National Park Service
U.S. Department of the Interior

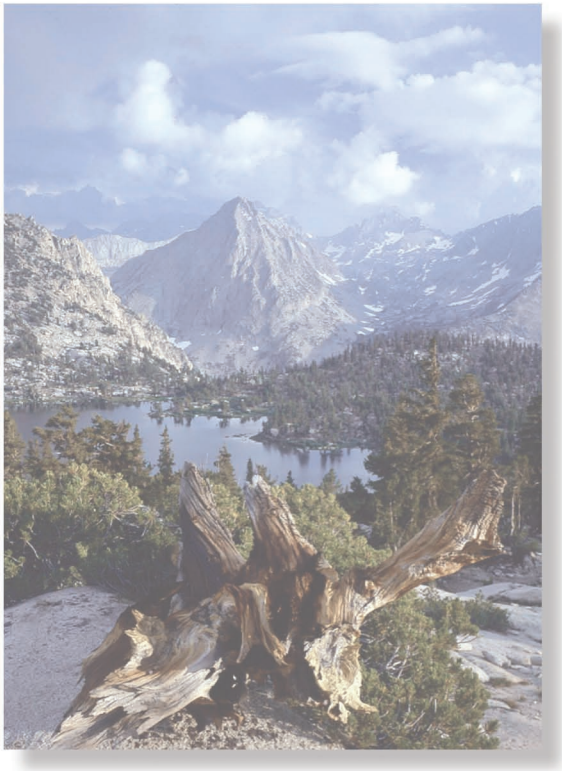
Natural Resource Program Center

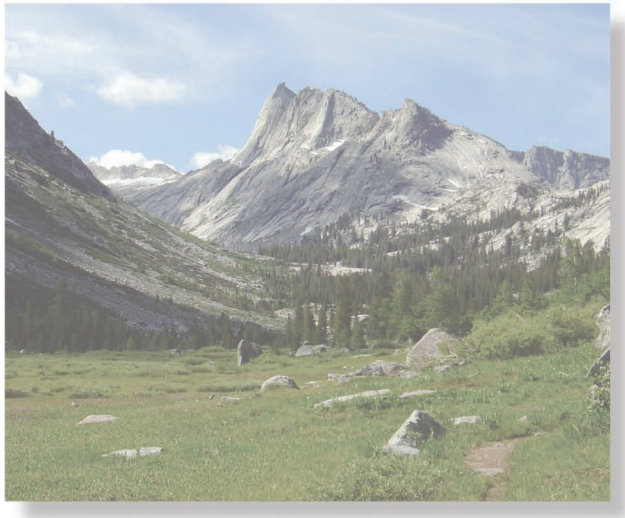
# Sierra Nevada Network
# Vital Signs Monitoring Plan

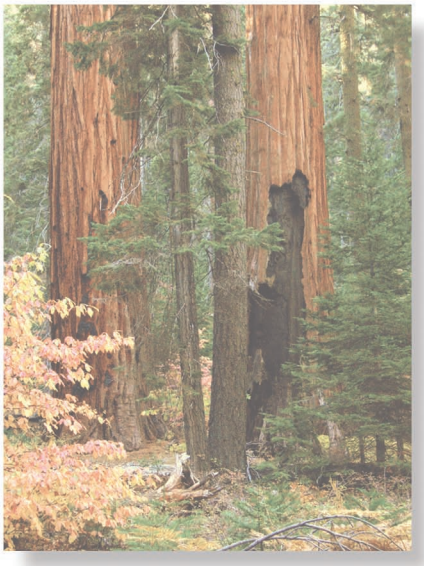
## *Appendices A-H*

Natural Resource Report NPS/SIEN/NRR—2008/072











ON THE COVER

Images from each of the Sierra Nevada Network's parks. Clockwise from top left: Devils Postpile National Park (NPS photo), Bullfrog Lake in Kings Canyon National Park (photo: Howard Weamer Photography), giant Sequoias, Sequoia and Kings Canyon National Parks (photo: Anthony Caprio), view of Yosemite National Park (photo: Stan Jorstad) and Deadman Canyon photo in Kings Canyon National Park (photo: Greg Stock).

# Sierra Nevada Network Vital Signs Monitoring Plan

## *Appendices A-H*

Natural Resource Report NPS/SIEN/NRR—2008/072

Linda S. Mutch
Sierra Nevada Network, Sequoia & Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Meryl Goldin Rose
Sierra Nevada Network Inventory & Monitoring Program
Yosemite Field Station
P.O. Box 700, El Portal, California 95318

Andrea M. Heard
Sierra Nevada Network, Sequoia & Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Rosamonde R. Cook, Ph. D.
528 Spruce Street
Riverside, CA 92507

Gary L. Entsminger
Acquired Intelligence, Inc.
23625 V66 Trail
Montrose, CO 81401

With Contributions from:

Tony Caprio, Laura Clor, Athena Demetry, Annie Esperanza, Sandy Graban, Sylvia Haultain, Justin Hofman, Bill Kuhn, Scott Martens, Tani Meadows, Barbara Moristch, Lara Rachowicz, Tom Rodhouse, Peter Rowlands, Don Schweizer, Kirk Steinhorst, Sarah Stock, Leigh Ann Starcevich, Leona Svancara, Steve Thompson, Liz van Mantgem, and Harold Werner.

Layout, design: Barbara BC Gleason/BGleason Design & Illustration, LLC.

30 September 2008

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

The Natural Resource Publication series addresses Natural Resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high priority, current Natural Resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly-published newsletters.

Views, statements, findings, conclusions, recommendations and data in this report are solely those of the author(s) and do not necessarily reflect views and policies of the U.S. Department of the Interior, NPS. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

This report is available from the Natural Resource Publications Management Web site (http://www.nature.nps.gov/publications/NRPM) or from the Sierra Nevada Network Web site at (http://science.nature.nps.gov/im/units/sien/) on the Internet.

Please cite this publication as:

Mutch, L. S., M. Goldin Rose, A. M. Heard, R. R. Cook, and G. L. Entsminger. 2008. Sierra Nevada Network vital signs monitoring plan: Appendices A-H. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

NPS D—046, September 2008

**List of Appendices**.....v

Appendix A: Summary of Legislation, National Park Service Policy, and Other Guidance Relevant to Natural Resources Monitoring ..... 1

Appendix B: Biology, Ecology, Landscape, and Ecosytem Processes in Sierra Nevada Network Parks ..... 11

Appendix C: Air Quality Synthesis ..... 45

Appendix D: Evaluation of Existing Water Resources Information in the Sierra Nevada Network ..... 69

Appendix E: Summary of Significant Baseline Inventories and Monitoring in Sierra Nevada Parks ..... 129

Appendix F: Ecosystem Conceptual Models..... 175

Appendix G: Identifying and Prioritizing Vital Signs ..... 267

Appendix H: Protocol Development Summaries..... 283

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix A: Summary of Legislation, National Park Service Policy, and Other Guidance Relevant to Natural Resources Monitoring*

**Natural Resource Report NPS/SIEN/NRR—2008/072**

Meryl Goldin Rose, Ecologist
Sierra Nevada Network Inventory & Monitoring Program
Yosemite Field Station
P.O. Box 700, El Portal, California 95318

Layout, design and illlustration on figure 1-3, page 9: Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Goldin Rose, M. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix A. Summary of Legislation, National Park Service Policy, and Other Guidance Relevant to Natural Resources Monitoring. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Appendix A: Legislation

| SUMMARY OF LEGISLATION, NATIONAL PARK SERVICE POLICY, AND GUIDANCE RELEVANT TO DEVELOPMENT AND IMPLEMