and assist studies of chytrid fungus and the role of contaminants in amphibian declines and quickly apply results to future management actions. These data will be important if translocations of individuals are necessary to mitigate further decline of the species. Current spatial analyses that determine relative exposure of areas to contaminant deposition also must be consulted in selection of new ecological restoration areas.

• *Aquatic Biological Impacts - Fish* – The biggest fish-related issue in SEKI are the effects of introduced and transplanted species on native biota. In restoration areas where introduced trout have been eradicated, annual surveys for trout presence are needed for the first three years after eradication to trigger mitigation actions if trout recolonization occurs. Continue removing introduced trout from remote areas with opportunities for ecological restoration of vulnerable fauna, including MYLFs, Yosemite toads and pure or relatively pure populations of Little Kern golden and Kern River rainbow trout. Continue assisting the California Department of Fish and Game with restoration and monitoring of federally threatened Little Kern golden trout and genetic analysis of remote introduced California golden trout populations that may be genetically pure. The genetic integrity of 1) Kern River rainbow trout in the Kern River between Junction Meadow and the park boundary and 2) rainbow trout in their native range in the Kaweah and Kings Rivers should be investigated, and if any pure or relatively pure strains are found, determine the feasibility of restoration possibilities. Re-establish periodic fish monitoring in ten survey transects sampled in 1980, 1985 and 1990. Conduct fish sampling in the Middle Fork Kaweah River from the park boundary to the confluence with the Marble Fork to determine the current status of the fish assemblage.

Some time-sensitive issues related to *Water Rights* were elevated during the report review by NPS Water Resources Division staff. Although not identified as a priority issue

during the 2003 scoping workshop, SEKI wanted to capture some of the water rights issues in this report. In the past, SEKI diverted most or all of the flow from Merritt Spring in Wilsonia for various uses in the Grant Grove area. SEKI stopped diverting flow from Merritt Spring in 2003, and now uses it only as a backup/emergency water source. Nevertheless, in the exercise of its riparian right, the park must consider the riparian rights and overlying rights of some landowners in Wilsonia downstream from the spring. The park's historical use of water diverted from the spring may be subject to question. Depending on how important these sources are for park visitor and administrative needs, a study should be considered to determine whether springs recharge the ground water beneath Wilsonia. If flows from other springs are diverted by the park in a fashion similar to Merritt Spring, the use of these other springs could also be questionable.

Each of these major issue categories has aspects that affect SEKI's water resources, though some are not under NPS control. It is therefore important to recognize that multi-agency communication and coordination are essential to successfully manage SEKI's vast watersheds. The next step for SEKI will be to work with watershed stakeholders, building from this report and developing a Water Resources Stewardship Report that designs strategies which work toward appropriate *desired conditions* for water resources.

INTRODUCTION

Sequoia and Kings Canyon National Parks (SEKI) protect 865,952 acres (350,431 ha) including a variety of water resources, along the western slope of the Sierra Nevada mountain range. Sequoia National Park was established as the nation's second national park in 1890. Kings Canyon National Park was established in 1940.

Designated as a unit of the International Biosphere Preserve Program, 85% of SEKI is designated Wilderness (National Park Service 1999). Biosphere Reserves are sites that are part of a world-wide network of natural reserves recognized for their roles in conserving genetic resources; facilitating long-term research and monitoring; and encouraging education, training, and the demonstrations of sustainable resources use (National Park Service 2001a). The parks contain approximately 3,365 lakes and ponds (U.S. Fish and Wildlife Service 2005) and 2,144 miles (3,450 km) of rivers and streams (U.S. Geological Survey 2005). Five major rivers originate in the two parks --- Kaweah, Kern, Kings, San Joaquin and Tule. Water from these rivers fuels important irrigation needs in the agriculturally-rich San Joaquin Valley. The waters from SEKI are thus not only important to park managers but also to water users throughout the region.

Historically, water in SEKI had been managed for human consumption and recreation. Maintaining natural aquatic systems was not a consideration, and as a result the aquatic resources are probably among the most altered resource in these two parks (National Park Service 1989). It is important for the National Park Service (NPS) to differentiate between natural versus anthropogenic-impacted environments so that mandated management is appropriately implemented for SEKI's water resources. Information that is gathered through inventory and monitoring of water resources in the parks can be used to determine how the water resources influence the ecosystem and are affected by changes (anthropogenic and/or natural changes).

Water Resources Planning

The NPS Water Resources Division initiated a program in 1991 that assists parks with their water resources planning needs. Recent changes in NPS general planning (new 2004 *Park Planning Program Standards*) and resources planning (draft *Director's Order 2.1: Resource Stewardship Planning*) required programmatic revision to the existing NPS Water Resources Planning Program to assure that its products support the new NPS planning framework within which planning and decision-making are now accomplished. Within this new planning framework, six discrete elements of planning are in place that is captured in six planning-related documents (Figure 1).

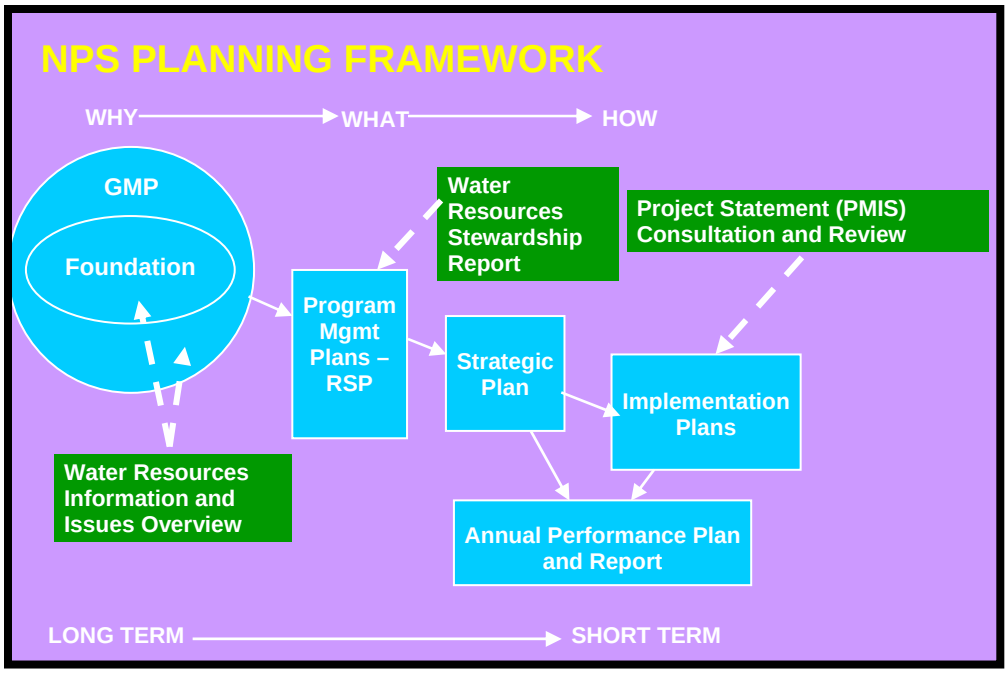

Figure 1. The 'new" NPS framework for planning and decision making (blue boxes). Green boxes represent WRD planning or assistance. RSP = Resource Stewardship Plan.

The *Foundation for Planning and Management* defines the legal and policy requirements that mandate the park's basic management responsibilities, and identifies and analyzes the resources and values that are fundamental to achieving the park's purpose or otherwise important to park planning and management.

The *General Management Plan* uses information from the *Foundation for Planning and Management* to define broad direction for resource preservation and visitor use in a park, and serves as the basic foundation for park decision-making, including long-term direction for d*esired conditions* of park resources and visitor experiences.

The *Program Management Plan* tiers off the *General Management Plan* identifying and recommending the best strategies for achieving the desired resource conditions and visitor experiences presented in the *General Management Plan*. Program planning serves as a bridge to translate the qualitative statements of *desired conditions* established in the *General Management Plan* into measurable or objective indicators that can be monitored to assess the degree to which the *desired conditions* are being achieved. Based on information obtained through this analysis, comprehensive strategies are developed to achieve the *desired conditions*. The *Program Management Plan* component for natural and cultural resources is the *Resource Stewardship Plan* (Figure 1).

The *Strategic Plan* tiers off the *Program Management Plan* identifying the highest-priority strategies, including measurable goals that work toward maintaining and/or restoring the park's *desired conditions* over the next 3 to 5 years.

Implementation Plans tier off the *Strategic Plan* describing in detail (including methods, cost estimates, and schedules) the high-priority actions that will be taken over the next several years to help achieve the *desired conditions* for the park.

The *Annual Performance Plan and Report* measures the progress of projects from the *Implementation Plan* with objectives from the *Strategic Plan*.

The *Water Resources Information and Issues Overview* and the *Water Resources Stewardship Report* will support this new planning framework. The *Water Resources Information and Issues Overview* (Figure 1) addresses the needs of either the *Foundation for Planning and Management* document or phase one of the *General Management Plan*, but is flexible in design in order to serve other unique park needs, as warranted. The *Water Resources Stewardship Report* (Figure 1) is designed specifically to address the water resource needs in a park's *Resources Stewardship Plan*.

Water Resources Information and Issues Overview Objectives and Structure

This report is a *Water Resources Information and Issues Overview* (WRIIO) for SEKI. The objectives of this report include identifying major water resources-related issues and presentation of relevant information and management considerations to better assist NPS managers with meeting their management objectives at SEKI.

The report is divided into five major parts. The first part includes a description of the applicable park-specific, Federal and State legislation that provides the mandates and foundation for management decisions related to water resources.

The second part contains a description of the parks' natural resources, with emphasis on water resources. This section provides the reader with an overview of SEKI's diverse environments, including some of the existing water-related information and issues.

The third part presents priority water-related issues generated from the November 19, 2003 Water Resources Scoping Workshop at SEKI (Figure 2). This section introduces the parks' water-related issues that were voted by the workshop participants as the "highest priority" and begins to identify some of the "information needs and strategies" that will better assist NPS management in providing a greater level of water resource protection.

Figure 2. November 19, 2003 Water Resources Scoping Workshop (Weeks, 2003).

The fourth part briefly describes SEKI's current staffing for natural resources, illustrating the need to seek external funding and human resources through partnerships in order to meet the demands for SEKI's water resource management.

The fifth part is the "Considerations for Future Actions." This section summarizes recommendations presented in the "Water Resources Issues" section, providing NPS management considerations for further addressing the identified issues, based on the information made available to the authors. Issue-specific recommendation(s) previously proposed by NPS management via SEKI planning documents (i.e., General Management Plan, Resources Management Plan) are included.

The initial information-gathering effort for this report included meetings in SEKI in 2003. During this time, the authors visited with park staff at Ash Mountain Headquarters, which provided a better understanding of the diverse water resources and associated issues. Information was derived from many sources, including interviews with SEKI staff and reviews of existing natural resources information from park files with emphasis on water resources.

Location and Demography

SEKI is located in east-central California (Figure 3). Park headquarters at Ash Mountain (in Sequoia National Park) is located 175 miles (282 km) north of Los Angeles and 215 miles (346 km) southeast of San Francisco. Kings Canyon is the northern NPS unit and consists of two sections (Figure 4). The small, detached General Grant Grove section, and the remainder of Kings Canyon National Park, which comprises over 90% of the total acreage of the park, is located in the subalpine and alpine region that forms the headwaters of the South and Middle Forks of the Kings River and the South Fork of the San Joaquin River. Sequoia National Park lies south of Kings Canyon and adjoins it (Figure 4). The park consists of a single unit that rises from the low western foothills to Mount Whitney on the crest of the Sierra Nevada at 14,494 ft (4,418 m) (msl). The park contains the majority of the headwaters of the Kaweah and Kern Rivers, and a small portion of the headwaters of the Tule River.

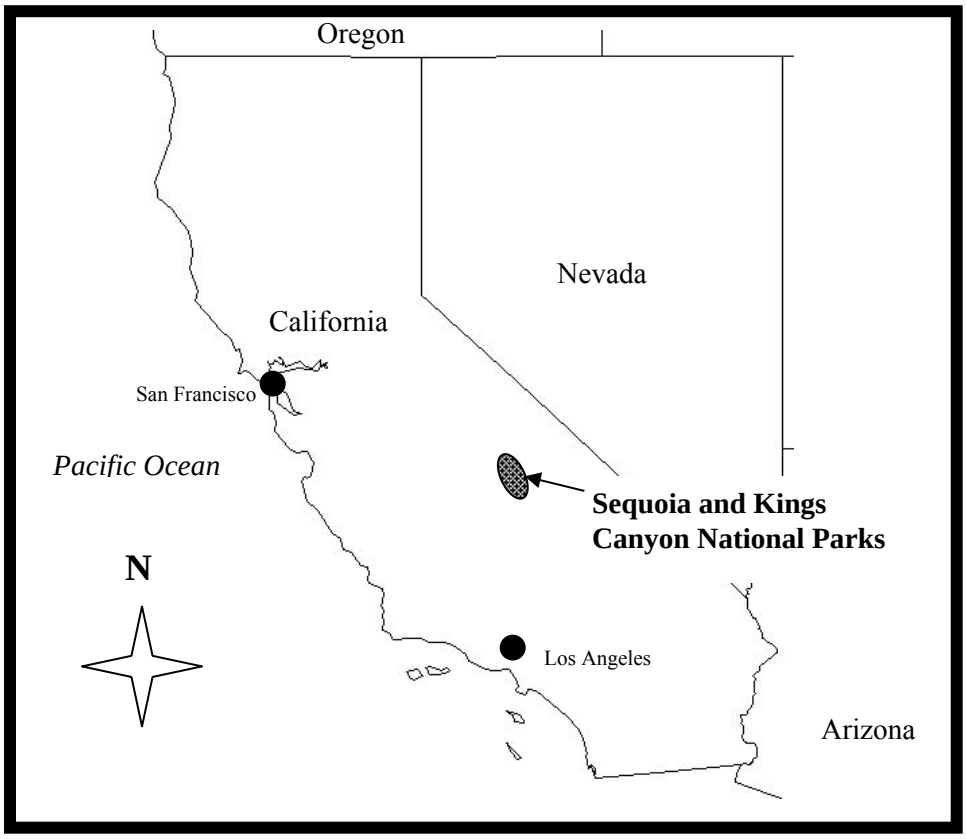

Figure 3. Regional Map, Sequoia and Kings Canyon National Parks.

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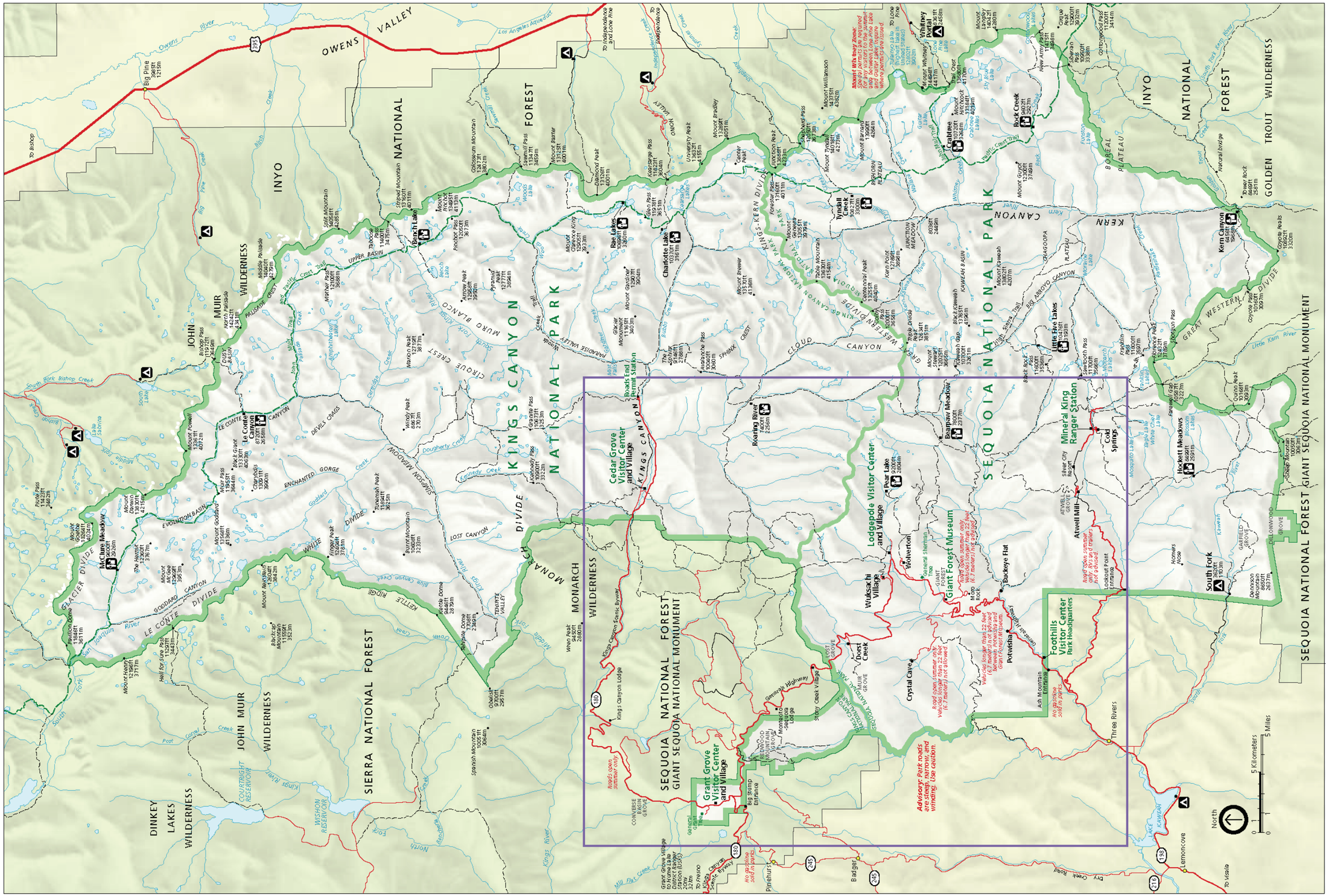


Figure 4. Sequoia and Kings Canyon National Parks

Legislation and Management

Park-specific

Numerous laws and executive orders enacted since 1890 have affected the current status of Sequoia and Kings Canyon National Parks, including the following significant pieces of legislation, as described in the Draft SEKI General Management Plan (National Park Service 2004a):

- On September 25, 1890, Sequoia National Park was established when President Benjamin Harrison signed legislation that created it as the second U.S. national park. The enabling legislation highlights natural resources preservation as the primary purpose for establishment, stating that *whereas, the rapid destruction of timber and ornamental trees in various parts of the United States, some of which trees are the wonders of the world on account of their size and limited number growing, makes it a matter of importance that at least some of said forests should be preserved*. This legislation also intended Sequoia to be *dedicated and set apart as a public park, or pleasuring ground, for the benefit and enjoyment of the people*, and managed *for the preservation from injury of all timber, mineral deposits, natural curiosities or wonders . . . [and for] their retention in their natural condition*. This legislation also states that fishing shall be permitted in accordance with regulations.

- On October 1, 1890, legislation increased the size of Sequoia National Park by almost three times (including the addition of Giant Forest), established General Grant National Park and extended the same protection to these areas as the original legislation.

- On July 3, 1926, legislation further enlarged Sequoia National Park and again stipulated the same protection for these new lands

- On March 4, 1940, legislation established Kings Canyon National Park, eliminated General Grant National Park while adding its lands to Kings Canyon National Park and again called for the same level of protection for this new park.

- On June 21, 1940, a Presidential proclamation added Redwood Canyon to Kings Canyon National Park.

- On August 6, 1965, legislation enlarged Kings Canyon National Park with the addition of Cedar Grove and Tehipite Valley and stated that management of these lands shall be consistent with all applicable park laws and regulations.

- On November 10, 1978, the National Parks and Recreation Act (Public Law 95-625) transferred U.S. Forest Service lands from the Sequoia National Game Refuge to Sequoia National Park to *assure the preservation* of Mineral King Valley while enhancing its *ecological values* and allowing for *public enjoyment*.

- On September 28, 1984, the California Wilderness Act established the Sequoia/Kings Canyon Wilderness and transferred lands in the Jennie Lakes area to Kings Canyon National Park.

- On November 3, 1987, the entire park segments of the Middle Fork and South Fork of the Kings River were established as Wild and Scenic Rivers; the lowest 7.6 miles (12.2 km) of the South Fork of Kings River within the park was also declared Recreational. The entire park segment of the North Fork of the Kern River was established as Wild and Scenic on November 24, 1987.

- On December 28, 2000, the addition of Dillonwood sequoia grove to Sequoia National Park was authorized by Public Law 106-574. The area was officially added on December 4, 2001, thanks to major contributions by Save-the-Redwoods League and the Wildlife Conservation Board.

Several areas within SEKI's boundary contain private inholdings. While some NPS regulations do not generally apply to private lands within the parks, there are several federal, state and local laws that do apply. These include but are not limited to the Clean Water Act, Clean Air Act and California Environmental Quality Act.

Other legislative provisions affecting these parks include:

- *Wilderness Areas:* On September 28, 1984, the California Wilderness Act (Public Law 98-425) created the Sequoia/Kings Canyon Wilderness, which designated 722,590 acres (, or 83.5%, of Sequoia and Kings Canyon National Parks as wilderness. As a result, these lands became subject to the provisions of the Wilderness Act of September 3, 1964 (Public Law 88-577), which defines wilderness as *an area of undeveloped federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions….* The act also added 1,756 acres to Kings Canyon National Park, including the Chimney Rocks area, which was determined suitable for wilderness but not designated. At the same time, three additional areas in Sequoia National Park were recommended for wilderness but not formally designated, including 35,321 acres in Redwood Canyon and the North Fork of the Kaweah River and 56,201 acres on Hockett Plateau. The 15,600 acre Mineral King area that was added to Sequoia National Park in 1978 also has been determined suitable for wilderness, minus the road corridor and existing development. The 1,518 acre Dillonwood addition of 2001, however, was found to be not suitable for wilderness. Two partially-developed areas are designated as potential wilderness, including Bearpaw High Sierra Camp and Oriole Lake, which would become wilderness if facilities are ever removed. SEKI manages all of these backcountry areas as wilderness, and thus a total of 832,756 acres, or 96.2%, of Sequoia and Kings Canyon National Parks are being managed to preserve wilderness character.

- *Wild and Scenic Rivers:* The Wild and Scenic Rivers Act of October 2, 1968 (Public Law 90-542) states that designated rivers *shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations*. The act was amended on November 3, 1987 (Public Law 100-150) to designate as wild and scenic all 29.5 miles of the Middle Fork of the Kings River and all 31.7 miles of the South Fork of the Kings River within Kings Canyon National Park. The lower 7.6 miles of the South Fork of the Kings River within Kings Canyon National Park was also designated as recreational. An additional amendment on November 24, 1987 (Public Law 100-174) designated as wild and scenic all 28.9 miles of the North Fork of the Kern River within Sequoia National Park.

- *Hydroelectric Facilities:* Congress authorized the construction of hydroelectric facilities on the East, Marble and Middle Forks of the Kaweah River in (and adjacent to) Sequoia National Park. The authorization resulted in the construction of four storage dams above Mineral King Valley in 1899. The Kaweah No. 3 Hydroelectric Plant was then mistakenly constructed on the Park's boundary (versus adjacent to it) beginning in 1907. This led to some congressionally approved land swapping that resulted in the current boundary configuration in the area of the power plant. Kaweah No. 3 became operational in 1913 and was granted a 50-year lease. The project dams and diverts water on the Middle and Marble Forks of the Kaweah River inside Sequoia National Park and generates electricity at the plant on the park boundary.

  On June 21, 1963, Public Law 88-47 authorized the NPS to renew the hydroelectric lease and allow operations to continue on the Marble and Middle Forks of the Kaweah River until no later than August 6, 1974.

  In 1974, Public Law 93-522 authorized the NPS to renew the hydroelectric permit and allow operations to continue on the Marble and Middle Forks of the Kaweah River for ten more years. This law also required the NPS to study the impacts of these hydroelectric facilities on park resources and report to Congress by 1984.

  In 1978, Public Law 95-625 transferred the Mineral King area along with the four storage dams on tributaries of the East Fork of the Kaweah River from the U.S. Forest Service to the NPS. It also amended Public Law 93-522 to include these hydroelectric facilities in the Mineral King addition.

  In 1984, the impacts of these hydroelectric facilities on park resources were determined to be not significant (Jordan/Avent and Associates 1984), resulting in a renewal of the license and permit. On June 19, 1986 Public Law 99-338 authorized the NPS to issue a new ten-year permit to Southern California Edison (SCE) for operations to continue at the Kaweah hydroelectric facilities, and to issue not more than one additional permit, which was issued in 1996. The current permit expires on September 8, 2006, when these hydroelectric facilities are required to terminate operations and restore the affected areas.

The broad ideals and vision that the NPS is striving to achieve through the legislative mandates and NPS policies described above are articulated by the following SEKI mission statement (National Park Service 2004a):

> *The mission of Sequoia and Kings Canyon National Parks is to protect forever the greater Sierran ecosystem - including the sequoia groves and high Sierra regions of the parks - and its natural evolution, and to provide appropriate opportunities to present and future generations to experience and understand park resources and values.*

The legislations and policies described above also were incorporated into SEKI's Strategic Plan and Resource Management Plan (RMP). In the SEKI Strategic Plan, broad direction is provided using mission goals that are statements based on the parks' purpose and significance. The mission goals describe what success would be like for the resource. Essentially they are visions for the future; a list of desired conditions that should exist to fully accomplish the parks' purpose and maintain its significance. The SEKI RMP states resource goals that elaborate on the parks' mission goals, including the following goals for natural resource conditions and visitor experiences:

> MISSION GOAL Ia: Natural and cultural resources and associated values are protected, restored, maintained in good condition and managed within their broader ecosystem and cultural context.
>
> - Native plants are preserved as part of natural functioning ecosystems.
> - Natural populations of wildlife in which animal behavior and ecological processes are essentially unaltered by human activities are perpetuated
> - Air quality is restored to natural conditions.
> - Geological resources, including cave natural and cultural resources and karstic processes, which are of scientific, scenic and recreational value, are restored, protected, and maintained.
> - Aquatic and water ecosystems are restored/and or maintained so that physical, chemical, and biotic processes function uninfluenced by human activities:
>
> - Aquatic environments are inventoried and classified by physical and chemical characteristics and biotic communities present.
> - A long-term monitoring program is developed to record ambient conditions and to document changes and trends in physical and chemical characteristics and biotic communities.
> - Changes within the aquatic environments that are caused by facilities, management activities or visitor use pattern are located and documented and unnatural changes are mitigated.
> - Park watersheds meet state water quality standards or applicable federal standards.
> - Impacts of acid deposition and contaminants from external influences are detected and evaluated.

- Lakes with exotic trout are restored to natural conditions.
- Extant native species or genetically unique groups are restored to their former range.
- Waters incapable of sustaining fish populations through natural reproduction will be allowed to become fishless.

MISSION GOAL Ib: Legally designated and protected wilderness is managed to meet the standards and ideals of the Wilderness Act and as a component of a larger regional wilderness area.

- Natural resources within wilderness areas are restored to natural conditions.
- Natural resources within wilderness areas are managed to preserve wilderness character.

MISSION GOAL Ic: The parks' contribute to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on the best available scholarly and scientific information.

- A thorough knowledge of the state of the parks' natural resources is known.
- Scientific research that promotes an understanding of the parks' resources and the impacts that affect those resources is encouraged.
- The general ecosystem elements and processes of the parks, the natural forces controlling them, and the potential for human activities to affect them are understood.
- A Long-Term Ecological Monitoring Program, including vital signs and a complete inventory of the parks' natural resources, is implemented.
- Giant sequoia ecology and the impacts of human activities on the trees and the ecosystem they inhabit are known.
- Current and potential effects on the parks' natural resources from external stressors, including exotic organism invasions, air pollution, anthropogenic global change, and boundary/island effects are known and understood.
- An information storage and analysis system that effectively and efficiently provides the parks with accurate and comprehensive parks' natural resources information is developed.
- Significant natural resources information is made available to the visitor, the public, and the park staff.

MISSION GOAL IIa: Visitors safely enjoy and are satisfied with the availability, accessibility, diversity, and quality of park facilities, services, and appropriate recreational opportunities.

MISSION GOAL IIb: Park visitors and the general public understand and appreciate the preservation of the parks and their resources for this and future generations.

MISSION GOAL IVa: Sequoia and Kings Canyon National Parks use current management practices, systems, and technologies to better preserve park resources and to better provide for public enjoyment.

MISSION GOAL IVb: Sequoia and Kings Canyon National Parks increase managerial resources through initiatives and support from other agencies, organizations, and individuals.

In SEKI's Aquatic/Water Resources Management Plan (National Park Service 1989), the park-specific goal and objectives for management of water resources were:

Goal

To restore and/or maintain natural aquatic environments in which physical, chemical, and biotic processes function uninfluenced by human activities; and to inform all visitors and employees of aquatic hazards.

Objectives

- To inventory and classify aquatic environments by physical and chemical characteristics and biotic communities present; identify both common and unique aquatic systems.
- To maintain long-term monitoring stations in representative aquatic environments to record ambient conditions and to document changes and trends in physical and chemical characteristics and biotic communities; to be able to detect and distinguish between daily, seasonal, and long-term shifts or cycles.
- To locate and document the magnitude and direction of changes in aquatic environments which are caused by management activities or visitor use patterns; and to develop and implement management programs to mitigate those activities.
- To detect and evaluate conditions and characteristics of external influences such as acid precipitation.
- To recognize aquatic conditions that are potentially hazardous to human health and safety; to implement programs to advise visitors of health hazards and to take corrective action where the cause is not natural.
- To monitor the quality of water entering and leaving these Parks with regard to compliance with local, State and Federal standards for surface water.
- To comply with State and local water quality requirements at each of the Parks' water and sewage systems.
- To acquire sufficient knowledge about the water quality of these Parks to be able to provide intelligent input into State and local water management planning.
- To monitor water chemistry within Little Kern golden trout habitat.
- To develop fishing regulations and other management practices that favor survival and perpetuation of native over exotic species.
- To restore extant native species or genetically unique groups to their former range.

- To allow waters incapable of sustaining fish populations through natural reproduction to become barren of fish.
- To mitigate human influences affecting the natural densities and age-class distributions of native species.
- To inventory distribution and abundance of all fish species at 10-year intervals.
- To monitor the distribution of fishing effort and fisherman success.
- To enforce and document fisherman compliance with regulations.
- To monitor effect of existing management practices on fish populations.
- To control, and if possible eliminate, exotic beaver and other exotic organisms.

Federal

Management of SEKI's water resources is also guided by many additional federal laws and NPS policies. (For further information access the web pages for the U.S. Environmental Protection Agency (www.epa.gov) and the U.S. Fish and Wildlife Service (www.fws.gov).)

- The *National Park Service Organic Act* of 1916 created the NPS and includes a significant management provision stating that the NPS *shall promote and regulate the use of the federal areas known as national parks, monuments, and reservations by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for future generations*. The Organic Act also authorizes the NPS to *regulate the use* of national parks and develop rules, regulations and detailed policies to implement the broad policies provided by Congress. Rules and regulations for the national park system are described in the *Code of Federal Regulations* (Title 36).

- The *General Authorities Act* of 1970 strengthened the 1916 *Organic Act*, stating that lands in all NPS units, regardless of title or designation, shall have a common purpose of preservation. All water resources in the national park system, therefore, are equally protected by federal law. It is the primary duty of the NPS to protect those resources unless otherwise indicated by Congress.

- The *Redwood National Park Act* of 1978 amended the *General Authorities Act* of 1970, identifying the *high public value and integrity of the national park system* as reason to manage and protect all park system units. The act further stated that no activities should be allowed that will compromise the *values and purposes for which these various areas have been established*, except where specifically authorized by law or provided for by Congress.

- The *National Parks Omnibus Management Act* of 1998 outlines a strategy to improve the ability of the NPS to provide high-quality resource management, protection, interpretation and research in the national park system by:

- Fostering the collection and application of the highest quality science and information to enhance management of units of the national park system;
- Authorizing and initiating cooperative agreements with colleges and universities, including but not limited to land grant schools, along with creating partnerships with other Federal and State agencies, to construct cooperative study units that will coordinate multi-disciplinary research and develop integrated information products on the resources in national park system units and/or the larger region surrounding and including parks;
- Designing and implementing an inventory and monitoring program of national park system resources to collect baseline information and to evaluate long-term trends on resource condition of the national park system, and;
- Executing the necessary actions to fully and properly apply the results of scientific study to park management decisions. Additionally, all NPS actions that may cause a significant adverse effect on a park resource must conduct unit resource studies and administratively record how study results were considered in decision making. The trend in resource condition in the national park system shall be a critical element in evaluating the annual performance of the NPS.

- The *National Environmental Policy Act* (NEPA) of 1969 requires that any action proposed by a federal agency that may have significant environmental impacts shall *utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment*.

- The *Clean Air Act* of 1970 (as amended in 1990) regulates airborne emissions of a variety of pollutants from area, stationary, and mobile sources. The amendments to the act were added primarily to fill gaps in earlier regulations pertaining to acid rain, ground level ozone, stratospheric ozone depletion and air toxics, and also to identify 189 hazardous air pollutants. The act directs the U.S. Environmental Protection Agency to study these pollutants, identify their sources, determine the need for emissions standards and develop and enforce appropriate regulations.

- The 1972 *Federal Water Pollution Control Act*, also known as the *Clean Water Act*, strives to restore and maintain the integrity of U.S. waters. The Clean Water Act grants authority to the states to implement water quality protection through best management practices and water quality standards. Section 404 of the act requires that any dredged or fill materials discharged into U.S. waters, including wetlands, must be authorized through a permit issued by the U.S. Army Corps of Engineers, which administers the Section 404 permit program. Additionally, Section 402 of the act requires that pollutants from any point source discharged into U.S. waters must be authorized by a permit obtained from the National Pollutant Discharge Elimination System (NPDES). All discharges and storm

water runoff from major industrial and transportation activities, municipalities, and certain construction activities generally must be authorized by permit through the NPDES program. NPDES permitting authority typically is delegated to the state by the U.S. Environmental Protection Agency.

- The *Endangered Species Act* of 1973 requires the NPS to identify all federally listed endangered, threatened and candidate species that occur within each park unit and promote their conservation and recovery. The act requires that any activity funded by federal monies that has the potential to impact endangered biota must be consulted through the Secretary of Interior. It requires agencies to protect designated critical habitats upon which endangered and threatened species depend. Although not required by law, it also is NPS policy to identify, preserve and restore state and locally listed species of concern and their habitats.

- *Executive Order* 13112: *Invasive Species* enhances and furthers the existing authority of the federal government to assist in preventing and controlling the spread of invasive species.

- *Executive Order* 11990: *Wetlands Protection* requires the NPS to 1) exhibit leadership and act to minimize the destruction, loss, or degradation of wetlands; 2) protect and improve wetlands and their natural and beneficial values; and 3) to refrain from direct or indirect assistance of new construction projects in wetlands unless there are no feasible alternative to such construction and the proposed action includes all feasible measures to minimize damage to wetlands.

- *Executive Order* 11988: *Floodplain Management* has a primary objective …*to avoid to the extent possible the long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct and indirect support of floodplain development wherever there is an practicable alternative*. For non-recurring actions, the order requires that all proposed facilities must be located outside the boundary of the 100-year floodplain. Barring any feasible alternatives to construction within the floodplain, adverse impacts are to be minimized during the design phase of project planning.

- *Executive Orders* 11644 and 11989: *Off-Road Vehicle Use* direct federal land management agencies to control the use of off-road vehicles (ORV) on public lands. Executive Order 1164 requires ORV trails and areas to be designated in a manner that protects the resources of public lands. Executive Order 11989 requires federal agencies to ban ORV use in an area if such use is causing or will cause adverse effects on soil, vegetation, wildlife, habitat, or cultural or historic resources.

State of California

The following paragraph is excerpted from page 16 of the Vital Signs Monitoring Plan Phase 1 Report of the Sierra Nevada Network (National Park Service 2004b):

> The California State Water Resources Control Board (SWRCB) and nine Regional Water Quality Control Boards (RWQCB) are responsible for protecting and enhancing California's water resources under the Porter-Cologne Water Quality Control Act. Each RWQCB adopts Basin Plans, which contain beneficial use designations, water quality objectives and implementation programs. Sierra Nevada Network parks (SIEN), which includes SEKI, fall under jurisdiction of the Central Valley RWQCB 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 must assess 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 a process to bring listed waters back into compliance. SIEN parks do not contain any 303(d) listed waters (State Water Resources Control Board 2002). The State also has authority to designate waters as Outstanding Natural Resource Waters - the highest level of protection afforded to a water body. SIEN parks do not have any Outstanding Natural Resource Waters, but national park waters are strong candidates for this designation.

The laws and regulations governing California's water quality can be retrieved at (http://www.swrcb.ca.gov/water_laws/index.html). Many entities, including federal, state and local agencies and private landowners, have an interest, mandated or otherwise, in SEKI's water resources. Effective protection of water resources requires these entities to understand the various policy, regulatory and management designations associated with the parks' waters in order to foster coordination and cooperation in SEKI.

All federal lands and waters within the parks are under proprietary jurisdiction of the National Park Service. Both federal and state agencies have authority for the enforcement of appropriate regulations. Water laws and regulations at the state and local level are often patterned after federal laws, or serve in response to federal directives.

Water Rights (following provided by NPS Water Resources Division, Water Rights Branch, McGlothlin, 2005)

Overview – NPS Policy and Authorities

Water rights, whether federal or state law-based, are needed by the park to meet the water needs of park personnel and visitors, and to protect the parks' water or its water-dependent resources. Because SEKI is located at the headwaters of drainage basins, the risk to resources from private water development in or adjacent to the park is relatively low.

Legislative authorities for NPS water rights in California include California Water Commission Act, NPS Organic Act, Wild and Scenic Rivers Act, and various park-

specific enabling acts. The NPS will obtain and use water in accordance with these legal authorities. The NPS will consider authorities under California and federal law on a case-by-case basis and will pursue those that are most appropriate to accomplish the purposes and protect water-related resources at SEKI. While preserving its legal remedies, the NPS will work with state water administrators to protect park resources and, if conflicts amongst multiple water users arise, will seek their resolution through good faith negotiations.

Authority for the determination and adjudication of water rights under California law is given to the SWRCB, which issues water rights for surface water and ground water flowing in known and definite channels, pursuant to the Water Commission Act or the Water Code, initiated on December 19, 1914. California law also recognizes other water rights to use surface waters other than rights initiated under the water code, including rights initiated before December 19, 1914, and riparian water rights. All rights, regardless of type, are limited to reasonable use (California Constitution, Article X, Section 2). The Water Code allows SWRCB to adjudicate all rights to the use of surface waters within a given stream system, regardless of origin. The NPS can hold each of these different types of California water rights or Federal reserved water rights. These types of water rights are described below.

State Appropriative Water Rights

A State appropriative water right allows a specific amount of water from a specific water source, such as a river or subterranean streams flowing through known and definite channels, to be diverted, impounded, or withdrawn for a specific use. The California Water Commission Act governs the acquisition and exercise of rights to reasonable and beneficial use of surface streams, other surface bodies of water, or ground water flowing in known and definite channels by priority of appropriation. When a water right is granted, it becomes appurtenant to the land where the water is being used for as long as the water is being used. If the land is sold, the water right transfers with the land to the new owner, unless the conveyance document excludes water rights from the conveyance. The State uses the Prior Appropriation Doctrine to allocate water. This doctrine establishes a right to the use of water based upon "first in time, first in right." Water rights are given priority based upon the date of application. There are two forms of state appropriative rights – rights obtained pursuant to the Water Code, and so-called "pre-1914 rights". Post-1914 rights are governed by a licensing system. Prior to the Water Code, appropriative water rights could be acquired by simply taking and beneficially using water. Successful assertion of an appropriative right which was initiated prior to December 19, 1914 requires evidence of both the original appropriation and the maintenance of the right by continuous and diligent application of water to beneficial use. Pre-1914 rights may be documented in a Statement of Water Diversion and Use filed with the SWRCB.

NPS water right records show that SEKI has at least one licensed right and may, with the acquisition of private lands within the parks, also have pre-1914 rights.

Riparian Rights

The owner of land abutting natural water sources (stream, lake, spring) has the right to take water from that source for "reasonable use". These rights do not require compliance with the Water Code, but are, rather, confirmed through the courts. All return flows must be returned to the original water source. Riparian rights apply only to lands adjacent to and within the same watershed as a water body and the water must be used upon riparian land. Under a claim of riparian right, water cannot be generally stored and withheld for a deferred use, although storage of water in tanks for later use pursuant to a riparian right is allowed. A riparian owner shares the water supply co-equally with other riparian owners. If a water shortage exists, the burden is shared by all riparian users.

The United States has the same right as any other riparian landowner (California State Water Resources Control Board, 1990: *in re*: Water of Hallett Creek Stream System, 1988, 243 Cal. Rptr. 887). Although they are very poorly defined, NPS has riparian rights for consumptive water uses in the parks; state law does not recognize a riparian right for instream flow purposes. Riparian rights may have been acquired by the United States with the purchase of private lands and are also associated with lands within the parks that were formerly public domain.

Federal Reserved Water Rights

The federal reserved water right is a judicially-created water right – the result of a series of United States Supreme Court opinions dating back to 1907. The United States Supreme Court has held that where water is needed to fulfill the purposes of a reservation of federal land, Congress intended (often impliedly) to reserve that amount of water needed to fulfill the purpose of the reservation. Such reservations of water have been recognized for national forests, national parks, and national recreation areas. A reservation of water is implied to meet only the "primary" purposes of the reservation; water needed for "secondary" purposes should be obtained through a state's appropriative system.

In order to fully assess the existence and nature of a federal reserved water right associated with SEKI, an examination of the legislation creating SEKI would be necessary. If needed to fulfill the purposes of the federal reservation, a federal reserved right may be either for consumptive purposes (e.g., involving diversion of water from the stream) or for non-consumptive purposes (e.g., involving instream uses of water). A federal reserved right associated with these purposes would be limited to that amount needed to accomplish those purposes. The effective date of a federal reserved water right is the date the reservation was made. While a federal reserved water right ordinarily comes into existence upon the reservation of federal land for a specific purpose, its existence can be confirmed, and its exact contours (i.e., purpose, amount, timing, source) ascertained, only through adjudication. Until such adjudication, the existence and contours of a federal reserved right are a matter of estimation.

In 1952, Congress passed the McCarran Amendment, which consented to the joining of the United States in state suits determining the water rights of all users in a watershed. This allows federal reserved water rights to be determined in conjunction with state water rights. Once adjudicated, federal reserved rights are recognized and may be administered through the state's water rights administrative system. No adjudications have been initiated by the State within the vicinity of SEKI.

Land Use and Land Disturbance

Historical Perspective

This section is referenced from Dilsaver and Tweed (1991), Strong (1996), and the Vital Signs Monitoring Plan Phase 1 Report of the Sierra Nevada Network (National Park Service 2004b).

The lands in SEKI were first used by Native Americans thousands of years ago. Local groups included the Monache and Yokuts in the west slope canyon country and the Tubatulabal in the Kern River drainage. Although these groups lived with limited impact on the lands, they used fire to stimulate plant growth and assist in hunting, which resulted in alteration of the local vegetation. It was not until 1856 that the first white settler, Hale Tharp, arrived in the Kaweah drainage and trekked to Giant Forest. By 1861, he built a cabin and trail in Giant Forest for use as summer rangelands for horses and cattle. Ultimately, Caucasian diseases were fatal to a large percentage of the local Native Americans. The surviving natives eventually moved out of the area to escape the fate of these diseases.

The settlers that replaced the Native Americans largely came for utilitarian reasons, including sheep and cattle grazing, gold and silver mining, logging or road and trail building. These activities ruled the area for 30 years, and combined with no government control of public land use, inflicted widespread damage to the mountain ecosystems.

In particular, sheepherders started uncontrolled fires to facilitate sheep movement, while the sheep were effective at grazing almost up to mountain summits and their sharp hoofs severely damaged moist areas. A few local ranchers also ran cattle in the mountains in summer and competed for available pasture land.

Prospectors spent many years unsuccessfully mining for minerals until 1873, when silver was discovered in Mineral King, triggering a rush of land claims and mine construction. Although these mines also proved unprofitable, they facilitated the construction of the Mineral King Road in 1879, as well as a mill and a tramway to Empire Mine.

Logging, however, had a much greater impact than mining. As early as 1853, some of the finest giant sequoias (*Sequoiadendron giganteum*) were cut for exhibits on the east coast. Several mills were supplying local markets by the 1860s, and then distant markets by the mid-1870s due to the completion of the Southern Pacific Railroad in the San Joaquin Valley. In 1885, the Kaweah Colony claimed, perhaps fraudulently, extensive tracts of land in Giant Forest and built an eighteen-mile road through rugged country to the edge

of the forest. They constructed a small sawmill and only produced a small amount of lumber, when the federal General Land Office set aside eighteen townships, including these claimed lands, for possible parklands and prevented their acquisition by private parties. In 1889, log flumes were introduced to the area that allowed harvest of previously inaccessible timberlands. One flume was used by the Kings River (then Sanger) Lumber Company to harvest nearly every tree in Converse Basin, which perhaps was the most superb stand of giant sequoias in existence.

The campaign to create Sequoia National Park was conducted by San Joaquin Valley residents that had a common goal to conserve the region's 1) giant sequoia groves and 2) water quality and water supply from an intact forested watershed. The effort was initiated in response to developments at the time in which many of the regional giant sequoia groves were being obtained and harvested by logging groups. Sequoia National Park was established on September 25, 1890, making it the second oldest national park in the United States. The original boundary proposal included what local supporters believed were the largest and best of the unclaimed sequoia groves remaining in the world.

One week later, on October 1, 1890, Congress tripled the size of the new park and preserved additional sequoia groves that at the time were under the control of logging enterprises. Because the two acts of 1890 established boundaries along section lines, Sequoia National Park also included mixed conifer forestlands and considerable tracts of both foothill and High Sierra. The second act also created four-square-mile General Grant National Park to protect the General Grant Tree and surrounding forest.

In 1891, one year after the creation of the parks, the Kaweah Colony's land claims were denied. Most of the colonists moved away, while a few leased 160 acres (65 ha) of private lands within Sequoia National Park from the Atwell estate and began harvesting timber. The threat of legal action, however, ended this enterprise soon thereafter. In 1903, the federal government completed the road to Giant Forest, which served as the main access road into the park for many years.

In 1890, Congress had provided no funds or management direction for the new parks, and thus protecting the parks was difficult at first. Military personnel were sent to protect the area from trespassers and looters, but not enough troops were provided for adequate protection. The guards also lacked authority to make arrests, which failed to deter repeated illegal entries into the parks by sheepherders, cattle stockmen and hunters. Continued widespread grazing nearly eliminated available feed for military patrol horses, the lack of trails made many parts of the parks inaccessible, and snow prevented animal protection in the parks in fall, winter and spring.

In 1900, Congress began to provide a limited amount of funding for protection and improvement of the parks. However, since national parks had neither a clear mandate nor a strong advocate in Washington D.C., the federal government yielded to local business pressures and allowed commercial development in the parks. In particular, the Mount Whitney Power Company was allowed to build a series of hydroelectric power plants on the Kaweah River, as well as roads, flumes and dams in the park.

After 1900, military personnel were gradually replaced by civilian rangers until 1914, when the military withdrew permanently and Walter Fry became the first civilian superintendent of Sequoia and General Grant National Parks. The creation of the National Park Service in 1916 instantly provided a committed staff of professionals and a permanent advocate for national parks, thus bringing marked change to park administration. Changes included increased funding for protection and interpretation personnel and development of roads, trails, and visitor facilities.

By 1930, better infrastructure and road access combined with promoting visitation through advertising were attracting record numbers of visitors to the parks. A private concessionaire had built more than 200 wood and tent cabins in Giant Forest, including lodging, dining and retail facilities. By 1934, the road and trail system of the two were virtually complete and looked much like it looks today.

Sequoia National Park was enlarged significantly in 1926 and 1978. The 1926 enlargement contained superlative alpine areas, including Mt. Whitney, the highest mountain in the contiguous United States. The 1978 enlargement notably included the Mineral King area, which previously had been a part of the Sequoia National Forest. Alpine and subalpine in character, the Mineral King basin had been proposed by the Forest Service for development as a major downhill ski resort. Congress added the basin to the national park with the specific instruction that it would be preserved undeveloped. In recent years, a new appreciation has developed which suggests that the parks' "buffer lands" are far more important than previously thought, and that the parks' greatest value is in its wholeness.

The small General Grant National Park existed unchanged for fifty years. In 1940, however, responding finally to a two-decade-long political campaign, Congress created Kings Canyon National Park. In addition to incorporating the four square miles of General Grant National Park and several other adjacent sequoia groves, the new Kings Canyon National Park also featured the great glacial canyons and scenic alpine headwaters of the South and Middle Forks of the Kings River. Because the new park contained two separate tracts, one featuring giant sequoia trees and the other canyons and alpine scenery, Kings Canyon's dual nature was readily apparent from the beginning. In 1940, as a political compromise, the floors of the park's two great glacial canyons were left outside its boundaries as possible reservoir sites. This situation was rectified in 1965 when Congress added the floors of Kings Canyon and Tehipite Valley to the park.

Present Day

This section is excerpted from Appendix B of the Vital Signs Monitoring Plan Phase 1 Report of the Sierra Nevada Network (National Park Service 2004b):

> In 2004, Sequoia and Kings Canyon National Parks have five major developed areas that cover 1,000 acres (405 ha). There are approximately 1,000 buildings and 152 miles (245 km) of paved and unpaved roads. The developed areas in Sequoia National

Park are Ash Mountain, Lodgepole/Giant Forest, and Mineral King. Developed areas in Kings Canyon National Park are Grant Grove and Cedar Grove. These developments are located at low and middle elevations and are accessed from the western side of the parks.

The Ash Mountain area is located in the foothills along General's Highway and is the main entrance into Sequoia National Park. Located at Ash Mountain are the Foothill's Visitor Center, park headquarters, and employee housing. The Giant Forest, Lodgepole and Wuksachi areas are also along the General's Highway, 17 to 27 miles (27 to 43 km) from Ash Mountain and at elevations from about 6,400 to 7,000 ft (1,951 to 2,134 m)(msl). Historically, Giant Forest was the center of visitor services in Sequoia National Park. From 1997 to 2002, the NPS removed most of the structures associated with the visitor services and restored the sequoia groves to a more natural condition. Several buildings and parking areas were retained and include the Giant Forest Museum, the Beetle Rock Education Center, the Pinewood Picnic Area, and parking areas and comfort stations associated with specific attractions and trail heads. Wuksachi, built from 1985-1999 to replace visitor services removed from Giant Forest, is the newest development in the park. There are three hotel buildings, a main lodge, fire station and employee housing located in the Wuksachi area. Lodgepole is also a well developed area and popular visitor destination. Facilities at Lodgepole include a visitor center, market, campground, maintenance facilities and employee housing. The Mineral King area is the most removed of the developed areas in Sequoia National Park. It has a separate park entrance that is accessed by traveling 25 miles (40 km) on the Mineral King Road out of Three Rivers. Mineral King contains two campgrounds, a ranger station, pack station and employee housing. In addition there are 58 private and 62 active permit cabins located along or near Mineral King Road. A small and remote developed area that is surrounded by designated wilderness also exists near Oriole Lake in Sequoia National Park. This area contains five cabins that are owned by four private landowners, and four additional tracts that are owned by the NPS.

In Kings Canyon National Park, Grant Grove is located roughly 3 miles (4.8 km) from the Highway 180 entrance station and is at an elevation of about 6,600 ft (2,012 m) (msl). Grant Grove has many visitor accommodations, including a visitor center, the John Muir Lodge, campgrounds, restaurants, and gift shop. In addition, there are also park offices, employee housing and a pack station in the area. Cedar Grove is located along the South Fork of the Kings River in the valley of Kings Canyon. Facilities in this area include campgrounds, ranger stations, a lodge, employee housing and parking lots associated with specific visitor attractions and trail heads. Adjacent to Grant Grove and the Kings Canyon Highway but hidden from public view is the Wilsonia subdivision. This area contains 56 privately-owned tracts covering 190 acres (77 ha), and 92 additional tracts that the NPS has acquired and now owns.

DESCRIPTION OF NATURAL RESOURCES

Climate

SEKI is located within a Mediterranean climate which typically has only two real seasons, the dry season which starts in summer and continues through fall and the wet season which occurs from late fall through spring. In most years, the summer months remain completely dry with no rain from late May to September (Despain 2003). As a result of the vast range of elevation within the park, there are three distinct weather regions. The lowest elevation region is called the foothills, which ranges from about 1,000 to 5,000 ft (305 to 1,524 m) (msl). The next region is the middle-elevation, also known as montane, which ranges from about 5,000 to 9,000 or 10,000 ft (1,524 to 2,743 or 3,048 m) (msl) depending on aspect. The highest elevation is called the subalpine/alpine, which includes everything above 9,000 to 10,000 ft (2,743 to 3,048 m) (msl) depending on aspect (National Park Service 2004c).

The foothills region follows a Mediterranean climate pattern with dry summers and wet winters. These common winter rains produce an average annual rainfall accumulation of 26 inches (68.6 cm). The average annual high temperature in the foothills is 76°F (24.4°C) with an average low of 48°F (8.9°C). The maximum and minimum temperature ranges from 18°F (-7.8°C) to 114°F (45.6°C) (National Park Service 2004c). Ash Mountain Headquarters located inside Sequoia National Park is at an elevation of 1,700 ft (518 m) (msl) with an average temperature at this site of 63°F (17.2°C) (Jordan/Avent and Associates 1980).

In the middle (montane) elevations, the temperatures are cooler and the precipitation is greater than in the foothills. The average annual precipitation for the middle elevations is 40 to 45 inches (102 to 114 cm). A large portion of the precipitation in the montane region arrives as snow; accumulation typically begins in December and can remain through May (National Park Service 2004c). Giant Forest at an elevation of 6,400 ft (1951 m) (msl) has an average snowfall of 40 inches (102 cm) (Jordan/Avent and Associates 1980). In the montane region, the average annual high temperature is 57°F (13.9°C) with an average annual low of 35°F (1.7°C), while the extremes have ranged from -6°F (-21.1°C) to 96°F (35.6°C) (National Park Service 2004c).

Due to its extreme elevation, the subalpine/alpine region (above 9,000 to 10,000 ft (2,743 or 3,048 m) (msl) depending on aspect) is prone to fast changing weather conditions, including infrequent thundershowers. The alpine region commonly has summer night time temperatures below freezing. Because of these consistently low temperatures the alpine region receives much of its precipitation in the form of snow (Jordan/Avent and Associates 1980). Snow depth averages increase greatly with increased elevation. From February to March the average snow depth at 7,900 ft (2,408) (msl) is five feet and at 10,500 ft (3,200 m) (msl) the average depth is 12 feet (3.6 m) (National Park Service 1989). Typically, the majority of this snowpack accumulates from January through March and melts from April to June (Werner, pers. comm. 2005).

The parks have an extensive climate database. Currently, there are over 30 active climate stations within SEKI, these stations measure precipitation and snow water equivalents. A few decommissioned stations also have associated data. Within the parks there are five Remote Area Weather Stations (RAWS), some collecting data year-round and the others collecting data only during the fire season. RAWS gather data on temperature, precipitation, relative humidity, and wind speed and direction (National Park Service 1999). The climate stations are located at many different elevations. Station locations range from the foothills (approximately 1,500 ft (457 m) (msl)) to subalpine/alpine (over 10,000 ft (3,048 m) (msl)) environments, covering all climate regions within SEKI. Due to the distribution of stations and the type of data collected, an accurate representation of precipitation, temperature and snowfall for each climate region could be created if the data were compiled in an appropriate manner. The data for the climate stations and the RAWS can be typically found in a digital format online.

Wind patterns in SEKI are complex due to the rugged and non-uniform terrain and intense daytime solar radiation. To the west of the southern Sierra Nevada are the San Joaquin Valley, coastal range, and Pacific Ocean. To the east are the Owens Valley, Inyo Mountains and Great Basin. All of these surrounding terrain features influence the meteorology of the southern Sierra (Ewell et al. 1989).

The Sierran hydrologic cycle is strongly dominated by snowfall and snowmelt (Stoddard 1995). In a water balance study of the Emerald Lake basin (Kattelmann and Elder 1991), where elevations range from 9,200 to 11,000 ft (2,804 to 3,353 m) (msl), snow dominated the water balance during the study period (October 1985-September 1988), accounting for 95% of the precipitation. The spring snowmelt periods accounted for more than 85% of the annual stream flow. Evaporation from snow was the principal water loss to the atmosphere, accounting for approximately 80% of the total evaporation.

Parks containing significant natural resources, including SEKI, should gather and maintain baseline climatological data for perpetual reference (National Park Service 2001a).

Physiography

More than 400 miles (644 km) long and from 60 to 80 miles (97 to 129 km) wide, the Sierra Nevada forms a massive barrier over 14,000 ft (4,267 m) in height, separating the Great Valley of California from the arid regions of the Great Basin to the east. The Great Valley, known as the San Joaquin Valley in its southern portion and as the Sacramento Valley in its northern portion, is almost entirely surrounded by mountains. The west slope of the Sierra rises eastward from the floor of the valley in a broad gently sloping gradient into which great canyons and gorges have been incised by Sierran rivers and glaciers (Duriscoe et al. 1982).

SEKI lies within the Sierra Nevada physiographic region (U.S. Geological Survey 2004a). The Sierra Nevada region is primarily comprised of a massive granite mountain range with a steep east facing scarp, which is the result of the original faulting that

formed the range (Fenneman 1931). The significantly less steep western side of the range is covered by numerous streams, and in the past was covered by glaciers (Matthes 1950). These streams have formed several of the deepest stream-cut canyons in the country, such as the Kings River Canyon which has a maximum depth of 8,000 ft (2,438 m) (Atwood 1940). The upper end of many of the canyons in the park give testimony to glacial activity with their characteristic "U" shape. The most striking of this glacial evidence is found in Kern Canyon (Matthes 1950). The Sierra Nevada mountain range displays a vast range of topography; SEKI is home to Mt. Whitney, the highest peak in the contiguous 48 states at 14,494 ft (4,418 m), while the foothill area of the park begins at 1,370 ft (418 m) (National Park Service 2004c). SEKI encompasses the headwaters of the Kaweah, Kern, Kings, San Joaquin and Tule Rivers, which together provide a large amount of irrigation water to neighboring Fresno, Kern and Tulare counties (Matthes 1950).

As a result of the vast elevation range in the park, three physiographic subdivisions have been recognized, as described in the "Climate" section. The *foothills* (1000 – 5000 ft (305 – 1524 m)) are home to a vegetation community consisting of a mosaic of oak species and chaparral types (National Park Service 2004d). The *montane* region (5,000 – 9,000 or 10,000 ft (1524 – 2743 or 3048 m) depending on aspect) include coniferous tree species more adapted to this elevation. The giant sequoia, the Parks' namesake, occurs in the montane region in small scattered groves (National Park Service 2004d). The *subalpine/alpine* region (above 9,000 to 10,000 ft (2743 to 3048 m) depending on aspect) contains hardier tree and plant species, and mostly exposed rock above timberline.

Geology

SEKI is contained completely within the Sierra Nevada mountain range. The Sierra Nevada is comprised of a single large westward tilted granitic batholith (Figure 5), consisting of rocks like granite, diorite, and monzonite (National Park Service 2004e). Weathering of silicate minerals in SEKI supplies alkalinity important to the neutralization of incoming acidity (i.e., acid deposition) on an annual basis (Williams et al. 1993). The batholith is an intrusive igneous rock that is formed by magma cooling slowly at depth; a result of a subduction zone along California's coast wherein the Pacific plate sank under the less dense North American plate, heating the subducted plate at depth and producing magma that ascended through the overlying lithosphere (Matthes 1950). The Sierra Nevada is the largest fault block range in the country stretching about 430 miles (692 km) long and an average of 60 miles (97 km) wide (Chronic 1986). The great height of the Sierra Nevada's was achieved with four major uplift periods. The uplifts began about 60 million years ago and ended no more then 1 million years ago with the Sierra Nevada at their present height (Matthes 1950). These uplifts occurred along a parallel fault system that accounts for, and is located just below, the steep eastern face of the Sierra Nevada mountain range (Figure 5).

In addition to the large granite block, there are small areas in the park of metamorphic rock. The slow cooling of the magma which caused the granite batholith was due to an overlying roof consisting of metamorphic rock with a sedimentary and igneous origin. This roof acted to keep the batholith intruded within the earth where it cooled slowly, producing the large amount of granite that is present in the park today (Matthes 1950).

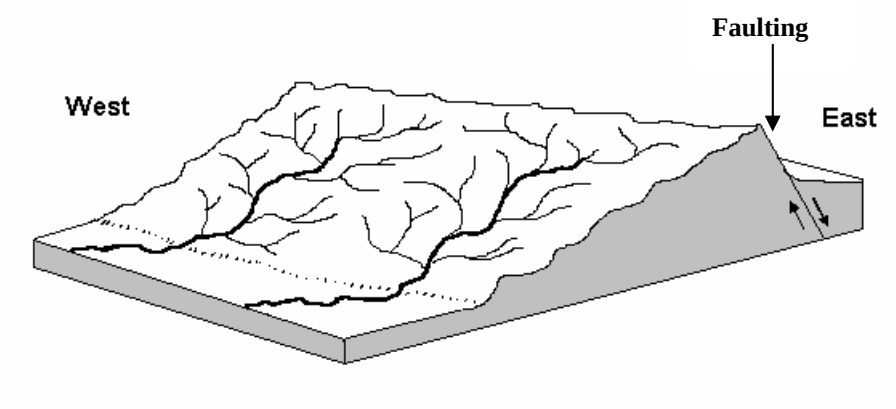


Figure 5. Tilted Sierra granite block as a result of faulting (modified after Fenneman, 1931).

Although much of this metamorphic roof has been eroded due to glacial and stream action, some areas have been preserved (Chronic 1986). Some of the remaining roof rock in the parks is marble, which is a metamorphosed limestone. Marble becomes soluble when water containing small amounts of carbon dioxide, which is obtained from the atmosphere, comes into contact with it. The marble succumbs to this carbonic acid and is washed away in solution, and when this occurs underground caves can be created (Matthes 1950). SEKI is home to over 200 marble caves formed in this fashion. One of the 200 caves in SEKI is Lilburn Cave, which stretches almost 17 miles (27 km), making it California's longest cave (National Park Service 2004a).

Mining

The following paragraphs are summarized from the SEKI RMP (National Park Service 1999):

> High-grade ore deposits have played a significant role in the history of the Sierra Nevada. In the central Sierra, some of the world's largest deposits of gold were found in the mid-1800s. Although no significant mineral deposits were ever discovered further south in SEKI, active mines existed in both parks near the turn of the 20th century and during World War II. However, most mining activity occurred in the 19th century in Mineral King.
>
> There are a total of 15 known and inventoried mine sites in SEKI. Mining activity was limited to two sites in central Kings Canyon in the watershed of the Middle Fork of the Kings River, two sites on the Great Western Divide near Triple Divide Peak, two sites in lower Redwood Canyon near Grant Grove and several sites in Mineral King. Despite its name and a "rush" in the 1870s, Mineral King never produced commercially viable quantities of ore. Commercially interesting mineral deposits are mostly associated with vein quartz (hydrothermal) and contact metamorphism concentrations and ores. Mined areas in the parks are known to contain silver, lead, copper, molybdenum, aluminum, iron and zinc. All mining operations in the parks

were small, but the largest occurred in Mineral King at the White Chief and Black Wolf Falls mines. Both sites include adits that are approximately 50 ft (15 m) long. No significant smelting or processing of ore occurred in the parks.

Today, these abandoned mined lands (AML) provide glimpses of a historic past. Abandoned mine sites contain cultural resources reflective of the mining activities and the time of the mine's operation. Cultural materials at sites are known to include, anvils, pick axes, tobacco tins, barrel stays and other metal objects. However, mines may produce serious toxic waste problems through the release of heavy metals or acid wastewater, while open shafts or unstable adits are dangerous for visitors, staff, and park resources. Fortunately, a 1998 and 1999 AML inventory of the parks revealed only a few potential problems. A shallow water-filled shaft along Franklin Creek in Mineral King may be leaching minerals into the stream. At the site, unusual colors and crystal growths associated with a seep are present. Also in Mineral King, a shaft leading to water lies in the upper areas of the White Chief mine site. The shaft is within 200 ft (61 m) of a frequently used trail and possibly should be considered for closure or remediation. All other AML sites in the parks do not appear to pose a health risk to visitors or an environmental hazard to park resources.

The NPS will take the following kinds of actions to meet legal and policy requirements relating to mining and minerals.

- When possible sample water quality in watersheds affected by mining.
- Continue to informally monitor mine site for changing conditions.
- Continue to informally monitor mine sites to insure the continued protection of cultural resources.
- Work towards a complete inventory of "prospects" or small mine sites in the Parks.

Today, there are no active mining sites or claims within SEKI. Cultural resources at mining sites generally are protected by their remoteness and small size. Wooden cultural artifacts have generally rotted away, while remaining artifacts are generally metal and badly rusted.

Soils

Until now, the only detailed soil mapping has been done in portions of the Marble Fork and Middle Fork drainages of the Kaweah River, which were completed as part of an Acid Rain Study in the mid-1980s (Huntington and Akeson 1987). There are also soil maps done for the area from Silver City to the Mineral King valley, which was completed in the early 1970s as part of the EIS analysis for the proposed ski area in Mineral King. These soils were mapped to Order 4 resolution and account for approximately 8% of SEKI's total acreage. However, soils across all of the parks' acreage are scheduled to be mapped in the near future by the Natural Resources Conservation Service. All soil surveys will follow National Cooperative Soil Survey Standards (National Park Service 2001a) and will be adequate to inform management of park resources. The NPS will

actively seek to understand and preserve the soil resources of SEKI, and to prevent, to the extent possible, the unnatural erosion, physical removal, or contamination of the soil, or its contamination of other resources.

Hydrology

Watersheds

The NPS will manage watersheds as complete hydrologic systems, and will minimize human disturbance to the natural upland processes that deliver water, sediment, and wood debris to streams (National Park Service 2001a). Watersheds are delineated by the U.S. Geological Survey using a nationwide system based on surface hydrologic features. This system divides the country into 21 regions, 222 subregions, 352 accounting units, and 2,262 cataloguing units. A hierarchical hydrologic unit code (HUC) consisting of 2 digits for each level in the hydrologic unit system is used to identify any hydrologic area. The 6-digit accounting units and the 8-digit cataloguing units are generally referred to as basin and sub-basin, respectively. HUC is defined as the Federal Information Processing Standard (FIPS) and generally serves as the backbone for the country's hydrologic delineation. The 8 digit cataloguing units that include SEKI are Upper Kaweah (18030007), Upper Kern (18030001) and Upper King (18030010) located in the Tulare-Buena Vista Basin, and Upper San Joaquin (18040006) located in the Upper San Joaquin Basin (see Figure 6; U.S. Geological Survey 2004b).

A research component of watershed management is found with the SEKI watershed program. This program is a long-term cooperative study of anthropogenic effects on Sierran ecosystems (Moore 1999). The SEKI program was designed to collect a set of core baseline measurements on surface water chemistry, vegetation dynamics, precipitation amount and chemistry, dry deposition chemistry, meteorology, soil solution chemistry and soil mapping. Initially, the SEKI program focused exclusively on four sites along an elevational gradient in the Middle Fork and Marble Fork drainages of the Kaweah River. The sites, which include Chamise Creek (2,461 ft (750 m)) in the chaparral vegetation zone, Tharp's Creek (6,781 ft (2,067 m)) and Log Creek (6,781 ft (2,067 m)) in the mixed conifer zone, and Emerald Lake Outflow (9,209 ft (2,807 m)) in the subalpine zone, were established between 1983 and 1985. Research in the subalpine zone was subsequently expanded to include two additional sites at the Marble Fork of the Kaweah (8,400 ft (2,560 m)) and Topaz Lake (10,500 ft (3,200 m)). The goal of the watershed program is to build upon our long-term research base to understand the interacting effects of fire and fire exclusion, air pollution and climatic change on key ecosystem elements and processes in Sierran watersheds. 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.

In 1990, the Tharp's watershed was burned as a pilot study to determine the effects of fire on biogeochemical and hydrologic processes in a mixed-conifer forest. Coinciding with

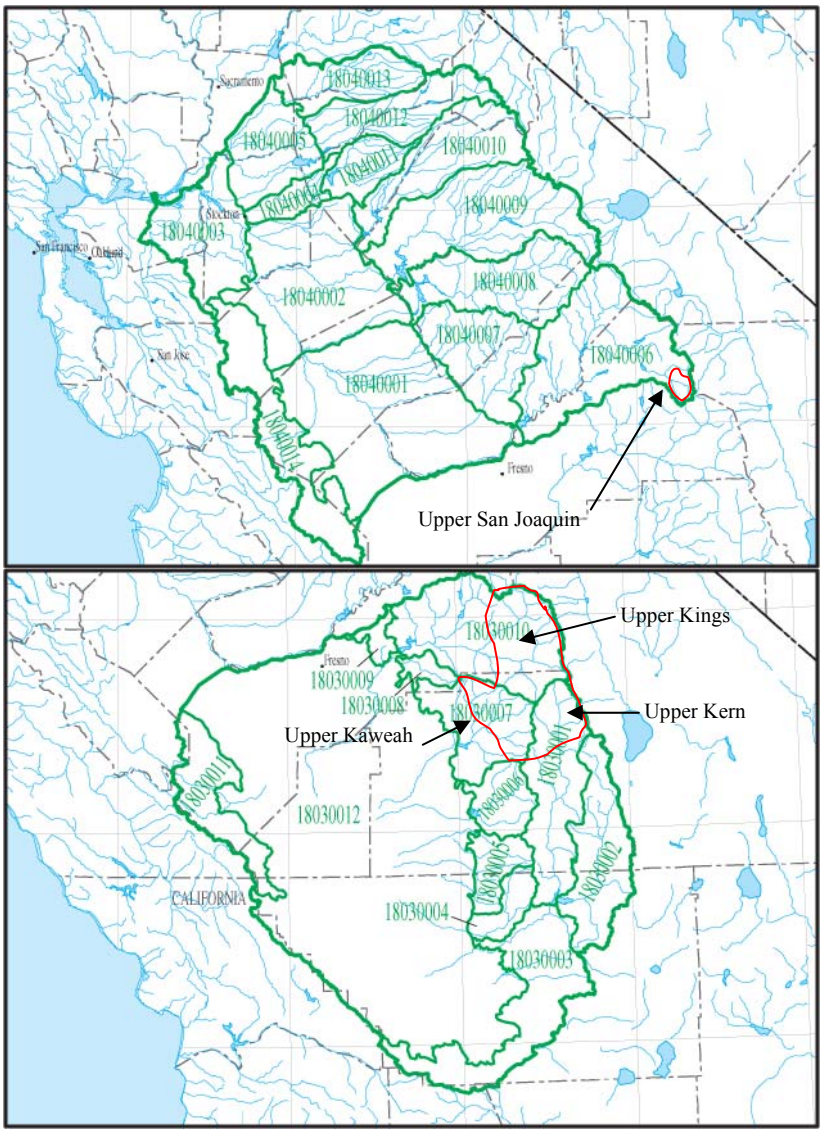


Figure 6. San Joaquin Basin (top) and Tulare-Buena Vista Lakes Basin (bottom) with Sub-Basins Identified. Note: approximate SEKI boundary outlined in red. (modified after U.S. Geological Survey, 2004b)

the start of the Mineral King Risk Reduction Project in 1995, the SEKI watershed program expanded its efforts to determine the effects of fire on hydrology and stream chemistry. Three sites were monitored from 1995-2004 as part of a study examining the effects of landscape scale prescribed fire on ecosystem properties and functions (Moore 1999). The sites included a 20,000 ha (49,422 acre) watershed, the East Fork of the Kaweah, and two 100 ha (247 acre) watersheds, Deadwood and Trauger's, that are nested in the East Fork of the Kaweah. Water quality parameters (stream flow, pH, specific conductance, ANC, base cations, ammonium, nitrate, sulfate, chloride and phosphate) were analyzed in the two 100 ha (247 acre) streams before and after prescribed fire burned 60% of the Deadwood watershed (Heard 2005). Parameters were also analyzed in

the larger East Fork of the Kaweah River in which 11 percent of the watershed area was treated with multiple fires over seven years. The Deadwood prescribed burn consumed large amounts of litter, duff and downed fuels and portions of the under-story vegetation, while mature trees were less affected. Change in water yield due to the burns was not detected in either watershed, likely because evapotranspiration is dominated by the larger unaffected trees. Changes in stream chemistry, however, were detected in the 100 ha (247 acre) watershed (but not in the 20,000 ha (49,422 acre) watershed). Changes were detected for specific conductance (53.5 to 68.2 µS/cm), ANC (0.546 to 0.660 meq/L), chloride (0.42 to 0.76 mg/L), sulfate (0.37 to 1.70 mg/L), calcium (6.21 to 7.99 mg/L), sodium (4.78 to 4.86 mg/L), potassium (1.19 to 1.46 mg/L), nitrate (0.002 to 0.051 mg/L), and phosphate (0.020 to 0.033 mg/L). Sulfate, calcium, nitrate and chloride concentrations were still elevated two years following the burn, while ammonium and magnesium concentrations were not affected by the burn (Heard 2005).

This study showed that the effects of large scale prescribed burning are more pronounced in headwater streams than at the landscape scale, due to larger percent watershed and riparian areas burned in the 100 ha (247 acre) versus the 20,000 ha (49,422 acre) watersheds (Heard 2005). Results indicate that treatments must be larger or more frequent than burning 11% of watershed area over seven years for detectable changes to occur in water yield and stream chemistry at landscape scales. Monitoring in the East Fork Kaweah was recently stopped due to lack of funding, but SEKI is hoping to continue the program in the near future.

The Kings River Experimental Watershed (KREW) is another watershed management effort that includes the Upper Kings River watershed of SEKI. KREW is a long-term watershed research study initiated in 2000 to provide much needed information for forest management plans regarding water quantity and quality. This watershed research is designed to: 1) quantify the variability in characteristics of headwater stream ecosystems and their associated watersheds, and 2) evaluate the effect of fire and fuel-reduction treatments on the riparian and stream conditions (Hunsaker and Eagan 2003). Attention has been given to developing a suite of measurements that will facilitate modeling in several disciplines: hydrology, meteorology and climate change, fire behavior and effects, soil erosion, and biogeochemistry. Preliminary sampling from the KREW project has revealed "hotspots" of high nitrogen (Hunsaker and Eagan 2003). This information and future data will be important in guiding sampling plans and in assessing potential sources of nitrogen, and possibly other anomalous parameters in streams.

Surface Water

Sixty percent of California's water originates from small streams in the Sierra Nevada, yet very little information exists about how these streams are affected at the source (Hunsaker and Eagan 2003). The water is considered some of the highest quality water in the state. Five major rivers originate in SEKI: Kaweah, Kern, Kings, San Joaquin and Tule. These rivers provide valuable irrigation water to the rich agricultural lands in Fresno, Kern, Kings and Tulare counties as well as providing recreation and industrial activities outside the parks.

Lakes and Ponds

Most of SEKI's estimated 3,365 lakes and ponds are located at high elevations, above 8,900 ft (2,712 m) (msl). Though a few lakes exceed 70 acres (28 ha), most are only a few acres in size. They vary in depth from about one foot (0.3 m) to over 100 ft (30 m) (National Park Service 1989).

Virtually all lakes in the Sierra Nevada originally were fishless (Christenson 1977). Pleistocene glaciers excluded fish from the high Sierra. As glaciers retreated, trout moved upstream from lower elevations, but were separated from the high lakes by natural barriers (i.e., steep canyon walls, high waterfalls, etc.). Because of the high elevation and lack of nutrients, many park lakes have relatively low productivity (National Park Service 1989).

Rivers and Streams

There is an estimated 2,144 miles (3,450 km) of mapped rivers and streams in SEKI. There also is an unknown additional amount of unmapped, primarily intermittent streams. The sizes of the drainages in SEKI are presented in Table 1.

Table 1. Size of drainages in Sequoia and Kings Canyon National Parks.

Drainage	**Area (ha)**	**Area (acre)**
South Fork, San Joaquin	16,816	41,554
Middle Fork, Kings	63,066	155,842
South Fork, Kings	100,172	247,535
Main Stem Tributaries, Kings	1,431	3,536
Dry Creek (Kaweah)	164	405
North Fork, Kaweah	16,479	40,721
Main Stem, Kaweah	43,236	106,840
East Fork, Kaweah	20,412	50,440
South Fork, Kaweah	9,767	24,135
North Fork, Tule River	1,389	3,432
Soda Springs Creek (Kern)	1,216	3,005
Kern River	75,162	185,733

Inside SEKI's boundary, 61.2 miles (98.5 km) of the Middle and South Forks of the Kings River and 28.9 miles (46.5 km) of the North Fork of the Kern River are designated as *Wild and Scenic Rivers* to protect their free-flowing nature (National Park Service 2004a). In compliance with the Wild and Scenic Rivers Act, SEKI has prepared a *Comprehensive River Management Plan* for these designated river sections to address resource protection, development of lands and facilities, user capacities, and other management practices to meet the purposes of the act (National Park Service 2004a).

Anthropogenic modifications of stream morphology have occurred in SEKI. For example, to address the declining fishery in the East Fork of the Kaweah River, located above Mineral King, 41 structures (e.g., rock dams, log dams, concrete dam, etc.) were installed (Cassel 1935). The objective of this effort was to increase the number of pools along the stream for the fishery and to create some natural rearing ponds.

Locations for water stage monitoring within SEKI are presented in Appendix B. There is considerable annual variation in flows. The largest streams produce peak flows around 2900 cfs (82,000 L/sec). These flows drop to about 50 to 90 cfs (1,500 to 2,500 L/sec) during August (National Park Service 1999). The Mediterranean climate found at SEKI produces two true seasons, the winter wet season (October – April) and the summer dry season (May – September). Streams in the Sierra reflect this pattern. They all reach their highest flows in the spring after rains at lower elevations and warmer temperatures in the high country have melted snow. By late summer, however, raging spring rivers are tiny trickles with a few pools left (Despain 2003). This creates some water management challenges at SEKI, especially over high-demand holidays. The U.S. Geological Survey designs water supply systems based on "firm yield", which is the surface-water yield that meets the demands of the Labor Day period when water usage by visitors will be at peak and surface-water yield almost at minimum.

Rantz and Dale (1964) evaluated the present and potential sources of water supply for the Lodgepole-Clover Creek area. Lodgepole Camp is a public campground on the Marble Fork of the Kaweah River. Water supply for the camp is obtained by diverting water from Silliman Creek, which gravity feeds to a 20,000-gallon reservoir (replaced by a 200,000-gallon reservoir in late 1964). Although Clover Creek was recommended as the primary source of water for this development, it was determined that the creek would not meet the demand of a proposed campground expansion. Rantz and Dale (1964) thus recommended obtaining water from Silliman Creek via a gravity pipeline to supply this system.

The U.S. Geological Survey provided a water-supply appraisal of the South Fork Kings River tributaries in Kings Canyon National Park in the 1960s. The purpose of the study was to evaluate the potential water supply available for use in the Cedar Grove campground area, Cedar Grove maintenance area, and the proposed campground area at Copper Creek. Sheep Creek at the Cedar Grove camp area had a "firm yield" of about 610 gpm. Lewis Creek at the Cedar Grove maintenance area had a firm yield of about 780 gpm. Copper Creek had an estimated firm yield of about 800 gpm. Water quality from all three surface water sources was considered excellent. It was the opinion of the U.S. Geological Survey that considerable expansion of the facilities was feasible (Mullen and Bader 1967).

Floodplains and Riparian - In managing floodplains on park lands, the NPS will (National Park Service 2001a):

- Protect, preserve, and restore the natural resources and functions of floodplains;

- Avoid the long- and short-term environmental effects associated with the occupancy and modification of floodplains; and
- Avoid direct and indirect support of floodplain development and actions that could adversely affect the natural resources and functions of floodplains or increase flood risks.

When it is not practicable to locate or relocate development or inappropriate human activities to a site outside and not affecting a floodplain, the NPS will:

- Prepare and approve a statement of findings, in accordance with procedures described in D.O. 77-2 (Floodplain Management);
- Use non-structural measures as much as practicable to reduce hazards to human life and property, while minimizing the impact to the natural resources of floodplains; and
- Ensure that structures and facilities are designed to be consistent with the intent of the standards and criteria of the National Flood Insurance Program (44 CFR Part 60).

The Marble Fork runs through the Lodgepole area, which has a history of flooding. Midwinter floods, which are the largest, have damaged campsites within 100 feet (30 m) of the stream. No buildings occur within the 100-year floodplain in the Lodgepole area (National Park Service 2004a). Cedar Grove is in a relatively broad portion of the lower valley of the South Fork of the Kings River. No buildings exist within the 100-year floodplain, although a portion of the Sentinel campground loop closest to the river is within this floodplain, along with sections of the roads within the canyon (National Park Service 2004a). The only NPS facility within the 100-year floodplain at Mineral King is a small segment of the Cold Spring campground,

The quality of the riparian (near-stream) ecosystems associated with floodplains is directly related to the condition of adjacent uplands within their watersheds. The degradation of forest streams and their associated watersheds is often the result of non-point sources such as past timber harvesting, roads, fire suppression, and catastrophic wildfires (Hunsaker and Eagen 2003).

Hydroelectric - Some waters are captured within the park and used to generate electricity. A conduit with a capacity of about 90 cfs (Jordan/Avent & Associates 1980) transports water diverted from both the Marble and Middle forks of Kaweah River to the Kaweah No. 3 Power Plant. Since 1964, permits specified that when minimum flow is 11 to 30 cfs, depending on the time of year, water would not be diverted. Water has been diverted since 1913, and before the minimum flow requirement was instituted in 1964, operation of the power plant during periods of low flow removed most water and may have caused serious problems with the ecology of the river. Water is also diverted from the East Fork of the Kaweah River for similar purposes. Though diverted below the Parks' boundary, a series of dams was constructed in an upstream area that is currently part of Sequoia National Park. The dams were built to provide partial regulation of flow to the diversion (National Park Service 1989).

SEKI prepared a report to Congress on the impacts of the hydroelectric facilities on SEKI (Jordan/Avent and Associates 1980). This report did not find impacts to be significant. Both the permit and license were subsequently renewed. Congress authorized the NPS to permit the Southern California Edison Company to operate the Kaweah hydroelectric facilities for 10 years and to issue not more than a one 10-year permit (PL 99-338). The current permit runs through September 8, 2006. Southern California Edison will have to terminate the operation of hydroelectric generating facilities within the park on or before the expiration of the current permit and restore the affected areas, subject to appropriate compliance (National Park Service 2004a).

Section 7 of the Wild and Scenic Rivers Act states that, "the Federal Energy Regulatory Commission (FERC) shall not license the construction of any dam, water conduit, reservoir, powerhouse, transmission line, or other project works under the Federal Power Act" on or directly affecting any river designated as wild and scenic. This part of Section 7 is not relevant to the already designated river segments because there are no FERC licensed projects on them. However, as stated above, hydroelectric impoundments and diversions are located on the Marble and Middle Forks of the Kaweah River and on tributaries to the East Fork of the Kaweah River (National Park Service 2004a).

Under the Wild and Scenic Rivers Act, no federal agency may recommend authorization of a water resources project (i.e., any construction within the bed or banks of a river that would affect the free-flowing condition of the river) without first receiving a determination from the river managing agency that the project would not affect the river's free-flowing condition on its outstandingly remarkable values and without seeing approval from Congress (National Park Service 2001a).

Wetlands

Wetlands represent transitional environments between terrestrial and aquatic systems where the water table is at or near the surface or the land is covered by shallow water (Cowardin et al., 1979). Flora within these wetland systems exhibit extreme spatial variability, triggered by very slight changes in elevation. Temporal variability is also great because the surface water depth is highly influenced by changes in precipitation, evaporation and/or infiltration. Cowardin and colleagues (1979) developed a wetland classification system that is now the standard in the federal government. In this system, a wetland must have one or more of the following attributes: (1) at least periodically, the land supports predominately hydrophytes; (2) the substrate is predominately undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. There are four federal government agencies responsible for identifying and delineating wetlands: the U.S. Army Corps of Engineers, Environmental Protection Agency, Fish and Wildlife Service, and Natural Resources Conservation Service.

The U.S. Fish and Wildlife Service developed wetlands data through the National Wetlands Inventory (NWI) program. NWI maps that included lands in SEKI were produced in 1996 from aerial photos (Werner 2004), but these maps have less accuracy

than on-site delineation. Until recently, less than 50% of these mapped data has been converted to digital and little spatial and attribute accuracy validation has occurred (National Park Service 1999). SEKI therefore conducted an accuracy assessment of these NWI maps to evaluate their usefulness, improve knowledge of wetland locations and vulnerabilities, and facilitate long-term planning and daily management of wetlands (Werner 2003). Results show that where wetlands and deep-water habitats were indicated on NWI maps, they typically existed, but the maps omitted nearly half as many additional wetlands. Although there were considerable differences in vegetation taxonomy on the maps versus field measurements, the palustrine and riverine habitats had the most problems while the lacustrine sites were the most accurate. Therefore, for projects in SEKI where wetland accuracy is critical, on-site delineation or evaluation is highly recommended, while NWI maps can be used as an indicator of what to expect in the field.

Wet meadows in SEKI are common in both forested and alpine areas from 5,900 to 11,800 ft (1,798 to 3,597 m) (msl). Wet meadows vary in size from less than one hectare to several hectares (National Park Service 1989).

Reed canary grass (*Phalaris arundinacea*) is a perennial non-native grass species that is aggressively invading mid-elevation meadows in Sequoia and Kings Canyon National Parks. It is considered native to some parts of California, but not to Sequoia and Kings Canyon National Parks. Reed canary grass is a source of particular concern for park managers because it spreads rapidly, can alter stream and meadow hydrology, is very tenacious, and tends to exclude all other vegetation. Reed canary grass is present only in moist meadows and riparian sites in Grant Grove and in one small patch in Lodgepole (National Park Service 2004f).

In 2002, park resource management personnel began removing small satellite populations. After attempting removal of this plant by hand, park staff determined that hand digging is too disruptive to fragile meadow soils. In 2002, the park began managing sites on meadow perimeters using a combination of hand removal and approved glyphosate herbicides. The stems were cut shortly before flowering and the grass was allowed to resprout. Three weeks after cutting, the resprouts were treated with herbicide. These targeted spot treatments have been successful, resulting in a 90% reduction in reed canary grass cover (National Park Service 2004f).

Halstead Meadow is a 39-acre (15.7 ha) wet montane meadow located at 7,000 ft (2,134 m) (msl) along Halstead Creek, a tributary of the Marble Fork of the Kaweah River in Sequoia National Park. In the late 1920s and early 1930s, the flow of Halstead Creek was drastically altered when the Generals Highway was constructed through the center of the meadow. With the highway embankment effectively forming a dam across the meadow, hydrologic sheetflow was altered and concentrated into a single culvert. The concentrated flow at the culvert outlet has created severe gullying and erosion on the downstream side of the road. The gully is 14.8 ft (4.5 meters) deep and extends approximately 330 feet (100 m) downstream. This extreme downcutting has resulted in a significant drop in the water table in several parts of the meadow. This portion of the stream channel and associated meadow vegetation downstream of the roadbed has been actively eroding for decades, with sporadic

short-term efforts to slow the loss of soil proving unsuccessful. In those areas affected by a water table drop, the vegetation community has shifted to a drier type dominated by *Rumex salicifolius* and *Elymus glaucus* ssp. *glaucus*, whereas wetter portions of the meadow are dominated by *Scirpus microcarpus* and *Oxypolis occidentalis*. The erosion gully at Halstead Meadow is a significant unresolved resource issue in SEKI.

This section of road is scheduled to be rehabilitated by the Federal Lands Highway Program (FLHP) in FY06, at the earliest. The Pacific West Region FLHP coordinator Dave Kruse has said that it's highly likely that FLHP can fund drainage improvements and gully restoration if subject matter experts agree that the road has caused the problem. This funding would include project design, compliance, construction, and restoration, and may include revegetation. Thus, a small technical assistance investment now will provide large benefits to the project in the future. SEKI also has from $6,000 to $10,000 of fee demonstration funds available for hydrological consulting and design for this project.

Restoring such a severe gully is beyond the expertise of park staff. SEKI therefore requested and received technical assistance from Colorado State University, the NPS Water Resources Division, and the NPS Pacific West Region. In 2003 and 2004, the site was visited and assessed by one hydrologist and one wetland specialist from Colorado State University, three hydrologists from NPS Water Resources Division, and one fluvial geomorphologist from NPS Pacific West Region. Other attendees to the on-site scoping session included FLHP designers, engineers, and compliance specialists, and SEKI Natural Resources and Maintenance staff. All specialists agreed that the road caused alteration of significant portions of the upstream and downstream meadow areas. SEKI then successfully sought funding to hire a research team to install wells in Halstead Meadow and several other reference meadows in SEKI to determine the probable historic condition of the meadow and thus a target for restoration. The study will be conducted in 2005 by Dr. David Cooper of Colorado State University and will provide topographic specifications to which the meadow should be restored by the FLHP.

Snow, Ice and Glaciers

Though snow occasionally falls at all elevations within SEKI, the snowpack accumulates primarily at a starting elevation of 6,000 ft (1,829 m) (Esperanza, pers. comm. 2005). Winter snowpack in SEKI is a natural storage system for the precipitation that accumulates during the winter months. In California, agricultural and metropolitan areas depend on meltwater obtained from the Sierra Nevada to augment local water supplies (Elder 1988). The amount of water stored as snowpack increases through mid-April at higher elevations. Meltoff typically begins in March or April and continues through May or June. In order to understand the timing and volume of runoff, a good understanding of the spatial variation of snowpack properties is needed. The factors contributing to variation in snow water equivalent (slope, aspect, elevation, vegetation type, surface roughness, energy exchange) are exaggerated in alpine areas found in SEKI, resulting in a heterogeneous snowpack that changes markedly in space and time. Elder (1988) mapped the distribution of snow water equivalents in the Emerald Lake watershed of Sequoia National Park, identifying similar snow properties based on topographic parameters that account for variations in both accumulation and ablation.

Seasonal ice and snow cover affects the characteristics of aquatic ecosystems. They control the amount of light reaching the unfrozen water beneath the ice (Prowse and Stephenson 1986). Ice can also prevent gas exchange between underlying waters and the atmosphere and may commonly lead to depletion of dissolved oxygen and the build up of reduced gasses such as CO_2, CH_4 and H_2S (Rouse et al. 1997). The processes associated with ice formation during freeze-up and break-up have a wide range of effects on the bed, banks, and biota of lakes and rivers. These include frazil ice (aggregate of ice crystals formed in supercooled turbulent water) impact on fish and invertebrates, anchor ice growth, elevated water levels, channel blockage and increased scouring (Prowse 1994).

Processes active during breakup of snow cover in stream channels may be responsible for some of the erosion occurring in riparian areas and meadows in the Sierra Nevada (Kattelmann 1988). Blockage of stream channels with ice and snow causes snowmelt runoff to saturate the snowpack near streams and develop new channels in the snow. With little resistance to flow in these channels, water velocities and erosive power increase. Where the snow channels contact the substrate, large amounts of soil can be eroded and moved downstream. This material is redeposited where snow channels break apart and water velocity slows down. This may cause greater sediment movement than is commonly thought to occur from snowmelt runoff in the forest zone (Kattelmann 1988).

Detailed evaluation of meteorological and climatic parameters in an alpine watershed is required to evaluate the energy balance of the snow cover to improve estimates of the timing and magnitude of snowmelt generation (Marks et al. 1992). Marks and colleagues (1992) monitored radiation, temperature, humidity, wind, and precipitation at several sites in Sequoia National Park's Emerald Lake watershed, integrating the data into continuous time series of hourly averages for the 1986 snow season. These data, although difficult at times to collect, provided for a unique evaluation of the snow cover energy balance in a remote alpine watershed.

Glacier ice is a metamorphic rock that consists of interlocking crystals of the mineral ice and owes its characteristics to deformation under the weight of overlying snow and ice. Snow that survives a year or more gradually increases in density until it is no longer permeable to air, at which point it becomes glacier ice. Although now a rock, such ice has a density of about 0.9 g/cm^3 and will float in water (Skinner and Porter 1992). Glaciers generate their own stream systems, either on their surface or within and below the ice, in a similar manner to streams in limestone regions. During the peak period of melting in early summer, the stream that emerges at the terminus of most Sierra Nevada glaciers provides sustained flow to the drainage below. Yet in winter, discharge is reduced to a mere trickle or locked solid. These extremes between summer and winter provide an interesting mix of meltwater features on and around glaciers (Hambrey and Alean 1994).

The mass of a glacier is constantly changing as the weather varies from season to season and, on longer time scales, as local and global climate change. These ongoing environmental changes cause fluctuations in the amount of snow added to the glacier surface and in the amount of snow and ice lost by melting (Skinner and Porter 1992).

The development of meltwater channels on the surface of a glacier depends on the rate of melting, the rate of deformation of the ice, the extent of crevasses and the pattern of other structures. Surface channel systems develop best on stagnant and on cold glaciers, but will not appear at all on those with a large number of crevasses. Not a great deal is known about the internal drainage systems of glaciers. Nevertheless, using dye tracers it is possible to monitor how fast water travels through glaciers (Hambrey and Alean 1994).

Ground Water

Not much is known about ground water in SEKI (National Park Service 1999), however, some basic hydrogeologic principles can be inferred from the parks' geology and geomorphic features. For example, meadow areas in SEKI represent the most predictable and the largest, volume for volume, ground water storage units (LeBlanc 1970). Glacial deposits can also influence local groundwater flow. Streams that issue from the edge of glaciers pick up large loads of unconsolidated sediments, dumping the coarser materials some distance downstream. These outwash gravels occur in the form of outwash fans and outwash terraces and constitute another productive aquifer system. Where moraines dam melt water, fine-grained sediments can accumulate producing aquitards or confining beds (Mandel and Shiftan 1981).

One warm spring and one hot spring are known in the Kern drainage and there are unconfirmed reports of others in Kings Canyon including a thermal meadow. Many mineral and cold water springs occur throughout SEKI (Werner, pers. comm. 2004)

In 1963, the U.S. Geological Survey made a site visit to the Ash Mountain area in Sequoia National Park to look at the potential for using ground water in place of existing surface water sources (Alder Creek and Middle Fork Kaweah River). They concluded that due to the lack of permeable alluvial deposits in the area, a well would be restricted to consolidated rock with anticipated yields of less than 5 gallons per minute, with a high percentage of failure (< 1 gpm); so test drilling was not recommended (Dale 1964). However, wells were subsequently constructed in the area, and although some were abandoned due to poor water quality, one currently remains in use.

In 1963, the U.S. Geological Survey also made a ground-water reconnaissance investigation of the Grant Grove area in Kings Canyon National Park. Water supplied to the Grant Grove development came from a number of springs in the area, including Merritt Spring and Winter Spring. At the time of the investigation both Winter Spring and Merritt Spring were measured at 9 gpm each, with a combined flow from four other springs in the area (Round Meadow) estimated at 30 gpm (Dale 1966). This supply was adequate during normal water years, but during a series of dry years there was a deficiency of supply to meet facility demands at Grant Grove. Two test wells drilled in Round Meadow, 13S/28E-32H1 and 13S/28E-32K1, maintained sustained yields of about 75 gpm and 40 gpm, respectively. Chemical analysis indicated calcium bicarbonate water of excellent chemical quality (Dale 1966).

The U.S. Geological Survey evaluated water sources for the Lost Grove area in Sequoia National Park in 1967. The sources of water at the time were two small springs, which were not adequate to support a drinking fountain and comfort station. Mitten and Bertoldi (1968) proposed three options for alternate water supply to be considered (in decreasing order of priority); 1) an infiltration gallery installed in a local tributary, 2) ground water well installed near the western end of the small meadow, and 3) a ground water well drilled through the unconsolidated material and into the basement complex at the site near the comfort station.

In the interest of developing a ground water supply to accommodate public facilities, the NPS evaluated the Long Meadow area in Sequoia National Park. Long Meadow was deeply scoured by glaciers. Most of the marshy meadow is underlain by alluvium, which is underlain by glacial till. Studies by Croft (1968) and Bertoldi and Miller (1969) indicated that the average saturated thickness of this unconsolidated material is about 70 ft, with a maximum thickness of approximately 150 ft (46 m) as determined by a seismic survey. According to LeBlanc (1970), the probability of finding water in fractures of the granitic rocks, underlying the unconsolidated material, is high. In 1983, the U.S. Geological Survey evaluated the Wolverton Creek-Long Meadow area in Sequoia National Park for availability of groundwater resources (Wahrhaftig et al. 1984). The imperviousness of the till and lack of springs along the north side of the Tahoe moraine north of Wolverton Creek suggested that the till barrier along the north side does not contribute significantly to the readily available ground water of the Wolverton-Long Meadow area. Thus the ground water basin is confined to the alluvium south of the moraine. However; if a large fraction of the annual yield is drawn yearly out of the ground water basin, the water table would lower well below the outlet to the meadow. If so, Wolverton Creek would dry up for part of the year as the meadow recharged, and changes in vegetation of the meadow may result (Wahrhaftig et al. 1984). It was determined that the average storage capacity of the shallow aquifer underlying Long Meadow is about 170 acre-feet, producing a dependable ground-water supply of about 50 gallons per minute (72,000 gallons per day). Furthermore, the withdrawal of this quantity of ground water from the Long Meadow area was not expected to impact ground water or surface water in the General Sherman Tree area (Akers 1986). Bertoldi and Miller (1969) recommended monitoring water quality from wells in the area for nitrogen, chloride, phosphorus and coliform bacteria to monitor potential ground water impacts from the upgradient comfort station.

Karst

The NPS will manage karst terrain to maintain the inherent integrity of its water quality, spring flow, drainage patterns and caves. Local and regional hydrological systems resulting from karst processes can be directly influenced by surface land use practices. If existing or proposed developments adversely impact karst processes, these impacts will be mitigated. Where practicable, these developments will be placed where they will not have an effect on the karst system (National Park Service 2001a).

SEKI contains over 200 known karst features. Several major cave systems have been located including Lilburn Cave, which is the most extensive in California with over 20 miles (32 km) of measured passage (Despain 2003). Karst and its water produce biologically rich karst riparian areas that enhance species diversity and richness of life in SEKI.

According to Despain (2003), the similar direction of many of the caves in Sequoia and Kings Canyon points to rock structure as the determining factor in cave passage development. Primarily, this means that the caves follow the marble lenses and the structure of the metamorphic rocks. They typically develop across vertically tilted, narrow beds of marble, flanked by insoluble schist and quartzite. The beds and contacts provided porosity and allowed caves across the park to form. This trend, from 130° to 310° is common in the geography of central California. So for someone trying to predict how water might flow through karst in SEKI, a good beginning is to observe what streams and valleys lie downstream at 130° or 310°. In some cases, karst springs will be found in these spots (Despain 2003).

A major spring known as Tufa Falls, located in White Chief Valley in Mineral King Basin, is an important water supply for private land owners and the NPS. The Mineral King area is known for impressive alpine caves and karst features. Studies have included hydrogeology, hydrochemistry and dye tracing information and data to help better understand groundwater flow through this area. Waters from Tufa Falls originate from karst conduits beneath the ridge separating White Chief Valley from Eagle Lake Valley (Schultz 1996, Schultz and Tinsley 1996).

Spring flow behavior is complicated in many of SEKI's karst systems. At Big Spring in Kings Canyon National Park, two distinct types of flow patterns during the high runoff season (usually February through early June) have been observed (Urzendowski et al. 1993). The first is an ebb and flow, which is an out-of-phase response where water stage drops in a room in Lilburn Cave (Z-Room) resulting in an instantaneous rise at Big Spring. The second type of flow is a high sustained flow at Big Spring implying an in-phase response between the Z-Room and Big Spring stages, which occurs when flows at the spring are at least two to three times that of the normal base flow.

Water Quality

The pollution of surface waters and ground waters by point and non-point sources can impair the natural function of aquatic and terrestrial ecosystems and diminish the utility of park waters for visitor use and enjoyment. The NPS will determine the quality of SEKI water resources and avoid, whenever possible, the pollution of park waters by human activities occurring within and outside park boundaries (National Park Service 2001a).

Surface Water

The concentrations of major cations, anions and other dissolved constituents are very dilute in high elevation surface waters of SEKI. As a group, high Sierran lakes and

streams are extremely base-poor and classically "acid sensitive" (Stoddard 1995). The great potential for acidification of Sierran lakes is confirmed by the very low alkalinity of these waters (0 to 8 mg/L as $CaCO_3$), producing a weak buffering capacity (Tonnessen and Harte 1982). The alpine lakes and streams also have conductivity readings below 20 µS/cm, contributing to a poorly buffered system susceptible to external influences (e.g., atmospheric deposition, nutrient inputs, etc.). The ionic potential typically increases as you drop in elevation, where conductivities may exceed 100 µS/cm by the time the rivers reach the park boundary (National Park Service 1999). This is partially due to the influence from marble, schist, and other metamorphic rocks along the western side of the park. Waters are typically very clear with turbidities generally well under 0.5 NTU, though meadow water may exceed 1.0 NTU. Nutrients like phosphate or nitrate concentrations are generally less than 40 µg/L and ammonia is generally undetectable. Except for mineral springs, thermal springs and some wet meadows, the water is normally saturated with oxygen (6.8 to 8.8 mg/L). Typical pH concentrations are slightly acidic, but can vary from about 5.5 to 8.5, with some sites exceeding this range. Bacteria (fecal coliform and fecal streptococci) concentrations are generally very low (0 to 5 colonies/100 ml), but can quickly elevate following rain or snowmelt, especially when downstream of meadows. Most of the bacteria appear to come from natural sources (National Park Service 1999).

The NPS (Williams and Melack 1997) collected ten years of measurements on precipitation and stream runoff from the Tharp's Creek basin in Sequoia National Park. Nitrate, ammonium and sulfate were retained in this subalpine basin, except after a prescribed burn when an export of sulfate occurred. The basin biologically assimilates most of the acidifying ions, and weathering reactions are producing ample quantities of basic solutes. A positive relation between sulfate and discharge suggests that sulfate deposited from the atmosphere is temporarily stored as organic matter, and that its release is controlled by the extent of mineralization and flushing of soil water (Williams and Melack 1997).

Williams et al. (1995) found nitrate concentrations in streams in the high-elevation Emerald Lake watershed to reach an annual peak during the first part of snowmelt runoff, with maximum concentrations in stream water of 20 µeq/L. The solute composition of streams in the Emerald Lake watershed can be divided into three periods: snowpack runoff, a transition period in summer as snowpack runoff decreases and little precipitation occurs, and a low-flow period from late summer through winter (Williams et al. 1993). Each period has different geochemical controls on solute composition of surface waters. The acidity in Emerald Lake's watershed snowpack runoff is neutralized by cation exchange in local soils and talus. Processes occurring below the soil zone exerted the dominant geochemical controls on the composition of stream waters during the period of low flow (Williams et al. 1993).

In 1991, the U.S. Geological Survey initiated the National Water-Quality Assessment (NAWQA) program. The long-term goals of this program are to assess the status of and trends in the quality of freshwater streams and aquifers, and to provide a sound

understanding of the natural and human factors that affect the quality of these resources. SEKI is located within one of the NAWQA study units, the San Joaquin-Tulare Basin.

Water quality and limnological studies have been conducted in several areas of SEKI (National Park Service 1989). Several lakes draining into the headwaters of the South Fork of the Kings River were studied in the late 1970s (Erman 1977, Erman and Taylor 1978, Silverman and Erman 1979, Taylor and Erman 1979, Taylor and Erman 1980). Water chemistry in the East Fork of the Kaweah River was reported by several State and Federal agencies (Dean, 1969, 1971, Federal Water Pollution Control Administration 1969, Troyer, 1971, 1973). James (1975) studied human impacts on two lakes in the Kaweah drainage, and Hoffman and Ferreira (1976) examined effects of two fires in the Roaring River drainage on water quality. A sample of high lakes in SEKI was surveyed for pH and trace elements in 1965 (Bradford et al. 1968), and repeat-surveyed from 1980-1983 (Bradford et al. 1983). In 1985, the U.S. Environmental Protection Agency conducted the Western Lake Survey, a synoptic sampling of 719 lakes in the western United States, including 70 lakes in seven national parks (including SEKI). The goal of the Western Lake Survey was to document the chemical status of lakes in regions of the United States considered sensitive to acidic deposition. Sixty-nine of the 70 lakes in national parks were resampled in 1999, including lakes in SEKI (Clow et al. 2003).

In 1978, a water quality monitoring program was initiated in SEKI. The U.S. Geological Survey (Menlo Park, CA) developed the program in collaboration with the NPS. Portions were implemented annually during 1978-1980 (National Park Service 1989). This included a reconnaissance of major streams and continuous measurement of water temperature, flow and conductivity at those low-elevation streams. Monitoring by the parks began in 1981, but only occurred during the summer. Initially, it was oriented toward providing baseline information for 20 long-term monitoring stations, but was expanded to include relating management practices and visitor use patterns to water quality impacts and public safety (National Park Service 1989).

From 1980 to 1983, lake waters were sampled in SEKI and Yosemite National Park to evaluate the influence of acid deposition on the sensitive lake waters in the Sierra Nevada mountain range (Bradford et al. 1983). Comparison of these data with earlier sampling in 1965 (Bradford et al. 1968) showed no significant increases in lake water acidity, total electrolyte concentration and concentrations of trace elements sampled. Mean pH measurements ranged from 6.0 in 1965 to 6.3 in 1983. The total concentration of measured alkali and alkaline earth metals measured was generally less than 5 mg/L indicating that lake waters would have a low capacity to buffer against inputs of acidity. The snow water acidity (pH = 5.6) was neutralized by contact with soil and parent material during the spring thaw to pH = 6.3 in stream water entering the lakes. Because most of the precipitation occurs in the form of snow, input waters may have a greater residence time in the soils and parent materials resulting in a greater degree of buffering (Bradford et al. 1983).

In 1985, the Western Lake Survey (Landers et al. 1987) found that Sierra Nevada lakes were some of the most dilute and weakly buffered waters in the nation. Between 1985

and 1999, Clow et al. (2003) documented changes in the chemistry of lakes and precipitation in high elevation national parks in the western United States. For SEKI lakes, their results showed a statistically significant decrease in lake SO_4, which the authors attributed to increased precipitation during the mid-1990s relative to the late 1980s. They also measured a significant downward trend in lake NO_3 in Emerald Lake (including data back to 1983 from long-term monitoring). There were no significant differences in NH_4 concentrations, but concentrations generally were near or below the analytical reporting limit during both surveys. Total phosphorus (P) concentrations in Emerald Lake, however, showed a strong increasing trend during 1985–1999, which may be due to increasing atmospheric deposition of aeolian P from increases in particulate emissions in California's Central Valley, which is upwind of the Sierra. Sickman (2001) showed that increased P deposition may have stimulated phytoplankton productivity in Emerald Lake, which in turn may have contributed to the declines in late-season NO_3 levels observed during the late 1980s and early 1990s. Alkalinity showed a statistically significant decrease, which reflects a general decrease in solute concentrations and specific conductance that may be due to climatic variability or other influences. Changes in pH showed a slightly downward trend of generally less than 0.15 pH units, and although H+ concentrations showed a significant increase, many of the observed differences were not much larger than the analytical uncertainty of the pH measurements. There also was little detectable change in base cation concentrations.

In 1997, the NPS Water Resources Division completed a comprehensive summary of existing surface water quality data for SEKI, the *Baseline Water Quality Inventory and Analysis, Sequoia-Kings Canyon National Parks* (National Park Service 1997). This document presents the results of surface water quality data retrievals for Sequoia and Kings Canyon National Parks (SEKI) from six of the United States Environmental Protection Agency's (EPA) national databases: (1) Storage and Retrieval (STORET) water quality database management system; (2) River Reach File (RF3); (3) Industrial Facilities Discharge (IFD); (4) Drinking Water Supplies (DRINKS); (5) Water Gages (GAGES); and (6) Water Impoundments (DAMS).

Locations for water gages, impoundments, drinking water intakes and industrial discharge are located in Appendix B. The stations yielding the longest-term records within the parks' boundary are: (1) Log Creek (SEKI 0157); (2) Emerald Lake (SEKI 0225); (3) Emerald Lake (SEKI 0230); (4) Tharps Creek (SEKI 0158); (5) Chamise Creek (SEKI 0115); and (6) Emerald Lake outflow near Giant Forest, CA (SEKI 0231). The stations yielding the longest-term records within the study area, but outside of the parks' boundary, are: (1) Kaweah River at Three Rivers (SEKI 0044); (2) Left Bank of the Kaweah River at Three Rivers (SEKI 0046); (3) Kings River South Fork at Cedar Grove (SEKI 0305); (4) East Fork Kaweah River Overflow below Cond 1 near Three Rivers (SEKI 0061); and (5) Squirrel Creek below Mineral King Highway near Hammond (SEKI 0043).

The following summarizes results of the SEKI water quality criteria screen from the National Park Service (1997) document, where 12 groups of parameters exceeded screening criteria at least once within the study area. Dissolved oxygen, pH, cadmium,

copper, mercury, and zinc exceeded their respective EPA criteria for the protection of freshwater aquatic life. Chloride, cadmium, lead, and mercury exceeded their respective EPA drinking water criteria. Fecal-indicator bacteria concentrations (total coliform and fecal coliform) and turbidity exceeded the WRD screening limits for freshwater bathing and aquatic life, respectively. Alkalinity was below the threshold used by the NPS Air Resources Division for determining potential sensitivity to acid deposition (buffering capacity). Corresponding sampling locations are presented in Appendix A.

Dissolved oxygen concentrations were measured 641 times at 78 monitoring stations from 1951 through 1993. Three observations at three stations in SEKI, Mineral King Mineral Spring (SEKI 0067), a hot spring near the Kern River (SEKI 0091), and Little Bearpaw Meadow (SEKI 0151), were less than the 4 milligrams per liter (mg/L) EPA criterion for the protection of aquatic life in September 1993.

The **pH** was measured 3,607 times at 407 monitoring stations from 1951 through 1994. Of the 3,599 observations used in the criteria analysis, 1,373 observations at 124 stations were outside the pH range of 6.5 to 9.0 standard units (SU) (EPA chronic criteria for freshwater aquatic life). Eleven observations at 11 stations were greater than or equal to pH 9.0 from 1985 through 1992 and 1,362 observations at 115 stations were less than or equal to pH 6.5 from 1951 through 1994. The highest pH of 10.2 SU was reported in the East Fork Kaweah River (SEKI 0033) in September 1985. Approximately 74 percent of the observations less than or equal to pH 6.5 were reported from three stations in Emerald Lake (SEKI 0225, SEKI 0230, SEKI 0231) from 1982 through 1993. The lowest pH of 4.42 SU was reported at a spring along a tributary to the South Fork Kings River (SEKI 0340) in September 1992.

Turbidity was measured 519 times at 163 monitoring stations from 1971 through 1993. Four observations at three stations, the Kaweah River near Sequoia National Park Headquarters (SEKI 0100, SEKI 0102) and the South Forks Kings River above Copper Creek (SEKI 0297), exceeded the WRD screening criterion of 50 Jackson Candle/Formazin/Nephelometric turbidity units (JTU/FTU/NTU) in 1982. The highest reported value of 90 FTU was reported in the Kaweah River near Sequoia National Park Headquarters (SEKI 0100) in April 1982.

Total coliform concentrations were measured 296 times at 43 monitoring stations from 1968 through 1982. Of the 290 observations used in the criteria analysis, 16 observations at eight stations in the East Fork Kaweah River and its tributaries (SEKI 0043, SEKI 0053, SEKI 0056, SEKI 0061, SEKI 0068, SEKI 0069, SEKI 0076, SEKI 0083) exceeded the WRD bathing water screening criterion of 1,000 Colony Forming Units/Most Probable Number per 100 milliliters (CFU/MPN/100 ml) from 1968 through 1972. The highest value of 15,000 CFU/100 ml was reported in Squirrel Creek below the Mineral King Highway near Hammond (SEKI 0043) in September 1971.

Fecal coliform concentrations were determined 872 times at 113 monitoring stations from 1970 through 1988. Of the 868 observations used in the criteria analysis, 21 observations at ten stations, in the Giant Forest area (SEKI 0174, SEKI 0175, SEKI 0179, SEKI 0183, SEKI 0196), the Kaweah River near Sequoia National Park Headquarters (SEKI 0100, SEKI 0102), the East Fork Kaweah River (SEKI 0033), the North Fork Kaweah River (SEKI 0144), and the Marble Fork Kaweah River (SEKI 0237), exceeded the WRD bathing water screening criterion of 200 CFU/MPN/100 ml from 1983 through 1988. Eleven of the 21 observations exceeding the criterion were reported from five stations in the Giant Forest area near sewage sprayfields (SEKI 0174, SEKI 0175, SEKI 0179, SEKI 0183, SEKI 0196) from 1983 through

1988, including the highest value of 755 CFU/100 ml in East Creek (SEKI 0175) in October 1985.

Total alkalinity was determined by low-level (less than 10 mg/L as CaCO3) gran analysis 766 times at 59 monitoring stations from 1982 through 1993. Seven-hundred-fifty-nine observations at 54 lake stations were below the NPS Air Resources Division's 200 microequivalents per liter (µeq/L) threshold, indicating sensitivity to acid deposition. Approximately 90 percent of the observations below the threshold were reported from two stations in Emerald Lake (SEKI 0225, SEKI 0230) from 1982 through 1993.

Chloride concentrations (including dissolved and total) were measured 2,668 times at 243 monitoring stations from 1951 through 1993. One total concentration, 370 mg/L, at a hot spring near the Kern River (SEKI 0091), exceeded the secondary drinking water criterion of 250 mg/L in September 1993.

Cadmium concentrations (including dissolved and total) were measured 58 times at nine monitoring stations from 1977 through 1993. Two dissolved concentrations of 10 micrograms per liter (µg/L) in the South Fork Kings River at Cedar Grove (SEKI 0294, SEKI 0305) and one dissolved concentration of 4 µg/L in the Kaweah River at Three Rivers (SEKI 0046) exceeded the acute freshwater criterion of 3.9 µg/L from 1980 through 1983. The two observations of 10 µg/L at the two stations in the South Fork Kings River at Cedar Grove (SEKI 0294, SEKI 0305) also exceeded the drinking water criterion of 5.0 µg/L in September 1980.

Copper concentrations (including dissolved and total) were measured 130 times at 63 monitoring stations from 1973 through 1993. Seven dissolved concentrations, ranging from 20 µg/L to 40 µg/L, at two stations in the Kaweah River at Three Rivers (SEKI 0044, SEKI 0046), exceeded the acute freshwater criterion of 18 µg/L from 1973 through 1987. Five of the seven observations exceeding the criterion were reported from the Left Bank of the Kaweah River at Three Rivers (SEKI 0046), including the highest concentration of 40 µg/L in April 1987.

Lead concentrations (including dissolved and total) were measured 70 times at ten monitoring stations from 1973 through 1993. Ten dissolved concentrations, ranging from 15 µg/L to 60 µg/L, at two stations in the Kaweah River at Three Rivers (SEKI 0044, SEKI 0046), equaled or exceeded the drinking water criterion of 15 µg/L from 1973 through 1985. Eight of the ten observations exceeding the criterion were reported from the Left Bank of the Kaweah River at Three Rivers (SEKI 0046) from 1973 through 1985. The highest value of 60 µg/L was reported once at each of the two stations at Three Rivers (SEKI 0044, SEKI 0046) in September 1973.

Mercury concentrations (including dissolved and total) were measured 63 times at nine monitoring stations from 1973 through 1993. Four dissolved concentrations, ranging from 2.0 µg/L to 7.0 µg/L, at two stations in the Kaweah River at Three Rivers (SEKI 0044, SEKI 0046), equaled or exceeded the drinking water criterion of 2.0 µg/L from 1974 through 1982. The highest of these four concentrations, 7.0 µg/L from the Left Bank of the Kaweah River at Three Rivers (SEKI 0046), also exceeded the acute freshwater criterion of 2.4 µg/L in August 1974.

Dissolved zinc concentrations were measured 105 times at 57 monitoring stations from 1973 through 1993. One concentration, 300 µg/L, from the Left Bank of the Kaweah River at

Three Rivers (SEKI 0046), exceeded the acute freshwater criterion of 120 µg/L in April 1987.

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/100 ml), general minerals, and general physical and inorganic chemical parameters. Monitoring frequency is dependent on the classification of the water system and the source (National Park Service 1999, Schwarz 2004). 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).

In 2000, the University of California, Davis analyzed human pathogens found in manure from domestic and wild animals along the John Muir Trail (JMT) in Kings Canyon, Sequoia and Yosemite national parks (Derlet and Carlson 2002). Results from 186 trail miles found a low prevalence of human pathogens in animal manure on the JMT.

From 2003 to 2005, the University of California, Davis is investigating the prevalence and concentration of coliform bacteria in Sierra Nevada wilderness area lakes and streams. Researchers are collecting water samples from over 120 lakes and streams, including multiple sites in SEKI. Preliminary data from 2003 and 2004 suggest that most SEKI backcountry wilderness water contains non-harmful aquatic bacteria with an average of 15 CFU/ml (Derlet and Noponen 2005). In addition to aquatic bacteria, however, some samples contained coliform or other potentially pathogenic bacteria.

Ground Water

Relative to surface water, there is minimal information available for ground water quality in SEKI. Ground water through karst in SEKI is easily polluted because it is not filtered by porous rock or sediments, and can move pollutants in a short time. The typical transit time for water and pollutants in karst streams is measured in hours (Despain 2003). Natural sources can also influence ground water quality. For example, a deep well drilled in the foothills contained sulfur and arsenic from local geology, making the water supply non-potable (National Park Service 1999).

Air Quality

The NPS is responsible to preserve, protect and enhance air quality and air quality related values of the National Park System units under both the Organic Act (16 U.S.C. 1, 1a-1) and the Clean Air Act (National Park Service 2001a). SEKI periodically experiences

some of the worst air quality in the United States (Peterson and Arbaugh 1992, Cahill et al. 1996). One of the most damaging pollutants is ozone (National Park Service 1999).

The unique regional topography drastically influences surface air circulation characteristics. Stagnant air is commonly present in the San Joaquin Valley with an inversion layer that exists during all seasons, extending from the surface to as high as 4,500 ft (1,372 m) (msl) in the winter (Duriscoe et al. 1982). Poor ventilation throughout the San Joaquin Valley leads to a build up of pollutants, which are generated in the basin. Upcanyon movement of air is assisted by the surface heating of the mountain slopes during the day. Air is thus "drawn" up the western slope of the Sierra Nevada from the San Joaquin Valley transporting pollutants generated in the valley (Duriscoe et al. 1982).

As previously stated, SEKI contains parts of five drainage basins: Kaweah, Kern, Kings, San Joaquin and Tule. The Kaweah River basin is the most exposed to valley pollutants, due to its relatively straight east-west canyon system and proximity to valley sources. The Kings River basin is somewhat more isolated from valley sources, but Cedar Grove is a sensitive area. The San Joaquin River and Kern River basins include only isolated backcountry areas in these parks. These areas are not expected to receive high concentrations of gaseous pollutants. Maintaining the long-term data set from Emerald Lake and vicinity should be given high priority. This data will be valuable in monitoring future environmental changes due to climatic change and increased urbanization (Sickman and Melack 1998).

There are currently two year-round air quality monitoring stations located within SEKI: Ash Mountain and Lower Kaweah (Esperanza, pers. comm. 2005). Primary support for these monitoring sites is from the NPS Air Resources Division. Sponsors for data collection at these air quality stations have been variable, but include the California Air Resources Board (CARB), Environmental Protection Agency (EPA) and Western Ecological Research Center of the USGS Biological Resources Division (BRD). These stations have been collecting air quality data since the early 1980's. The types of data collected at each current air quality monitoring station in SEKI are presented in Table 2.

Atmospheric Deposition

In 1980, SEKI began involvement in the management of air quality, becoming part of the National Atmospheric Deposition Program's (NADP) monitoring network with the installation of a station at Giant Forest (Duriscoe 1983). In 1982, a major inter-disciplinary program began investigating effects of atmospheric deposition on SEKI's natural resources. This study included a limnological investigation of three study areas: one located in an alpine area, another in a mid-elevation mixed conifer forest, and the third at a foothill chaparral site (National Park Service 1989). In 1983, SEKI began receiving funds from the National Acid Precipitation Assessment Program to establish an acid deposition research program. SEKI was selected for this program due to its location in the southern Sierra Nevada where poorly buffered granitic bedrock and low alkalinity lakes are challenged by significant air pollution, making it one of the most sensitive areas in the country to acid precipitation as classified by the E.P.A. (Parsons and Graber, 1985;

El-Amamy et al. 1984). The California Air Resources Board began an intensive 5-year acid deposition research and monitoring program in SEKI in 1984, funded through the Kapiloff Acid Deposition Act (California Air Resources Board 1986). This CARB program enhanced studies that were underway in SEKI, making it possible to gather information on effects of acidic deposition on Sierra ecosystems that would not have been possible by the NPS program alone.

Table 2. Air quality monitoring stations in Sequoia and Kings Canyon National Parks.

Park	Site	Type	Network **
Sequoia	Ash Mountain	Meteorology	NPS – ARD
		Ozone	NPS – ARD
		Particulate Matter	SEKI Fire
		PM 2.5 and 10	IMPROVE
		Dry deposition	CASTNet
Sequoia	Lower Kaweah	Meteorology	NPS – ARD
		Ozone	NPS – ARD
		Wet deposition	NADP/NTN
		Mercury	MDN
		Webcam	NPS – ARD

** Clean Air Status and Trends Network (CASTNet)
Interagency Monitoring of Protected Visual Environments (IMPROVE)
Mercury Deposition Network (MDN)
National Atmospheric Deposition Program/National Trends Network (NADP/NTN)
National Park Service – Air Resources Division (NPS - ARD)

Stoddard (1995) found atmospheric loads to dilute lakes in the Sierra Nevada mountains of California to be very low compared to high deposition levels found in the eastern U.S., and fell almost entirely as snow. Sulfur and nitrogen deposition is of particular concern because it has the potential to reduce buffering capacity of sensitive (low ANC) lake and streams. Nitrogen deposition can also act as a fertilizer, changing aquatic chemistry and biota (National Park Service, 2002). Deposition monitoring in the western U.S. from 1984-2002 shows that nitrogen deposition has increased at least 25% in the region over that time (Lehman et al., in press), although no significant trends in nitrogen have been shown at the SEKI monitoring site (Blett, 2005). The low atmospheric loads were thought to be enough to eventually acidify low acid-neutralizing capacity (ANC) lakes. Of the ten lakes studied by Stoddard (1995), High Lake was the only lake to become acidic during snowmelt. It appears that episodic acidification occurs only in Sierran watersheds with the most extreme characteristics. All lakes exhibited increases in NO_3^- concentrations during early snowmelt; these were accompanied by increases in base cations, primarily Ca^{2+}. In the first few days of snowmelt, NO_3^- concentrations at High Lake increased more rapidly than concentrations of base cations resulting in ANC values below zero. Export of both NO_3^- and SO_4^- from the watersheds exceeded the inputs from

the snowpack, suggesting that other sources (e.g., watershed minerals, stored inputs from the previous summer, transformations of other inputs) of these anions are important. Williams and Melack (1991) found solute concentrations in meltwater to be higher when the rate of snowmelt decreased.

In 2002, a NPS project entitled the "Western Airborne Contaminants Assessment Project" (WACAP) was initiated to determine the risk to ecosystems and food webs in western national parks from the long-range transport of airborne contaminants. It has been designed and implemented by the National Park Service's Air Resource Division in cooperation with national parks, the U.S. Environmental Protection Agency, the U.S. Geological Survey, and several universities (National Park Service 2004g). The contaminants of concern are compounds and elements known as Persistent Bioaccumulative Toxics (PBTs). This group contains a variety of persistent organic pollutants (POPs) such as PCB, DDT, and HCH; as well as elements such as mercury (Hg). These materials are direct or indirect products of human industrial activity and can be transported thousands of miles in the atmosphere. The project design centers around eight national parks in the west (Noatak, Denali, Gates of the Arctic, Glacier, Olympic, Ranier, Rocky Mountain, and Sequoia) representing a latitudinal gradient as well as a coastal to interior gradient.

During 2003, an integrated research plan for the WACAP was prepared, peer reviewed, and published as an EPA report. The entire document is now available at www2.nature.nps.gov/air/Studies/air_toxics/wacap.htm. A Quality Assurance Project Plan (QAPP) has been completed. Field and laboratory methods were developed and tested, and field and laboratory equipment was purchased. Analytical approaches that determine over 100 organic compounds for various sample types (e.g., snow, lake water, vegetation) were developed and tested (National Park Service 2004g). Snow has been sampled each year in the parks beginning in 2003. Field activities during August and September, 2003, involved 8-12 persons working at two lakes in Sequoia National Park and two lakes in Rocky Mountain National Park. Samples were collected from willow, pine needles, lichen, lake water, sediment and fish. Atmospheric modeling approaches have also been developed to begin looking at the geographic locations that comprise seasonal air masses impacting WACAP sites. Contaminant analyses show that both current-use and banned (in the U.S.) semi-volatile organic compounds are present in snow, water and vegetation in high-elevation ecosystems in Sequoia National Park. As scientists continue to examine additional WACAP samples over the next several years, including fish and lake sediments, a deeper understanding will be developed regarding the impacts these contaminants have on the WACAP sites (National Park Service 2004g).

In 2001, monitoring equipment was installed below Tufa Falls to evaluate the amount of atmospheric carbon captured by Spring Creek. By knowing how much water flows from the spring and the types and amounts of dissolved minerals in the water, the amount of atmospheric carbon being captured by Spring Creek can be determined. Over the course of a year, this karst system will capture many tons of carbon (Despain 2003).

Biological Resources

Water resources are critical to the sustenance of SEKI's populations of flora and fauna. Conversely, biological resources are intimately linked to hydrological systems. For example, recent climate history can be estimated using tree-ring chronologies, and biological monitoring data can indicate environmental condition and ecological health of water resources.

Since a comprehensive evaluation of biological resources extends beyond this report, the following two sections concentrate on park biological resources that are influenced by water resources, listed as endangered, threatened, candidate or special concern species under the federal Endangered Species Act (ESA) or listed as endangered, threatened, special concern or protected species under the California Endangered Species Act (CESA). Along with providing some basic background information, the purpose of this section is to begin exposing some of the biological concerns that might serve as indicators to water-related issues.

The National Park Service is mandated by the ESA and other laws to protect the habitat and populations of wildlife within the parks. The National Park Service has exclusive jurisdiction to manage wildlife resources within the parks, however, SEKI works cooperatively with the California Department of Fish and Game on a variety of issues. Within SEKI, state management of fish and wildlife resources is required to be consistent with the provisions of NPS management policies. Therefore, some aspects of state management may not apply within the parks.

Flora

Terrestrial Vegetation

SEKI supports a diverse assemblage of vegetation types due to the presence of extreme topographic differences, a large elevation gradient and its location on the west slope of the Sierra Nevada. The list of known SEKI flora includes more than 1,500 taxa of vascular plants, which is more than 20% of the almost 6,000 vascular taxa known to occur in California (National Park Service 2004d). In addition, a rich lichen flora has been documented in the parks and species lists are available online at http://www.ies.wisc.edu/nplichen. Following the elevation gradient, the terrestrial vegetation types roughly can be divided into three zones: foothills (low elevations), coniferous (middle elevations), and subalpine/alpine (high elevations).

The SEKI foothills zone occurs in the Kaweah River drainage of Sequoia National Park and the southern Redwood Creek area of Kings Canyon National Park, ranging from 1,370 ft (418 m) (msl) at the parks' boundary to approximately 5,000 ft (1,524 m) (msl). Grasslands, blue oak savanna and chaparral intermix in the lower elevations of this zone to produce a diverse mosaic of vegetation. The grasses in the grasslands and blue oak savanna are primarily composed of non-natives that have become naturalized since their introduction in the mid-1800s, however, the woody species that occupy the blue oak

savanna and chaparral are largely composed of native taxa (National Park Service 2004d). These vegetation types thrive in the Mediterranean climate that occurs in lower SEKI elevations, where most of the precipitation is deposited during cool wet winters and summers are hot and dry. Chaparral communities, in particular, are well-adapted to drought and fire events that heavily influence these habitats. In the higher elevations of the foothills zone, blue oak and chaparral are replaced by California black oak and the lower edge of coniferous forest. Although vast foothill lands cover much of lowland central California, very little is designated for long-term preservation, making the foothill habitat protected in Sequoia National Park an especially significant resource.

The coniferous zone occupies the middle elevations of both Sequoia and Kings Canyon National Parks, ranging approximately from 5,000 to 9,000 or 10,000 ft (1,524 to 2,743 or 3,048 m) (msl) depending on aspect. Heavier precipitation and cooler temperatures in this zone provide snow cover during winter and available water in summer, facilitating the growth of conifers. Although incense cedar, ponderosa and sugar pine, white fir, and giant sequoia occur in the lower band of this zone. Giant sequoias commonly grow in groves, demonstrating an affinity to very specific habitat conditions. The giant sequoia presently occurs in approximately 75 groves, all of which are located on the west slope of the Sierra Nevada, and about one-third of all wild sequoias are located in 39 named groves in SEKI (National Park Service 2003). The Giant Forest and General Grant groves in SEKI are recognized to contain the five largest trees on earth. Further, the enabling legislation of Sequoia and General Grant (now Kings Canyon) National Parks specifically protects the giant sequoia and attaches the highest level of significance to the biological resources in these parks (26 Stat. 478, 16 USC 41).

The upper band of the coniferous zone is dominated by almost-pure stands of red fir and lodgepole pine, and contains a smaller abundance of Jeffrey pine and western white pine. This habitat grows tall forests with dense canopies that prevent most sunlight from reaching the forest floor. The resulting shade causes deep winter snows to persist into late spring, and limits the summer development of understory herbaceous cover in all but the wetter sites. The extensive coniferous zone protected in SEKI sustains a diverse mix of tree species and forms some of the most contiguous stands of old-growth coniferous forest that persist in the world. These rare old-growth forests in relatively pristine states possess very high recreational and scientific value and represent a significant resource.

The subalpine/alpine zones occur in the upper elevations of SEKI and ranges approximately from 9,000 or 10,000 ft (2,743 or 3,048 m) (msl) depending on aspect to the Sierra crest at 14,494 ft (4,418 m) (msl). Occupying the lower band of this zone are sparsely populated subalpine woodlands that represent the limit of tree life in SEKI. Dominated by foxtail pine in the south and whitebark pine in the north, and also inhabited by sporadic stands of mountain hemlock, subalpine woodlands provide critical habitat at high elevation where biological productivity is suppressed due to short growing seasons. Governed by dry and cold conditions, dead foxtail pines can continue to stand for centuries and persist as downed logs for additional centuries, attracting decomposers and providing cover and food for fauna (National Park Service 2004d). Whitebark pines often

grow in tight stands that make excellent cover, and their annual crops of nuts provide essential nutrition for fauna at these elevations.

The upper band of this zone contains the alpine habitats that are dominated by rocky shallow soils and driven by harsh winters and very short growing seasons. Herbs are able to inhabit these elevations by using a perennial life-history strategy and by forming low-growing vegetation mats that exploit warm surface temperatures in summer. Hugging the ground also facilitates insulation by snow from freezing temperatures and desiccating winds in winter. The vegetation in the subalpine/alpine zone protected in SEKI occupies the heart of the largest wilderness area in California and carries out ecosystem processes in lands of very high recreational and scientific significance.

Aquatic Vegetation

An inventory is needed to determine how many taxa of aquatic plants occur in these parks as well as their distribution and abundance. However, a few studies conducted in lakes and streams have contributed to knowledge of aquatic vegetation in SEKI.

Research on the ecological effects of visitor use in ten lakes in the Rae Lakes, Kearsarge Lakes and Sixty Lake Basin areas found that high use lakes had lower concentrations of nitrate, higher concentrations of iron, and more bottom coverage by rooted macrophytes and algae than low use lakes (Taylor and Erman 1979). Mean nitrate concentrations ranged from 0-156 μg/liter, but most lakes had 3 μg/liter or less. Mean total iron concentrations ranged from 4-38 μg/liter, while mean benthic flora frequencies ranged from 0-100%. They concluded that additional micronutrients, such as iron, were deposited by humans in high use lakes that increased growth and nitrogen uptake by aquatic vegetation, thereby depleting nitrate concentrations. *Nitella* and *Isoetes* dominated the aquatic flora in all lakes except for the two Rae Lakes and two lakes without plants. *Anacharis (Elodea) canadensis*, *Rhizoclonium*, *Oedogonium* and *Nitella* dominated Lower Rae Lake while *Nitella* and *Rhizoclonium* dominated Upper Rae Lake, although *Anacharis* also was present.

Silverman and Erman (1979) recorded phytoplankton and periphyton densities in two lakes each in Rae Lakes and Sixty Lake Basin and for both groups found higher mean densities in early season that decreased as the season progressed. Average net phytoplankton densities ranged from zero to almost 10^6 counts/liter. Phytoplankton densities were about 100 times greater in Rae Lakes than in Sixty Lake Basin in early July, but generally were similar in both areas by late July. *Asterionella* made up 82-98% of the phytoplankton populations early in the season while *Fragilaria* and *Dinobryon* comprised up to 33% of the populations later in the season. Periphyton densities ranged from 0-96 counts/cm^2, but generally were between 0-5 counts/cm^2. Periphyton populations were dominated by *Ankistrodesmus* and *Mougeotia*.

A study of plankton in 41 Sierra lakes documented 129 taxa of algae, with desmids (Chlorophyta) being the most diverse and diatoms (Bacillariophyta) and *Dinobryon* (Chrysophyta) being the most abundant (Kubly 1983).

A survey of trout populations in 137 SEKI lakes used visual means to record whether algae and aquatic plants were present but did not record species or quantify densities (Zardus et al. 1977). They recorded the presence of *Isoetes*, *Potamogeton* and reeds in only a few of the 137 lakes surveyed. Two native taxa of *Potamogeton* and the native *Ceratophyllum demersum* occur in the North Fork Kaweah River (Werner, pers. comm. 2004). In 2002, one of the *Potamogeton* taxa was common and the other *Potamogeton* and *Ceratophyllum demersum* were rare. The native aquatic plant *Ranunculus aquatilus* is known to occur in Zumwaldt Meadow in the South Fork Kings River drainage (McGinnis, pers. comm. 2004).

A non-native alga (*Nitella* sp.) was introduced to Rae Lakes in 1919 by the U.S. Department of Fish Culture to supplement the diet of introduced trout (Coleman 1925). Another non-native, Canadian waterweed (*Anacharis (Elodea) canadensi*s), also was introduced to Rae Lakes (Taylor and Erman 1979), possibly to increase the amount of oxygen available to trout. A third invasive non-native, *Potamogeton crispus*, is common in the North Fork Kaweah River (Werner, pers. comm., 2004) and likely is a threat to the native *Potamogeton* taxa with which it co-occurs (Demetry, pers. comm. 2004).

Fauna

Terrestrial Wildlife

The diversity of terrestrial wildlife in SEKI is driven by its extreme range of elevation, vegetation and habitat. Approximately 265 native terrestrial vertebrate species are known to occur in SEKI (National Park Service 2004h). The known native terrestrial assemblage includes 70 mammals, 169 birds, 21 reptiles and five amphibians. Twenty-five additional terrestrial vertebrates may be present but have unconfirmed status, and current inventory surveys may detect further additional species. Of the native terrestrial vertebrates, five are extirpated, including the grizzly bear, elk, California condor, coast horned lizard and side-blotched lizard, 126 are uncommon or rare and 19 are of accidental occurrence in SEKI (detected outside of their normal range). Therefore, only 115 of the 265 known native terrestrial vertebrates, or 43%, are common in SEKI.

The foothills ecosystem supports many native animals year-round and many others seasonally. Native terrestrial vertebrate species that are common in the SEKI foothills include the mule deer, black bear, bobcat, gray fox, coyote, dusky-footed woodrat, Botta's pocket gopher, brush mouse, red-tailed hawk, California quail, western scrub jay, lesser goldfinch, wrentit, acorn woodpecker, American dipper, western rattlesnake, gopher snake, mountain kingsnake, western fence lizard, southern alligator lizard and three species of slender salamanders.

Terrestrial vertebrate species that are common in the SEKI coniferous zone include the mule deer, black bear, mountain lion, coyote, chickaree, California ground squirrel, golden-mantled ground squirrel, Stellar's jay, western tanager, violet-green swallow, white-throated swift, Wilson's warbler, olive-sided flycatcher, hermit thrush, western

bluebird and American dipper. Although uncommon in this zone, the rubber boa, western fence lizard, northern alligator lizard and ensatina are sometimes observed.

Terrestrial vertebrate species that are common in the SEKI subalpine/alpine zone include the marmot, pika and alpine chipmunk, while the Belding's ground squirrel, white-tailed jackrabbit and elusive bighorn sheep are sometimes seen. Birds include the Clark's nutcracker, mountain bluebird, rosy finch, white-crowned sparrow, yellow-rumped warbler and American dipper.

Aquatic Wildlife

The diversity of aquatic wildlife in SEKI reflects its extreme range of elevation and the presence of various aquatic habitats, including streams, ponds, lakes, wet meadows and riparian areas. For the purposes of this report, aquatic wildlife is defined as entirely aquatic or amphibious taxa that depend on occupying an aquatic habitat for all or part of their life cycles. Aquatic wildlife does not include taxa that frequent, but are not dependent on, aquatic environments.

Approximately 46 native aquatic vertebrate species are known to occur in SEKI (National Park Service 2004h). The known native aquatic assemblage includes two mammals, 30 birds, three reptiles, six amphibians and five fishes. Sixteen additional aquatic vertebrates may be present but have unconfirmed status, and current inventory surveys may detect further additional species. One of the native aquatic vertebrates is extirpated (the foothill yellow-legged frog), 15 are uncommon or rare and 19 are of accidental occurrence. Therefore, only 11 of the 46 native aquatic vertebrates, or 24%, are common in SEKI.

Common aquatic vertebrate species in the foothills zone include the rainbow trout, Pacific treefrog, California newt, western pond turtle and Sierra garter snake, while the western toad and great blue heron are sometimes seen. The foothill yellow-legged frog has been extirpated from the SEKI foothills and the distribution and abundance of the western pond turtle has been highly reduced. Implicated in these declines are the introduction of hydroelectric structures, contaminants and non-native species, including the brown trout, green sunfish and bullfrog, which also may be impacting native fishes.

The coniferous ecosystem provides habitat for a different mix of native aquatic fauna. Aquatic vertebrate species that are common in this zone include the rainbow trout, Kern River rainbow trout, Little Kern golden trout, Pacific treefrog, Sierra garter snake and western terrestrial garter snake. Although rainbow trout is native only to the lower edge of the coniferous zone, where steep gradients prevented its migration to higher elevations, it has been introduced to higher elevations where it is now common. Further, the Little Kern golden trout is native to Soda Springs Creek within SEKI , but has also been transplanted to Coyote Creek, which is outside of its native range.

The subalpine/alpine zone, although food-limited and climatically challenging, also is inhabited by a wide range of native aquatic fauna. The only aquatic native vertebrate that is now common to high elevations across most of SEKI is the Pacific treefrog. Although

the Kern River rainbow and Little Kern golden trout continue to occur in the upper Kern River drainage, they have been highly impacted by competition and genetic introgression by several species of transplanted and non-native trout. These introduced species include the rainbow trout, eastern brook trout and hatchery golden trout, which have established self-sustaining populations in approximately 50% of SEKI lakes (Knapp and Matthews 2000). Introduced trout also are the primary cause in the severe decline of Sierra Nevada populations of the mountain yellow-legged frog (MYLF), which historically was common in subalpine lakes but today is a candidate for listing under the federal ESA. Although recovery efforts have begun for some MYLF populations in SEKI, few reproducing populations exist due to trout predation on tadpoles and subadults. In turn, high-elevation populations of the western terrestrial garter snake have been impacted, which are native predators of MYLFs. Although the Yosemite toad continues to occupy subalpine meadows, today it also is a candidate for listing under the federal ESA. Possible stressors of the Yosemite toad include habitat alteration by riparian grazing and other factors such as competition and predation by introduced trout.

Although many studies have contributed to our understanding of aquatic wildlife in SEKI, the majority were conducted from 1977 to the present, when decades of criticisms to improve ecological understanding in the national parks were finally heeded. In 1977, per recommendations in the Leopold Report (Leopold et al. 1963), SEKI (and other parks) began to investigate the effects of a century of trout introductions on native biota.

Amphibians - The MYLF is an amphibian species that is endemic to high elevations in the Sierra Nevada, including SEKI, and the mountains of southern California (Stebbins, 1985; Jennings and Hayes, 1994). The species was first described by Camp (1917) as two subspecies, *Rana boylii muscosa* in southern California and *Rana boylii sierrae* in the Sierra Nevada. Zweifel (1955) combined the two subspecies into one species, *Rana muscosa*, and named the foothill yellow-legged (FYLF) frog as a distinct species, *Rana boylii*. However, a recent genetic analysis of mitochondrial DNA from MYLFs indicates large genetic differences across the species' range (Macey et al. 2001). Four distinct subgroups were found that should be considered as potential units for conservation, including southern California and southern, central and northern Sierra Nevada. A large biogeographic break also was found in the range of the MYLF (and four additional species of amphibians and reptiles) between Tulare and Calaveras counties, possibly at the area of Mather Pass in Kings Canyon National Park (Vredenburg, pers. comm. 2004). Additional data from this study suggest that *R. aurora*, *R. cascadae*, and *R. muscosa* form a clade within the *R. boylii* species group.

MYLFs in the Sierra Nevada occur in many types of lentic habitats, including lakes, ponds, tarns, wet meadows, and streams (Zweifel 1955, Mullally and Cunningham 1956, Pope 1999), from about 6,000 to 12,000 ft (1829 to 3658 m) (msl) in elevation (Stebbins 1985, Jennings and Hayes 1994, U.S. Fish and Wildlife Service 2003a). Individuals typically are found in shallow, warm water areas, and sunny riverbanks, and seem to prefer sloping banks with rocks or vegetation to the water's edge (Stebbins 1985). Tadpoles take 2 to 3 years to metamorphose and thus suitable breeding sites require permanent water (Bradford 1983), such as perennial ponds and lakes. Adult MYLFs are

highly aquatic and seldom found more than one meter from water, but will cross upland areas when moving between summer and winter habitats (Matthews and Pope 1999). Adults and tadpoles overwinter in water, requiring aquatic habitats deep enough to prevent freezing (Bradford 1983) or with nearshore ledges and deep underwater crevices (Matthews and Pope 1999). Thus, MYLF populations use a complex of lakes, ponds, streams and wet meadows rather than single lakes or ponds, using different types of habitats for different life stages and different seasons (Pope 1999, Vredenburg 2004).

Several studies estimate that the MYLF has declined in or disappeared from 70-90% of historically occupied sites in the Sierra Nevada (Bradford 1991, Jennings and Hayes 1994, Drost and Fellers 1996, Knapp and Matthews 2000, U.S. Fish and Wildlife Service 2003a), and 99% of the historical range in southern California (U.S. Fish and Wildlife Service 2002a). As a result, the southern California distinct population segment (DPS) was recently issued an endangered status under the federal ESA (U.S. Fish and Wildlife Service 2002a), and the Sierra Nevada DPS was issued a warranted but precluded status and placed on the candidate list for threatened or endangered status (U.S. Fish and Wildlife Service 2003a). Primary threats to MYLFs include habitat modification through predation, fragmentation and isolation of populations by introduced trout, disease and airborne contaminants (U.S. Fish and Wildlife Service 2003b). MYLF populations in SEKI represent the southern edge of the species' range (Jennings and Hayes 1994) and thus may be particularly vulnerable to local extinction if the range decreases over time.

One of the first investigations of contaminant deposition in Sierran aquatic biota (Cory et al. 1970) found DDT residues in MYLFs, with higher concentrations present in animals from the west side of the Sierra versus the east side.

Data sheets from the study of introduced trout populations in 137 SEKI lakes (Zardus et al. 1977) show that MYLFs were only observed swimming in open water in two of the 137 lakes, likely due to the high percentage of lakes containing predatory trout.

Bradford published several papers on the biology of the MYLF and investigated possible causes of its decline, including chemicals and introduced trout. He found that adults and tadpoles need deep lakes that do not freeze solid in winter in order to survive to the next summer, underscoring the need for deep fishless lakes for long-term persistence of populations (Bradford 1983, 1984). Mass mortality and extinction of a mountain yellow-legged frog population may have been caused by a native bacterium, *Aeromonas hydrophila* that is a natural but occasional stressor of MYLFs (Bradford 1991). He also found that the distribution of remaining frog populations and introduced trout did not overlap, indicating a negative effect of trout introductions (Bradford 1989). Further, the near ubiquity of introduced trout in the High Sierra has massively fragmented existing frog populations and prevented recolonization of sites from which frogs have been extirpated (Bradford et al. 1993, 1994a). Bradford and colleagues found that MYLFs are rare or absent in sites with a pH of less than 6.0, however, since these sites are rare in the High Sierra, acidic deposition is an unlikely cause for amphibian declines in the Sierra Nevada (Bradford and Gordon, 1992, Bradford et al. 1992, 1994b, 1994c, 1994d, 1998).

Since 1996, Vredenburg has been investigating reproductive and predator-avoidance behavior, animal movement patterns, population biology and phylogeography of the MYLF in SEKI to help explain its population declines and contribute to its conservation. Vredenburg presented experimental evidence that introduced trout in lakes prevent successful breeding by MYLF through predation on tadpoles and recently metamorphosed individuals (Vredenburg 2002, 2004). Vredenburg documented that the MYLF tadpole life-stage is the stage most-vulnerable to predation by introduced trout. Since trout also eliminate virtually all frog migration between fishless, frog-containing sites, they argue that introduced trout are likely the major cause of the MYLF decline observed thus far (Vredenburg 2002, 2004). Vredenburg also investigated the possible role of ultraviolet radiation in the decline of the MYLF. He found that shielding eggs from sun exposure did not affect egg hatching success, thus presenting experimental evidence that ultraviolet radiation is not a cause of the MYLF decline (Vredenburg 2002). MYLF tadpoles also have been observed cannabilizing MYLF egg masses (Vredenburg 2000) and feeding on carcasses of dead metamorphosed frogs (United States and Fish Wildlife Service 2003b) and tadpoles (Boiano, pers. observ. 2004).

Since 1997, Knapp, Matthews and colleagues have been conducting research in SEKI and the adjacent Sierra Nevada to investigate the effects of introduced trout on the distribution and abundance of the MYLF (Knapp and Matthews 2000), Pacific treefrog (Matthews et al. 2001), western terrestrial garter snake, *Thamnophis elegans* (Matthews et al. 2002) and large-bodied benthic macroinvertebrates and crustacean zooplankton (Knapp et al. 2001). For all of these faunal groups, they found that the number of sites occupied and the number of individuals detected per site were significantly lower in sites containing introduced trout versus fishless sites. Sample sizes were very large for both species of amphibians (1,728 sites), garter snakes (2,103 sites) and invertebrate groups (533 sites), providing evidence of landscape-scale declines of native species resulting from trout introductions. However, they also found that in lakes where fish disappeared due to the cessation of stocking in SEKI, these high-elevation aquatic systems were resilient and generally recovered to predisturbance levels within 11-20 years (Knapp et al., 2001). In the study area containing 1,728 sites (540 mi^2 (1,400 km^2)), they also developed probabilistic models to predict amphibian site occupancy (Knapp et al. 2003). They found that the probability of frog presence was highly influenced by lake depth, elevation, fish presence/absence, substrate, and the degree of lake isolation. In 2004, Knapp is continuing to survey MYLF populations in SEKI to estimate colonization and extinction rates and document the number of populations infected by chytridiomycosis.

Since 1997, Matthews and Pope have been determining movement patterns and habitat use by a metapopulation of MYLFs in SEKI. Using telemetry, they found that home range size was largest (570 – 105,563 ft^2 (53 - 9807 m^2)) in September and individuals may move hundreds of meters between summer and winter habitats (Matthews and Pope 1999). Using passive integrated transponder surveys, they observed overland movements of more than 216 feet (66 m) in 17% of tagged frogs, documented movement between lakes one kilometer apart and found that 97% of tagged frogs wintered in the same lake in consecutive years (Pope and Matthews 2001). They determined that MYLF adults eat aquatic and terrestrial invertebrates and anuran larvae, particularly Pacific treefrog (*Hyla*

regilla) tadpoles, and that availability of larval anuran prey may be an important factor in distribution, body condition and survival of adults (Pope and Matthews 2002). MYLF tadpoles primarily graze on benthic detritus, algae and diatoms along the bottoms of waterbodies (Bradford 1983). Matthews (2003) found that short-distance translocations caused MYLFs to lose body mass and documented that seven of twenty frogs translocated 472 – 2,067 ft (144 - 630 m) returned to their original capture site within 30 days.

In the 1990s, Bradford witnessed the disappearance of MYLF populations from the SEKI Tablelands, a largely fishless area, and hypothesized that pollution may have been a factor. Bradford and Fellers then translocated healthy individuals from elsewhere in SEKI to assess their response to the compromised environment. These reintroduced individuals did not persist, perhaps due to relatively high pesticide concentrations in the area (Bradford and Fellers, unpublished data).

Sparling et al. (2001) sampled tissues from populations of Pacific treefrogs from areas surrounding central California for cholinesterase, an enzyme inhibited by organophosphorous pesticides. They found cholinesterase activity in Sierra Nevada tadpoles was depressed compared with sites in the Coast Range or north of the Central Valley. Organophosphorus residues were detected in up to 50% of the tissue samples with reduced cholinesterase activity that were collected from the Sierra. Additionally, endosulfan was detected in up to 86% of some populations and 4,4 -DDT, 2,4 -DDT and 4,4 -dichlorodiphenyldichloroethylene were detected in up to 40% of some populations.

Davidson and colleagues constructed maps of the spatial pattern of declines for eight declining California amphibian taxa, including the MYLF, FYLF and Yosemite toad (*Bufo canorus*), and compared the observed patterns to those predicted by hypotheses of airborne pesticides, habitat destruction, UV-radiation and climate change (Davidson et al., 2002). In four species, MYLF, FYLF, California red-legged frog (*Rana aurora draytonii*) and cascades frog (*Rana cascadae*), they found a strong positive correlation between declines and the amount of upwind agricultural land use. This result indicates that airborne pesticides may be an important factor in these species' declines and that ranid frogs may be particularly sensitive to agrochemicals. Additionally, UV-radiation and climate change were not correlated with the observed patterns of decline for all eight species.

Cowman and colleagues are currently assessing the effects of contaminants on Sierran amphibians. Work includes field survey transects, field cage experiments and laboratory experiments on amphibian species in Sequoia, Yosemite and Lassen Volcanic national parks. The study aims to determine if local conditions affect Pacific treefrog tadpole survival and whether survival differs between parks that naturally receive different pesticide exposures. Initial results show that tadpole survivorship to metamorphosis was greatest at Lassen and malformations of hind limbs (brachymelia) were observed in tadpoles and newly metamorphosed frogs at all three parks (Cowman et al. 2002).

Currently, Bradford and colleagues are investigating the distributions of airborne contaminants relative to the distributions of amphibians with an emphasis on the MYLF (Bradford et al. 2003). Once a month in 2003, the team sampled contaminant concentrations in water weekly from one high-elevation lake and monthly from three high-elevation lakes, two mid-elevation streams and two low-elevation streams. They also collected tissue from Pacific treefrogs to measure bioaccumulation of contaminants in amphibians. Initial results show significant differences in cholinesterase activity between sites (Bradford et al., unpublished data). The project is planned to be expanded to 14 pairs of lakes in 2005 to increase the spatial aspect of the study.

In the past several years the newly identified fungal pathogen, *Batrachochytrium dendrobatidis*, has been implicated in the decline of amphibians worldwide (Berger et al. 1998), including the MYLF. The fungus causes oral chytridiomycosis (abnormal development of mouthparts) in MYLF tadpoles (Fellers et al. 2001) and infected individuals normally die soon after metamorphosis. Additional information on chytridiomycosis include publications on field identification in MYLFs (Vredenburg and Summers 2001) and how to determine if abnormal mouthpart development in MYLF tadpoles is due to chytridiomycosis or seasonal temperature changes (Rachowicz 2002).

A research team from the University of California is currently trying to determine the origin of chytridiomycosis and understand how anthropogenic environmental changes influence its prevalence and spread in the MYLF. Preliminary results indicate that the prevalence of the disease in the MYLF is quite high, that chytridiomycosis causes mortality of virtually all individuals in most infected populations, and that the disease is spreading into previously uninfected populations (Briggs 2004). A graduate study integrated with this project is exploring the hypothesis that the Pacific treefrog is acting as a disease reservoir for chytrid fungus (Bingham 2003). Samples are being collected in SEKI in 2003 and 2004 to determine why Pacific treefrogs appear to thrive in sites where MYLFs are being infected with chytridiomycosis.

Recent reports documented that amphibians are also being infected by viruses (Mao et al. 1999). In 2001, mass-mortality of a SEKI population of MYLFs was preliminarily diagnosed as being caused by a virus outbreak (Knapp, unpublished data). Although viruses are infecting amphibians, viral prevalence in MYLF populations appears low compared to chytridiomycosis, and thus the role of viruses in the decline of MYLFs is currently unclear.

The Yosemite toad is another amphibian species that is endemic to high elevations in the Sierra Nevada, including SEKI (Stebbins 1985, Jennings and Hayes 1994). First described by Camp (1916), Yosemite toads occur in many types of lentic habitats (Mullally 1953, Karlstrom and Livezey 1955, Karlstrom 1962) from about 6,400 to 11,300 ft (msl) in elevation (Stebbins 1985, Jennings and Hayes 1994). However, individuals are typically found in shallow, warm water areas of wet meadows, small permanent and ephemeral ponds, and flooded grassy areas adjacent to lakes (Karlstrom 1962). Suitable breeding sites generally are the shallow water edges of meadows, slow-flowing streams or lakes (Mullaly 1953, Karlstrom 1962), often dominated by short

emergent sedges or rushes (Karlstrom 1962, Jennings and Hayes 1994). Breeding ponds were usually found to be less than 12 inches deep (Mullally 1953). Water depth and temperature thus highly influence egg and tadpole survival (Kagarise Sherman and Morton 1993).

Two recent genetic studies of the Yosemite toad arrived at somewhat different conclusions. Shaffer et al. (2000) indicate that the Yosemite toad and Western toad (*Bufo boreas*) should continue to be recognized as distinct species, at least until additional molecular data become available. Nevertheless, they recommend that Yosemite toad populations in Yosemite and Kings Canyon national parks should be considered separate management units and managed as such. Stephens (2001) examined 173 western toads and eight Yosemite toads from the Shaffer et al. (2000) sample and indicated that Sierra Nevada *Bufo* occur in northern and southern evolutionary groups, in which toads of both species are more closely related to each other within a group than they are to members of their own species in the other group. However, Stephens (2001) also concluded that further genetic analysis of Yosemite toads from throughout their range is needed to determine the appropriate taxonomy of *Bufo* in the Sierra Nevada.

Several studies estimate that the Yosemite toad has declined in or disappeared from approximately 50 - 70% of historically occupied sites (Jennings and Hayes 1994, Drost and Fellers 1996). As a result, the species was recently issued a warranted but precluded status under the ESA and placed on the candidate list for threatened or endangered status (U.S. Fish and Wildlife Service 2002b). Primary threats to Yosemite toads include habitat degradation, airborne contaminants and drought, while disease and predation by introduced trout also have probably contributed to their decline (U.S. Fish and Wildlife Service 2002b). Habitat destruction includes effects from livestock grazing, road construction, timber harvest, vegetation and fire management, recreation, dams and water diversions. Yosemite toad populations in SEKI represent the southern edge of the species' range (Jennings and Hayes 1994) and thus may be particularly vulnerable to local extinction if the range decreases over time.

The U.S. Forest Service is developing long-term monitoring plans for the MYLF and Yosemite toad under Sierra Nevada Framework Plan (U.S. Forest Service 2001). Beginning in 2002, surveys were conducted across the range of the Sierra Nevada populations to test methods proposed in the monitoring plan. The NPS Sierra Nevada Network has begun a dialogue with these managers to integrate methods between their monitoring plan and the Sierra Network Inventory and Monitoring Plan.

Vredenburg and colleagues also conducted behavioral observations and genetic analyses of Mount Lyell salamanders (*Hydromantes platycephalus*) in SEKI. They detected individuals at very high-elevations for the species in areas with good cover (cracks in slabs) that were wet from melting perennial snowfields (Vredenburg et al. 2001). Initial results of genetic analyses show the same large genetic division between northern and southern populations as in the MYLF (Papenfuss, unpublished data). This work is being continued in a graduate study aiming to determine the genetic variation between

populations of Mount Lyell salamanders across its range and determine whether past climatic changes have shaped the species' phylogeographic pattern (Rovito 2004).

The bullfrog (*Rana catesbeiana*), an exotic species in California, is present in the North Fork Kaweah River and may be present elsewhere within the boundary of Sequoia NP (Werner, pers. comm. 2004). Bullfrog detections in California have not been higher than about 4,000 ft (1,219 m) (msl); no detections are known to have occurred at higher elevations.

Fish - The various golden trout in the Kern River system (*Oncorhynchus mykiss spp.*) were described in 1905 in a bulletin produced by the U.S. Fish Commission (Evermann 1905).

A survey of the status of introduced trout populations in 137 SEKI lakes (Zardus et al. 1977), after most stocking was stopped, estimated that 84 were definitely reproducing and likely self-sustaining, 13 were probably reproducing, 16 had little or no reproduction, 6 were definitely not reproducing and 18 were fishless. Stocking of approximately 7 lakes per year continued through 1988, when all stocking was terminated.

Fish populations were surveyed in the Middle Fork Kaweah River as part of a study to evaluate the impacts of a hydroelectric facility on the resources of Sequoia National Park (Jordan/Avent and Associates 1980, 1984). They documented the presence of native rainbow trout (*Oncorhynchus mykiss mykiss*), California roach (*Lavinia symmetricus*), Sacramento sucker (*Catostomus occidentalis*) and a single specimen of prickly sculpin (*Cottus asper*), as well as introduced brown trout (*Salmo trutta*).

In 1984 and 1985, Melack and colleagues surveyed for introduced trout populations in eight lakes and one vernal pond of the Emerald Lake system to assess their sensitivity to acidic inputs (Melack et al. 1987). They reported that only introduced brook trout (*Salvelinus fontinalis*) occured in Emerald, Aster, Heather, Pear and Hidden lakes, and that Topaz, Frog and Lyness Lakes and the pond were fishless. Trout did not occupy the inlet streams to Emerald Lake due to inadequate habitat and small waterfalls that prevent migration from the lake. Since stocking of brook trout in the Emerald Lake system ended in the 1960s, current populations are being maintained by natural reproduction.

From 1985 to 1988, Melack and colleagues conducted detailed studies of brook trout populations in Emerald, Aster, Heather and Pear Lakes (Melack et al. 1989), including analyses of abundance, size and age structure, behavior, reproduction, development and diet. They found that the Emerald Lake system contains dense, self-sustaining brook trout populations that are dominated by small, slow-growing adults that are three to six years old, while some live for more than ten years. Brook trout in lakes primarily feed on chironomid larvae, cladocerans and terrestrial insects, while those in streams feed on a variety of both terrestrial and aquatic insects. They concluded that although the episodic acidifications that seasonally occur in the system are unlikely to have a long-term impact on brook trout populations, any significant increases in year-round acidification could be

expected to reduce population sizes and change the condition, size structure and growth rates of individuals.

Monitoring of the distribution, abundance and genetic integrity of the federally threatened Little Kern golden trout (LKGT; *Oncorhynchus mykiss whitei*) populations in SEKI has been conducted by CDFG since 1984 with assistance from SEKI staff. A study of LKGT behavior (Konno 1985) found that LKGT migrate very little in streams, remaining in a similar area for several years. Individuals usually move less than ten meters (33 ft), but occasionally move up to 50 meters (164 ft). Although rare, individuals can move 400 meters (1,312 ft) or more, especially if disturbed. Smaller fish are more likely to move downstream, while larger fish tend to move upstream. Adults in lakes must migrate into tributary streams to find suitable reproductive habitat. In 2002, fin clips were collected from the LKGT population in Soda Springs Creek to conduct a new genetic analysis using recently-developed techniques. Samples are being analyzed by the University of California and final results are expected in 2005.

The Kern River rainbow trout (*Oncorhynchus mykiss gilberti*) is native to the mainstem Kern River (up to Junction Meadow) and several of its tributaries within the park. However, a long history of stocking hatchery coastal rainbows in the Kern has likely compromised the genetic integrity of most, if not all, of SEKI's native Kern River rainbows. There also is a problem with determining the genetic purity of the existing Kern River rainbows because there are no historic tissues available for comparison (Werner, pers. comm. 2005).

The California golden trout (CGT; *Oncorhynchus mykiss aguabonita*) also has been compromised by hybridization with introduced rainbow trout. In response, the U.S. Forest Service and CDFG have collaborated on a conservation strategy for the CGT (Stephens 2001, U.S. Forest Service 1999, 2002). A report is complete for recent investigations of the genetic integrity of CGT populations in the headwaters of Golden Trout Creek adjacent to SEKI (Cordes et al. 2001). Unfortunately, results indicate that all of the lake populations of CGT tested had compromised genetics due to introgression with rainbow trout alleles introduced into the system. Genetic analyses are now being conducted on CGT that were historically introduced into non-native but remote habitats in SEKI to identify pure stock for species restoration projects. Although these CGT populations are not native to the park, SEKI has interest in these populations because they serve as potential refugia for pure strains of declining taxa. NPS staff collected fin clips from a population in LeConte Canyon in 2003, and CDFG staff are collecting samples from many SEKI sites in 2004. Samples are expected to be analyzed by the University of California in the next few years depending on funds.

Many studies of CGT were conducted in the 1990s, including research on habitat use (Knapp and Dudley 1990, Knapp and Vredenburg 1996a, 1996b, Knapp et al. 1998, Knapp and Preisler 1999, Matthews 1996a, Matthews et al. 1994) and impacts from livestock grazing and degraded streams (Knapp and Matthews 1996, Matthews 1996b). A synthesis of important finding learned from these studies is that undercut stream banks, aquatic vegetation, and narrow sedge-lined streams with deeper water are the habitat

features preferred by CGT, but are also the features typically damaged by livestock grazing.

In 1980, the SEKI fish and wildlife biologist established 12 survey transects designed to monitor fish assemblages every five years in low-to-middle elevation SEKI streams. All transects were surveyed in 1980, 1985 and 1990 but became opportunistic after 1990. Three transects documented dramatic changes in which introduced brown trout displaced the native rainbow trout, while one transect documented the arrival of green sunfish and black bullhead. In 1990, very detailed habitat data was collected at each site. Transects are expected to be maintained for their long-term value as reference sites. Monitoring of fish assemblages in SEKI is also performed by CDFG on a periodic basis with assistance from SEKI staff when available. Fish-monitoring transects in SEKI are located in the South Fork Kings River and Marble, Middle and North Forks of the Kaweah River.

Knapp conducted an inventory of high-elevation lentic waterbodies and their adjacent sections of tributaries in SEKI from 1997 to 2002 (Knapp, unpublished data). A total of 3,772 high-elevation waterbodies were detected in SEKI using a combination of topographic maps, field surveys and a geographic information system. A total of 3,641 waterbodies were visited and classified as 2,816 perennial waterbodies, 317 unmapped ponds, 1 stream widening, 254 marshes, 62 unmapped marshes, 168 ephemeral waterbodies and 23 meadows.

An early faunal survey was conducted between 1914 and 1920 in the Sierra Nevada along an east-west transect through Yosemite National Park (Grinnell and Storer 1924). They seldom detected MYLFs in lakes with introduced trout, however, MYLFs were abundant in fourteen fishless sites along the transect. This finding provided the earliest historical documentation that introduced trout and MYLF generally do not co-occur. These fourteen sites were resurveyed for amphibians in 1992 and 1993, and MYLFs were detected at only two sites. (Drost and Fellers 1996). These two detections, however, consisted of a single tadpole at one site and a single adult at another site (U.S. Fish and Wildlife Service 2003b).

Many studies have been conducted on the impacts of introduced trout on native biota in the High Sierra and SEKI. Important contributions to our understanding of this issue come from landscape analyses with large sample sizes that correlate the presence of introduced trout with the absence or near-absence of native biota such as amphibians and large invertebrates (Corn and Knapp 2000, Knapp 1996, Knapp and Matthews 2000, Matthews and Knapp 1999). Field experiments then determined how to remove introduced trout from wilderness lakes without using chemicals (Knapp and Matthews 1998) and documented the rapid recovery of native biota following removal of introduced trout from lakes (Knapp et al. 2001, Vredenburg 2004).

SEKI applied these research findings by proposing in an environmental assessment to remove introduced trout populations from ten lakes that have nearby reproducing populations of native biota, and simultaneously measuring the recovery of native biota (National Park Service 2001b). Following approval of the assessment, we began to

restore six lakes and adjacent streams in 2001 using gill nets and backpack electrofishers. By the end of 2003, SEKI had eradicated one and virtually eradicated four of the six trout populations. The sixth population has been significantly reduced, but is being recolonized by trout via a large river that flows through the site. This river also is the migration route for frogs attempting to reach the lake from the closest frog donor pond about a kilometer away. Recovery data show significant increases in the abundance of MYLFs in the five nearly-restored lakes, including increases of 2,870%, 2700%, 910%, 280% and 130% in the average number of individuals detected per survey in 2003 versus 2001 (National Park Service 2004i). In the sixth lake being recolonized by trout and located relatively far from the donor pond, SEKI has detected no MYLFs since 2001. We will begin restoring all of the remaining restoration lakes identified in the environmental assessment by 2005.

Turtles - *The following paragraphs are summarized from the Draft Summary of Population Trends for Western Pond Turtles (Clemmys marmorata) in the Foothills of Sequoia National Park (Werner 2005):*

> The western pond turtle (*Clemmys marmorata*) is the only native turtle in or near Sequoia National Park and virtually the only native turtle on the west coast of the United States. They were so abundant in the Tulare Lake area that between the 1870s and about the 1930s, millions of turtles were sold as food in San Francisco. By 1992, this species had become so rare that it was partitioned for federal listing as endangered, but the U. S. Fish and Wildlife Service found that listing was "not warranted" at that time. Most of the decline was attributed to habitat loss (conversion of wetland to farmland, alteration of water courses, mining, logging, grazing, urbanization), but also included predation by introduced species (bullfrogs, large and small-mouth bass, sunfish), population fragmentation, incidental catch by anglers, excessive human disturbance, roads paralleling watercourses, poaching, chemical spills, and gunshot.
>
> Within Sequoia National Park, western pond turtles are restricted to the foothills. The highest record in the Park is about 5,180 ft (1,579 m) near Crystal Cave. Within the park's foothills, most turtles are seen below about 3,000 ft (914 m) in the warmest and lowest-gradient river in the park - the North Fork of the Kaweah River. They are rarely encountered in the steeper and colder rivers where there is severe whitewater during snowmelt and much less vegetation and organic debris in the water. The turtles also occur in both perennial and ephemeral streams along stream reaches that are sunny, and appear to avoid closed canopy. The riparian habitat typically consists of white alder (*Alnus rhombifolia*), willow (*Salix* sp.), oaks (*Quercus* sp), western sycamore (*Platanus racemosa*), and numerous shrubs and annual grasses, sedges, and forbs. These riparian sites are located within blue-oak woodland and some within chamise chaparral. Within the pools on the North Fork Kaweah River, pondweed (*Potamogeton* sp) is common during the summer and fall.
>
> Western pond turtle populations have been monitored annually since 1992 in a 1.79 km (1.1 mi) segment of the North Fork Kaweah River and since 1993 (almost annually) in 0.76 km (0.47 mi) segment of Sycamore Creek. During the survey period

in the North Fork Kaweah, turtle population estimates dropped from a peak of 177 in 1993 to 17 in 2004. There was a distinct drop in numbers beginning in 1997 followed by recovery in 2000 and another drop after 2001. The drop in 1997 coincided with a suspected poaching activity in the area and the presence of a large population of predatory bullfrogs, while the drop after 2001 is less certain. However, abnormalities were regularly found on turtles, and the growing concern for pesticide drift upon the park raised the concern that the problems impacting the turtle population may be more insidious than bullfrogs or poachers. Of the 238 marked individuals in the North Fork segment, 14.7% had abnormalities. These included missing feet or toes, lumps under the skin, either extra or missing scutes, or odd shapes to the shell. Originally the author considered these abnormalities to be either the result of inter- and intraspecific interactions or homozygosity in a small population. While those possibilities could be contributing to the problems of local turtles, pesticide drift also should be considered.

In Sycamore Creek, turtle population estimates showed a significant, gradual decline from 51 in 1993 to 40 in 2003, and a slight increase in the turtles' mean weight, suggesting a loss of recruitment. This site is on an ephemeral stream that lacks bullfrogs and is unlikely to be known by poachers. Sycamore Creek turtles had abnormalities on 20.8% of the 77 marked turtles. If this decline is real and not just a normal population fluctuation, pesticide drift needs to be considered as a potential contributing factor.

Invertebrates - Although an inventory is needed to determine how many invertebrate taxa occur in the parks, information has been collected in various studies, many of which targeted aquatic invertebrates. Over 100 invertebrate taxa have been identified in SEKI streams and lakes (National Park Service 1989), the majority being aquatic insects. Most surveys in SEKI and California have described invertebrate families and genera versus species. However, how assemblages of aquatic invertebrates respond to habitat alterations has been well-studied (Erman 1996). Thus, we can generally predict the response of SEKI invertebrates to stressors, of which the greatest threats to biodiversity in stream systems are habitat loss/degradation and non-native species (Erman 1996).

Caves in the foothills are biologically productive and contain a diverse mix of cave-adapted and endemic invertebrates. These taxa are dominated by spiders and also include harvestmen, scorpions, pseudoscorpions, centipedes, millipedes and both terrestrial and aquatic isopods (Krejca 2003). The ensatina, a terrestrial salamander, also is occasionally seen in foothill caves. Aquatic invertebrate taxa common to foothill streams include stoneflies, midges, mosquitoes and water striders, while rare taxa include a primitive stonefly, a dobsonfly and a mountain midge (Abell 1977).

Caves in the coniferous zone contain an invertebrate assemblage that includes spiders, snails, springtails, millipedes, beetles, crickets, diplurans, mites and aquatic isopods (Krejca 2003). Aquatic invertebrates common to coniferous streams, ponds and lakes include stoneflies, midges, mosquitoes, caddisflies, mayflies and water striders.

In the few caves located in the subalpine zone, invertebrates detected include diplurans, springtails, a spider and a harvestman (Krejca 2003). Aquatic invertebrates common to subalpine streams, ponds and lakes include stoneflies, midges, mosquitoes, caddisflies, mayflies, water striders, backswimmers, water boatmen and predaceous diving beetles. However, the larger and more-conspicuous taxa in the subalpine aquatic invertebrate assemblage have been extirpated or reduced in lakes and streams containing introduced trout (Bradford et al. 1994d, 1998, Jenkins et al. 1994, Herbst 2004, 2005).

Surveys for cave-adapted invertebrates in many SEKI caves in 2003 and 2004 have detected unique and specialized taxa, many of which show high levels of endemism (Krejca 2003, 2004). At least one survey has been conducted in 16 park caves, with several of these caves surveyed during each season of summer, fall and spring. Sampling techniques consist primarily of hand collections made using visual searches aided by hand lenses, forceps, paintbrushes and aspirators, and secondarily of baited trapping. A series of individuals representing each taxa from each cave was collected for taxonomic identification. Associated data also were collected about each organism to improve understanding of biological interactions in caves, including location and substrate of each detection, time searched, individuals seen vs. collected and air temperature. Additionally, high-resolution digital images were collected of the majority of cave-adapted taxa as well as common accidentals. Many cave-adapted taxa have been detected that are undescribed and may be new species, including a pseudoscorpion (probably Chthoniidae) from Clough Cave, a dipluran (probably Japygidae) from Soldier's Cave and an aquatic flatworm (probably *Sphalloplana*) from Crystal Cave.

Various studies have contributed information on invertebrates in these parks. One of the earliest invertebrate surveys states that a non-native amphipod (*Hyalella azteca*) was introduced to Rae Lakes in 1919 to enhance the food supply for introduced trout (Coleman 1925). Although a native copepod was still abundant in Rae Lakes in 1925 (Coleman 1925), by 1975 *Hyalella* was dominant while the copepod comprised only a small percentage of the zooplankton population (Silverman and Erman 1979). In 1975, typical zooplankton densities in Rae Lakes and Sixty Lake Basin ranged from 0-10 individuals/liter.

Abell (1977) created five abundance-diversity assemblages for aquatic invertebrates in streams of Sequoia National Park. Type A or weak fauna occur in very small streams and some springs and have low density and diversity. Type B or normal fauna occur in small to moderately large streams, have several common or abundant taxa and density and diversity are normal and positively related. Type B+ or diverse fauna occur in moderate to large streams with high-quality riffle habitat and have a relatively high number of common and abundant taxa. Type C or unproductive fauna occur in small streams with little riffle habitat and have normal diversity but usually only one common or abundant taxa. Type D or punitive perturbed fauna normally occur in larger streams, have little diversity but the dominant taxa are abundant and likely were altered from typical community structure by special site-specific conditions. Although distinct associations of taxa were not observed, the most frequently collected taxa were midges (Chironomidae), mayflies (*Baetis and Paraleptophlebia*), black flies (Simuliidae), and caddisflies

(*Micrasema and Hydropsyche*). Also found were three special interest taxa in the Kaweah drainage, including a primitive stonefly (*Oroperla barbara*) at high elevation, an isolated population of dobsonfly (*Corydalus cognata*) that is common in the eastern U.S.A. and a brown mountain midge (*Denterophlebia*) that occurs from 660 to 7,000 ft (201 – 2,134 m) (msl) and may be a new species.

In a survey of 137 SEKI lakes, Zardus et al. (1977) collected zooplankton samples and recorded the overall categorical abundance as high, medium or low, and also used zooplankton size to assist in determining the reproductive status of introduced trout populations. They recorded field notes at each site on insects apparent at the water's edge and on the surface, and from every trout population detected they collected stomach samples that were not analyzed but were archived at SEKI.

In 1977, a survey of the littoral bottom fauna in eleven lakes in the Rae Lakes, Kearsarge Lakes and Sixty Lake Basin areas found that high use lakes had more abundant macroinvertebrates than low use lakes (Taylor and Erman 1980). Macroinvertebrate density averaged 5,418 individuals/m^2 and ranged from 2,599 to 7,540 individuals/m^2. Midges (Chironomidae), aquatic worms (Oligochaeta) or fingernail clams (*Pisidium*) were the most common taxa collected. The authors state that enrichment typically stimulates an increase in benthic productivity, and thus elevated invertebrate densities in high use lakes may be due to increased levels of nutrients deposited by humans.

Kubly (1983) documented 52 zooplankton species, including about 50% typically limnetic species and about 50% littoral or benthic species. The most abundant groups included 19 taxa of rotifers, 14 taxa of cladocerans and 13 taxa of copepods. The most frequently collected taxa were the rotifer *Keratella testuda*, the cladoceran *Holopedium gibberum* and certain diaptomid copepods. The densities of zooplankton ranged from 1-388 individuals/liter, with a typical density of less than 50 individuals/L. Increasing elevation was correlated with a decrease in zooplankton species richness and abundance, while increasing pH was correlated with an increase in species richness.

Tonnessen and Harte (1982) were the first to study the effects of acid inputs on Sierran zooplankton. In the laboratory they determined that lowering the pH to 4.0 caused rotifer population levels to decrease, almost eliminating *Keratella* spp. in one experiment.

Stoddard (1987) surveyed the zooplankton communities in 75 Sierra lakes, approximately 35 of which are located in SEKI. He recorded a total of 24 species of microcrustaceans, including 17 cladocerans, three calanoid copepods, three cyclopoids and one anostracan. Sixteen of these species were observed to occur in five community types. The distributions of four of these community types were well predicted by fish presence and elevation or fish absence and lake depth, while phosphate was the only significant predictor of the fifth community type. He reported that large-bodied species (e.g., *Daphnia middendorffiana, Diaptomus shoshone, Diaptomus eiseni*) only occurred in fishless lakes while small-bodied species (e.g., *Daphnia rosea, Diaptomus signicauda, Bosmina longirostris, Holopedium gibberum*) were dominant in fish-containing lakes,

and thus fish presence or absence was the most important predictor of individual species distributions.

Melack et al., (1987) characterized the zooplankton assemblage and its population dynamics in Emerald Lake and investigated the effects of increased acid and nutrient inputs on Sierra zooplankton. They found the same small-bodied community reported by Stoddard (1987) to dominate other deep Sierra lakes containing introduced brook trout (e.g., *Daphnia rosea, Diaptomus signicauda, Bosmina longirostris, Holopedium gibberum*), and also found *Keratella cochlearis*, *Polyarthra vulgaris* and *Conochilus unicornis*). Abrupt population declines were seen for *Daphnia rosea, Diaptomus signicauda* and *Conochilus unicornis* between a pH of 5.6 and 5.5, and for *Bosmina longirostris, Holopedium gibberum* and *Keratella cochlearis* below a pH of 5.0. *Polyarthra vulgaris* was the most tolerant taxon, remaining abundant at a pH of 4.0. They determined that Sierra zooplankton assemblages are sensitive to acid and nutrient inputs and will exhibit changes in community structure due to changing rates of nutrient or acid loading, making them good indicators of acid stress. In eight lakes (including Emerald) and one vernal pond in the Marble Fork Kaweah drainage, a total of 22 zooplankton taxa were collected, including two calanoid and two cyclopid copepods, ten cladocerans and eight rotifers. Large-bodied zooplankton assemblages were found to dominate the four fishless sites, while small-bodied assemblages were found to dominate the five sites containing introduced brook trout.

The same study also characterized the macroinvertebrates of the Emerald Lake stream system and used experimental stream channels to examine the effects of acidification on lake macroinvertebrates and stream drift (Kratz et al. 1994). They found that chrironomid larvae dominated the inlet and outlet streams. Other taxa commonly collected included Simuliid larvae (*Simulium* sp., *Prosimulium* sp., *Twinnia* sp.), *Baetis* nymphs and *Rhyacophila* larvae in the inlet and outlet streams, and ephemerellid and leptophlebid mayflies (*Drunsella spinifera*, *Serratella* sp., *Paraleptophlebia* sp.), nemourid stonefly nymphs (*Malenka* sp., *Amphinemoura* sp., *Zapada* sp.), tipulid larvae (*Dicranota* sp., *Hexatoma* sp.), water mites (Acaridae), oligochaetes and sphaeriid clams (*Pisidium* sp.) in the outflow stream. Dominating the lake assemblage were chironomids and sphaeriid clams, while oligochaetes and water mites were commonly collected and a population of the sponge *Spongilla lacustris* was present. Increased drift rates were seen in the experimental stream channels shortly after acidification, in which 46% of drifting Baetis mayflies was dead compared to 0% in the control channels. Of the enhanced drift, 54% was due to toxic drift while 46% was due to behavioral drift. Overall, the results show a number of acid-sensitive taxa in the Emerald Lake system, and although many likely will not be affected by moderate, temporary reductions in pH, these taxa are good indicator organisms for long-term monitoring of acidity trends in Sierra lake systems. In eight lakes (including Emerald) and one vernal pond in the Marble Fork Kaweah drainage, a total of 25 macroinvertebrate taxa were collected. The Chironomidae were the most widespread taxon in the watershed, followed by clams (*Pisidium* sp.), water mites (Hydracarina) and alderfly larvae (*Sialis*). The five lakes containing introduced brook trout had a significant absence of large or mobile, conspicuous taxa, including baetid mayflies (*Callibaetis*), hemipterans, dytiscid beetles and caddisflies.

An additional study by Melack et al. (1989) in Emerald Lake and the Marble Fork Kaweah drainage continued to survey zooplankton and macroinvertebrates. They found the zooplankton in Emerald Lake to be dominated by rotifers, with *Polyarthra vulgaris* reaching mean densities near 800,000/m^3, while the most abundant crustacean, *Daphnia rosea*, had maximum densities near 20,000/m^3. The stream benthos and drift were diverse with dipteran taxa, with the Chironomidae comprising the bulk of the species and chironomid and simuliid larvae being the most abundant. They zooplankton in Emerald Lake appear most promising for long-term monitoring of acidity. In particular, *Daphnia rosea,* and *Diaptomus signicauda* decline with decreasing pH, while *Bosmina longirostris* and *Keratella taurocephala* increase with decreasing pH, at least down to pH 5.0. Conversely, sampling invertebrates in either the benthos or drift presents logistic, monetary, and interpretive problems for reliable quantitative sampling, and thus is less promising for long-term acidic monitoring.

In 1992, an investigation on the influence of acidity on biota in 33 lakes in Kings Canyon National Park sampled introduced trout, amphibian, macroinvertebrate and zooplankton communities (Bradford et al. 1994b, 1998). Zooplankton taxonomic groups frequently collected included diaptomid copepods, cladocerans and rotifers. They also documented many macroinvertebrates including mayflies, stoneflies, caddisflies, damselflies, true flies, true bugs, dytiscid beetles, water mites, sphaerid clams and amphipods. Limnephilid caddis larvae (*Hesperophylax*), large microcrustaceans (*Daphnia, Diaptomus*) and mountain yellow-legged frog tadpoles (*Rana muscosa*) were rare or absent in acidic lakes (pH <6) but commonly collected from non-acidic lakes (pH ≥6). Additionally, amphibian tadpoles and large, mobile and conspicuous invertebrate taxa, including *Daphnia middendorffiana, Diaptomus eiseni*, *Diaptomus shoshone*, large mayflies, hemipterans, limnephilid caddis larvae and dytiscid beetles, were rare or absent in trout lakes but relatively common in lakes lacking trout. Furthermore, trout lakes were dominated by smaller, more cryptic invertebrate taxa such as *Daphnia rosea*, *Keratella spp.*, chironomids and oligochaetes.

Jenkins et al. (1994) surveyed 30 Sierra lakes above 8,000 ft (2438 m) (msl), most of which are in SEKI, to assess the long term effects of acidity on the biota of lakes. The macroinvertebrate communities generally were not diverse and population densities usually were low. Common taxa collected in benthic samples at each site included mayflies, odonates, hemipterans, alder flies, caddis larvae, dytiscid beetles, chironomids, snails, and fingernail clams. Similar to Bradford et al. (1994b, 1998), large or active epibenthic taxa, such as mayfly nymphs and water boatmen were rare or absent in lakes containing trout but were commonly collected in lakes lacking trout. The number of taxa collected was positively related to pH and negatively related to nitrate and elevation.

The first phase of a study to evaluate the potential for recovery of high-elevation stream invertebrate communities following the removal of introduced trout is being conducted in 2003 and 2004 in four streams in the Upper Bubbs Creek drainage of Kings Canyon National Park. The first of 2 years of pre-trout-removal surveys was conducted in July of 2003 in one stream in which trout will be removed (treatment), two streams in which

trout will remain (controls) and one fishless stream (target). Fieldwork consisted of quantitative sampling of benthic macroinvertebrates in separate collections from riffles and pools, the density of algal periphyton and organic matter in replicate samples and basic physical and chemical features of each stream reach (75 m (246 ft) lengths) in order to place the ecology of these streams into an environmental context (Herbst 2004, 2005). Preliminary results indicate lower diversity (15 taxa), higher chlorophyll *a* density (5.18 $\mu g/cm^2$), higher visible macroalgae cover (61%) and the absence of conspicuous taxa in the fish-containing treatment stream versus higher diversity (20 taxa), lower chlorophyll *a* density (0.21 $\mu g/cm^2$), lower visible macroalgae cover (16%) and the presence of conspicuous taxa (mayfly: Heptageniidae - *Cinygmula*; hemipteran: Corixidae - *Cenocorixa*; predaceous beetles: Dytiscidae – *Stictotarsus*, *Hydroporus*, *Agabus*; and Triclad flatworm: Planariidae - *Dugesia*) in the fishless target stream. The second year of pre-trout-removal surveys was conducted in July of 2004, while the 2 years of post-trout-removal surveys will be conducted from 2008-2009, following the trout removal.

In 2004, repeated surveys were conducted in several SEKI and YOSE meadows to improve our knowledge of invertebrate assemblages in Sierra Nevada meadows and the relationship of invertebrate occurrence with meadow biological and physical characteristics and stressors (Holmquist, in progress). The pilot study also will provide an assessment of invertebrates as indicators of meadow condition and change within the context of long-term ecological monitoring.

Listed and Sensitive Taxa

The terms federally-listed, state-listed and sensitive are used to describe SEKI taxa that hold a special status designation. The term federally-listed is defined here to include those taxa that are listed under the federal ESA as endangered, threatened or as candidates for listing, while the term state-listed includes those taxa that are listed under the California ESA as endangered or threatened. Those taxa that are listed as federal or California species of special concern, California protected or Forest Service sensitive, are rare or endemic in California, or have a limited distribution are referred to as sensitive species. As little is known about the status and habitat requirements of many special status taxa in SEKI, several research and management efforts are currently being implemented to improve our understanding of these taxa.

SEKI contains over 865,000 diverse acres that are designated for long-term preservation and habitat protection and thus supports an incredibly rich and diverse assemblage of flora and fauna. Over 1,500 taxa of vascular plants are known to occur in SEKI, of which 138 are considered special status plants and 24 are on the California Native Plant Society (CNPS) 1B list of plants that are rare, threatened or endangered in California or elsewhere (Akin 2004, pers. comm.). Examples of CNPS 1B taxa in SEKI are the Kaweah monkeyflower and Kaweah Brodiaea (endemics), Evalyn's jewel flower (limited distribution) and Tompkins' sedge (rare), which is the only state-listed plant in SEKI.

The parks also are known to have 265 terrestrial vertebrates and 47 aquatic vertebrates, of which 51 taxa (16%) hold special status designations (National Park Service 2004h).

There are five extant native vertebrates known to occur in SEKI that are federally-listed, including the Sierra Nevada bighorn sheep as endangered, the bald eagle and Little Kern golden trout as threatened and the mountain yellow-legged frog and Yosemite toad as candidates. Also known to occur in SEKI are six extant native vertebrates that are state-listed as their highest status, including the peregrine falcon, great gray owl and willow flycatcher as endangered and the red fox, wolverine and Swainson's hawk as threatened. Further, there are 40 extant native vertebrates known to occur in SEKI that are listed as sensitive. Some of SEKI's sensitive species include the white-tailed jackrabbit, fisher, ring-tailed cat, Townsend's big-eared and western mastiff bats, merlin, northern harrier, California spotted owl, California legless lizard, western pond turtle, Mount Lyell salamander, San Joaquin roach and Kern River rainbow trout. (Note that many of the taxa listed above are listed under more than one designation. For example, the Sierra Nevada bighorn sheep is federally endangered, California endangered, California protected and Forest Service sensitive.)

Non-native Taxa

Invasive non-native plants have caused changes in SEKI ecosystems through competition, hybridization and non-native disease exchange with native plants, and also by altering ecosystem processes (e.g., fire, water, and nutrient cycles). Although non-native plants occur throughout SEKI, the majority of invasions have occurred in lower elevation habitats, developed areas and road/trail corridors. Of the more than 1,500 vascular plant taxa that occur in SEKI, 196 taxa (13%) are non-native and more species are being discovered each year (National Park Service 2004d). Many of these non-natives appear to be rather innocuous, however, approximately 58 taxa have either caused or have a high potential to cause significant impacts to native vegetation (e.g., giant reed and Himalayan blackberry). Several are completely naturalized grasses that will be impossible to eradicate, but many are restricted to a small number of sites and can be isolated and eliminated with immediate action. A weed management program focused on early detection and eradication has been operating in SEKI since the mid-1990's and has prevented many non-native species from becoming established and widespread.

Non-native animals have caused changes in SEKI ecosystems through predation, competition, hybridization, disease exchange and alteration of trophic webs and nutrient cycles. Of the more than 335 vertebrates known to occur in SEKI, 25 vertebrates (7%) are non-native (National Park Service 2004h). Some non-native species in SEKI include the Virginia opossum, house sparrow, brown-headed cowbird, European starling, wild turkey, bullfrog, green sunfish, golden shiner, and eastern brook and European brown trouts. Additionally, three native vertebrates have been transplanted outside of their native ranges to other areas in SEKI, including the rainbow and Little Kern golden trout. Similar to non-native plants, several non-native taxa are quite established and would be very difficult to eradicate. Some examples include the European starling in the foothills zone and introduced trout in lakes and streams of the subalpine zone. However, by strategically-selecting isolated sites for restoration we hope to eradicate non-native fauna from contained areas to facilitate reestablishment by the local native community. Current examples of this type of restoration in SEKI include 1) removing trespass cattle from the

park and installing fence line on the park boundary to prevent future trespass and 2) removing introduced trout populations from small lakes and streams adjacent to reproducing mountain yellow-legged frog populations.

Management of Biological Resources

The most significant threats to SEKI ecosystems are climate change, the loss of a natural fire regime, non-native species, air pollution and habitat fragmentation (Sierra Nevada Ecosystem Project 1996). The SEKI vegetation management programs strive to improve understanding or the parks' flora and vegetation, protect rare species, restore natural fire regimes and disturbed habitats, monitor and control invasive non-native plants and monitor and manage impacts from recreational and administrative uses. The SEKI wildlife and aquatic management programs strive to provide baseline information on park wildlife, understand and mitigate resource threats and provide for resource safety (e.g., human-bear management). Wildlife and aquatic managers also are challenged by conflicts between wildlife and people, accidental mortality and poaching of wildlife and insufficient information on many wildlife species.

WATER RESOURCE ISSUES

The parks' water-related issues presented in this section were identified during an information-gathering effort by the authors and staff in SEKI. Along with a technical literature review, information sources included a full-day scoping meeting on November 19, 2003 with SEKI staff and professionals from other federal and state agencies and universities (Appendix C). The scoping meeting identified significant issues affecting the parks' water resources. Attendees at the meeting and other regional professionals that participated via E-mail then submitted five votes each for what they believed to be the most significant of these issues (Appendix D). Some votes were given to a major stressor, while some votes were given to specific issues within a major stressor. For example, votes were given to "climate change" and "understanding role of changing glaciers to hydrology of watersheds." Therefore, votes for specific issues within a major stressor were lumped with votes for the major stressor to obtain a total vote count for related themes. The most significant issues identified during the meeting include:

1) effects of contaminants, nutrients and atmospheric deposition (35 votes);
2) effects of climate change (32 votes);
3) effects of fire management (17 votes);
4) lack of inventory and monitoring of invertebrates (13 votes);
5) research, restoration and monitoring of amphibians (13 votes);
6) effects of pathogens on amphibians (7 votes);
7) removal of non-native fish to restore native biota and ecosystems (7 votes);
8) lack of inventory and quantification of groundwater resources (5 votes).

In the following discussion, issue numbers one through three listed above are described within individual chapters (e.g., "Contaminants, Nutrients and Atmospheric Deposition"), while numbers four through seven are described within individual sections of the chapter entitled "Aquatic Biological Impacts." Many additional issues receiving one or two votes each were also identified in the meeting. All issue statements and raw voting results are listed in Appendix D.

The Sierra Nevada Ecosystem Project (1996) and substantial research also identified numerous threats, or stressors, affecting Sierra Nevada ecosystems, including water resources. Localized stressors generally affect small areas, while systemic stressors are pervasive and can affect large areas. Based on best professional judgment and information, the following five systemic stressors appear to present the greatest threats to Sierra Nevada parks: 1) altered fire regimes; 2) non-native invasive species; 3) air pollution; 4) habitat fragmentation; and 5) rapid anthropogenic climatic change. It should be noted, however, that climate change could exacerbate and dominate all other stressors in importance in the coming decades.

Contaminants, Nutrients and Atmospheric Deposition

The effects of contaminants, nutrients and atmospheric deposition on water resources in SEKI was one of the top two major issues (along with effects of climate change)

identified by participants in the scoping meeting. Many specific issues under this broad category were identified, including, for example, "effects of contaminants on mountain yellow-legged frogs" and "effects of atmospheric nutrient deposition on chemical and biological components of water quality." It is recognized that contaminants and nutrients have significant potential to degrade SEKI's water quality and negatively affect biota.

As SEKI was developed, septic tanks proliferated. In the 1950s most old septic tanks were replaced by sewage treatment facilities, but many facilities were not adequate to handle the continuing increase in system demands and aging treatment facilities. For example, at Giant Forest, Lodgepole, and Grant Grove, contaminated water leaked into local streams (National Park Service 1989). However, one of the biggest threats to SEKI's water, according to the National Park Service (1999), is air pollution. Based on ozone data collected by the NPS for the years 2001 to 2004, SEKI is the most polluted national park, where ozone levels at Ash Mountain exceeded human health standards on an average of 66 summer days per year (National Park Service 2005).

SEKI is downwind of one of the most productive agricultural areas in the world - the San Joaquin Valley. From 1994-2003, an average of 190 million of pounds (86,184,000 kg) of pesticide active ingredient have been applied to crops in California (California Department of Pesticide Regulation 2005). In 2003, over 63 million pounds (28,576,800 kg) of pesticide active ingredient were applied to lands in Fresno, Kern and Tulare counties (California Department of Pesticide Regulation 2005). The waters of SEKI are exposed to these pesticides when they become volatilized or suspended in the atmosphere as particulates, then drift into the parks on prevailing winds (National Park Service 1999). Organophosphates have been found in precipitation as high as 9,842 ft (3,000 m) in Sequoia National Park (LeNoir et al. 1999), while other synthetic chemicals, such as PCBs, are also being deposited in SEKI (National Park Service 1999).

To reduce pesticide drift from the San Joaquin Valley requires reducing or significantly altering agriculture in the valley. There are developments to reduce pesticide drift with new types of equipment that reduce drift and some farmers are using organic techniques, but it is unlikely that there will be significant changes in the near future. The one tool that can be used to help bring change is to collect high-quality data (National Park Service 1999).

Fossil fuel combustion in the San Joaquin Valley would be expected to account for the majority of the anthropogenic sulfur and nitrogen in the airsheds of SEKI. Once released into the atmosphere, oxides of sulfur and nitrogen can be deposited or absorbed on a surface in the dry gaseous form. The gases may be oxidized and fall as solid particles (dry deposition) or fall as acid rain (Duriscoe et al. 1982). Sulphur dioxide (SO_2) will readily dissolve in water droplets if a catalyst is present, forming sulfuric acid. Ammonia will react with the sulfate ion to produce $(NH_4)_2SO_4$, an aerosol that can reduce visibility. Similar to sulphur dioxide, nitrogen dioxide (NO_2) can be further oxidized to form nitrate aerosols or be absorbed in water to form nitric acid. Deposition in the form of precipitation may have a more immediate toxic effect than dry deposition. Because sulfate and nitrate ions are already in solution, they are more mobile and can penetrate

deep into soils, lakes, streams and groundwater, and thus move throughout the drainage basin (Duriscoe et al. 1982).

Between 90 and 99% of the annual atmospheric load falls as snow between the months of November and April (Stoddard 1995). Williams et al. (1995) reported up to 90% of the annual wet deposition of N was stored in the seasonal snowpack of Emerald Lake's watershed. NO_3^- and NH_4^+ were released from storage in the form of an ionic pulse, where the first fraction of meltwater draining from the snowpack had concentrations of NO_3^- and NH_4^+ as high as 28μeqL^{-1} compared to bulk concentrations of < 5 μeqL^{-1} in the snowpack (Williams et al. 1995). Residence times for waters within the Emerald Lake watershed range from hours to days during snowpack runoff, increasing the potential for acidification from atmospheric deposition (Williams et al. 1993).

In the meantime, high-elevation lakes and streams in SEKI are very dilute and sensitive to change from atmospheric deposition of contaminants and nutrients. While chronic acidification presently is not a problem, episodic depression of acid-neutralizing capacity occurs during snowmelt (Melack and Sickman 1995, Melack et al. 1998), and episodic acidification also occurs during "dirty" rainstorms of summer and early fall (Stohlgren and Parsons 1987). If acid deposition were to increase (likely due to rapid population growth in the San Joaquin Valley), episodic acidification will become more frequent, and may alter aquatic communities. Although the actual threat posed by episodic acidification is unknown, recent research suggests Sierra Nevada waters may be fairly resilient and able to buffer current and potentially increased inputs (Leydecker et al. 1999).

There has been a slow, steady increase in atmospheric nitrogen deposition in park watersheds (Lynch et al. 1995). In spite of increasing nitrogen deposition, however, there has been a decrease in dissolved nitrogen leaving watersheds (Melack et al. 1998). These changes parallel a shift in the phytoplankton community of the heavily-studied Emerald Lake in Sequoia, from one dominated by phosphorus limitation to one dominated by nitrogen limitation. Mixed-conifer watersheds in Sequoia's Giant Forest also have shown net retention of nitrogen, with stream concentrations often below detection limits (Williams and Melack 1997). The consequences of increased nitrogen deposition and retention on terrestrial plant communities are unknown.

Some synthetic chemicals can have estrogenic or other effects as hormonal imitators in concentrations of parts per trillion. They can change wildlife reproductive capacity, longevity, intelligence, and behavior, and can lead to cancer or mutations (Colburn et al. 1996). Cause-and-effect links between synthetic chemical drift and ecosystem effects have not been established, but circumstantial evidence suggests such effects may be occurring. For example, offspring have only rarely been documented for peregrine falcons nesting at Moro Rock in Sequoia National Park. Abandoned eggs contained high quantities of DDE (13 mg/kg wet weight), and eggshells on average were 14.6% thinner than normal (Jarman et al. 1993). More recently, the pair produced eggs that lacked the normal smooth, waxy, brown-spotted shell; instead the shells were white and chalky. The foothill yellow-legged frog completely disappeared from SEKI in the 1970s, and today exists in the Sierra Nevada only in a few widely scattered populations along the western

foothills. The frog is much more common on the west side of the San Joaquin Valley (in the Coast Range foothills), upwind from pesticide drift. Synthetic chemical drift also may play a role in the decline of mountain yellow-legged frogs and other amphibians in the Sierra Nevada (Davidson et al. 2002).

Indeed, Sparling et al. (2001) found that tissue from amphibians with reduced cholinesterase activity contained pesticide residues, including chlorpyrifos, diazinon, endosulfan, DDTs and hexachlorocylohexane (HCH). Chlorpyrifos and diazinon are potent cholinesterase inhibitors (Sparling et al. 2001), while endosulfan has been shown in laboratory tests to induce deformities in ranid frogs at an average concentration of 7.4 parts per billion (Fellers et al. 2005). A similar level of pesticide concentration was measured in mountain yellow-legged frogs as they were inexplicably dying in fishless lakes in the Tablelands area of SEKI in the 1990s (Fellers et al. 2005).

Recently in the Tablelands and Sixty Lake Basin of SEKI, organophosphate insecticides, chlorpyrifos, and diazinon were measured in surface water, while DDE was measured in mountain yellow-legged frog tissue at one to two orders of magnitude higher in concentration than other organochlorines (46 +/- 20 and 17 +/- 8 ng/g wet weight at Tablelands and Sixty Lake Basin, respectively; Fellers et al. 2004). In contrast, hexachlorocylohexane (HCH) was measured at an unusually high concentration in one site in Sixty Lake Basin where frogs were abundant, indicating that HCH is not especially toxic to this species (Fellers et al. 2004). Yet another study measured contaminants in sediments from 61 amphibian habitats in the Sierra ranging from SEKI to Lassen National Park. Results show that endosulfan sulfate (median conc. 1.1 ng/g dry wt, max conc. 5.3 ng/g dry wt.) and alpha-chlordane (median conc. 0.3 ng/g dry wt, max conc. 1.5 ng/g dry wt.) were the most frequently detected chemicals (Drakeford et al. 2003).

All of these recent study results indicate that contaminants may be a significant factor contributing to amphibian declines. Many regional scientists theorize an interaction is occurring between contaminants and disease, in which amphibians are being stressed by many contaminants at any given time, and this stress suppresses immune system function (Sparling et al. 2001). Immunosuppression then increases an organism's susceptibility to diseases that occur in the local environment and spread rapidly through a population. A reduction in contaminant amounts used by regional industries is therefore likely to improve the health of amphibian populations. However, since the local economy is strongly tied to these industries, discussion of such a proposal needs to include diverse regional participation.

SEKI provides logistical support to ongoing studies of the effects of contaminants and disease on Sierran amphibians. We welcome investigators to continue using SEKI's habitats as a natural laboratory and help provide the information necessary for park staff to implement ecosystem management. The SEKI RMP (National Park Service 1999) has several related project statements, including:

- SEKI-N-170.121: Study Effects of Acid Deposition on Vegetation and Aquatic Ecosystems;

- SEKI-N-040.040: Evaluate Impacts of Nutrients on Lakes and Streams;
- SEKI-N-040.020: Watershed/Ecosystem Monitoring Project;
- SEKI-N-040.060: Determine Distribution of High-Elevation Amphibians;
- SEKI-N-020.041: Study Rare and Extirpated Fauna;
- SEKI-N-040.061: Evaluate/Reintroduce Foothill Yellow-Legged Frog.

Climate Change

The effects of climate change on water resources in SEKI was one of the top two major issues (along with effects of contaminants, nutrients and atmospheric deposition) identified by participants in the scoping meeting. Many specific issues under the broad category of climate change were identified, including, for example, global change effects on water quantity (e.g., water delivery patterns, timing of snowmelt and runoff, seasonality of water cycle) and water quality (e.g., biogeochemical cycling in watersheds, and transport and transformation of pollutants delivered to the park). It is recognized that climate change has significant potential to cause SEKI's precipitation/hydrologic cycle to behave in a manner over time that exceeds the historically-observed levels of variation.

Rapid anthropogenic climate change has the potential to become the greatest stressor on the ecosystems of SEKI (National Park Service 1999). Paleoclimatologists have used proxy data (i.e., ice cores, tree rings, etc.) to reconstruct the earth's historical climate. These data have resulted in remarkable discoveries, including the fact that climate has fluctuated dramatically in the past and the global mean temperature has risen approximately 1 degree Fahrenheit on average the past 100 years (Trenberth 1997, Rouse et al. 1997). Further, global temperature increases have become pronounced after the 1970s (Folland et al. 2001), primarily due to an increase in greenhouse gases (Mitchell et al. 2001, Dai et al. 2001, Karl and Trenberth 2003). In turn, northern hemisphere spring and summer snow cover, monitored by satellite imagery since 1973, decreased by 10% between 1987 and 1997 (Trenberth 1997).

Trying to define the source(s) for climate change has produced varied explanations from natural causes to human-induced impacts (i.e., burning fossil fuels, deforestation, etc.). Most of the scientific community believes the climate change we are currently experiencing is primarily human-induced. The burning of fossil fuels alters the balance of radiation on Earth through both visible particulate pollution (called aerosols) and gases that change the composition of the atmosphere. The latter are referred to as "greenhouse gases" because they are relatively transparent to incoming solar radiation, while they absorb and reemit outgoing infrared radiation, thus creating a blanketing effect that results in warming.

Hughes and Graumlich's (1996) 8000-year climatic reconstruction for the Sierra Nevada reveals that the increased global warming we are experiencing occurred most recently during the 12th and 14th centuries AD (Graumlich 1993). A sobering feature of these records is the documentation of regular multi-decadal droughts, of much greater length and severity than any experienced in the last 100 years. More recently, however, Dai et al. (2004) show that very dry areas over global land have increased from ~12% to 30%

since the 1970s, and that amount of global land in either very dry or very wet conditions has increased from ~20% to 38% since 1972. Their analysis shows that, after the middle 1980s, surface warming is the primary cause of extreme dryness and wetness; primarily in the United States, Europe, east Asia, southern Africa, and the Sahel. Since higher temperatures increase the water-holding capacity of air and its demand for moisture, they attribute warming as a primary cause for the widespread drying observed during the last two-three decades.

California's Sierra Nevada faces possible losses of biotic diversity and changes in ecosystem structure and function from anticipated global climatic change. As part of a larger federal program to determine the effects of global change in the United States (Committee on Earth Sciences 1989), the NPS developed an interdisciplinary research program to understand and predict the potential effects of climatic change on selected natural ecosystems. The Sierran national parks (Yosemite, Sequoia, and Kings Canyon) form the core study areas of this program. During the first phase (1991-1998), the program received $213,000/yr in project funds (Keeley et al. 1998). The Sierra Nevada Global Change Research Program (SNGCRP) proposes several questions including, "What hydrologic changes are likely to occur?" (Stephenson and Parsons 1993). This question recognizes the vital role of Sierran watersheds in supplying water for ecosystems and human use in much of California. SEKI has developed the project statement *SEKI-N-170.165*: Predict Effects of Global Change: Hydrological, Watershed and Micro-Climate Models to further support this work.

During the second phase (1999-2003), a project investigating forest dynamics in the Sierra was implemented with a goal to understand and predict the effects of global changes on montane forests. Results demonstrate that pre-fire growth rate, in addition to fire-induced crown scorch, influences probability of tree death following fire, suggesting that resource managers will need to consider the effects of stressors (such as climatic change) interacting with fire (U.S. Geological Survey 2002). They also developed a conceptual model describing the sensitivity of treeline to climatic change, with possible interactions between forest cover, hydrology, and species habitat.

In 2004, funding for the SNGCRP was continued for a third phase (2004-2008), however, it is now part of the broader Western Mountain Initiative (WMI), which also includes areas in the Rockies and Pacific Northwest. The integrated theme of the WMI is to understand and predict the responses - emphasizing sensitivities, thresholds, resistance, and resilience - of Western mountain ecosystems to climatic variability and change.

Fortunately, the Sierra Nevada is rich with paleoecological records that can provide important insights into future changes through reconstructions of past changes in climate, disturbance regimes, and vegetation. Appropriate models, such as the U.S. Geological Survey's Precipitation-Runoff Modeling System, is used to estimate local water balances on homogeneous subunits within individual watersheds. The outflows from individual subunits can be summed to estimate basinwide outflows under different climatic scenarios. Other efforts include the National Aeronautics and Space Administration's

Earth Observing System program, which monitors snow dynamics in the central and southern Sierra Nevada (Stephenson and Parsons 1993).

Treeline forests, in contrast to giant sequoia populations, have responded more strongly to climatic changes and, unlike treeline dynamics elsewhere in the world, Sierran treelines are controlled by both temperature and precipitation (Lloyd and Graumlich 1997). Increases in temperature over the next several decades will probably result in higher snowlines, earlier snowmelt, and prolonged summer droughts (Vaux 1991). This could extend ice-free seasons, which usually leads to increases in the ratio of evaporation + evapotranspiration to precipitation, resulting in less water found in the landscape (Schindler 1997). Unless precipitation increases substantially, an immediate effect on aquatic ecosystems could be the summertime drying of formerly perennial streams, with consequent effects on aquatic communities (National Park Service 1999). Changes in stream temperatures may also result, potentially eliminating certain invertebrate species or increase the length life cycles.

Recent modeling work by the Scripps Institution of Oceanography predicts that the average temperature in California will increase 2.1°C by 2090, which will result in a startling loss of 43% of the April snowpack in the southern Sierra Nevada (measured as snow water equivalent; Knowles and Cayan 2001). Since temperature increase is correlated with recession of glacier termini (Krimmel 2002), glacial area in the Sierra is expected to decrease dramatically this century. Although Sierra glaciers are relatively small, they are hydrologically important when considered in aggregate (Krimmel 1997), acting as natural reservoirs that delay runoff and provide surface and subsurface water through the dry months of summer (Cayan et al. 2001). Glacier loss will impact stream flows throughout the range, resulting in higher runoff peaks before April and reduced flows from snow and glacier melt after April (Knowles and Cayan 2001, Kim 2003). This reduction in spring and summer flows will cause less flushing of nutrients and an increase in surface water temperature (Hall and Fagre 2003). Ecologically, glacier loss will decrease aquatic habitat for flora and fauna, such as temperature-sensitive aquatic invertebrates, facilitate an advance in timberline, and alter the frequency of wildland fire (Hall and Fagre 2003). Anticipating changes to snowmelt and runoff also will be critical to SEKI's (and California's) water supply needs.

Because of the scarcity of real-time records, many regional climate summaries have relied heavily on modeled predictions, which are themselves of questionable validity (Schindler 1997). Basic research and long-term monitoring are needed to compliment on-going regional and global efforts to better understand the causes and consequences of climate change.

Glaciers are identified internationally as a critical place to look for early signs of global change because they are known to be sensitive to climate variations on a seasonal and yearly basis. Indeed, monitoring programs show that Glacier and North Cascades national parks have lost 73% and 44%, respectively, of their glacial cover since 1850 (Hall and Fagre 2003, North Cascades National Park 2003). It is not surprising that when the USGS held a global climate workshop at SEKI in March of 2003, many of the 40 scientists in

attendance asserted the need to begin glacier monitoring in the Sierra Nevada as an indicator of climate-induced resource change (U.S. Geological Survey 2003). Preliminary results of repeated photo points for several SEKI, YOSE and other Sierra Nevada glaciers show an approximate 50% loss of glacial cover in the past century (Basagic 2005), and the loss of glacial volume appears to be even greater.

SEKI therefore is currently seeking funding for a project proposal (PMIS; #94193) entitled, "Documenting Change and Establishing Baseline Conditions of Glaciers in SEKI and YOSE". The objectives are to use a new Sierra Nevada glacier database (Basagic 2005) to select representative index glaciers in SEKI and YOSE. At each index site, glacier area will be measured along with surface mass balance, and discharge for two seasons. One high-resolution aerial image will be acquired of each index glacier taken in fall at the time of maximum annual melt. On the ground photo points also will be established. These data and field methods will then be used to develop a long-term monitoring plan of SEKI and YOSE glaciers that will be implemented using NPS base funds and volunteer assistance. Meeting these objectives will help the NPS assess the range of variability and trends in glacier size, climate change at high elevations, and glacial contribution to summer runoff. The resulting information on magnitude and rate of glacial change will help us determine the stability of existing glaciers and their importance to downstream aquatic ecosystems in SEKI and YOSE.

Given the large amount of historical climate data that exist for SEKI and predictions for changing climate in the 21st century, it is imperative to continue collecting monitoring data at currently active climate stations. These precipitation and snow, air quality and RAWS stations are located from low to high elevation and in every climate region in SEKI. Appropriate compilation and analysis of these monitoring data will provide a representative picture of SEKI's climate over time. NPS policy states that units containing significant natural resources like SEKI will gather and maintain baseline climatological data for perpetual reference (National Park Service 2001a).

The NPS Sierra Nevada Network, which includes Sequoia, Kings Canyon, and Yosemite National Parks and Devils Postpile National Monument, is scheduled to begin implementation of a long-term monitoring program in 2007. There will be a water quality monitoring component included in this plan, in which a minimum number of parameters will be measured at each sampling location on a yet-to-be-determined frequency. These parameters are water temperature, pH, conductivity, dissolved oxygen and flow. However, the amount of monitoring funding targeted for water quality is limited, and thus the number of sample sites across the network and/or sampling frequency will also be limited.

SEKI is therefore looking to leverage these funds with partners to increase the size of the water quality monitoring program. A recent partnership between SEKI and the USGS established an interagency agreement to add a long-term backcountry water quality monitoring site in the Marble Fork Kaweah River to the USGS Hydrologic Benchmark Network. This site has been monitored for water quality by the University of California, Santa Barbara since the 1980s, and this agreement will supplement the support provided

by the university. In the agreement, SEKI performs the fieldwork of collecting and filtering approximately 25 water samples per year and then mailing them to USGS for chemical analysis. USGS provides annual funds to SEKI to help acquire a field intern in the spring and to ship samples to USGS, while USGS analyzes the samples. Sample frequency is concentrated around time of annual snowmelt in spring, with fewer samples in summer, fall and winter. Samples are analyzed for pH, conductivity, alkalinity, basic cations and anions, and nutrients.

A proposal by the University of California, Merced seeks a grant from the National Science Foundation to establish a Sierra Nevada Hydrologic Observatory that would monitor climatic conditions along several east-west transects that cross the range at varying latitudes. Various hydrologic metrics would be monitored over time along each transect to assess trends associated with climate change. A transect through Sequoia National Park has been discussed due to the long history of observations in the Kaweah River drainage, its location in the southern Sierra Nevada that receives significant atmospheric transport, and the infrastructure and logistical support available at SEKI.

Fire Management

The effects of fire management on water resources in SEKI was another significant issue identified by participants in the scoping meeting. Several specific issues under the broad category of fire management were identified, including, for example, the "role of low elevation fires by contributing nutrients to higher elevations" and "effects of fire regime on timing, hydrology, chemistry and erosion/sedimentation." It is recognized that fire management has significant potential to affect SEKI's water quality and biota in both positive and negative ways.

Fire is a primary force that affects the composition and structure of the parks' vegetation and wildlife in foothill, montane, and some subalpine areas. Fire affects air quality, soil transport, and soil chemistry, which in turn affects water chemistry. Next to elevation and photosynthesis, fire is probably one of the most significant influences in the area's ecosystem dynamics (National Park Service 1999).

With the introduction of livestock grazing, and suppression of lightning fires following Euroamerican settlement, most grove areas experienced a 100- to 130-year period without fire, which is an unprecedented fire-free period over the last several millennia (Swetnam et al. 1992). Between 1891 and 1967, Sequoia, General Grant, and Kings Canyon National Parks attempted to suppress all fires with a fair degree of success. This lack of fire resulted in ecosystem changes. Due to the buildup of dense vegetation along foothill streams and in their upper catchments, lack of fire apparently has reduced annual streamflow in the foothills, probably to the detriment of aquatic communities (National Park Service 1999).

Whiting et al. (1989) presented preliminary data on the stratigraphic distribution of charcoal and fly-ash in the sediments of selected Sierra Nevada lakes. The objective of the analysis was to identify temporal patterns in the input of charcoal and the by-products

of fossil fuel combustion into the lakes. The charcoal record for most lakes generally corresponded to the overall pattern of fire frequency in the region. The high charcoal abundances observed in some lakes suggest that fires have occurred in these airsheds at greater frequency or intensity than in other times. For example, Emerald Lake indicated a constant decline in charcoal deposition from 1920 to the present, possibly the result of fire suppression policies (Whiting et al. 1989).

Sierran forests have produced one of the longest and best-replicated networks of tree-ring based fire history reconstructions in the world (Swetnam 1993). Swetnam's 2000+ year (annual- & seasonal-resolution) fire scar chronologies from sequoia groves demonstrate substantial variation in fire frequency and size across all temporal and spatial scales.

Beginning in 2005, SEKI will receive regional NPS funding to assess fire impacts on nutrients and sediments in Redwood Creek watershed and Lilburn Cave (PMIS #104769). SEKI has planned a controlled burn in this watershed, however, the effects of the fire on nutrient and sediment dynamics in this system and other karst resources are unknown. For this study pre-fire sediment and nutrient budgets will be defined as well as nutrient cycling in the hydrologic system, and results will be compared to post-fire conditions. This study will provide 1) information on pre- and post-burn sediment transport and erosion rates, 2) information on pre- and post-burn dissolved nutrient loadings to Redwood Creek and their impacts to the cave ecosystem, 3) improved instrumentation and infrastructure for future studies in this area, and 4) information for fire managers on limiting fire impacts.

The major fire management issues identified in the scoping meeting are as follows:

- Role of low elevation fires in contributing nutrients to higher elevations;
- Effects of fire regime on timing, hydrology, chemistry, and erosion/sedimentation;
- Short and long term effects of fire (e.g., SO_4 elevated 20 years later);
- Cascading effects of fire variability on attributes of hydrology and ecology;
- Ecosystem impacts from chemicals in fire retardants (toxic and nutrient);
- A need to continue studying fire and its ecological and biogeochemical aspects.

SEKI provides logistical support for ongoing fire studies and welcomes investigators to continue conducting fire research and help provide the information necessary for park staff to implement ecosystem management. SEKI has developed other project statements related to fire management, including *SEKI-N-020.100*: Assess Effects of Fire on Fauna.

Aquatic Biological Impacts

Invertebrates

A large and diverse assemblage of invertebrate taxa occurs in SEKI, occupying the numerous habitats that follow the elevation gradient from foothill chaparral through montane forest to alpine rock, and from foothill rivers to subalpine lakes, ponds and wet meadows. However, relatively little is known about this vast group of invertebrates due

to incomplete museum collections for the regional area and the lack of taxonomic work conducted to date (Kimsey 1996).

A lack of adequate baseline information for invertebrates was therefore identified as the primary invertebrate-related issue by participants in the scoping meeting. More basic inventory data are needed to assess the diversity and distribution of invertebrates in SEKI, and monitoring data are needed to understand the effects of management actions on invertebrate taxa and communities.

The following paragraphs are excerpted from pages 19-23 of the Vital Signs Monitoring Plan Phase 1 Report of the Sierra Nevada Network (National Park Service 2004b):

> Aquatic invertebrates provide an important food source for many taxonomic groups, including birds, fish, amphibians, reptiles and other invertebrates. Aquatic invertebrates have not been inventoried or well-studied at the species level in most of the Sierra Nevada or in California as a whole (Erman 1996). A few extensive surveys in some areas of the Sierra Nevada have enabled specialists to conclude that the percentage of endemism in aquatic invertebrates for the Sierra Nevada is much higher than that for terrestrial invertebrates (Kimsey 1996, Shapiro 1996). The apparent reason is the discrete and isolated nature of small aquatic habitats in mountainous areas (Erman 1996). The composition of zooplankton and benthic invertebrate communities is altered by introduced trout (Erman 1996), however, with larger taxa tending to decline in the presence of trout. Herbst and Boiano (in progress) are evaluating the recovery of aquatic invertebrate communities following trout removal in two high-elevation SEKI streams.
>
> While little information is available to estimate the number of invertebrate species in Sierra Nevada parks, a few recent projects have focused on gathering more baseline data. A pilot invertebrate inventory that focused on chironomid midges and bees in Sequoia National Park identified 11 taxa of chironomid midges that are new records for California (Kimsey and Cranston 2002). Another study examining aquatic and terrestrial invertebrates in meadows has identified meadows as key producers and exporters of invertebrate populations to other communities (montane and subalpine forests, for example), and is examining invertebrates as potential indicators of change in meadow communities (Holmquist, in progress). An inventory of cave biota (Krejca, in progress) completed fieldwork in 2004, newly documenting many invertebrate taxa in SEKI (and YOSE).

SEKI has developed several project statements related to invertebrates (National Park Service 1999), including:

- SEKI-N-020.080 Inventory Insect and Arachnid Species
- SEKI-N-060.011 Inventory of Cave Fauna
- SEKI-N-040.000 Inventory of Aquatic Resources
- SEKI-N-040.020 Watershed/Ecosystem Monitoring Project

Amphibians

Amphibian species are declining worldwide, and are more threatened and declining more rapidly than birds or mammals (Stuart et al. 2004). Many declines are due to habitat loss and overutilization, however, 48% of rapidly declining species are threatened by undetermined processes. These poorly understood declines put hundreds of species at risk of extinction because appropriate conservation strategies are not yet known. Although declines are most prevalent among Neotropical stream-associated species, significant declines are occurring nonrandomly across the globe. Several amphibian species are declining in the Sierra Nevada, much of which is managed by several federal agencies as designated wilderness, national park, national forest, or rangeland. Most notable among these declines are the mountain yellow-legged frog (MYLF) and Yosemite toad, which are candidates for the federal Endangered Species Act, and the foothill yellow-legged frog, which disappeared from SEKI in the 1970s.

The widespread introduction of trout into high-elevation lakes in the Sierra Nevada has been shown to be a primary cause for the decline of the mountain yellow-legged frog (Bradford et al. 1993, Knapp and Matthews 2000, Vredenburg 2004). In lakes where trout have established self-sustaining populations, trout feed on frogs and tadpoles, compete for food resources (macroinvertebrates and zooplankton) and virtually eliminate reproduction. Introduced trout also have migrated from lakes to establish self-sustaining populations in most Sierran streams, which are used by frogs as dispersal corridors. Trout presence in streams therefore prevents frogs from recolonizing and causes fragmentation of the remaining frog populations. Research has shown, however, that removal of introduced trout from lakes facilitates rapid recovery via recolonization from adjacent frog populations (Knapp and Matthews 1998, Vredenburg 2004).

Inventories of lentic waterbodies in SEKI, YOSE and adjacent national forest lands were then initiated in the late 1990s to determine the presence of amphibian and introduced trout species and measure habitat characteristics. These data have allowed SEKI to select the most appropriate areas for removal of introduced trout – lakes that are located 1) near ponds where frog populations have persisted that can quickly recolonize restored habitats, and 2) in remote areas where little recreational angling is done by backcountry users. This method allows SEKI management to target sites that will benefit quickly from ecological restoration while minimizing impacts to recreational anglers.

In 2001, SEKI prepared an environmental assessment to remove introduced trout from ten lakes and adjacent streams, and comments received by the parks' superintendent demonstrated an 80% public approval rating of the project (National Park Service 2001b). SEKI began restoration fieldwork in six of these lakes in the summer of 2001 and continued fieldwork through the summer of 2004. Restoration consists of removing introduced trout from lakes using gill nets and from adjacent streams using backpack electrofishers. Restoration sites are located in Sixty Lake Basin and Upper LeConte Canyon and are near reproducing mountain yellow-legged frog populations. Shoreline visual encounter surveys also are conducted to measure the number of individuals and life stage structure of MYLF populations in each restoration lake.

From 2001 through 2004, SEKI has removed of a total of 8,418 introduced trout from these six lakes, including virtually complete eradication from five of the six restoration lakes. As a result, these six lakes showed a 40-fold increase in the average number of frogs and tadpoles detected per survey in 2004 versus 2001 (Figure 7), while one of these lakes showed a 77-fold increase. SEKI also began restoring a seventh lake in 2004 and removed 2,799 introduced trout. Due to this success, SEKI will begin restoration in the remaining three lakes in 2005. Although current base funding supports two field crews, SEKI was awarded funding from the NPS Pacific West Region to hire a third crew for three seasons beginning in 2005. The award will allow SEKI to begin two of these remaining three lakes in 2005 versus 2007, thereby gaining two critical years of restoration toward the recovery of a declining amphibian species.

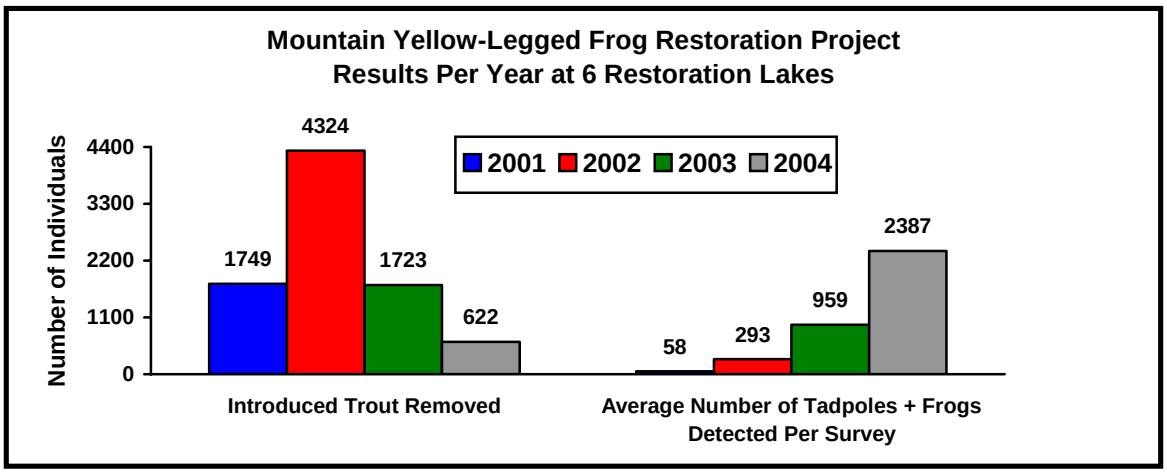


Figure 7. Number of introduced trout removed per year and average number of mountain yellow-legged frogs detected per survey per year in six original restoration lakes in Kings Canyon National Park. Data are from fieldwork conducted from 2001-2004.

There are limitations, however, to the current methodology being used to remove introduced trout from the parks' waters. Although mechanical removal does not use poisons to eradicate trout, thereby minimizing impacts to non-target taxa and wilderness habitat, it takes several years to eradicate each trout population. Alternative removal strategies that achieve eradication more quickly need to be investigated, including the use of 1) rotenone or antimycin and 2) sterile predatory fish (e.g., tiger muskie). Additionally, since there is strong support and lack of support for removal of introduced trout among different segments of the public, recent results should be shared with public groups.

Frogs have also declined in some fishless areas, however, and recent research suggests that contaminants and diseases may also be contributing to Sierran amphibian declines (Fellers et al. 2001, Sparling et al. 2001, Davidson et al. 2002, Fellers et al. 2004). Refer to pages 73-77 in the "Contaminants, Nutrients and Atmospheric Deposition" section for a discussion of the effects of pesticides and contaminants on amphibians.

In 2004, chytrid fungus (*Batrachochytrium dendrobatidis*) was documented to have spread into previously uninfected areas in SEKI where MYLFs have persisted with relatively abundant populations, including Milestone Basin and Sixty Lake Basin. Researchers from the University of California collected blood and skin samples from infected and healthy frogs in each area in an attempt to learn more about how the disease infects individuals and spreads through populations. Plans are being developed to investigate both basins throughout 2005 to continue investigating the effects of chytrid fungus on frog populations over time.

In 2004, a study on chytrid fungus translocated healthy MYLF tadpoles to areas where chytrid fungus 1) is currently infecting a frog population, 2) infected a frog population in the past decade, and 3) does not occur. Analysis of a portion of these individuals thus far shows that most individuals placed in the chytrid site became infected, while all individuals placed in sites where chytrid occurred in the past did not become infected. These results are encouraging because it suggests that MYLFs may not become infected if they recolonize or are translocated to areas where chytrid fungus exterminated frog populations in the past. However, the experiment was conducted using tadpoles, which require about ten times as many zoospores of chytrid fungus to become infected versus subadults. Replication of this study using subadults should therefore be conducted to further test this preliminary conclusion.

The recent trend of chytrid fungus infection decimating large populations of MYLFs is alarming and a major threat to the persistence of the species. It is unknown, however, whether the disease is one of the causal factors in the decline of the species or the symptom of another causal factor, such as contaminants that stress frogs and reduce their resistance to disease. Research of these phenomena in SEKI will continue in 2005 and likely in ensuing years to improve scientific understanding and inform resource management. It also will be educational to observe the recent establishment of chytrid fungus in Sixty Lake Basin, where ecological restoration has begun to increase the abundance a few MYLF populations. Tracking the effects of chytrid fungus in this basin will help guide the direction of future restoration projects.

Recent genetic work on the MYLF shows several clades with distinct genetics in the Sierra Nevada (Macey et al. 2001). If translocations of frogs are performed in restoration projects, watershed management plans or research studies, source populations that occur within the range of the local clade should be used. Whether these genetic differences are enough to constitute different subspecies or even species also should be investigated.

Monitoring the distribution and abundance of MYLF populations is critical toward conservation of the species due to the severe decline that has occurred due to introduced trout and the further decline that is likely due to contaminants and disease. Monitoring data will allow resource managers and researchers to detect if the number of MYLF populations and/or number of MYLF individuals reaches critically low levels that would require more aggressive intervention. Simultaneous monitoring of Yosemite toads is also needed for responsible management of this additional declining amphibian species and candidate to the federal Endangered Species Act. SEKI plans to coordinate with

University of California, USFS and YOSE ecologists to leverage funding and personnel toward a more effective amphibian monitoring program across the Sierra Nevada.

The major amphibian-related issues identified in the scoping meeting are as follows:

- Effects of pesticides, contaminants, and diseases on amphibians;
- How will diseases and contaminants affect methods for restoring MYLFs?;
- Controversial methods for restoring MYLFs (tiger muskie, poisons);
- Public opposition to removal of introduced trout for frog restoration;
- Genetics of mountain yellow-legged frogs: are there two different species in SEKI?;
- Use of translocations as a tool to investigate causes of frog declines;
- Using current research in genetics to create watershed management plans; need to know which life stage is best for translocations for frog reintroduction.

SEKI has developed several amphibian-related project statements, including:

- SEKI-N-040.060: Determine Distribution of High-Elevation Amphibians;
- SEKI-N-020.030: Evaluate Impacts of Exotic Species;
- SEKI-N-040.061: Evaluate/Reintroduce Foothill Yellow-Legged Frog;
- SEKI-N-020.040: Evaluate Status of T & E Fauna;
- SEKI-N-040.020: Watershed/Ecosystem Monitoring Project;
- SEKI-N-040.000: Inventory of Aquatic Resources;
- SEKI-N-020.041: Study Rare and Extirpated Fauna.

<u>Fish</u>

The native fish assemblage in the Sierra Nevada has been significantly altered by a variety of stressors, but primarily by dams and diversions and introduced species (Moyle 1995, 2002, Moyle et al. 1996). The most comprehensive recent assessments of the status of fish and fisheries for the Sierra Nevada are the Sierra Nevada Ecosystem Report (SNEP; Moyle et al. 1996) and Inland Fishes of California (Moyle 2002). The SNEP Report states that:

> "The native fish fauna of the Sierra Nevada consists of 40 native taxa. Eleven (28%) of these taxa, including five kinds of trout, are endemic to the Sierra Nevada, and most (85%) are endemic to the Californian region, of which the Sierra Nevada forms the core…The fish fauna and fisheries of the Sierra Nevada have changed dramatically since the influx of Euro-Americans began in 1850 (Moyle 1995). Four broad patterns are evident: 1) Anadromous fishes have been excluded from most of the riverine habitat they once used on the west side of the range; 2) Most resident native fishes have declined in abundance and the aquatic communities of which they are a part have become fragmented; a few have had expanded ranges as a result of introductions; 3) Thirty species of non-native fishes have been introduced or have invaded most waters of the range, including extensive areas that were once fishless; and 4) Sierra Nevada fisheries have largely shifted from native fishes, especially salmon and other migratory fishes, to introduced fishes."

SEKI has documentation of ten extant fish taxa, of which five are native (Little Kern golden trout, Kern River rainbow trout, rainbow trout, Sacramento sucker and California roach) and four are introduced (brook trout, brown trout, green sunfish and golden shiner) (Werner, pers. comm. 2005). Two of the native taxa (Little Kern golden trout and rainbow trout) also have been introduced to portions of the parks outside of their native ranges. Another non-native species (black bullhead) was introduced but became extirpated on its own after several years. An additional seven species could occur in the park, including four natives (hardhead, Sacramento pikeminnow, prickly sculpin and riffle sculpin) and three non-natives (brown bullhead, carp and goldfish). Of these possible native species, there is one report of a single sculpin, and hardhead and pikeminnow may have been present historically but confirmed records are lacking. Surveys are needed to determine the current status of these species in SEKI.

Although 60% of the extant assemblage is native, every native taxa may have experienced at least a reduction in distribution and abundance in its native range and some may be extirpated from the parks. The three native taxa of trout are threatened by hybridization with introduced trout taxa and/or predation and competition from non-native brook trout, brown trout and green sunfish. The remaining two native taxa (Sacramento sucker and California roach) have been impacted by the construction of dams on the Kaweah, Kern, Kings and Tule Rivers and by the presence of non-native brown trout, green sunfish and bullfrog. Of the native assemblage in the Kaweah River, only the rainbow trout, Sacramento sucker and California roach are known to be extant.

Participants in the scoping meeting identified removal of exotic/introduced species as the most important fishery-related issue. Exotic/introduced species are responsible for a significant part of the impairment that has occurred among the fish assemblage native in the Sierra Nevada and SEKI, as well as many components of native aquatic ecosystem. SEKI has begun to remove introduced trout from several high-elevation lakes and streams to facilitate restoration of aquatic ecosystems that were historically fishless. These sites are relatively straightforward to restore because they are small to moderate in size and isolated by barriers from introduced trout in downstream habitats. Restoration of the golden trout complex and native fish assemblage which occupy river systems is much more complicated due to the larger size and continuity of these habitats. Nevertheless, the California Department of Fish and Game (CDFG) has been the lead agency implementing restoration plans for the golden trout complex and surveying low elevation river habitat in and adjacent to the parks. SEKI cooperates with CDFG to restore and better understand the status of these taxa and habitats, and welcomes investigators to conduct research that will inform management of the native fish assemblage in SEKI.

The major fishery-related issues identified in the scoping meeting are as follows:

- Removal of exotic/introduced species
- When removing exotic fish, check for genetic variability and integrity. Should we maintain genetically-pure populations that are not native to area where transplanted?

- How can we efficiently and permanently remove exotic/introduced fish from as many water bodies as possible?
- Need to define (and restore?) historical distribution of native trout species in SEKI.

SEKI has developed fishery-related project statements, including:

- SEKI-N-040.031: Study Genetics of Extant Rainbow Trout;
- SEKI-N-040.032: Evaluate Status of Kern Rainbow Trout;
- SEKI-N-040.030: Determine Pristine Distribution of Fish Species;
- SEKI-N-020.040: Evaluate Status of T & E Fauna;
- SEKI-N-040.000: Inventory of Aquatic Resources;
- SEKI-N-020.030: Evaluate Impacts of Exotic Species;
- SEKI-N-020.041: Study Rare and Extirpated Fauna;
- SEKI-N-040.020: Watershed/Ecosystem Monitoring Project.

DIVISION OF NATURAL RESOURCES STAFFING

The SEKI Division of Natural Resources staff is presented in Figure 8, which includes both permanent and seasonal positions. Currently SEKI is divided into five districts that include the Ash Mountain (headquarters), Giant Forest/Lodgepole, Grant Grove, Cedar Grove and Mineral King areas of the park (National Park Service, 1999). Infrastructure for accomplishing water resource management goals is somewhat limited since the majority of SEKI's 865,000 acres (350,046 ha) is designated wilderness. Although SEKI has a moderately-sized natural resources staff, several of the positions must serve multiple disciplines at SEKI. For example, the parks' aquatic ecologist manages aquatic resources, which includes programs to manage water quality, hydrologic processes, wetlands, floodplain issues, fisheries, declining amphibian issues, aquatic invertebrates, other aquatic fauna such as karst fauna, and aquatic flora including riparian zones. Ecological restoration of lakes and streams to restore native biota is a major emphasis. Additionally, the Chief of Natural Resources reports directly to SEKI's Superintendent and is responsible for the parks' natural resource management program and reporting progress on goals under the Government Performance and Results Act (GPRA).

Meeting the current natural resource objectives requires funding and human resources that greatly exceed SEKI's current Natural Resources program. Partnerships have helped to alleviate some of the inadequate natural resource support. Many of the park projects that directly or indirectly relate to water resources have been summarized in the preceding sections of this report.

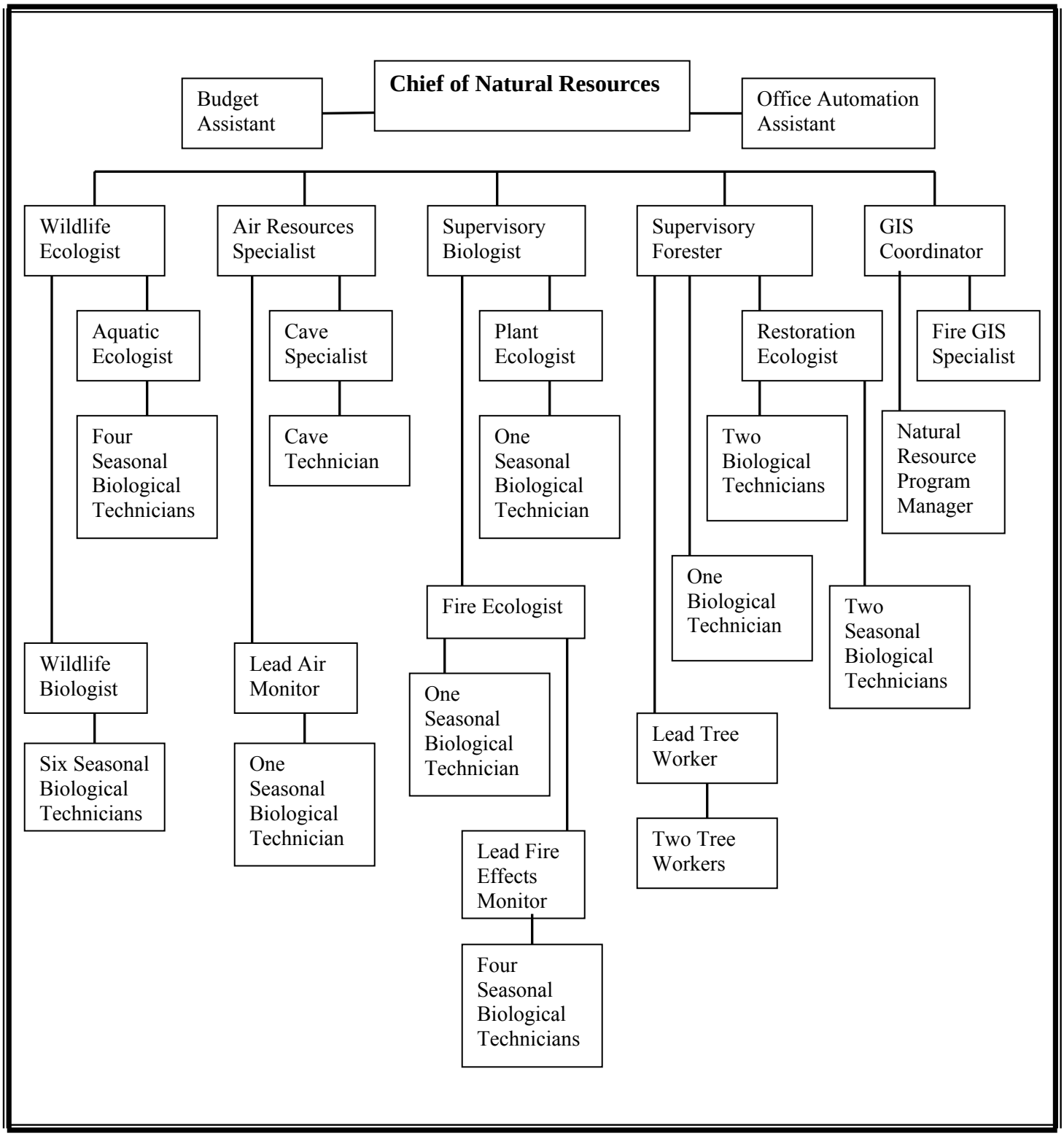


Figure 8. Sequoia and Kings Canyon National Parks, Natural Resources Program: Organization and Structure.

CONSIDERATIONS FOR FUTURE ACTION

The water-related issues and natural resource data presented in this report are supported through regional and local research and monitoring efforts. Identification of available water resource information has also contributed toward exposing "data gaps" that translate to natural resource needs for SEKI. The action items listed below include both funded activities that should be continued and possibly expanded and unfunded activities that, if initiated and implemented, will complement existing activities and improve understanding and management of significant water resource issues in SEKI.

Specific issues and considerations for future actions presented in this report are listed below. Some additional issues and considerations for future action were also included on water rights, which were elevated by the NPS WRD Water Rights Branch during the draft review:

❖ Contaminants, Nutrients and Atmospheric Deposition

- Continue monitoring wet and dry deposition chemistry and seek to expand the network to include deposition along an elevation gradient.

- Continue and expand monitoring air quality and analyzing samples for gaseous and fine particle pollutants. Support sampling efforts by NPS Air Resources Division to evaluate long-range transport of airborne contaminants.

- Continue supporting and assisting research on atmospheric transport and deposition of contaminants and nutrients into watersheds. Particularly, continue long-term research and monitoring of water chemistry and hydrology in headwater catchments of the Marble Fork Kaweah River and continue research of the effects of airborne contaminant deposition on amphibians and aquatic ecosystems.

❖ Climate Change

- Continue monitoring water quality and quantity to assess water resource trends in response to expected changes to climate. This effort includes 1) assisting with design and implementation of Vital Signs water quality monitoring for the Sierra Nevada Network, 2) collecting water samples in Marble Fork Kaweah River for USGS Hydrologic Benchmark Network, 3) conducting monthly snow surveys in winter at all existing survey stations, 4) maintaining all existing RAWS stations and 5) accessing data stored by the USGS for three gauges on the Kaweah River.

- Support and assist the Sierra Nevada Global Change Research Program in SEKI that is implemented by the USGS as part of the broader Western Mountain Initiative. By investigating what hydrologic changes are likely to occur in SEKI and the larger Sierra Nevada and predicting the effects of these changes, this data will help SEKI anticipate and adapt to changing environmental conditions.

- Conduct investigations of climate and glacier interactions by establishing a network of a few carefully-selected index glaciers. Selection of SEKI and YOSE glaciers could be made from a database of Sierra Nevada ice (Basagic 2005). Glaciers on Mount Darwin in SEKI and Mount Lyell in YOSE are known to have a good historical record, are relatively easy to access and are the largest in each park, and therefore should have a high priority for monitoring alpine climate. Investigations should address how the expected shrinkage of glaciers will affect downstream aquatic habitat and species. Establishing river gaging stations close to glaciers will allow evaluation of glacial influence on water quantity, quality and temperature. Determine whether species, such as the Mount Lyell salamander (*Hydromantes platycephalus*), may be impaired by predicted loss of snowpack.

- Support and assist the University of California, Merced in establishing the Sierra Nevada Hydrologic Observatory to study and monitor water resources over time. Three to four transects are proposed to extend from the west to the east sides of the Sierra at different latitudes. The Kaweah River watershed should be selected as part of the southern transect given the history of research and monitoring in the watershed and the infrastructure and support available through SEKI.

- Support and assist the Scripps Institute of Oceanography in installing and maintaining research gauges in several SEKI drainages to evaluate trends in onset of snowmelt and complement identical investigations begun in YOSE and DEPO.

- Conduct an inventory of ground water resources in SEKI and attempt to quantify ground water amounts.

❖ Fire Management

- Continue supporting and assisting research of the effects of fire on ecosystems, including effects to physical/chemical and biological/ecological processes. For example, how do natural fires and controlled burns affect not only timing of runoff, water chemistry and sediment transport in watersheds but also the distribution and abundance of aquatic organisms such as amphibians, fish and aquatic invertebrates?

- Monitor water quality in streams that drain areas planned for controlled burns both before and after fire to determine how burning affects water chemistry.

- Investigate the effects of fires in higher productivity, low elevation areas that may contribute nutrients to lower productivity, high elevation watersheds.

❖ Aquatic Biological Impacts - *Invertebrates*

- Build upon recent invertebrate sampling results in SEKI, including the inventory of karst fauna and evaluation of high elevation stream invertebrate communities,

to obtain funding to conduct an inventory of invertebrates throughout SEKI. Although an expensive proposition due to the size and diversity SEKI's lands, knowledge of invertebrates is arguably one of the larger data gaps for these parks.

- Use data and recommendations from inventory of karst fauna to establish a cave invertebrate monitoring program in several SEKI caves.

- Use data and recommendations from evaluation of high elevation stream invertebrate communities in selection of future ecological restoration areas and any plans to create aquatic diversity management areas in SEKI.

- Consider biomonitoring of aquatic invertebrates to complement monitoring of water chemistry in SEKI. Assist any utilization of 1) aquatic invertebrates in the Vital Signs water quality monitoring program and 2) meadow invertebrates in the Vital Signs monitoring plan.

❖ Aquatic Biological Impacts - *Amphibians*

- Build upon success of the MYLF restoration project to create a programmatic plan to implement restoration in additional high elevation basins in SEKI. Improve upon limitations of current restoration methodology. Consult current genetic analysis of the species to ensure that restoration occurs in all basins containing significantly unique genetic groups of MYLFs.

- Support and assist proposed work by the University of California to study any founder effects that may occur in new MYLF populations that are begun by a few individuals in restoration areas. These data will be important if translocations of individuals are necessary in the future to mitigate further decline of the species.

- Continue supporting and assisting studies of chytrid fungus and quickly apply results to future management actions. Particularly important questions to which we need answers include "How does chytrid fungus become established in a new basin?" and "Is chytrid fungus native to the Sierra or a recent introduction?" and "Can MYLFs be restored to previous chytrid infection sites?"

- Continue supporting and assisting studies of the role that contaminants may have in amphibian declines. An especially critical need is to determine whether stress from accumulation of contaminants in amphibian tissue is responsible for the recent increased incidence of chytrid fungus infection in MYLF populations.

- Apply results of spatial analyses that determine relative exposure of areas to contaminant deposition in future selection of ecological restoration areas so that work is conducted in areas that are more sheltered to contaminant loads and therefore more probable to support amphibian populations.

❖ Aquatic Biological Impacts - *Fish*

- In restoration areas where introduced trout have been eradicated, survey for the presence of trout annually in the first three years after eradication to trigger mitigation actions if trout recolonization occurs. This should be done concurrent with site visits for monitoring of amphibian populations.

- Remove any artificial structures that were placed in the East Fork of the Kaweah River above Mineral King to enhance sportfishing.

- Continue removing introduced trout from remote areas with opportunities for ecological restoration of vulnerable fauna, including MYLFs, Yosemite toads, and pure or relatively pure populations of Little Kern golden and Kern River rainbow trout in their native range.

- Continue supporting and assisting California Department of Fish and Game with monitoring of federally threatened Little Kern golden trout and genetic analysis of remote introduced California golden trout populations.

- Determine the genetic integrity of Kern River rainbow trout in the Kern River between Junction Meadow and the park boundary and investigate their genetic relationship to upstream populations.

- Determine the genetic integrity of rainbow trout in their native range in the Kaweah and Kings Rivers. If any pure or relatively pure strains are found, determine the feasibility of restoration possibilities.

- Conduct fish sampling in the Middle Fork Kaweah River from the park boundary to the confluence with the Marble Fork to determine the current status of the historic native fish assemblage, including rainbow trout, California roach, Sacramento sucker, Sacramento pikeminnow, hardhead and sculpin spp.

❖ Water Rights

- The park holds no state appropriative right to Merritt Spring, but as owner of the land surrounding the spring, the park holds a riparian right. However, use of water pursuant to a riparian right must take into consideration the rights and uses of others. In the exercise of its riparian right, the park must consider the riparian rights and overlying rights of some landowners in Wilsonia downstream from the spring. The park's historical use of water diverted from the spring may be subject to question. (Lord, pers. comm. 2003).

- In early 2003, in response to Wilsonia's concerns, the park stopped diverting flow from Merritt Spring and now uses it only as a backup/emergency water source. In the longer term, the parks should consider a more in-depth review of the watershed that supplies the Grant Grove facilities. If flows from other springs are diverted by the parks in a fashion similar to Merritt Spring, the use of these other

springs could also be questionable. Depending on how important these sources are for park visitor and administrative needs, a study should be considered to determine whether Merritt Spring recharges the ground water beneath Wilsonia (Lord, pers. comm. 2003).

- In order to fully assess the existence and nature of a federal reserved water right associated with SEKI, an examination of the legislation creating SEKI would be necessary. If needed to fulfill the purposes of the federal reservation, a federal reserved right may be either for consumptive purposes (e.g., involving diversion of water from the stream) or for non-consumptive purposes (e.g., involving instream uses of water).

Future Planning

The complexity of the parks' issues elevates the need to expand upon the information contained in this WRIIO report by producing a Water Resources Stewardship Report. The report would build from this WRIIO by further developing the water-related issues, including strategies that address the high-priority issues and support the desired resource conditions included in SEKI's new GMP. This effort should strengthen existing partnerships and encourage other stakeholders to participate with the NPS during and after the second report is complete. Many of the issues presented in this report extend beyond NPS boundaries; thus, it is important to recognize the fact that multi-agency communication and coordination are essential to successfully manage SEKI's water resources.

The parks are encouraged to place a high priority in seeking funds, both internally and externally, to build from this report. Until a Water Resources Stewardship Report is prepared for SEKI, components of this report should be used in the development of time-sensitive management strategies and actions relating to water resource issues.

LITERATURE CITED

Abell, D. L. 1977. A survey of macroscopic invertebrates of Sequoia streams. Unpublished report for Sequoia Natural History Association, Three Rivers, CA. 84 pp.

Akers, J. P. 1986. Ground water in the Long Meadow area and its relation with that in the General Sherman Tree area, Sequoia National Park, California. U.S. Geological Survey, Water Resources Investigations Report 85-4178. Sacramento, CA. 15 pp.

Atwood, W. 1940. The Physiographic Provinces of North America. Gin and Company, Boston, MA. pp. 440-452.

Basagic, H. J. 2005. Quantifying twentieth century glacier change in the Sierra Nevada. Unpublished M.S. thesis, in preparation. Portland State University, Portland, OR.

Berger, L., R. Speare, P. Daszak, D. E. Green, A. A. Cunningham, C. L. Goggin, R. Slocombe, M. A. Ragan, A. D. Hyatt, K. R. McDonald, H. B. Hines, K. R. Lips, G. Marantelli, and H. Parkes. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. Proceedings of the National Academy of Science, USA 95: 9031-9036.

Bertoldi G. L., and G. A. Miller. 1969. Geophysical Survey and Pumping Test in Wolverton Creek Valley, Giant Forest Area, Sequoia National Park, California. U.S. Geological Survey, Water Resources Division, Menlo Park, CA. 17 pp.

Bingham, R. 2003. *Hyla regilla* as a disease reservoir and its impact on *Rana muscosa*: how different life histories affect persistence. Investigator's Annual Report, Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Blett, T. 2005 Personal communication. National Park Service, Air Resources Division. Lakewood, CO.

Boiano, D. 2004. Personal Observation. Aquatic Ecologist, Sequoia and Kings Canyon National Park, Three Rivers, CA.

Bradford, D. F. 1983. Winterkill, oxygen relations, and energy metabolism of a submerged dormant amphibian, *Rana muscosa*. Ecology 64:1171-1183.

Bradford, D. F. 1984. Temperature modulation in a high-elevation amphibian, *Rana muscosa*. Copeia 1984:966-976.

Bradford, D. F. 1989. Allotopic distribution of native frogs and introduced fishes in high Sierra Nevada lakes of California: implication of the negative effect of fish introductions. Copeia 1989:775-778.

Bradford, D. F. 1991. Mass mortality and extinction in a high-elevation population of *Rana muscosa*. Journal of Herpetology 25:174-177.

Bradford, D. F. and M. S. Gordon. 1992. Aquatic biota in the Sierra Nevada: current status and potential effects of acidic deposition on populations. Final Report, Contract No. A932-139, California Air Resources Board. Sacramento.

Bradford, D. F., C. Swanson, and M. S. Gordon. 1992. Effects of low pH and aluminum on two declining species of amphibians in the Sierra Nevada, California. Journal of Herpetology 26:369-377.

Bradford, D. F., C. Swanson, and M. S. Gordon. 1994b. Effects of low pH and aluminum on amphibians at high elevation in the Sierra Nevada, California. Canadian Journal of Zoology 72:1272-1279.

Bradford, D. F., D. M. Graber, and F. Tabatabai. 1994a. Population declines of the native frog, *Rana muscosa*, in Sequoia and Kings Canyon National Parks, California. Southwestern Naturalist 39:323-327.

Bradford, D. F., F. Tabatabai, and D. M. Graber. 1993. Isolation of remaining populations of the native frog, *Rana muscosa*, by introduced fishes in Sequoia and Kings Canyon National Parks, California. Conservation Biology 7:882-888.

Bradford, D. F., M. S. Gordon, D. F. Johnson, R. D. Andrews, and W. B. Jennings. 1994c. Acidic deposition as an unlikely cause for amphibian population declines in the Sierra Nevada, California. Biological Conservation 69:155-161.

Bradford, D. F., N. Tallent-Halsell, and E. Heithmar. 2003. Distributions of airborne agricultural contaminants relative to amphibian populations in the southern Sierra Nevada, California. 2003 temporal study plan. U.S. Environmental Protection Agency, Las Vegas, NV.

Bradford, D. F., S. D. Cooper, A. D. Brown, T. M. Jenkins, Jr., K. Kratz, and O. Sarnelle. 1994d. Distribution of aquatic animals relative to naturally acidic waters in the Sierra Nevada. Final Report, Contract No. A132-173, California Air Resources Board, Sacramento.

Bradford, D. F., S. D. Cooper, T. M. Jenkins, Jr., K. Kratz, O. Sarnelle, and A. D. Brown. 1998. Influences of natural acidity and introduced fish on faunal assemblages in California alpine lakes. Canadian Journal of Fisheries and Aquatic Sciences 55:2478-2491.

Bradford, G. R., C. A. Fox, A. L. Page and A. A. Elseewi. 1983. Evaluation of acidity and chemical composition of high elevation lakes in California. National Atmospheric Deposition Program (IR-7) Technical Committee Meeting. Nov. 7-10, 1983. Knoxville, TN. 22 pp.

Bradford, G. R., F. L. Bair, and V. Hunsaker. 1968. Trace and major element content of 170 high Sierra lakes in California. Limnology and Oceanography 13:526-530.

Briggs, C. J. 2004. Amphibian disease dynamics in a fragmented landscape. Investigators Annual Report, Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Cahill, T. A., J. J. Carroll, D. Campbell, and T. E. Gill. 1996. Air quality. Pages 1227-1260 *in* Sierra Nevada Ecosystem Project: final report to Congress. Volume II, Assessments and scientific basis for management options. Wildlands Resources Center Report No. 37, Centers for Water and Wildlands Resources, University of California, Davis.

California Air Resources Board. 1986. The Fourth Annual Report to the Governor and the Legislature on the Air Resources Board's Acid Deposition Research and Monitoring Program. Prepared by the Acid Deposition and Aerosol Research Section of the Research Division. Sacramento, CA. 374 pp.

California Department of Pesticide Regulation. 2005. Summary of pesticide use report data: 2003. California Environmental Protection Agency, Department of Pesticide Regulation, Sacramento, CA.

Camp, C. L. 1916. Description of *Bufo canorus*, a new toad from Yosemite National Park. University of California Publications in Zoology 17:59-62.

Camp, C. L. 1917. Notes on the systematic status of the toads and frogs of California. University of California Publications in Zoology 17(9):115-125.

Cassel, J. D. 1935. Report on stream improvement in the east branch of the Kaweah River above Mineral King in the Sequoia National Forest, summer 1935.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson. 2001. Changes in the onset of spring in the Western United States. Bulletin of the American Meteorological Society 82:399-415.

Christenson, D. P. 1977. History of trout introductions in California high mountain lakes. Pages 9-15 *in* Symposium on the management of high mountain lakes in California's National Parks. California Trout, Inc. and the American Fisheries Society.

Chronic, H. 1986. Pages of Stone - Geology of Western National Parks and Monuments: Vol. 2, Sierra Nevada, Cascades & Pacific Coast. The Mountaineers, Seattle, WA. 184 pp.

Clow, D. W., J. O. Sickman, R. G. Striegl, D. P. Krabbenhoft, J. G. Elliott, M. Dornblaser, D. A. Roth, and D. H. Campbell. 2003. Changes in the chemistry of lakes and precipitation in high-elevation national parks in the western United States, 1985-1999. Water Resources Research 39(6):1171-1183.

Colburn, T., D. Dumanoski, and J. Peterson Myers. 1996. Our Stolen Future. Penguin Books USA, Inc., New York, NY.

Coleman, G. A. 1925. Biological survey of the Rae Lakes region. California Fish and Game 11(2):57-62.

Committee on Earth Sciences. 1989. Our changing planet: the FY 1990 research plan. Committee on Earth Sciences. U.S. Global Change Research Program, Office of Science and Technology Policy, Washington, D.C. 118 pp.

Cordes, J. F., M. A. Blumberg, G. A. E. Gall, and B. May. 2001. Genetic status of California golden trout populations in the headwaters of Golden Trout Creek. Report to the Threatened Trout Committee, California Department of Fish and Game. 40 pp.

Corn, P. S., and R. A. Knapp. 2000. Fish stocking in protected areas: summary of a workshop. Proceedings: Wilderness Science in a Time of Change. RMRS-P-00, pages 301-303. Ogden, UT: U.S. Forest Service, Rocky Mountain Research Station.

Cory, L., P. Fjeld, and W. Serat. 1970. Distribution patterns of DDT residues in the Sierra Nevada mountains. Pesticides Monitoring Journal 3:204-211.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service, FWS/OBS-79/31.

Cowman, D. F., D. W. Sparling, G. M. Fellers, and T. E. Lacher. 2002. Effects of agricultural pesticides on translocated tadpoles of the Pacific treefrog in Lassen, Yosemite, and Sequoia National Parks. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, MD. http://www.pwrc.usgs.gov/resshow/cowman/cowman.html

Croft, M. G. 1968. Ground water reconnaissance of the Giant Forest area, Sequoia National Park, California. (Revised from 1966) U.S. Geological Survey, Sacramento, CA. 5 pp. + appendices.

Dai, A., G. A. Meehl, W. M. Washington, and T. M. L. Wigley. 2001. Ensemble simulations of the twenty-first-century climate changes: Business as usual versus CO_2 stabilization. Bulletin of American Meteorological Society 82:2377–2388.

Dai, A., K. E. Trenberth, and T. Qian. 2004. A global dataset of palmer drought severity index for 1870–2002: relationship with soil moisture and effects of surface warming. Journal of Hydrometeorology 5:1117-1130.

Dale, R. H. 1964. Ground water reconnaissance of the Ash Mountain area, Sequoia National Park, California. U.S. Geological Survey, Sacramento, CA. 7 pp.

Dale, R. H. 1966. Ground water reconnaissance of the Grant Grove area, Kings Canyon National Park, California. (Revised from 1964) U.S. Geological Survey, Sacramento, CA. 18 pp. + figures.

Davidson, C., H. B. Shaffer, and M. R. Jennings. 2002. Spatial tests of the pesticide drift, habitat destruction, UV-B and climate change hypotheses for California amphibian declines. Conservation Biology 16(6):1588-1601.

Dean, W. W. 1969. Water quality and quantity data, East Fork Kaweah River Basin, California, 1968. Basic data compilation. U.S. Geological Survey, Menlo Park, CA. 27 pp.

Dean, W. W. 1971. Water quality and quantity data, East Fork Kaweah River Basin, California, 1969. Open-file report, U.S. Geological Survey, Menlo Park, CA. 29 pp.

Demetry, A. 2004. Personal Communication. Restoration Ecologist. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Derlet, R. W., and J. R. Carlson. 2002. An analysis of human pathogens found in horse/mule manure along the John Muir Trail in Kings Canyon and Sequoia and Yosemite National Parks. Wilderness and Environmental Medicine 13:113-118.

Derlet, R. W., and M. N. Noponen. 2005. Prevalence of coliform and other pathogenic bacteria in Kings Canyon and Sequoia and wilderness and backcountry area lakes and streams. Scientific Research and Collecting Permit, Sequoia & Kings Canyon National Parks, Three Rivers, CA.

Despain, J. 2003. Hidden Beneath the Mountains, Caves of Sequoia & Kings Canyon National Parks. Cave Books, Dayton, OH. 128 pp.

Dilsaver, L. M., and W. C. Tweed. 1991. The Challenge of the Big Trees: A Resource History of Sequoia and Kings Canyon National Park. University of Arizona Press.

Drakeford, L., L. L. McConnell, G. M. Fellers, D. S. Sparling, D. F. Cowman, and P. Kleeman. 2003. Pesticide and POPs in sediment from amphibian habitats in the Sierra Nevada mountain range, USA [abstract]. Society of Environmental Toxicology and Chemistry 24th Annual Meeting in North America. 24:144.

Drost, C. A., and G. M. Fellers. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. Conservation Biology 10:414-425.

Duriscoe, D. M. 1983. An Air Quality Monitoring Plan for Sequoia and Kings Canyon National Parks. First Biennial Conference of Research in California's National Parks. University of California, Davis. Sept. 9-10, 1982. pp. 8-14.

Duriscoe, D., D. Ewell, and T. Nichols. 1982. An Assessment of the Air Quality in and around Sequoia and Kings Canyon National Parks and a Plan for its Management. Sequoia and Kings Canyon National Parks, Three Rivers, CA. 72 pp.

Elder, K. J. 1988. Spatial and temporal variation of net snow accumulation in a small alpine watershed, Emerald Lake Basin, Sierra Nevada, California. Unpublished M.S. thesis. University of California, Santa Barbara. 99 pp.

El-Amamy, M. M., G. R. Bradford, A. L. Page, S. C. Nodvin, and C. A. Fox. 1984. The alkalinity of pristine lakes in the high Sierra mountains. Presentation at the 77th Annual Air Pollution Control Association Meeting. June 24-29, 1984. San Francisco, CA. 9 pp.

Erman, D. 1977. Ecological evaluation of backcountry lakes subjected to varying amounts of human use. Whitaker's Forest Cooperative Natural Resources Research Station. Unpublished report. 104 pp.

Erman, D., and T. Taylor. 1978. The response of benthic plants and selective chemical and biological features to past levels of human use in some high mountain lakes in Kings Canyon National Park. Unpublished report for Western Region, National Park Service. University of California, Berkeley. 42 pp.

Erman, N. A. 1996. Status of aquatic invertebrates. Pages 987-1008 *in* Sierra Nevada Ecosystem Project: final report to Congress. Volume II, Chapter 35. Centers for Water and Wildland Resources, University of California, Davis.

Esperanza, A. 2005. Personal Communication. Air Resources Specialist. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Evermann, B. W. 1905. The golden trout of the southern high Sierras. Bulletin of the United States Fish Commission, Vol. 25.

Ewell, D. M., R. G. Flocchini, L. O. Myrup, and T. A. Cahill. 1989. Aerosol transport in the southern Sierra Nevada. Journal of Applied Meteorology 28(2):112-125.

Federal Water Pollution Control Administration. 1969. Water quality and aquatic biology, East Fork Kaweah River, Mineral King area, California. Department of the Interior, Washington, D.C. 36 pp.

Fellers, G. M., D. E. Green, and J. E. Longcore. 2001. Oral chytridiomycosis in the mountain yellow-legged frog (*Rana muscosa*). Copeia 101:945-953.

Fellers, G. M., D. W. Sparling, and P. Kleeman. 2005. Pesticide impacts on amphibian populations in the Sierra Nevada mountains: Results of field studies and laboratory experiments. Presentation at the Declining Amphibians Populations Task Force Meeting. January 13-14, 2005. Berkeley, CA.

Fellers, G. M., L. L. McConnell, D. Pratt, and S. Datta. 2004. Pesticides in mountain yellow-legged frogs (*Rana muscosa*) from the Sierra Nevada mountains of California, USA. Environmental Toxicology and Chemistry 23:2170-2177.

Fenneman, N. 1931. Physiography of Western United States. McGraw-Hill Book Company, Inc. New York, NY. pp. 396-417.

Folland, C. K., N. A. Rayner, S. J. Brown, T. M. Smith, S. S. Shen, D. E. Parker, I. Macadam, P. D. Jones, R. N. Jones, N. Nicholls, and D. M. H. Sexton. 2001. Global temperature change and its uncertainties since 1861. *Geophysical Research Letters* 106:2621-2624.

Graumlich, L. J. 1993. A 1000-year record of temperature and precipitation in the Sierra Nevada. Quaternary Research 39:249-255.

Grinnell, J., and T. Storer. 1924. Animal life in the Yosemite. University of California Press, Berkeley, CA.

Hall, M. H. P., and D. B. Fagre. 2003. Modeled climate-induced glacier change in Glacier National Park, 1850-2100. American Institute of Biological Sciences 53(2):131-140.

Hambrey, M., and J. Alean. 1994. Glaciers. Cambridge University Press. New York, NY. 208 pp.

Heard, A. M. 2005. Effects of a landscape scale prescribed fire on hydrology and stream chemistry. Unpublished M.S. thesis, Colorado State University, Fort Collins.

Herbst, D. B. 2004. Evaluating recovery of stream invertebrate communities following removal of introduced trout in Kings Canyon National Park, first progress report. Task Agreement No. J8C07030003 for Cooperative Agreement No. H8C07030001, Californian Cooperative Ecosystem Studies Unit, University of California, Berkeley.

Herbst, D. B. 2005. Evaluating recovery of stream invertebrate communities following removal of introduced trout in Kings Canyon National Park, second progress report. Task Agreement No. J8C07030003 for Cooperative Agreement No. H8C07030001, Californian Cooperative Ecosystem Studies Unit, University of California, Berkeley.

Herbst, D. B., and D. Boiano. In progress. Evaluating recovery of stream invertebrate communities following removal of introduced trout in Kings Canyon National Park. Cooperative Agreement No. H8C07030001, Californian Cooperative Ecosystem Studies Unit, University of California, Berkeley.

Hoffman, R. J., and F. F. Ferreira. 1976. A reconnaissance of the effects of a forest fire on water quality in Kings Canyon National Park, California. Open-file report 76-497. U.S. Geological Survey, Menlo Park, CA. 17 pp.

Holmquist, J. G. In progress. A pilot study and assessment of the efficacy of invertebrates as indicators of meadow change in Sierra Nevada Network Parks. Task Agreement No. J8R07030011 for Cooperative Agreement No. H8R07010001, Great Basin Cooperative Ecosystem Studies Unit, Reno, NV.

Hughes, M. K., and L. J. Graumlich. 1996. Multimillennial dendroclimatic records from the western United States. *In* R. S. Bradley et al., editors. Climatic Variation and Forcing Mechanisms. Springer-Verlag. pp. 109-124.

Hunsaker, C. T., and S. M. Eagan. 2003. Small stream ecosystem variability in the Sierra Nevada of California. The First Interagency Conference on Research in Watersheds, Oct. 27-30, 2003. Benson, AZ. 6 pp.

Huntington, G. L., and M. A. Akeson. 1987. Soil Resource Inventory of Sequoia National Park, Central Part, California; Pedologic Investigations in Support of Acid Rain Studies, Sequoia National Park, California. University of California, Department of Land, Air, and Water Resources, Davis. 263p.

James, G. J. 1975. Effects of human activities on mountain lakes in California. Unpublished Ph.D dissertation. University of California, Irvine. 85 pp.

Jarman, W. M., S. A. Burns, R. R. Chang, R. D. Stephens, R. J. Norstrom, M. Simon, and J. Linthicum. 1993. Determination of PCDDs, PCDFs, and PCBs in California peregrine falcons (*Falco Peregrinus*) and their eggs. Environmental Toxicology and Chemistry 12:105-114.

Jenkins, T. M. Jr., R. A. Knapp, K. W. Kratz, S. D. Cooper, J. M. Melack, A. D. Brown, and J. Stoddard. 1994. Aquatic biota in the Sierra Nevada: current status and potential effects of acid deposition on populations. Final Report, Contract No. A932-138, California Air Resources Board, Sacramento.

Jennings, M. R., and M.P. Hayes. 1994. Amphibian and reptile species of special concern in California. California Department of Fish and Game, Rancho Cordova.

Jordan/Avent and Associates.1980. A study to evaluate the impacts of Kaweah No. 3 hydroelectric facility on the resources of Sequoia National Park, Phase I Report, Volume One: description of project area setting. San Francisco, CA. 178 pp.

Jordan/Avent and Associates. 1984. A study to evaluate the impacts of Kaweah No. 3 hydroelectric facility on the resources of Sequoia National Park. San Francisco, CA. 177 pp.

Kagarise Sherman, C., and M.L. Morton. 1993. Population declines of Yosemite toads in the eastern Sierra Nevada of California. Journal of Herpetology 27:186-198.

Karl, T. R., and K. E. Trenberth. 2003. Modern global climate change. Science 302:1719-1723.

Karlstrom, E. L. 1962. The toad genus *Bufo* in the Sierra nevada of California: ecological and systematic relationships. University of California Publications in Zoology. 62:1-104.

Karlstrom, E. L., and R. L. Livezey. 1955. The eggs and larvae of the Yosemite toad *Bufo canorus* Camp.

Kattelmann, R. 1988. Oversnow flow in the Sierra Nevada. International Mountain Watershed Symposium, Subalpine Processes and Water Quality. Lake Tahoe, NV. June 8-10, 1988. pp. 220-225.

Kattelmann, R., and K. Elder. 1991. Hydrologic characteristics and water balance of an alpine basin in the Sierra Nevada. Water Resources Research 27(7):1553-1562.

Keeley, J. E., N. L. Stephenson, J. W. van Wagtendonk, D. L. Urban, T. W. Swetnam, L. J. Graumlich, and M. K. Hughes. 1998. Sierra Nevada forest dynamics: pattern, pace, and mechanisms of change. Proposal submitted to the U.S. Global Change Research Program. 15 pp.

Kim, J. 2003. Climate changes may increase extreme rain/snow events in California. Proceedings of the 83rd Annual Meeting of the American Meteorological Society, Long Beach, CA.

Kimsey, L. S. 1996. Status of terrestrial insects. Pages 735-741 *in* Sierra Nevada Ecosystem Project: final report to Congress. Volume II, Chapter 26. Centers for Water and Wildland Resources, University of California, Davis.

Kimsey, L. S., and P. Cranston. 2002. Final report for the inventory of the insect fauna of Sequoia and Kings Canyon National Parks. University of California, Davis Bohart Museum report to the Sierra Nevada Network Inventory & Monitoring Program.

Knapp, R. A. 1996. Non-native trout in natural lakes of the Sierra Nevada: an analysis of their distribution and impacts on native aquatic biota. Pages 363-407 *in* Sierra Nevada Ecosystem Project: final report to Congress. Volume III, Chapter 8. Centers for Water and Wildland Resources, University of California, Davis.

Knapp, R. A., and H. K. Preisler. 1999. Is it possible to predict habitat use by spawning salmonids? A test using the California golden trout (*Oncorhynchus mykiss aguabonita*). Canadian Journal of Fisheries and Aquatic Sciences 56:1576-1584.

Knapp, R. A., and K. R. Matthews. 1996. Livestock grazing, golden trout, and streams in the Golden Trout Wilderness, California: impacts and management implications. North American Journal of Fisheries Management 16:805-820.

Knapp, R. A., and K. R. Matthews. 1998. Eradication of non-native fish from a small mountain lake: gill netting as a non-toxic alternative to the use of rotenone. Restoration Ecology 6:207-213.

Knapp, R. A., and K. R. Matthews. 2000. Non-native fish introductions and the decline of the mountain yellow-legged frog from within protected areas. Conservation Biology 14:428-438.

Knapp, R. A., and T. L. Dudley. 1990. Growth and longevity of golden trout, *Oncorhynchus aguabonita,* in their native streams. California Fish and Game 76(3):161–173.

Knapp, R. A., and V. T. Vredenburg. 1996a. Spawning by California golden trout: characteristics of spawning fish, seasonal and daily timing, redd characteristics, and microhabitat preferences. Transactions of the American Fisheries Society 125:519-531.

Knapp, R. A., and V. T. Vredenburg. 1996b. A field comparison of the substrate composition of California golden trout redds sampled with two devices. North American Journal of Fisheries Management 16:674-681.

Knapp, R. A., K. R. Matthews, and O. Sarnelle. 2001. Resistance and resilience of alpine lake fauna to fish introductions. Ecological Monographs 71:401-421.

Knapp, R. A., K. R. Matthews, H. K. Preisler, and R. Jellison. 2003. Developing probabilistic models to predict amphibian site occupancy in a landscape landscape. Ecological Applications 13(4):1069-1082.

Knapp, R. A., V. T. Vredenburg, and K. R. Matthews. 1998. Effects of stream channel morphology on golden trout spawning habitat and population structure. Ecological Applications 1104-1117.

Knowles, N., and D. R. Cayan. 2001. Global climate change: Potential effects on the Sacramento/San Joaquin watershed and the San Francisco estuary. IEP Newsletter 14(3):23-29.

Konno, E. S. 1985. Little Kern golden trout migration patterns. Unpublished M.S. thesis, California State University, Fresno.

Kratz, K. M., S. D. Cooper, and J. M. Melack. 1994. Effects of single and repeated experimental acid pulses on invertebrates in a high altitude Sierra Nevada stream. Freshwater Biology 32:161-183.

Krejca, J. 2003. Inventory of karst fauna in Sequoia, Kings Canyon and Yosemite National Parks, first progress report. Contract No. P8558602608, Zara Environmental LLC, Buda, TX.

Krejca, J. 2004. Inventory of karst fauna in Sequoia, Kings Canyon and Yosemite National Parks, second progress report. Contract No. P8558602608, Zara Environmental LLC, Buda, TX.

Krejca, J. In progress. Inventory of karst fauna in Kings Canyon, Sequoia and Yosemite National Parks. Contract No. P8558602608, Zara Environmental LLC, Buda, TX.

Krimmel, R. M. 1997. Status of glacier monitoring and the remote sensing snow-and ice-data base in the conterminous USA. *In* Final report of the workshop on long-term monitoring of glaciers of North America and Northwestern Europe. U.S. Geological Survey Open File Report 98-31.

Krimmel, R. M. 2002. Glaciers of the western United States. *In* R. S. Williams, Jr., and J. G. Ferrigno, editors. Satellite image atlas of the world. U.S. Geological Survey Professional Paper 1386-J-2.

Kubly, D. M. 1983. Plankton of high Sierra lakes. Southern California Edison Research and Development Report No. 83-RD-47. University of California, Riverside. 96 pp.

Landers, D. H., J. M. Ellers, D. F. Brakke, W. S. Overton, P. E. Kellar, M. E. Silverstein, R. D. Schonbrod, R. E. Crowe, R. A. Linthurst, J. M. Omernik, S. A. Teague, and E. P. Meier. 1987. Characteristics of lakes in the western United States. Volume 1. Population descriptions and physico-chemical relationships. EPA-600/3-86/054a, U.S. Environmental Protection Agency. 176 pp.

LeBlanc, R. A. 1970. Water resources reconnaissance in the General Grant Grove area, Kings Canyon National Park, California. U.S. Geological Survey, Water Resources Division, Menlo Park, CA. 16 pp.

Lehman, C.M.B, V.C. Bowersox, S.M. Larson. *In press*. Spatial and Temporal Trends in Precipitation Chemistry in the United States, 1985-2002. Environmental Pollution.

LeNoir, J. S, L. L. McConnell, G. M. Fellers, T. M. Cahill, and J. N. Seiber. 1999. Summertime transport of current-use pesticides from California's central valley to the Sierra Nevada Mountain range, USA. Environmental Toxicology and Chemistry 18:2715-2722.

Leopold, A. S., S. A. Cain, C. M. Cottam, I. N. Gabrielson, and T. L. Kimball. 1963. Wildlife management in the National Parks: the Leopold Report. Advisory Board on Wildlife Management appointed by Secretary of the Interior Udall, United States Department of Interior.

Leydecker, A., J. O. Sickman, and J. M. Melack. 1999. Episodic lake acidification in the Sierra Nevada, California. Water Resources Research 35:2793-2804.

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

Lord, E. 2003. Personal Communication. National Park Service, Water Resources Division, Fort Collins, CO.

Lynch, J. A., J. W. Grimm, and V. C. Bowersox. 1995. Trends in precipitation chemistry in the United States: a national perspective. Atmospheric Environment 11:1231-1246.

Macey, J. R., J. L. Strasburg, J. A. Brisson, V. T. Vredenburg, M. Jennings, and A. Larson. 2001. Molecular phylogenetics of western North American frogs of the *Rana boylii* species group. Molecular Phylogenetics and Evolution 19:131-143.

Mandel, S. and Z. L. Shiftan. 1981. Groundwater Resources, Investigation and Development. Academic Press, Inc. New York, NY. pp. 23-42.

Mao, J., D. E. Green, G. Fellers, and V. G. Chinchar. 1999. Molecular characterization of iridoviruses isolated from sympatric amphibians and fish. Virus Research 63:45-52.

Marks, D., J. Dozier, R. E. Davis. 1992. Climate and energy exchange at the snow surface in the alpine region of the Sierra Nevada; Meteorological measurements and monitoring. Water Resources Research 28(11):3029-3042.

Matthes, F. 1950. Sequoia National Park: A Geologic Album. University of California Press, Los Angeles. 136 pp.

Matthews, K. R. 1996a. Golden trout habitat selection and movement patterns in degraded and recovering sites within the Golden Trout Wilderness, California. North American Journal of Fisheries Management 16:578-590.

Matthews, K. R. 1996b. Diel movement and habitat use of the golden trout *Oncorhynchus mykiss aguabonita* in their native habitat on the Golden Trout Wilderness, California. Transactions of the American Fisheries Society 125:78-86.

Matthews, K. R. 2003. Response of mountain yellow-legged frogs, *Rana muscosa*, to short distance translocation. Journal of Herpetology 37:621-626.

Matthews, K. R., and K. L. Pope. 1999. A telemetric study of the movement patterns and habitat use of *Rana muscosa*, the mountain yellow-legged frog, in a high-elevation basin in Kings Canyon National Park, California. Journal of Herpetology 33:615-624.

Matthews, K. R., and R. A. Knapp. 1999. A study of high mountain lake fish stocking effects in Sierra Nevada Wilderness. International Journal of Wilderness 5:24-26.

Matthews, K. R., K. L. Pope, H. K. Preisler, and R. A. Knapp. 2001. Effects of nonnative trout on Pacific treefrogs (*Hyla regilla*) in the Sierra Nevada. Copeia 2001:1130-1137.

Matthews, K. R., N. H. Berg, D. L. Azuma, and T. R. Lambert. 1994. Cool water formation and trout habitat use in a deep pool in the Sierra Nevada, California. Transactions of the American Fisheries Society 123:549-564.

Matthews, K. R., R. A. Knapp, and K. L. Pope. 2002. Garter snakes distributions in high elevation aquatic ecosystems: Is there a link with declining amphibian populations and nonnative trout introductions? Journal of Herpetology 36:16-22.

McGinnis, T. 2004. Personal Communication. Ecologist, U.S. Geological Survey, Biological Resources Division, Three Rivers, CA.

McGlothlin, D. 2005. Personal Communication. Supervisory Hydrologist. NPS Water Resources Division, Water Rights Branch. Ft. Collins, CO.

Melack, J., and J. Sickman. 1995. Snowmelt induced chemical changes in seven streams in the Sierra Nevada. Pages 221-234 *in* K. A. Tonnessen, W. W. Williams, and M. Tranter, editors. Biogeochemistry of Seasonally Snow Covered Basins, IAHS Publication 228, International Association of Hydrological Sciences, Wallingford, UK.

Melack, J. M., S. D. Cooper, R. W. Holmes, J. O. Sickman, K. Kratz, P. Hopkins, H. Hardenbergh, M. Thieme, and L. Meeker. 1987. Chemical and biological survey of lakes and streams located in the Emerald Lake watershed, Sequoia National Park. Final Report, Contract No. A3-096-32. California Air Resources Board, Sacramento. 345 pp.

Melack, J. M., S. D. Cooper, T. M. Jenkins, Jr., L. Barmuta, S. Hamilton, J. Sickman, and C. Soiseth. 1989. Chemical and biological characteristics of Emerald Lake and the streams in its watershed, and the responses of the lake and streams to acidic deposition. Final Report, Contract No. A6-184-32. California Air Resources Board, Sacramento. 376 pp.

Melack, J., J. Sickman, A. Leydecker, and D. Marrett. 1998. Comparative analyses of high-altitude lakes and catchments in the Sierra Nevada: susceptibility to acidification. Final Report, Contract No. A032-188, California Air Resources Board, Sacramento, CA. 610 pp.

Mitten, H. T., and G. L. Bertoldi. 1968. Reconnaissance for additional water to supply Lost Grove, Sequoia National Park, California. U.S. Geological Survey, Water Resources Division, Menlo Park, CA. 10 pp.

Mitchell, W., J. Chittleborough, B. Ronai, and G. Lennon. 2001. Sea level rise in Australia and the Pacific. *In* M. Grzechnik, and J. Chittleborough, editors. Proceedings of the Pacific Islands Conference on Climate Change, Climate Variability and Sea Level Rise, Linking Science and Policy. Flinders Press, South Australia.

Moore, C. 1999. 1999 annual Sequoia watershed report. 1999 annual fire report on research, monitoring, and inventory. U.S. Geological Survey, Biological Resources Division. pp. 124-132.

Moyle, P. B. 1995. Conservation of native freshwater fishes in the Mediterranean-type climate of California, USA. Biological Conservation 72:271-283.

Moyle, P. B. 2002. Inland Fishes of California. University of California Press, Berkeley.

Moyle, P. B., R. M. Yoshiyama, and R. A. Knapp. 1996. Status of fish and fisheries. Pages 953-973 *in* Sierra Nevada Ecosystem Project: final report to Congress. Volume II, Chapter 33. Centers for Water and Wildland Resources, University of California, Davis.

Mullally, D. P. 1953. Observations on the ecology of the toad *Bufo canorus*. Copeia 1953:182-183.

Mullally, D. P., and J. D. Cunningham. 1956. Ecological relations of *Rana muscosa* at high elevations in the Sierra Nevada. Herpetologica 12:189-198.

Mullen, J.R., and J. S. Bader. 1967. Water resources reconnaissance of South Fork Kings River, Kings Canyon National Park, California. (revised from 1966) U.S. Geological Survey, Water Resources Division, Menlo Park, CA. 7 pp. + figures.

National Park Service. 1971. Master Plan. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 1989. Aquatic/Water Resources Management Plan. Sequoia and Kings Canyon National Parks, Three Rivers, CA. 54 pp.

National Park Service. 1997. Baseline Water Quality Data, Inventory and Analysis, Sequoia and Kings Canyon National Parks. Tech. Report NPS/NRWRD/NRTR-97/121. National Park Service, Water Resources Division, Fort Collins, CO.

National Park Service. 1998b. National Park Service Procedural Manual 77-1: Wetland Protection, Technical Report NPS/NRWRD/NRTR-98/203. National Park Service, Water Resources Division, Fort Collins, CO. 32 pp.

National Park Service. 1999. Natural and Cultural Resources Management Plan. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2001a. Management Policies 2001. U.S. Department of the Interior. 137 pp.

National Park Service. 2001b. Preliminary Restoration of Mountain Yellow-legged Frogs: Environmental Assessment. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2002. Air Quality in the National Parks. 2nd Edition. NPS Air Resources Division, Department of the Interior. Denver, Colorado. http://www2.nature.nps.gov/air/pubs/aqnps.htm.

National Park Service. 2003. Sequoia and Kings Canyon Fire and Fuels Management Plan. Sequoia and Kings Canyon National Parks, Three Rivers, CA. 54 pp. http://www.nps.gov/seki/fire/ffmp/pdf/seki_ffmp_fmp_8description.pdf.

National Park Service. 2004a. Draft General Management Plan/Comprehensive Wild and Scenic River Management Plan for the Kings River and North Fork of the Kern River/Environmental Impact Statement. Sequoia and Kings Canyon National Parks, Three Rivers, CA. 406 pp.

National Park Service. 2004b. Draft Vital Signs Monitoring Plan Phase 1 Report of the Sierra Nevada Network. National Park Service, Three Rivers, CA.

National Park Service. 2004c. Weather in Sequoia and Kings Canyon National Parks. Sequoia and King Canyon National Park, Three Rivers, CA. http://www.nps.gov/seki/weather.htm#low.

National Park Service. 2004d. Plant Life of Sequoia and Kings Canyon National Parks. Sequoia and King Canyon National Park, Three Rivers, CA. http://www.nps.gov/seki/snrm/vegetation/vegetation.htm.

National Park Service. 2004e. Geology Overview. Sequoia and King Canyon National Park, Three Rivers, CA. http://www.nps.gov/seki/snrm/geology/geology.htm.

National Park Service. 2004f. Invasive Non-Native Plants. Sequoia and Kings Canyon National Parks, Three Rivers, CA. http://www.nps.gov/seki/snrm/nnp/html/badphar.htm.

National Park Service. 2004g. Western Airborne Contaminants Assessment Project. National Park Service, Air Resources Division, Lakewood, CO. http://www2.nature.nps.gov/air/Studies/air_toxics/docs/WACAP_FEB_2004_72_ppi.pdf.

National Park Service. 2004h. Wildlife of Sequoia and Kings Canyon National Parks. Sequoia and Kings Canyon National Parks, Three Rivers, CA. http://www.nps.gov/seki/snrm/wildlife/wildlife.htm.

National Park Service. 2004i. Mountain Yellow-legged Frog Restoration Project, 2003 Field Season Summary. Unpublished report, Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2005. Ozone Standard Exceedances in National Parks. National Park Service, Air Resources Division, Denver, CO. http://www2.nature.nps.gov/air/Monitoring/exceed2004.htm

North Cascades National Park. 2003. Draft long term monitoring of small glaciers at North Cascades National Park: a prototype park model. North Cascades National Park, Sedro-Woolley, WA. 27 pp.

Parsons, D. J., and D. M. Graber. 1985. Integrated watershed research undertaken at Sequoia National Park. Park Science 5(2):22-24.

Peterson, D. L., and M. J. Arbaugh. 1992. Mixed conifer forests of the Sierra Nevada. Pages 433-459 *in* R. K. Olson, D. Binkley, and M. Bohn, editors. The Response of Western Forests to Air Pollution. Ecological Studies Vol. 97, Springer-Verlag, New York.

Pope, K. L. 1999. Mountain yellow-legged frog habitat use and movement patterns in a high elevation basin in Kings Canyon National Park. Unpublished M.S. thesis, California Polytechnic State University, San Luis Obispo. 64 pp.

Pope, K. L., and K. R. Matthews. 2001. Movement ecology and seasonal distribution of mountain yellow-legged frogs, *Rana muscosa*, in a high-elevation Sierra Nevada basin. Copeia 2001:787-793.

Pope, K. L., and K. R. Matthews. 2002. Influence of anuran prey on the condition and distribution of *Rana muscosa* in the Sierra Nevada. Herpetologica 58:354-363.

Prowse, T. D. 1994. Environmental significance of ice to streamflow in cold regions. Freshwater Biology 32:241-259.

Prowse, T. D., and R. L. Stephenson. 1986. The relationship between winter lake cover, radiation receipts and the oxygen deficit in temperate lakes. Atmospheric Oceanography 24:386-403.

Rachowicz, L. J. 2002. Mouthpart pigmentation in *Rana muscosa* tadpoles: seasonal changes without chytridiomycosis. Herpetological Review 33: 263-265.

Rantz, S. E., and R. H. Dale. 1964. Water-supply reconnaissance, Lodgepole-Clover Creek area, Sequoia National Park, California. U.S. Geological Survey, Water Resources Division, Menlo Park, CA.

Rouse, W. R., M. S. V. Douglas, R. E. Hecky, A. E. Hershey, G. W. Kling, L. Lesack, P. Marsh, M. McDonald, B. J. Nicholson, N. T. Roulet, and J. P. Smol. 1997. Effects of climate change on the freshwaters of arctic and subarctic North America. *In* M. G. Anderson, N. E. Peters, and D. Walling, editors. Hydrological Processes 2:873-902.

Rovito, S. M. 2004. Phylogeography and environmental niche modeling of the Mt. Lyell Salamander, *Hydromantes platycephalus*. Scientific Research and Collecting Permit, Sequoia & Kings Canyon National Parks, Three Rivers, CA.

Schindler, D. W. 1997. Widespread effects of climatic warming on freshwater ecosystems in North America. *In* M. G. Anderson, N. E. Peters, and D. Walling, editors. Hydrological Processes 2:1043-1067.

Schultz, L. L. 1996. Hydrogeology of the White Chief/Eagle Lake Area of Mineral King Basin, Sequoia National Park, Sierra Nevada, California. Sonoma State University, Department of Geology. 23 pp.

Schultz, L. L., and J. C. Tinsley. 1996. Hydrogeology of the White Chief and Eagle Lake Areas, Mineral King Basin, Sequoia National Park. California Caver, No. 203, Summer 1996.

Schwarz, P. 2004. Re: Request for Water Quality Monitoring Information. Personal Communication e-mail.

Shaffer, H. B., G. M. Fellers, A. Magee, and R. Voss. 2000. The genetics of amphibian declines: population substructure and molecular differentiation in the Yosemite toad, *Bufo canorus*, (Anura, Bufonidae) based on single strand conformation polymorphism analysis (SSCP) and mitochodrial DNA sequence data. Molecular Ecology 9:245-257.

Shapiro, A. M. 1996. Status of butterflies. Pages 743-757 *in* Sierra Nevada Ecosystem Project: final report to Congress. Volume II, Chapter 27. Centers for Water and Wildland Resources, University of California, Davis.

Sickman, J. O. 2001. Comparative analyses of nitrogen biogeochemistry in high-elevation ecosystems of the Sierra Nevada and Rocky Mountains. Unpublished Ph.D. dissertation, University of California, Santa Barbara.

Sickman, J. O. and J. M. Melack. 1998. Nitrogen and sulfate export from high elevation catchments of the Sierra Nevada, California. Water Air and Soil Pollution 105: 217-226.

Sierra Nevada Ecosystem Project. 1996. Final report to Congress - Summary. Centers for Water and Wildland Resources, University of California, Davis.

Silverman, G., and D. C. Erman. 1979. Alpine lakes in Kings Canyon National Park, California: baseline conditions and possible effects of visitor use. Journal of Environmental Management 8:73-87.

Skinner, B. J., and S. C. Porter. 1992. The Dynamic Earth, an Introduction to Physical Geology. John Wiley & Sons, Inc. New York. pp. 297-325.

Sparling, D. W., G. M. Fellers, and L. L. McConnell. 2001. Pesticides and amphibian population declines in California, USA. Environmental Toxicology and Chemistry 20:1591-1595.

State Water Resources Control Board. 2002. 2002 California 305(b) report. California Environmental Protection Agency, State Water Resources Control Board.

Stebbins, R. C. 1985. A Field Guide to Western Reptiles and Amphibians. Second edition. Houghton Mifflin Company, Boston, Massachusetts. xiv + 336 pp.

Stephens, M. R. 2001. Phylogeography of the *Bufo boreas* (Anura, Bufonidae) species complex and the biogeography of California. Unpublished M.S. thesis, Sonoma State University. 62 pp.

Stephens, S. J. 2001. Draft biology, management and threats to the California golden trout. California Department of Fish and Game. 71 pp.

Stephenson, N. L., and D. J. Parsons. 1993. A research program for predicting the effects of climatic change on the Sierra Nevada. Sequoia and Kings Canyon National Parks, Research Division. *In* S. D. Veirs Jr., T. J. Stohlgren, and C. Schonewald-Cox, editors. Proceedings of the Fourth Conference on Research in California's National Parks. USDI NPS Transactions and Proceedings Series 9, 1993. pp. 93-109.

Stoddard, J. L. 1987. Microcrustacean communities of high-elevation lakes in the Sierra Nevada, California. Journal of Plankton Research 9(4):631-650.

Stoddard, J. L. 1995. Episodic acidification during snowmelt of high elevation lakes in the Sierra Nevada mountains of California. Water, Air, and Soil Pollution 85:353-358.

Stohlgren, T. J., and D. J. Parsons. 1987. Variation of wet deposition chemistry in Sequoia National Park, California. Atmospheric Environment 21:1369-1374.

Strong, D. 1996. From Pioneers to Preservationists: A Brief History of Sequoia and Kings Canyon National Parks. Sequoia Natural History Association, Three Rivers, CA. 62 pp.

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S. L. Rodriguez, D. L. Fischman, and R. W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306:1783-1786.

Swetnam, T. W. 1993. Fire history and climate change in giant sequoia groves. Science 262:885-889.

Swetnam, T. W, C. H. Baisin, A. C. Caprio, R. Touchan, and P. M. Brown. 1992. Tree ring reconstruction of giant sequoia fire regimes. Final Report to the National Park Service. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Taylor, T. P., and D. C. Erman. 1979. The response of benthic plants to past levels of human use in high mountain lakes in Kings Canyon National Park, California, U.S.A. Journal of Environmental Management 9:271-278.

Taylor, T. P., and D. C. Erman. 1980. The littoral bottom fauna of high elevation lakes in Kings Canyon National Park. California Fish and Game 66:112-119.

Tonnessen, K., and J. Harte. 1982. Acid rain and ecological damage: implications of the Sierra Nevada lake studies. The Institute of Governmental Studies, University of California, Berkeley, Public Affairs Report 23(6):1-9.

Trenberth, K. E. 1997. Global warming: It's happening. *In* National Center for Atmospheric Research, Natural Science vol. 1, article 9. 10 pp.

Troyer, J. G. 1971. Water quality survey – Mineral King Lakes. Unpublished report, Sequoia National Forest, California. 13 pp.

Troyer, J. G. 1973. The East Fork Kaweah River at Mineral King, an analysis of the quantity and quality of the water resources. Unpublished report. Sequoia National Forest, California. 26 pp.

Urzendowski, L., J. Hess, and M. Spiess. Analysis of the flow behavior of Big Spring, Kings Canyon Park, California. Cave Research Foundation 1993 Annual Report. pp. 30-32.

U.S. Fish and Wildlife Service. 2002a. Determination of endangered status for the southern California distinct vertebrate population segment of the mountain yellow-legged frog (*Rana muscosa*). Federal Register 67(127):44382-44392.

U.S. Fish and Wildlife Service. 2002b. 12-month finding for a petition to list the Yosemite toad (*Bufo canorus*). Federal Register 67(237):75834-75843.

U.S. Fish and Wildlife Service. 2003a. Candidate assessment and listing priority, mountain yellow-legged frog, *Rana muscosa*. U.S. Fish and Wildlife Service, Sacramento, CA. 56 pp.

U.S. Fish and Wildlife Service. 2003b. 12-month finding for a petition to list the Sierra Nevada distinct population segment of the mountain yellow-legged frog (*Rana muscosa*). Federal Register 68(11):2283-2303.

U.S. Fish and Wildlife Service. 2005. National Wetlands Inventory Database. http://wetlands.fws.gov.

U.S. Forest Service. 1999. Conservation strategy for the Volcano Creek golden trout. Inyo National Forest, California Department of Fish and Game, and U.S. Fish and Wildlife Service. 18 pp.

U.S. Forest Service. 2001. Sierra Nevada Forest Plan Amendment, Final Environmental Impact Statement. USDA Forest Service, Pacific Southwest Region.

U.S. Forest Service. 2002. Draft implementation plan for the California golden trout conservation strategy. Inyo National Forest, California Department of Fish and Game, and U.S. Fish and Wildlife Service. 23 pp. + appendices.

U.S. Geological Survey. 2002. Sierra Nevada forest dynamics: Pattern, pace, and mechanisms of change, annual report for fiscal year 2002. U.S. Geological Survey, Western Ecological Research Center, Sequoia and Kings Canyon Field Station, Three Rivers, CA.

U.S. Geological Survey. 2003. Sierra Nevada and western mountain global climate workshop. Sequoia National Park, Three Rivers, CA.

U.S. Geological Survey. 2004a. Physiographic Regions of the United States. http://tapestry.usgs.gov/physiogr/physio.html

U.S. Geological Survey. 2004b. Science in your watershed. http://water.usgs.gov/wsc/reg/18.html.

U.S. Geological Survey. 2005. National Hydrography Dataset. http://nhd.usgs.gov.

Vaux, H. J., Jr. 1991. Global climate change and California's water resources. Pages 69-96 *in* J. B. Knox, and A. F. Scheuring, editors. Global Climate Change and California. University of California Press, Berkeley.

Vredenburg, V. T. 2000. Natural History Notes: *Rana muscosa* (mountain yellow-legged frog), conspecific egg predation. Herpetological Review 31:170-171.

Vredenburg, V. T. 2002. The effects of introduced trout and ultraviolet radiation on anurans in the Sierra Nevada. Unpublished Ph.D. dissertation, University of California, Berkeley.

Vredenburg, V. T. 2004. Reversing introduced species effects: Experimental removal of introduced fish leads to rapid recovery of a declining frog. Proceedings of the National Academy of Sciences 101(20):7646-7650.

Vredenburg, V. T. 2004. Personal Communication. Post-doctoral Research Associate, University of California, Berkeley.

Vredenburg, V. T., and A. P. Summers. 2001. Field identification of chytridiomycosis in *Rana muscosa* (Camp 1915). Herpetological Review 32:151-152.

Vredenburg, V. T., T. Tunstall, H. Nguyen, J. Romansic, and S. Schoville. 2001. Natural History Notes: *Hydromantes platycephalus* (Mt. Lyell salamander). Behavior. Herpetological Review 32:178.

Wahrhaftig, C., J. G. Moore, and J. C. Tinsley. 1984. Geomorphology and glacial geology, Wolverton and Crescent Meadow areas and vicinity, Sequoia National Park, California. U.S. Geological Survey, Open-file Report 84-400. Menlo Park, CA.

Werner, H. 2003. Assessment of National Wetland Inventory maps for Sequoia and Kings Canyon National Parks, 2000-2001. Unpublished report, Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Werner, H. W. 2004. Accuracy assessment of National Wetland Inventory maps at Sequoia and Kings Canyon National Parks. Park Science 23(1):19-23.

Werner, H. W. 2004. Personal Communication. Wildlife Ecologist, Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Werner, H. W. 2005. Draft summary of population trends for western pond turtles (*Clemmys marmorata*) in the foothills of Sequoia National Park. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Whiting, M. C., D. R. Whitehead, and R. Wise. 1989. The charcoal and fly-ash deposition record of selected Sierra Nevada lakes. A completion report to PGE & SCE. Indiana University, Department of Biology, Bloomington, IN

Williams, M. W., and J. M. Melack. 1991. Solute chemistry of snowmelt and runoff in an alpine basin, Sierra Nevada. Water Resources Research 27:1575-1588.

Williams, M. R., and J. M. Melack. 1997. Atmospheric deposition, mass balances, and processes regulating streamwater solute concentrations in mixed-conifer catchments of the Sierra Nevada, California. Biogeochemistry 37:111-144.

Williams, M. W., A. D. Brown, and J. M. Melack. 1993. Geochemical and hydrologic controls on the composition of surface water in a high-elevation basin, Sierra Nevada, California. Limnology and Oceanography 38(4):775-797.

Williams, M. W., R. C. Bales, A. D. Brown, and J. M. Melack. 1995. Fluxes and transformations of nitrogen in a high-elevation catchment, Sierra Nevada. Biogeochemistry 28:1-31.

Zardus, M., T. Blank, and D. Schulz. 1977. Status of fishes in 137 lakes in Sequoia and Kings Canyon National Parks, California. Unpublished Report, Sequoia and Kings Canyon National Parks, Three Rivers, CA. 96 pp.

Zweifel, R. G. 1955. Ecology, distribution, and systematics of frogs of the *Rana boylei* group. University of California Publications in Zoology 54:207-292.

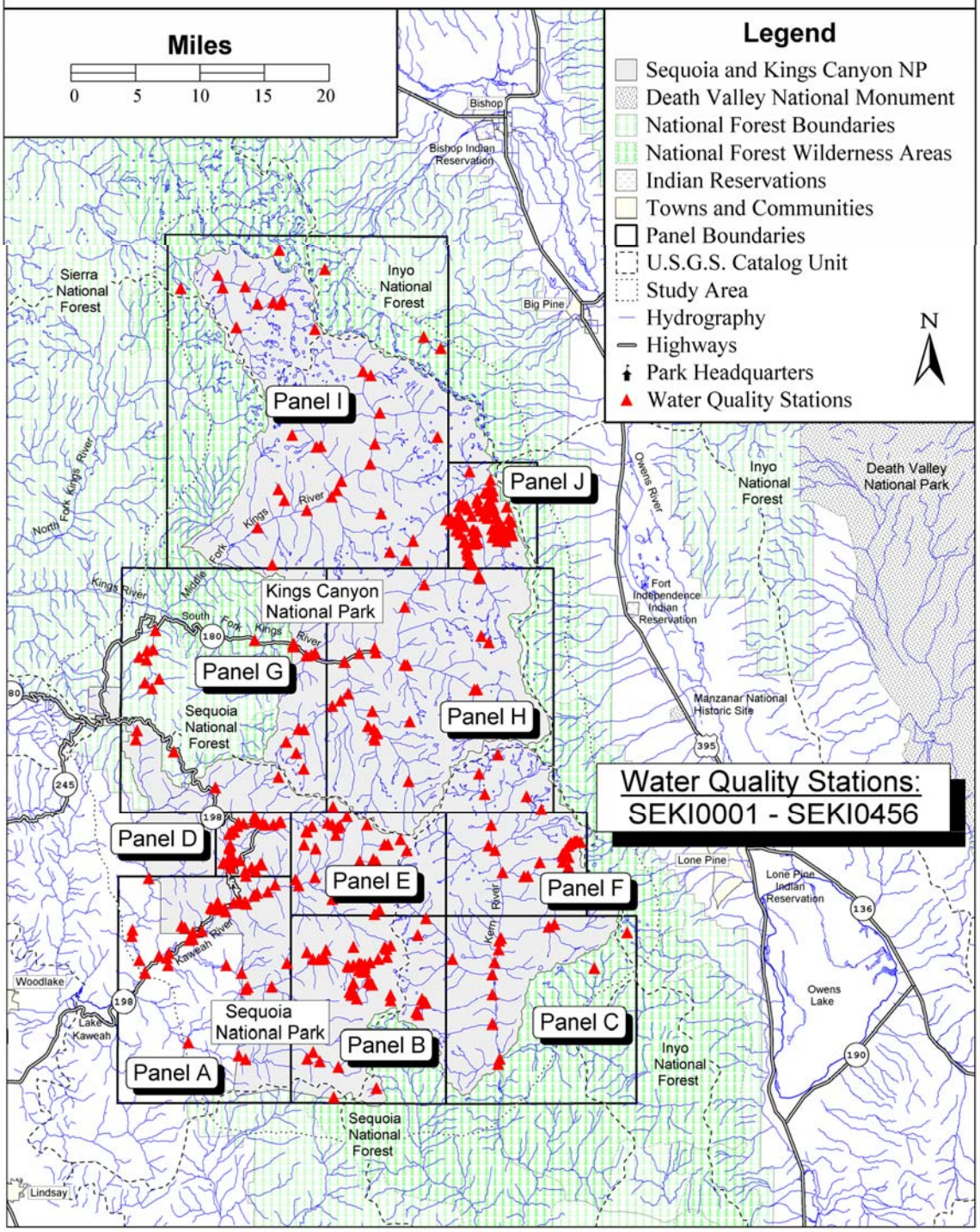
Appendix A.

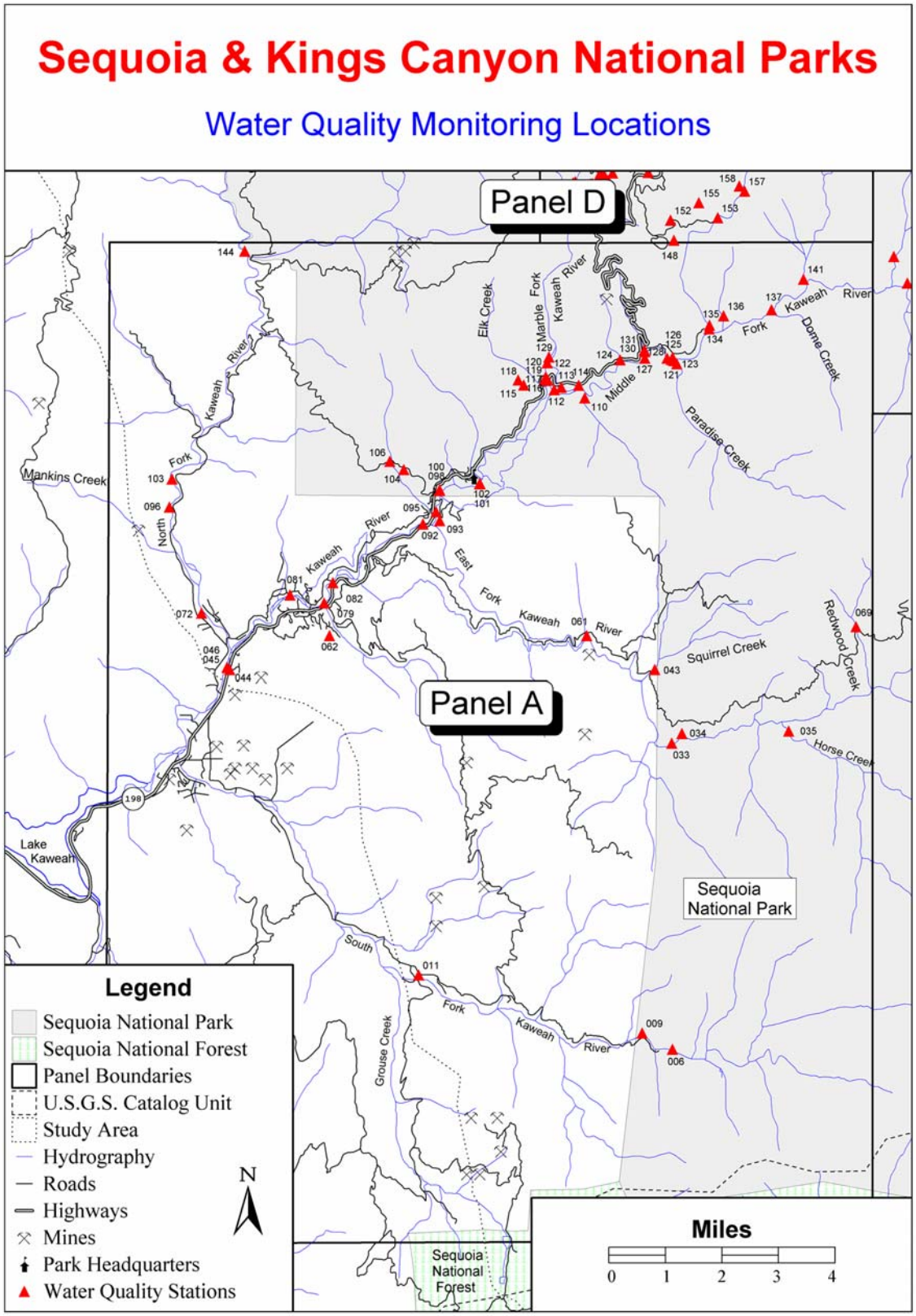
Water Quality Monitoring Locations

Sequoia & Kings Canyon National Parks

Water Quality Monitoring Locations

Graphic Panel Index




Sequoia & Kings Canyon National Parks
Water Quality Monitoring Locations
Panel D
Panel A
Elk Creek
Marble Fork Kaweah River
Middle Fork Kaweah River
Dorne Creek
Paradise Creek
Mankins Creek
North Fork Kaweah River
East Fork Kaweah River
Squirrel Creek
Redwood Creek
Horse Creek
South Fork Kaweah River
Grouse Creek
Lake Kaweah
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Sequoia National Park
Sequoia National Forest
Legend
Sequoia National Park
Sequoia National Forest
Panel Boundaries
U.S.G.S. Catalog Unit
Study Area
Hydrography
Roads
Highways
Mines
Park Headquarters
Water Quality Stations
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Miles
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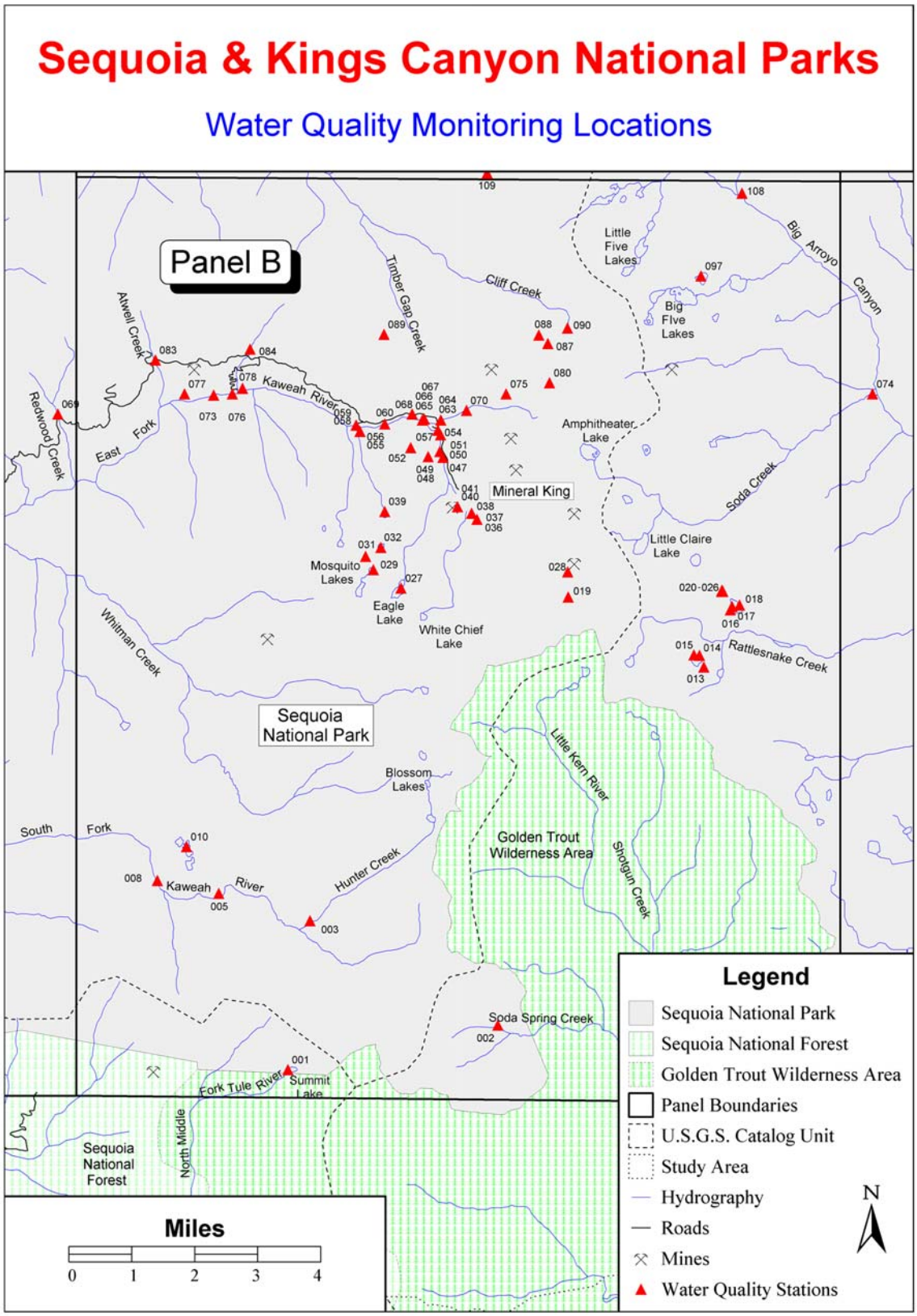
Sequoia & Kings Canyon National Parks
Water Quality Monitoring Locations
Panel B
Little Five Lakes
Big Five Lakes
Big Arroyo Canyon
Cliff Creek
Timber Gap Creek
Atwell Creek
Kaweah River
East Fork
Redwood Creek
Amphitheater Lake
Mineral King
Soda Creek
Little Claire Lake
Mosquito Lakes
Eagle Lake
White Chief Lake
Whitman Creek
Rattlesnake Creek
Sequoia National Park
Little Kern River
Blossom Lakes
Golden Trout Wilderness Area
Shotgun Creek
South Fork
Kaweah River
Hunter Creek
Soda Spring Creek
Fork Tule River
Summit Lake
North Middle
Sequoia National Forest
Miles
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Sequoia National Park
Sequoia National Forest
Golden Trout Wilderness Area
Panel Boundaries
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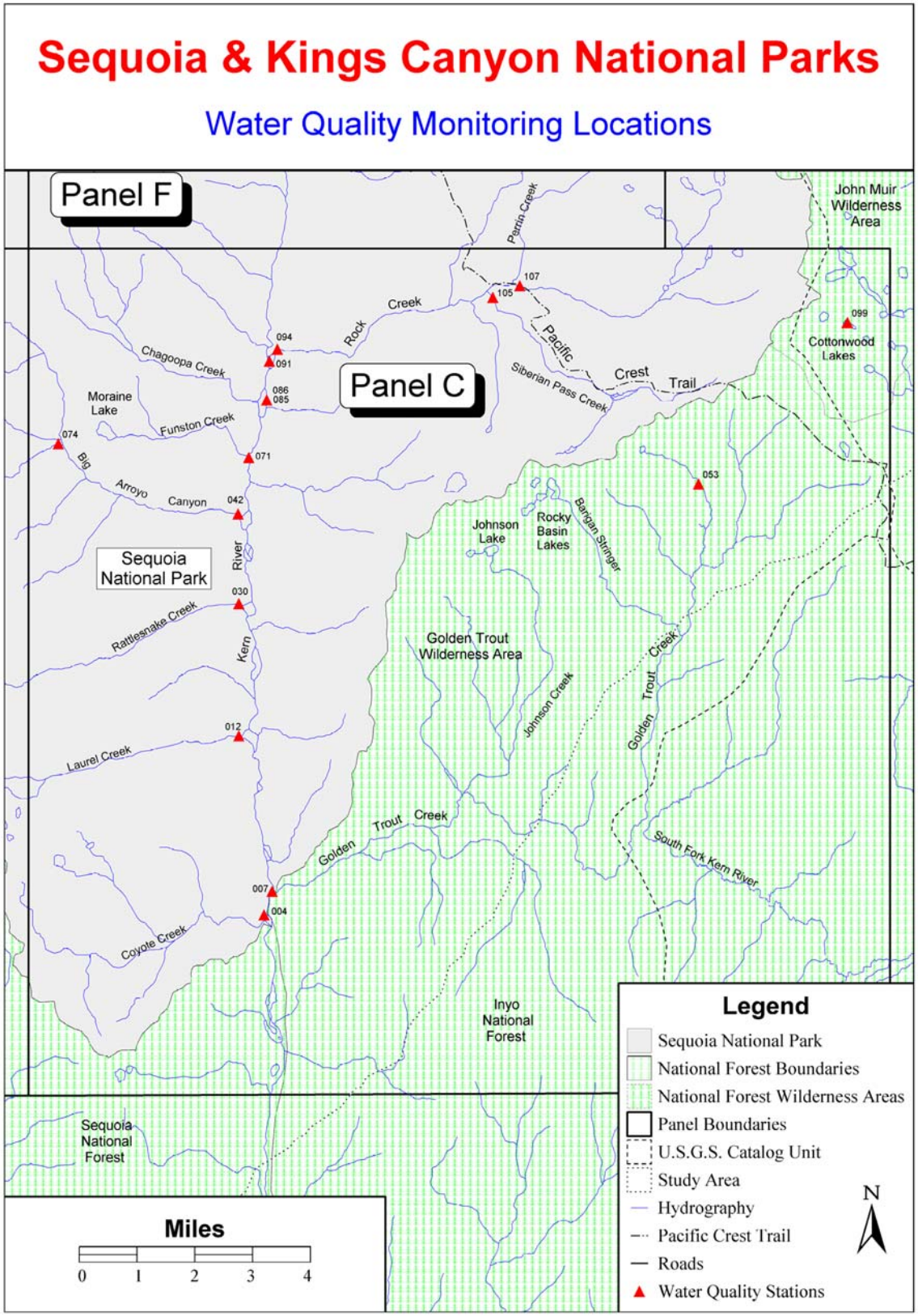
Study Area
Hydrography
Roads
Mines
Water Quality Stations
N


Sequoia & Kings Canyon National Parks
Water Quality Monitoring Locations
Panel F
Panel C
John Muir Wilderness Area
Pertin Creek
Rock Creek
Pacific Crest Trail
Siberian Pass Creek
Cottonwood Lakes
Chagoopa Creek
Moraine Lake
Funston Creek
Big Arroyo Canyon
Sequoia National Park
Kern River
Rattlesnake Creek
Laurel Creek
Coyote Creek
Johnson Lake
Rocky Basin Lakes
Bangan Stringer
Golden Trout Wilderness Area
Johnson Creek
Golden Trout Creek
South Fork Kern River
Inyo National Forest
Sequoia National Forest
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099
094
091
086
085
074
071
053
042
030
012
007
004
Legend
Sequoia National Park
National Forest Boundaries
National Forest Wilderness Areas
Panel Boundaries
U.S.G.S. Catalog Unit
Study Area
Hydrography
Pacific Crest Trail
Roads
Water Quality Stations
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Miles
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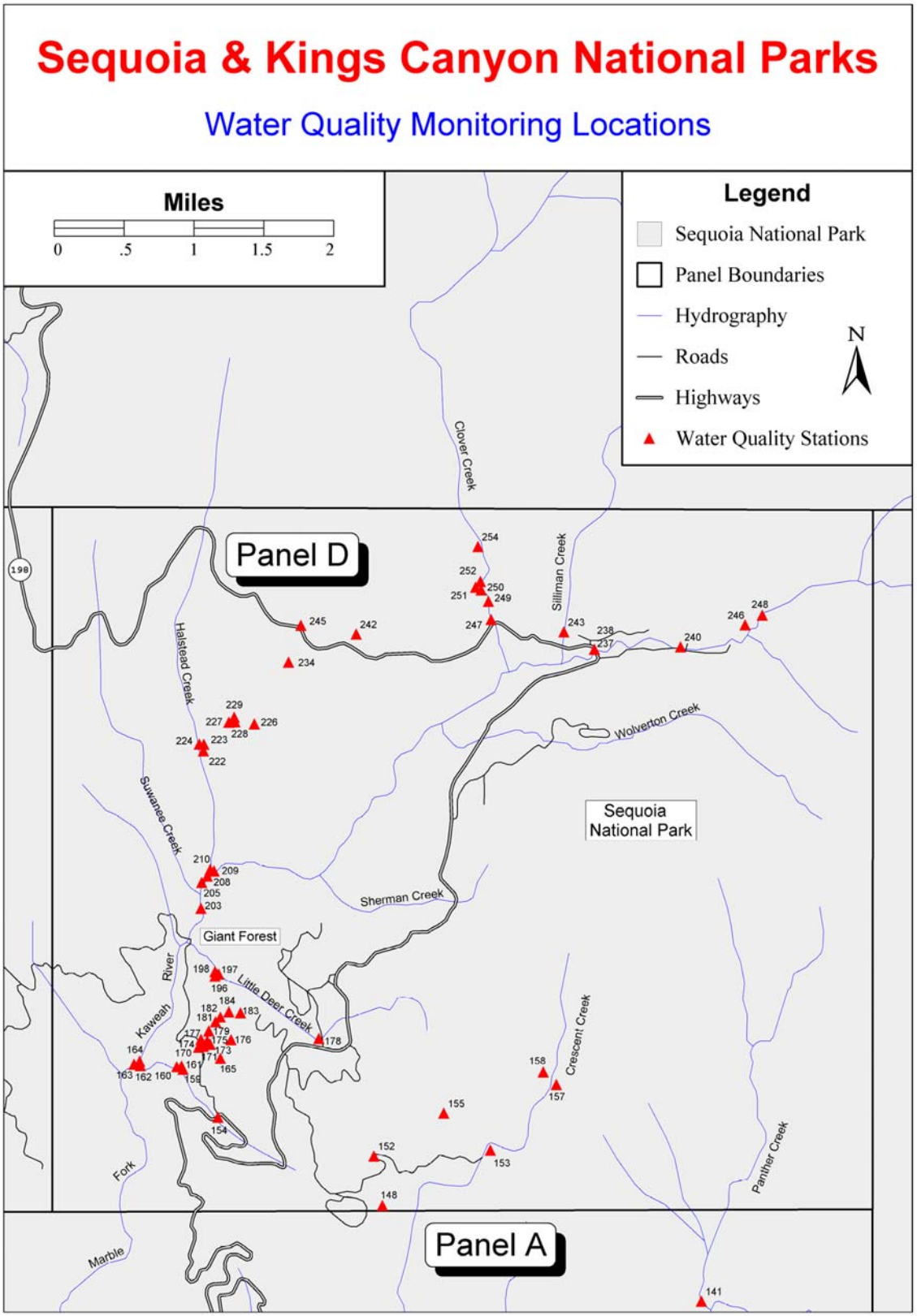
Sequoia & Kings Canyon National Parks
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Sequoia National Park
Panel Boundaries
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Roads
Highways
Water Quality Stations
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Panel D
Panel A
Clover Creek
Silliman Creek
Halstead Creek
Suwanee Creek
Wolverton Creek
Sherman Creek
Little Deer Creek
Kaweah River
Fork
Marble
Crescent Creek
Panther Creek
Sequoia National Park
Giant Forest
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254
252
250
251
249
247
245
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238
237
240
246
248
234
229
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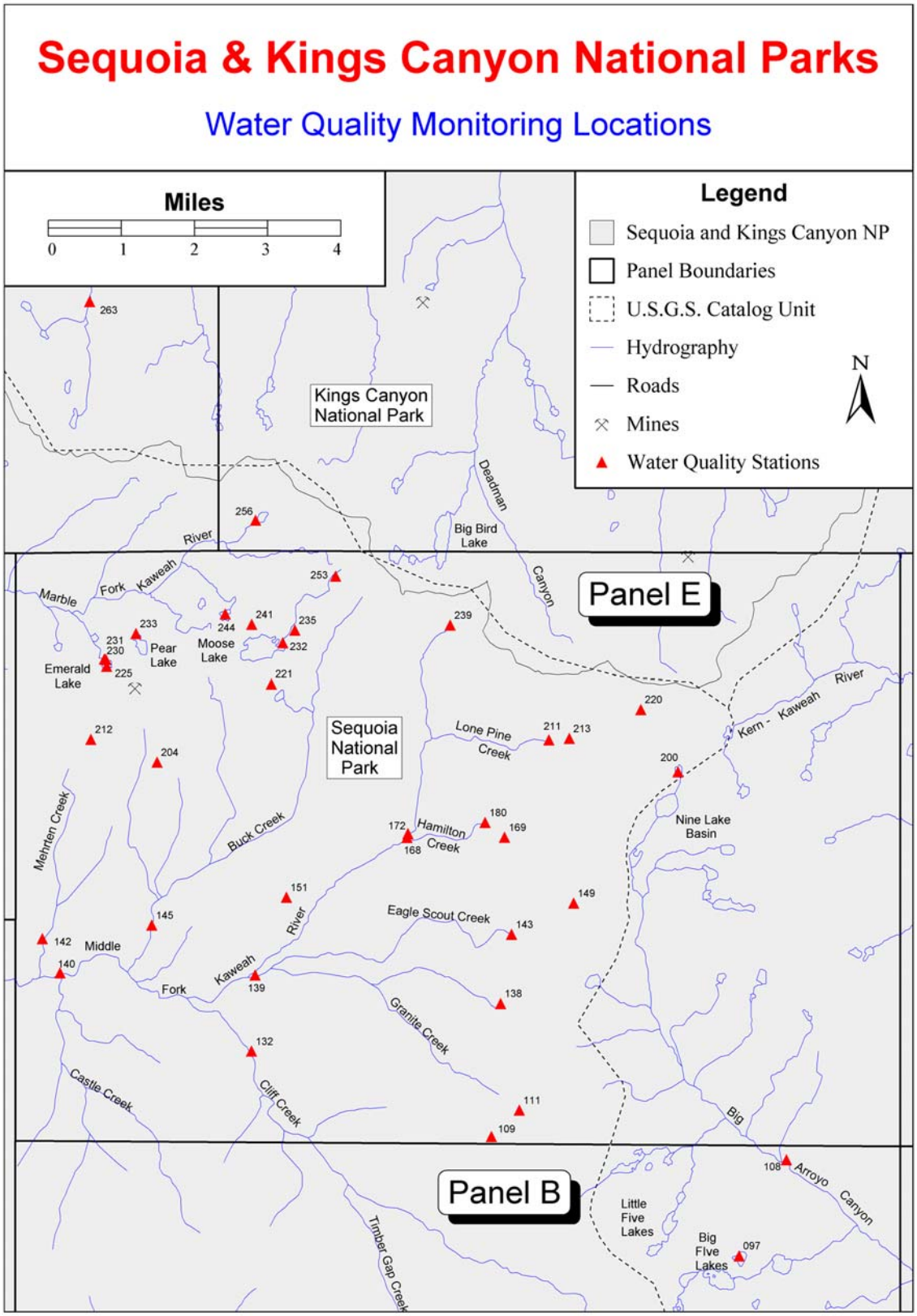
Sequoia & Kings Canyon National Parks
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Sequoia and Kings Canyon NP
Panel Boundaries
U.S.G.S. Catalog Unit
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Kings Canyon National Park
Panel E
Sequoia National Park
Panel B
Deadman Canyon
Big Bird Lake
Marble Fork Kaweah River
Emerald Lake
Pear Lake
Moose Lake
Lone Pine Creek
Kern - Kaweah River
Nine Lake Basin
Hamilton Creek
Buck Creek
Mehrten Creek
Eagle Scout Creek
Middle Fork Kaweah River
Granite Creek
Castle Creek
Cliff Creek
Timber Gap Creek
Big Arroyo Canyon
Little Five Lakes
Big Five Lakes
263
256
253
244
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225
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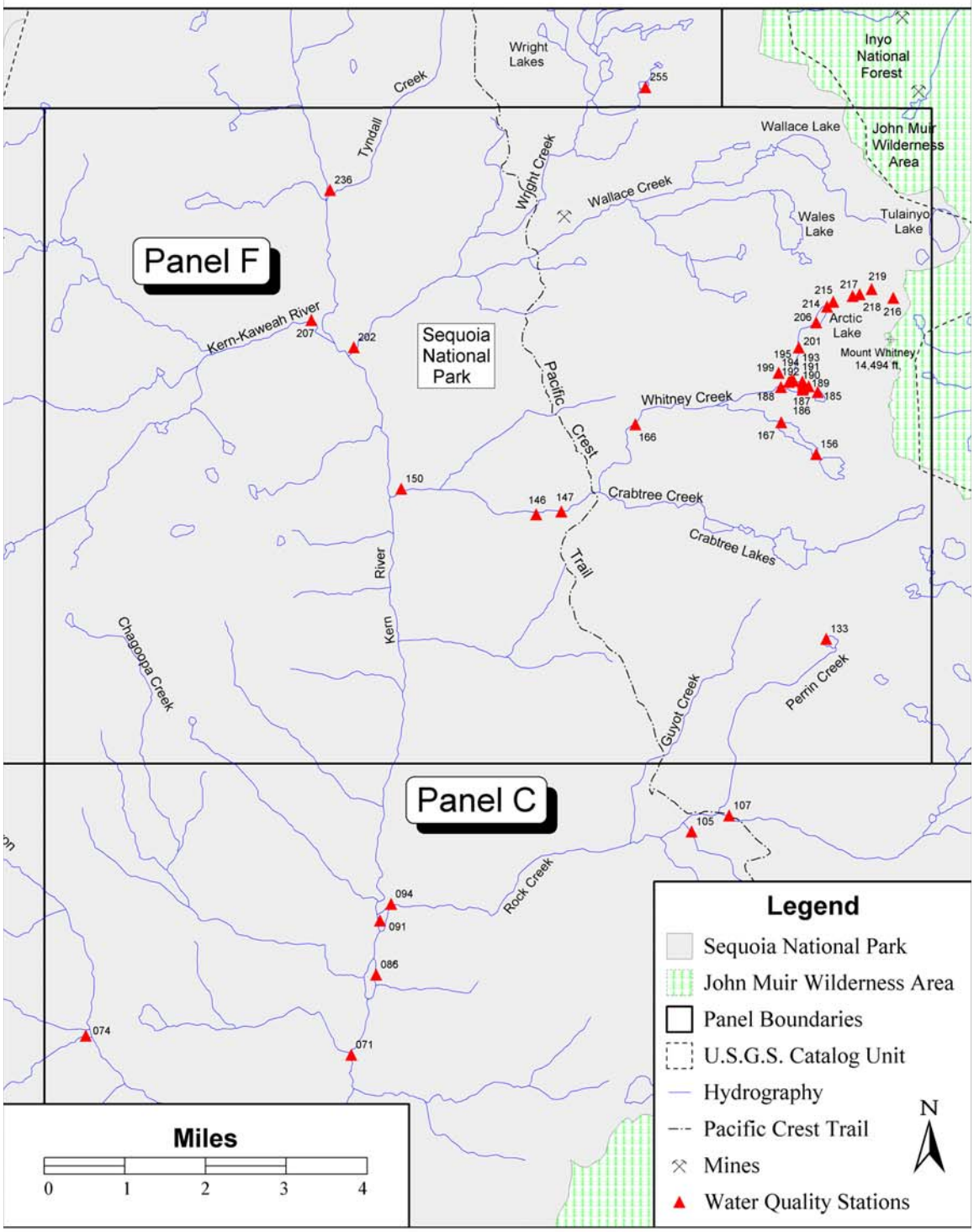
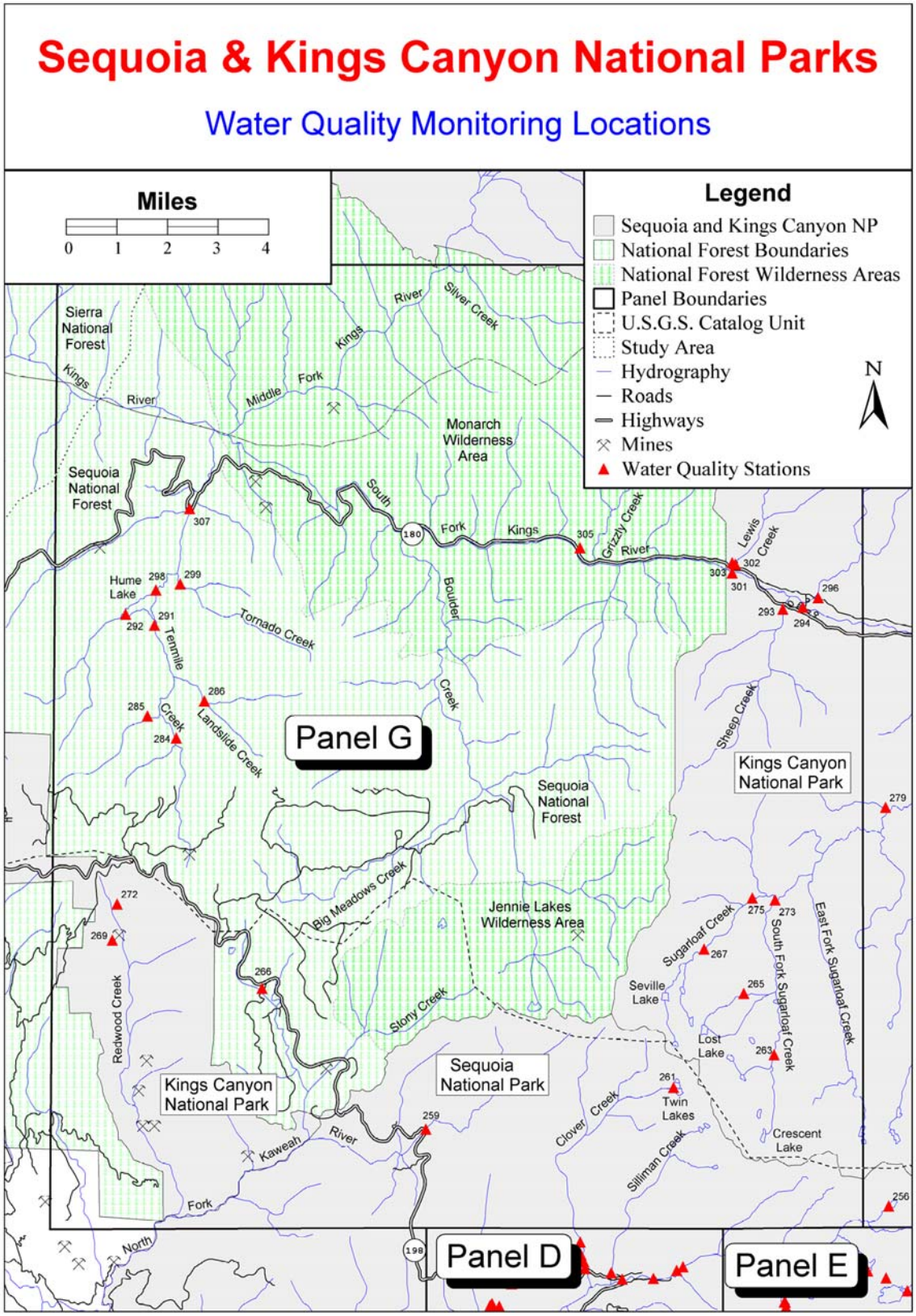
Sequoia & Kings Canyon National Parks

Water Quality Monitoring Locations




Sequoia & Kings Canyon National Parks
Water Quality Monitoring Locations
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Sequoia and Kings Canyon NP
National Forest Boundaries
National Forest Wilderness Areas
Panel Boundaries
U.S.G.S. Catalog Unit
Study Area
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Roads
Highways
Mines
Water Quality Stations
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Sierra National Forest
Sequoia National Forest
Kings River
Middle Fork
Silver Creek
Monarch Wilderness Area
South Fork Kings River
Grizzly Creek
Lewis Creek
Hume Lake
Tornado Creek
Tennile Creek
Landslide Creek
Boulder Creek
Sheep Creek
Panel G
Kings Canyon National Park
Sequoia National Forest
Big Meadows Creek
Jennie Lakes Wilderness Area
Sugarloaf Creek
South Fork Sugarloaf Creek
East Fork Sugarloaf Creek
Seville Lake
Lost Lake
Twin Lakes
Crescent Lake
Stony Creek
Redwood Creek
Kings Canyon National Park
Sequoia National Park
Clover Creek
Silliman Creek
Kaweah River
North Fork
Panel D
Panel E
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292
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286
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284
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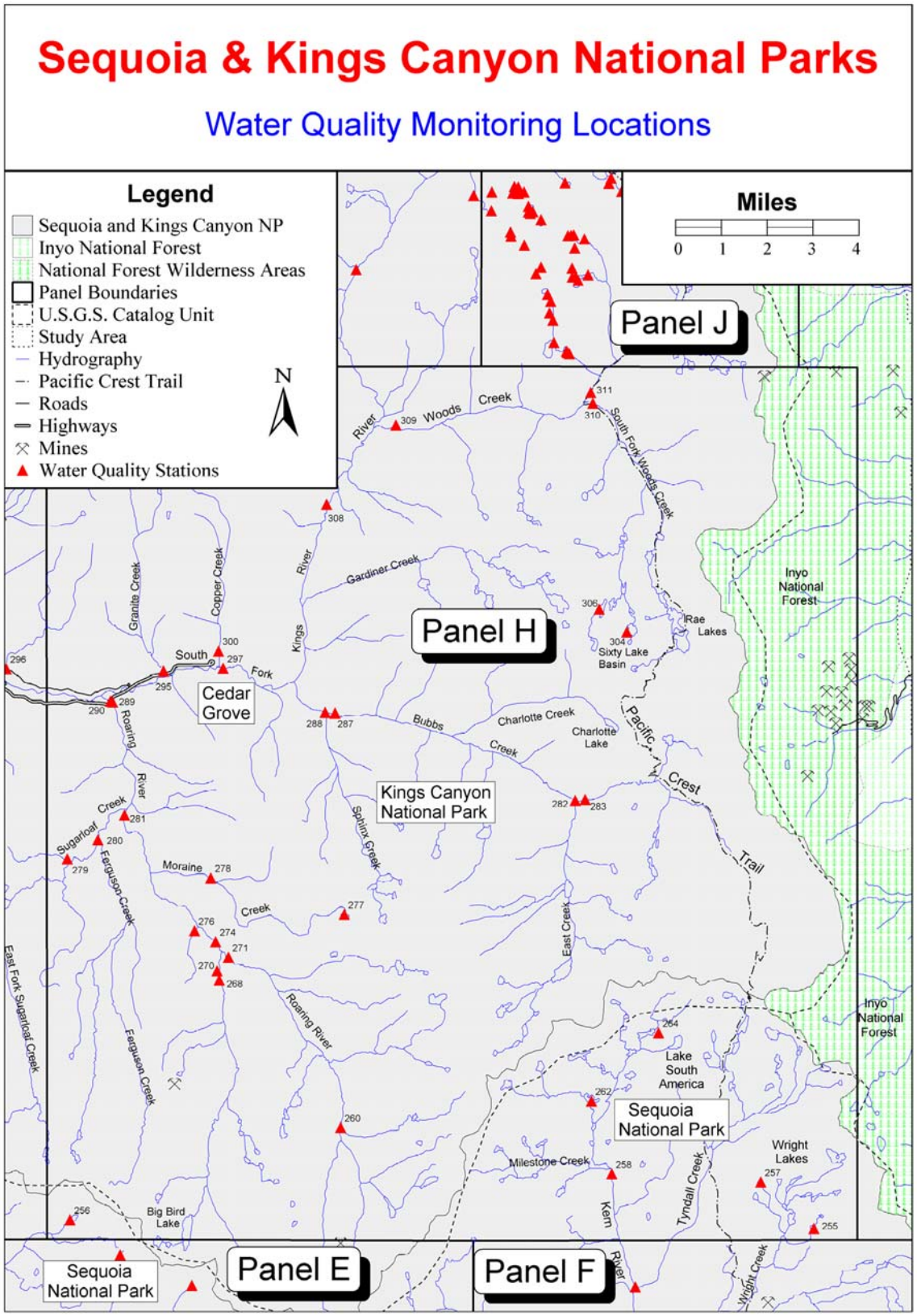
Sequoia & Kings Canyon National Parks
Water Quality Monitoring Locations
Legend
Sequoia and Kings Canyon NP
Inyo National Forest
National Forest Wilderness Areas
Panel Boundaries
U.S.G.S. Catalog Unit
Study Area
Hydrography
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Highways
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Water Quality Stations
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Miles
0 1 2 3 4
Panel J
Panel H
Panel E
Panel F
Kings Canyon National Park
Sequoia National Park
Cedar Grove
Inyo National Forest
Rae Lakes
Sixty Lake Basin
Charlotte Lake
Lake South America
Wright Lakes
Big Bird Lake
Woods Creek
South Fork Woods Creek
Gardiner Creek
Granite Creek
Copper Creek
Kings River
South Fork
Roaring River
Bubbs Creek
Charlotte Creek
Pacific Crest Trail
Sphinx Creek
East Creek
Sugarloaf Creek
Ferguson Creek
Moraine Creek
East Fork Sugarloaf Creek
Roaring River
Milestone Creek
Kern River
Tyndall Creek
Wright Creek
296
295
289
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300
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288
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268
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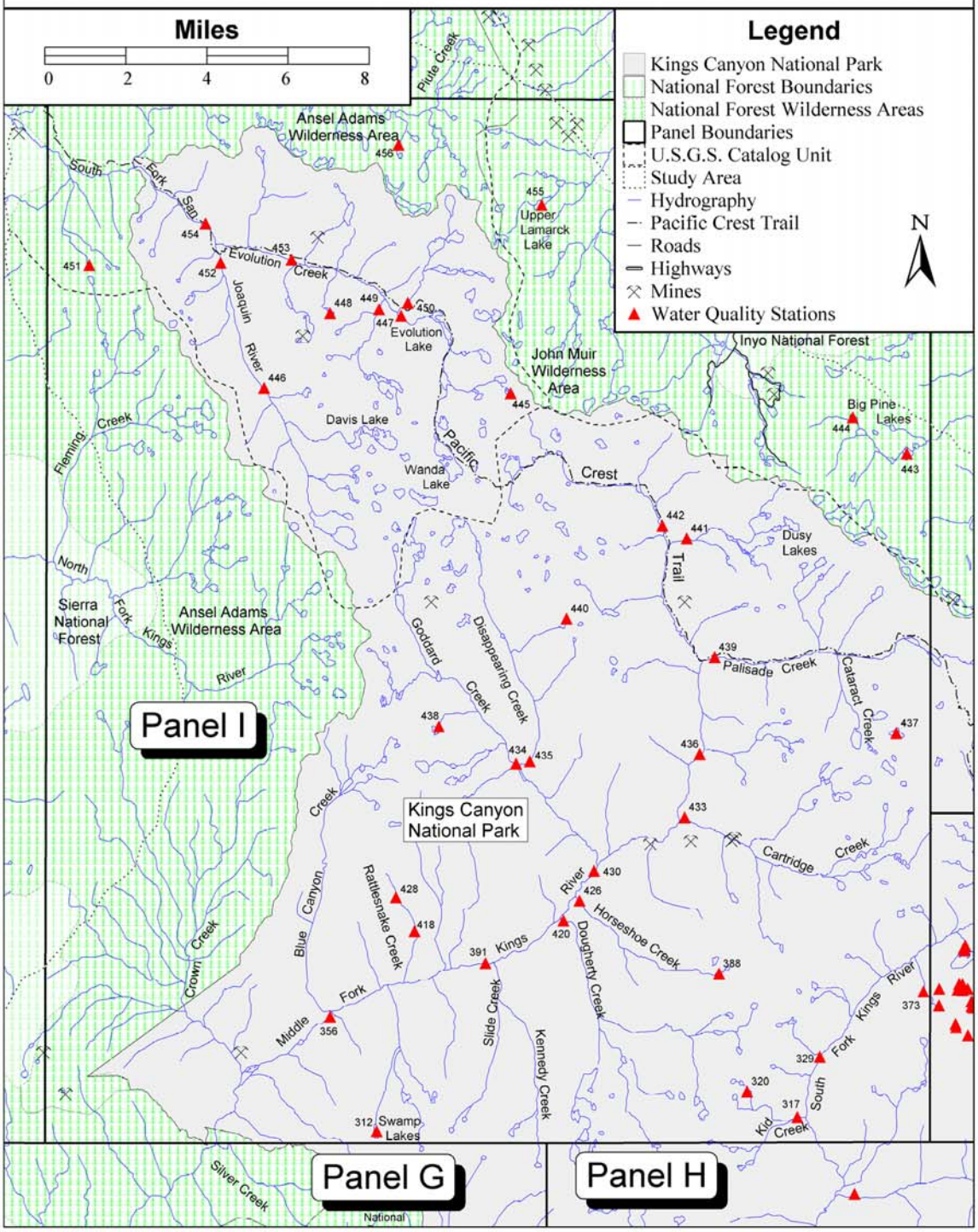
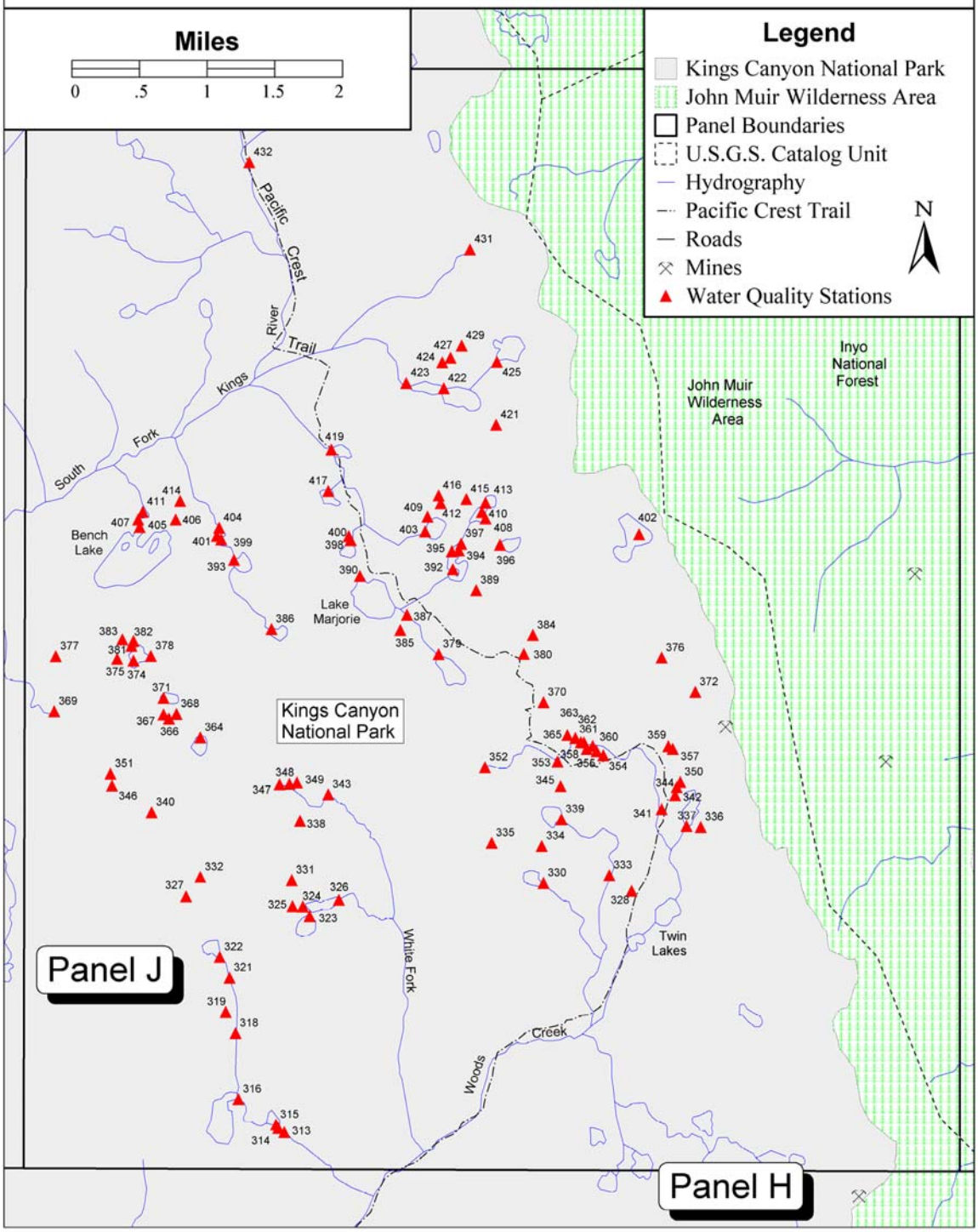
Sequoia & Kings Canyon National Parks

Water Quality Monitoring Locations



Sequoia & Kings Canyon National Parks

Water Quality Monitoring Locations



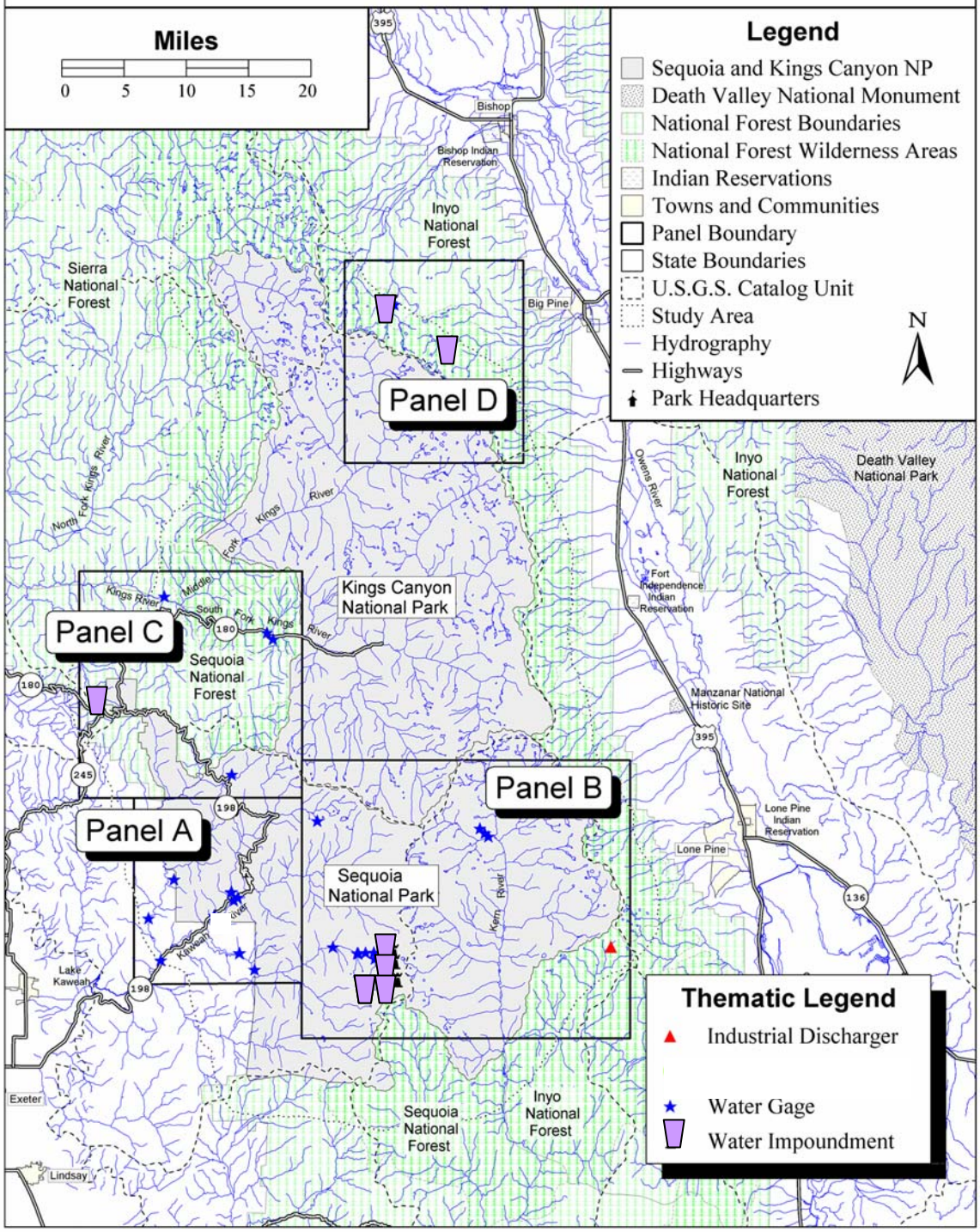
Appendix B.

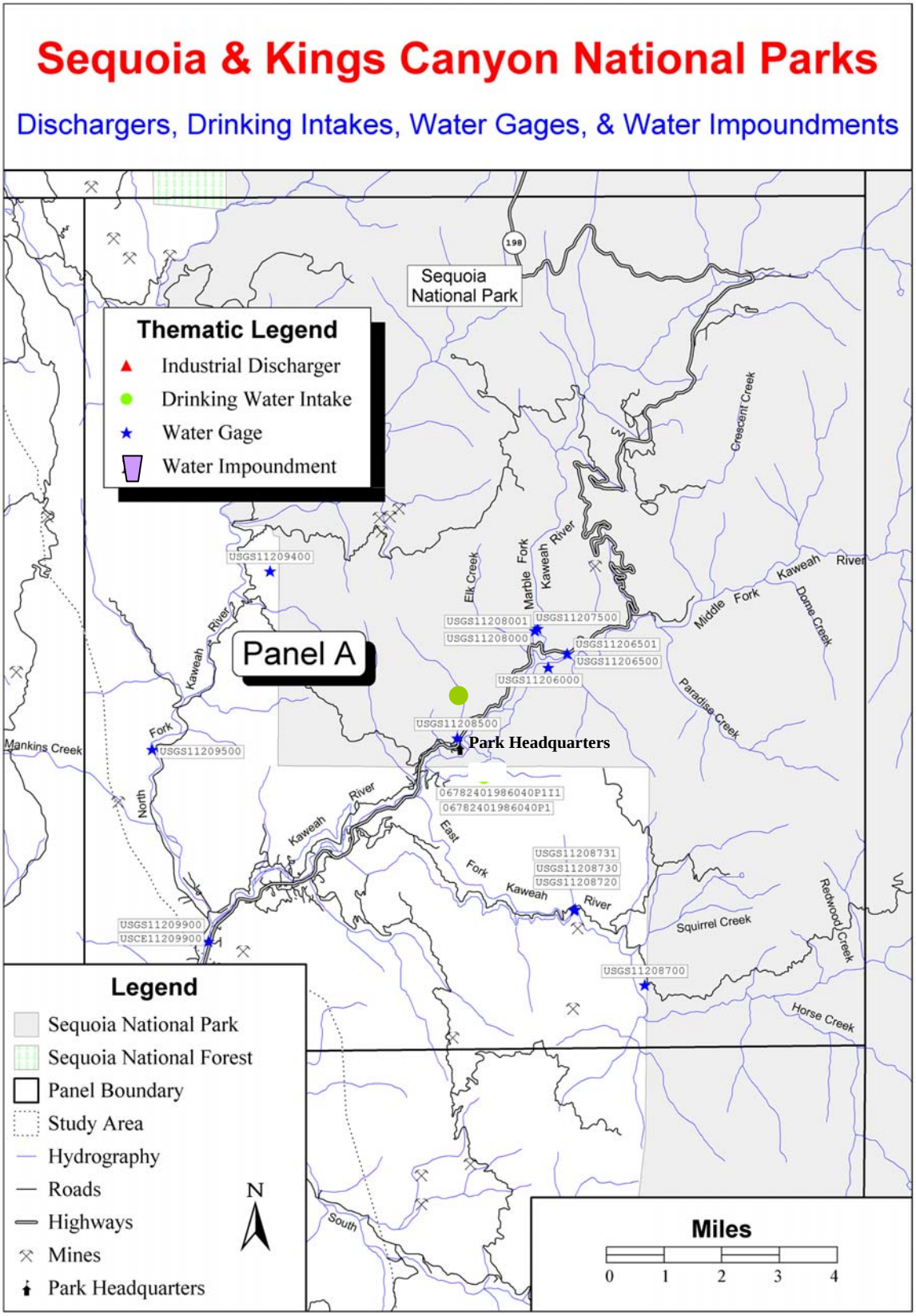
Locations for Water Gages, Impoundments, Drinking Water Intakes, and Industrial Discharge

Sequoia & Kings Canyon National Parks

Dischargers, Drinking Intakes, Water Gages, & Water Impoundments

Graphic Panel Index




Sequoia & Kings Canyon National Parks
Dischargers, Drinking Intakes, Water Gages, & Water Impoundments
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Thematic Legend
Industrial Discharger
Drinking Water Intake
Water Gage
Water Impoundment
Panel A
USGS11209400
USGS11208001
USGS11208000
USGS11207500
USGS11206501
USGS11206500
USGS11206000
USGS11208500
Park Headquarters
USGS11209500
06782401986040P1I1
06782401986040P1
USGS11208731
USGS11208730
USGS11208720
USGS11209900
USCE11209900
USGS11208700
Elk Creek
Marble Fork Kaweah River
Crescent Creek
Middle Fork Kaweah River
Dome Creek
Paradise Creek
Kaweah River
North Fork Kaweah River
Mankins Creek
East Fork Kaweah River
Squirrel Creek
Redwood Creek
Horse Creek
South
Legend
Sequoia National Park
Sequoia National Forest
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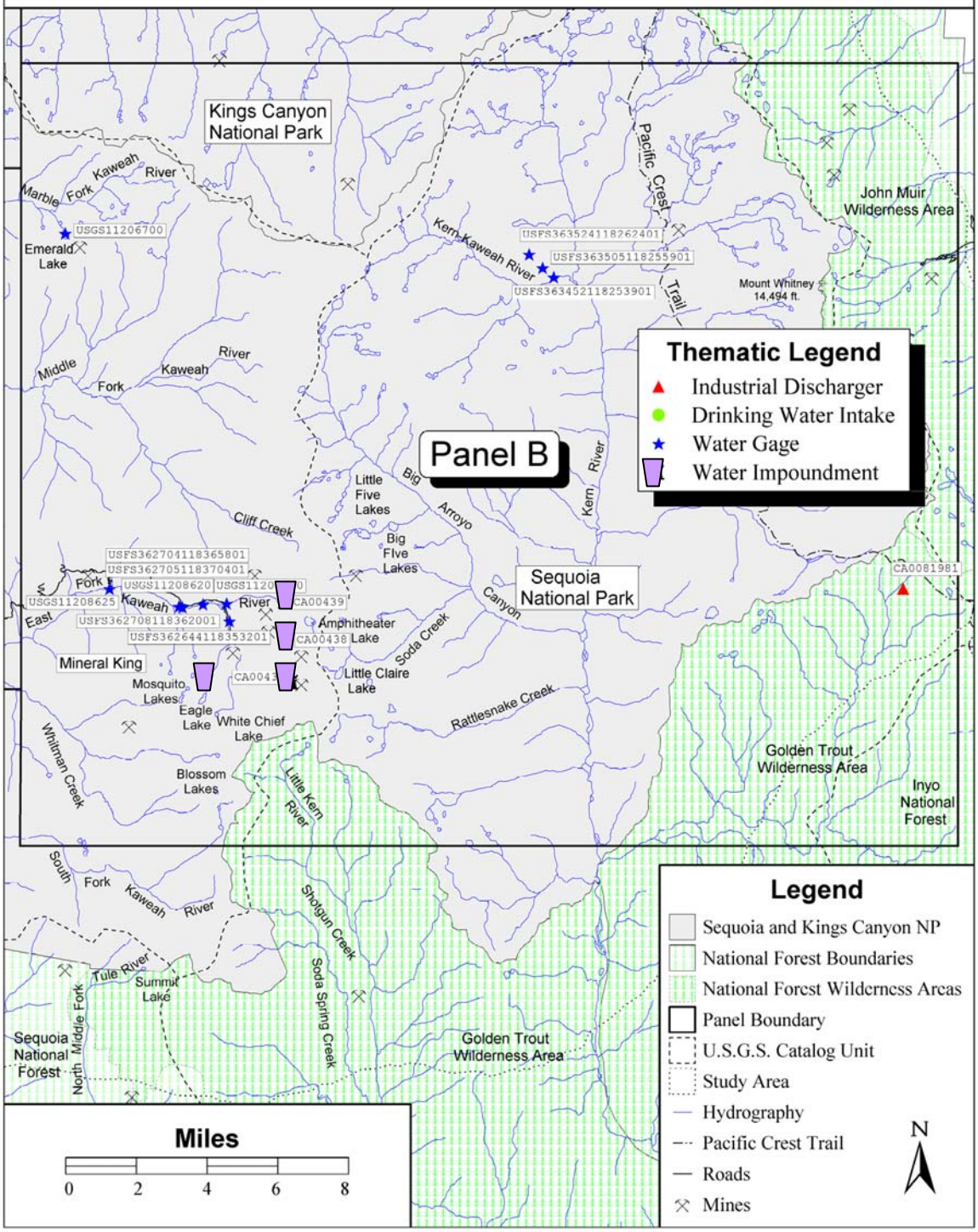
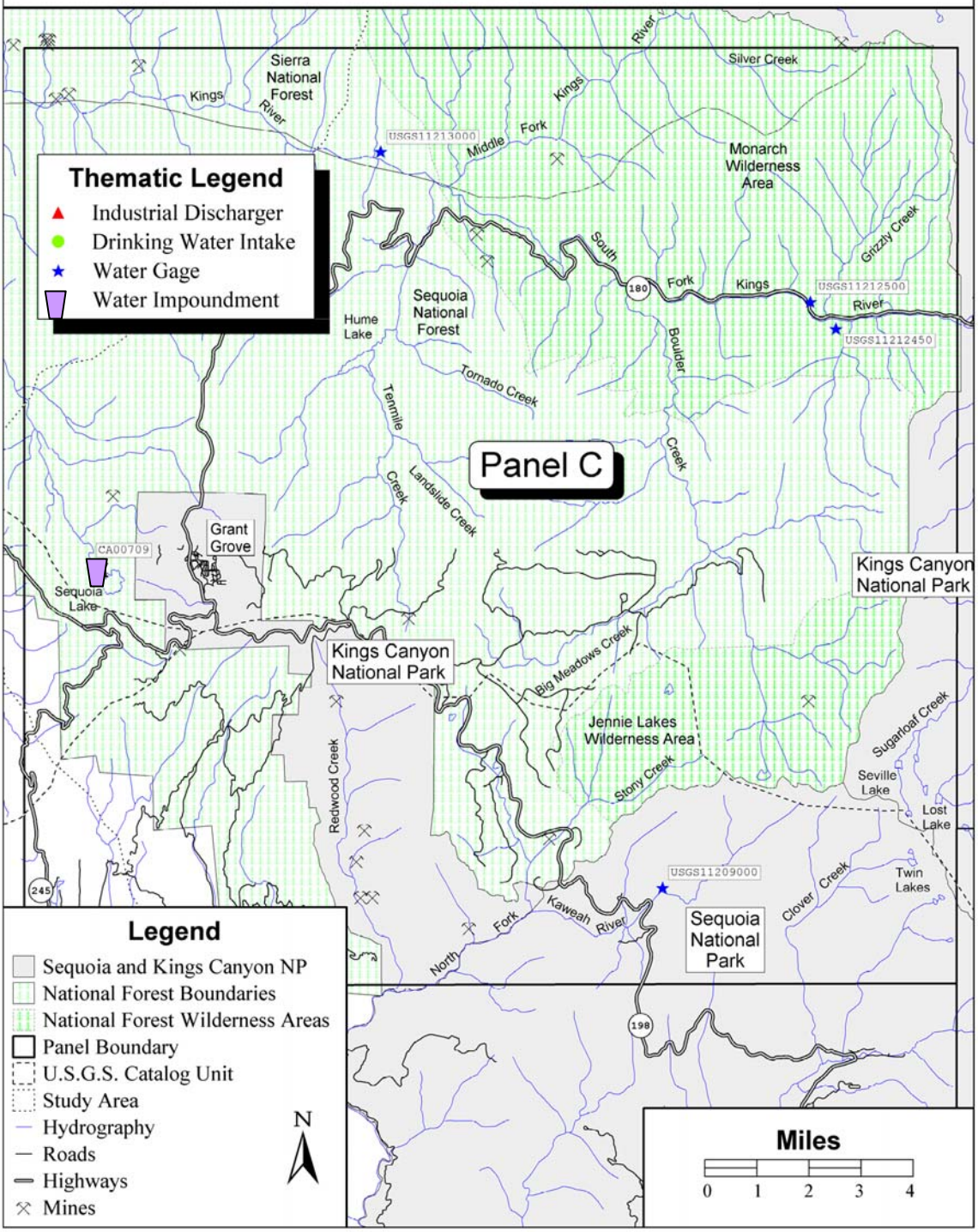
Sequoia & Kings Canyon National Parks

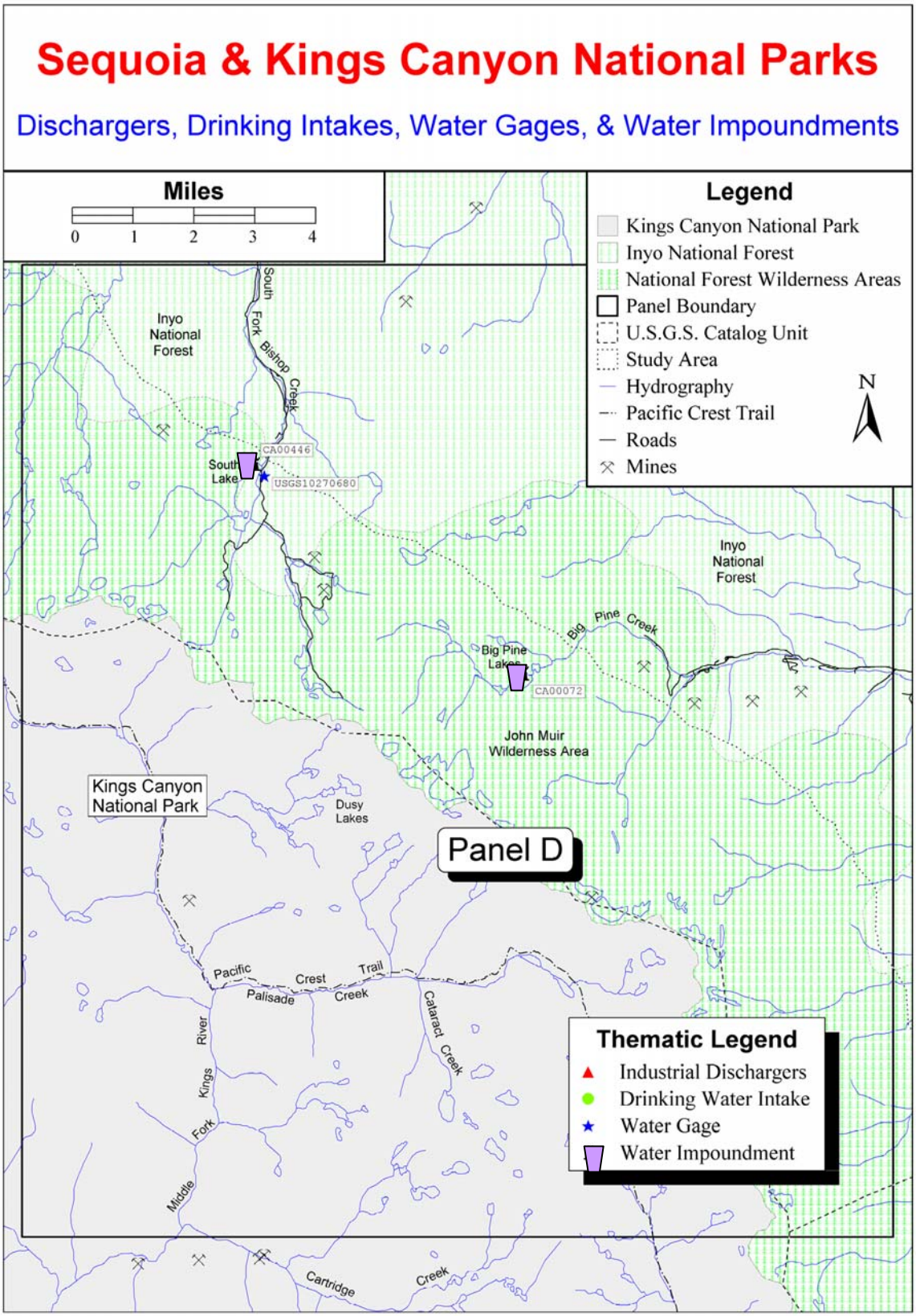
Dischargers, Drinking Intakes, Water Gages, & Water Impoundments



Sequoia & Kings Canyon National Parks

Dischargers, Drinking Intakes, Water Gages, & Water Impoundments




Sequoia & Kings Canyon National Parks
Dischargers, Drinking Intakes, Water Gages, & Water Impoundments
Miles
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Kings Canyon National Park
Inyo National Forest
National Forest Wilderness Areas
Panel Boundary
U.S.G.S. Catalog Unit
Study Area
Hydrography
Pacific Crest Trail
Roads
Mines
N
Inyo National Forest
South Fork Bishop Creek
CA00446
South Lake
USGS10270680
Inyo National Forest
Big Pine Creek
Big Pine Lakes
CA00072
John Muir Wilderness Area
Kings Canyon National Park
Dusy Lakes
Panel D
Pacific Crest Trail
Palisade Creek
Cataract Creek
Kings River
Middle Fork
Cartridge Creek
Thematic Legend
Industrial Dischargers
Drinking Water Intake
Water Gage
Water Impoundment

Industrial Facility Discharges, Drinking Water Intakes,
Water Gages, and Water Impoundments Within the SEKI Study Area
Industrial Facility Discharges

Site ID Station/Facility Name Address City Facility Receiving Water Name
CA0081981 SO. CA EDISON CO. MIDDLE FORK KAWEAH RIVER

Drinking Water Intakes

Avg. Daily Production
Site ID Station/Facility Name City Population Served (Gal./Day)

06782401986040P1 TREATMENT PLANT THREE RIVERS 200 5000.00
06782401986040P1I1 ALDER CREEK THREE RIVERS 200 5000.00

Water Gages

Drainage Area
Site ID Station Name Site Type (Square Miles) Begin Year
End Year

USCE11209900 KAWEAH R AT THREE RI Stream 418.00
USFS362644118353201 SPRING C NR MOUTH Stream
USFS362704118365801 MOSQUITO C NR MOUTH Stream
USFS362705118370401 EF KAWEAH BL MOSQUIT Stream 16.00
USFS362708118362001 EF KAWEAH BL MONARCH Stream
USFS363452118253901 FRANKLIN C NR MOUTH Stream
USFS363505118255901 WHITE CHIEF C NR MOU Stream
USFS363524118262401 EF KAWEAH BL EAGLE C Stream
USGS10270680 GREEN C COND OUTLET NR BISHOP CA Stream 1990 1994
USGS11206000 MF KAWEAH R NO 3 CONDUIT NR POTWISHA CAMP CA Stream 1976 1994
USGS11206500 MF KAWEAH R NR POTWISHA CAMP(RIVER ONLY) CA Stream 102.00 1950 1994
USGS11207500 MARBLE F KAWEAH R NO 3 CONDUIT A POTWISHA CA Stream 1976 1994
USGS11208000 MARBLE F KAWEAH R (R ONLY) A POTWISHA CAMP CA Stream 51.40 1950 1994
USGS11208500 MF KAWEAH TRIB NR HAMMOND CA 190.00 1967 1973
USGS11208700 E. F. KAWEAH R NR HA Stream 8220.00
USGS11208720 EF KAWEAH R CONDUIT 1 NR THREE RIVERS CA Stream 1975 1978
USGS11208730 EF KAWEAH R OVERFLOW BL COND 1 NR THREE RIVERS C Stream 85.80 1952 1978
USGS11209000 DORST CR NR KAWEAH C 611.00
USGS11209400 N. F. KAWEAH R NR KA Stream 8910.00
USGS11209500 NF KAWEAH R A KAWEAH CA 2900.00 1911 1981
USGS11209900 KAWEAH R A THREE RIVERS CA Stream 418.00 1959 1990
USGS11212450 GRIZZLY CR NR CEDAR 973.00
USGS11212500 SF KINGS R NR CEDAR GROVE CALIF 0800.00 1951 1957
USGS11213000 KINGS R NR HUME CA 3500.00 1922 1958

USGS11206501 MF KAWEAH R NR POTWISHA CAMP(TOTAL FLOW) CA Stream 102.00 1950 1994
USGS11206700 EMERALD LK OUTFLOW NR GIANT FOREST CA Lake 0.44 1984 1988
USGS11208001 MARBLE F KAWEAH R (TOTAL FLOW) A POTWISHA CAMP C Stream 51.40 1951 1994
USGS11208610 MONARCH C NR HAMMOND CA Stream 1.89 1968 1974
USGS11208620 EF KAWEAH R BL MOSQUITO C NR HAMMOND CA Stream 16.00 1968 1974
USGS11208625 EF KAWEAH R A SEQ NATL P BNDRY NR HAMMOND CA Stream 23.70 1968 1972
USGS11208731 COMBINED FLOW EF KAWEAH R NR THREE RIVERS CA Stream 85.76 1952 1978

Appendix C.

Participants that Attended or Participated via E-mail in the SEKI Water Scoping Workshop on November 19, 2003

Name	Primary Experience	Affiliation
Attended		
Danny Boiano	Aquatic Ecology	NPS SEKI (Report Co-author)
Don Weeks	Hydrology	NPS WRD (Report Co-author)
Jerry Mitchell	Chief Div. Nat. Rsrcs.	NPS YOSE (Meeting Facilitator)
Harold Werner	Wildlife Ecology	NPS SEKI
Annie Esperanza	Air/Water Resources	NPS SEKI
Peter Rowlands	Chief Div. Nat. Rsrcs. (Veg.)	NPS SEKI
Linda Mutch	Inventory & Monitoring	Sierra Nevada Network @SEKI
John Stednick	Watershed Science	Colorado State University
Andi Heard	Water Quality	Colo. St. Univ @ SEKI
Sean Eagan	Hydrology	USFS PSW Fresno
Dave Bradford	Amphibians/Contaminants	EPA Nat'l Exposure Research Lab
Jeff Holmquist	Invertebrate Ecology	Univ. California, San Diego
Christy McGuire	Fisheries	Cal. Dept. Fish & Game
Stan Stephens	Fisheries	Cal. Dept. Fish & Game
Amy Miller	Soil/Watershed Science	Univ. California, Santa Barbara
Dave Clow	Water Quality/Hydrology	USGS WRD
Dave Herbst	Aquatic Invertebrates	Univ. California, Santa Barbara
Roger Bales	Alpine Hydrology	Univ. California, Merced
Martha Conklin	Nutrient/Hydro Movement	Univ. California, Merced
Jim Sickman	Watershed Science	Univ. Louisiana, New Orleans
Nate Stephenson	Climate Change	USGS BRD @ SEKI
Curtis Stumpf	Watershed Management	SCA Intern @ SEKI (Note Taker)
Cheryl Bartlett	Plant Ecology	NPS SEKI (Note Taker)
Alysia Wilson	Interpretation	NPS SEKI (Note Taker)
Voted for Five Most Significant Issues via E-mail		
Marie Denn	Aquatic Ecology	NPS PWR
Paul Kennard	Geomorphology	NPS PWR
Kathy Tonnessen	Research Coordinator	NPS CESU Univ. MT, Missoula
Cathy Brown	Aquatic Ecology	USFS PSW Berkeley
Mike Dettinger	Hydroclimatology	USGS & Univ California, San Diego
Dan Cayan	Hydroclimatology	USGS & Univ California, San Diego
Jessica Lundquist	Hydroclimatology	Univ. California, San Diego
Roland Knapp	Aquatic Ecology	Univ. California, Santa Barbara
John Melack	Watershed Science	Univ. California, Santa Barbara
Vance Vredenburg	Aquatic Ecology	Univ. California, Berkeley

Appendix D.

Results of Voting for the Most Significant Water Resource Issues in SEKI by Participants in the Water Scoping Meeting held November 19, 2003

ISSUES (that we need to understand better)

Surface water

(1 vote) Quantify total amount of surface water and groundwater flowing out of SEKI
- Partitioning of snowmelt between surface and ground water
- Some unpublished data 20 yr Livermore (by Brad Estes?)

Contingent economic value of SEKI

(16 votes) Climate change (Bales, Stephenson)
- Timing of melt
- Seasonality of rest of water cycle
- Runoff
- Precipitation/hydrologic cycle
- Effects of loss of glaciers on water supply in the late summer to high elevation streams, ponds and lakes

(3 votes) Global change effects on water quantity (water delivery patterns and aquatic communities) and water quality (biogeochemical cycling in watersheds, and transport and transformation of pollutants delivered to the park)

(1 vote) Denn issues:
- How will global climate change affect the park's aquatic resources?
- What changes should we expect to see in local ecology?
- What, if anything, can we do to protect ecological systems?

(5 votes) Glacier monitoring (Kennard)

(5 votes) Dettinger's issues:
- How much water in various places and forms is needed to sustain the Park's various systems?
- What levels of hydrologic variability (in time and space) are needed to sustain those systems?
- What is the spatial reach of the influence of various components of the Park's hydrology? (e.g., if one of the lakes or glaciers or streams or meadows dried up, or if its quality degraded, what areas, organisms, landscape features, or structures/services would be lost or degraded?)
- Have these various hydrologic resources/features changed substantially during SEKI's tenure?
- Have they changed during the past few decades?
- Are they changing now?
- Where are they changing and for what reasons?

(1 vote) Cayan's issue:
- Establish hydroclimate network across Sierra Nevada Network, using transects at varying latitudes and elevations

(1 vote) Understanding role of changing glaciers to hydrology of watersheds (Clow & Bales)

(2 votes) How is the chemistry of the surface water and snow pack changing over time throughout the park, how is it effecting aquatic systems, and what can we do to mitigate damage to park resources? (Denn)

(2 votes) Data quality/longeveity of records: long term records, gaging station, long term flow records, metadata (Clow)

(15 votes) Contaminants (Nutrients, Pesticides, Hormones)
- Effects of contaminants on mountain yellow-legged frogs
- Metals sampled at 4 streams/Kaweah drainage Pb, Cd
- Spatial sampling of heavy metals (WACAP will pick up some)
- Organic contaminants
- **(1 vote)** Atmospheric transport of contaminants (particulates, virus, nutrients, metals, pathogens, pesticides, herbicides, xenoestrogens, hormones) into park (Esperanza)
- Road-melting salts

(4 votes) Pathogens (Werner, Boiano, Bradford)
- **(3 votes)** Chytrid fungus, observed worldwide, is decimating species populations (especially mountain yellow-legged frogs)
  - Is it airborne?
  - Is it a new fungus?
  - Is it native or introduced?
  - Is it more widespread today than in the past?
  - Is it stronger today than in the past?
  - Is it stronger in west Sierra vs weaker in east Sierra?
  - How does it spread (human/animal transport?)
  - How do populations initially become infected?
  - How does it spread from individual to individual?
  - Once a population is wiped out, do individuals translocated to that site become infected?

- Viruses (iridovirus, ranavirus, new viruses being introduced)
  - Mode of transport (people)/ known not to survive out of water
  - Same questions as fungus

- Human pathogens – giardia, cryptosporidium, campylobacter (Werner)

- Should we try to prevent new pathogens from entering SEKI?

(14 votes) Fire and lack of fire (Stephenson and Sickman)
- Role of low elevation fires by contributing nutrients to higher elevations
- Fire regime affects everything: timing, hydrology, chemistry, erosion/sedimentation
- Short term effects and long term (e.g. SO4 elevated 20 years later)
- Fire variability causes a cascade of varying hydrologic and ecological effects

(2 votes) Effects of fire suppression (Werner)
- Chemical impacts to the ecosystem of use of fire retardants (toxic and nutrient)
- BAER (emergency rehab) erosion suppression
- Erosion impacts to soils and siltation of streams

(1 vote) Continued studies of fire and its ecological and biogeochemical aspects (Melack)

(1 vote) Trophic cascade from exotic introductions (lakes, bats, fish, changes in nutrient levels) (Werner)

Effects of marijuana cultivation: terracing, nutrients, herbicides (Werner)

(1 vote) Cumulative effects of everything? (fire suppression, nutrients, exotic species)

(1 vote) Disruption of hydrologic/ecological systems (Herbst)
- Dams/diversions
- Dam Removals

Ground Water

Groundwater(springs) (Clow, Conklin, Stednick)

(2 votes) Lack of information
- Inventory of springs
- Water rights: Meritt Springs examples
- Age dating
- Water quality and quantity on karst formation
- Relation of fire suppression and water recharge and quality
- Identify groundwater extraction to replace surface diversions

(2 votes) Identify groundwater flowpaths and chemistry

Atmospheric Deposition / Land Use

(1 vote) Important for San Joaquin basin. We need to know how much deposition is occurring, of what constituents, and from where and when (Cayan)

(2 votes) Atmospheric deposition and its effects (including wet and dry deposition of nutrients, base cations, acidic ions, particulates and pesticides) (Melack)

(2 votes) Continued long-term studies of hydrology and solute chemistry in the Emerald basin and in Log and Tharps catchments with supporting measurements of meteorological conditions (Melack)

How to ensure that long-term data collected at Emerald Lake watershed and the Marble Fork of the Kaweah since 1983 gets continued after the Univ. of CA, Santa Barbara completes the current NSF grant

Chemical loading, in general, from atmospheric deposition - nutrients, base cations and acidity

(1 vote) Nutrient deposition effects (Bales, Clow, Sickman, Conklin, Esperanza)

(8 votes) How does nutrient deposition affect water quality? Aquatic (chemical and biological) effects of atmospheric deposition

(3 votes) Nutrient enrichment from atmospheric sources

(2 votes) Spatial and temporal pattern of nutrient N/P deposition (wet and dry) (Sickman, Clow, Esperanza)

Changes in nutrient limitation in lakes due to change in nitrogen/phosphorus cycling in watersheds

Particulate deposition: transport of pollutants, nutrients, pesticides and aeolian dust
- Particulate vs gaseous transport of different constituents

Nutrients and pharmaceuticals from visitor and stock

Effects of anthropogenic nutrients inputs from backcountry users and frontcountry wastewater facilities
Effects of social activities on wetlands around high lakes and select reaches of stream
Sewage facilities (leakage of sewage pipes)
Distribution of chemicals
Biological effects
Mass balance? <--> backcountry dispersed recreation effects
DEET/suncreen soaps

Effects of hazardous materials
Park gas stations (MTBE)
Asbestos? (not an issue)
Fire retardant
Petroleates from road runoff (oil, fuel, deicing materials, rubber)
Sand application on roads

Effects of land use changes in the valley (spatial examination) (Esperanza)

Water rights – park neighbors, illegal extraction (Stednick)

Wetlands
(3 votes for 1st six issues lumped together)
Social use: stock, trails on amphibians, small mammals, vegetation effects, stream incision, soil compaction (Werner)

Climate change (water cycle)

Stream downcutting due to roads or other infrastructure

Meadow encroachment by trees (climate change?)

Cascading effects of introduced fish in nearby streams

Grazing effects on rare communities - fen in Big Pete Meadow (Haultain)

Riparian and meadow system functioning - ability to remove excess nutrients from system; How do they deal with nutrients transported into park? (Conklin)

Inventory of invertebrates in riparian areas (Holmquist)

Inventory of vegetation communities in steep Sierran streams (Dolance, PSW Fresno)

Beaver impact on riparian areas (Werner)

(1 vote) How is the landform changing - are we losing wet meadows? Why? (Denn)

Floodplains / Riparian
Climate change effects on floodplains

More water rights and floodplain surveys needed (Stednick)

Inventory to define them in developed areas

Recurrence interval for different floods on data, but make sure data will be useful before time and money is invested (Eagan)

Riparian questions in wetlands (i.e. communities that are not water-limited)

Visitor Use

What would be good indicators to identify carrying capacity? (need biological data to determine carrying capacity)

List of activities to address: kayaking (new), angling, swimming

(1 vote) Trade off between visitor use and impacts of visitor use vs benefits of visitor appreciation; Who takes accountability on setting limits?

Visitor education to insure better treatment of resources (give children coupon to entice family to return)

(1 vote) Better planning for river access

Changing demographics and visitation numbers

Aquatic Biology: Flora

(1 vote) Eutrophication of high elevation lakes (Sickman)

Inventories of algal flora and macrophytes in lake, streams and special habitats (springs, etc.) (Herbst, Clow, Haultain)

Microbially mediated biogeochemical processes at sediment/water interfaces (Conklin, Sickman)

Exotic aquatic and riparian plant removal (How?) (Werner, Demetry)

Relationship of trout and algal blooms in streams (Herbst)

Landscape effects on algae and streams (Clow)

Snow algae/flora of glaciers

Nitrogen cycling capacity of snowpacks (algae and bacteria) (Sickman)

Aquatic Biology: Amphibians

(1 vote) Effects of pesticides, contaminants, and diseases on amphibians (Cayan)

(2 votes) Investigate reasons for decline of the mountain yellow-legged frog and Yosemite toad, including habitat issues, contaminants and disease (Brown)

(2 votes) How will diseases and contaminants affect methods for restoring mountain yellow-legged frogs?

(1 vote) Controversial methods for restoring mountain yellow-legged frogs (tiger muskie, poisons)

Gaining public approval for programmatic plan addressing parkwide threats to mountain yellow-legged frogs

(2 votes) Public opposition to removal of introduced trout for frog restoration

(1 vote) Genetics of mountain yellow-legged frogs: are there two different species in SEKI?

(1 vote) Use of translocations as a tool to investigate causes of frog declines

(1 vote) Using current research in genetics to create watershed management plans; need to know which life stage is best for translocations for frog reintroduction (Werner, Boiano)

(1 vote) Develop monitoring plans for the mountain yellow-legged frog and Yosemite toad (Werner, Boiano, Brown)

(1 vote) Research and restore foothill yellow-legged frogs (Werner, Boiano, Brown)

Inventory of Mount Lyell salamanders (distribution, abundance & genetics) (Werner, Boiano)

Research on the loss of the western pond turtle (Werner)

Development of Aquatic Diversity Management Areas (Herbst)

Aquatic Biology: Fish

Restoration of Little Kern Golden Trout

Genetic threats to Kern River rainbow trout from upstream plants of rainbow trout and California golden trout

(2 votes) Need to define (and some day restore) pristine distribution of native trout species in SEKI. What are historic fish fauna? Is reintroduction a possibility? (Werner)

(4 votes) Continue removal of exotic/introduced fish (to restore mountain yellow-legged frogs, other native species and aquatic ecosystems)

(1 vote) How can we efficiently and permanently remove exotic fish from as many water bodies as possible? (Denn)

(2 votes) When removing exotic fish, check for genetic variability and integrity. Should we maintain genetically-pure populations that are not native to where they have been transplanted (e.g. CGT) (Stephens, McGuire)

Knowledge of fish migration barriers (McGuire)

Effect of other exotic fish (e.g. green sunfish) (Werner)

Aquatic Biology: Fauna / Invertebrates

(2 votes) Inventory of macroinvertebrates (biogeographical, i.e. spatial distribution): lack of information

(8 votes) Establish monitoring baseline data for watersheds

Value of biomonitoring

Key species and indicators or lump indicators are known from other studies – need to set up sites in SEKI that are healthy/undisturbed (no exotic fish species) vs unhealthy/disturbed sites (drives future restoration)

(3 votes) Wet/dry meadow invertebrates as a vital sign

Increase knowledge base of invertebrates (Herbst, Holmquist)

Look for exotic invertebrates (Herbst)

Role of vernal pools in river ecology

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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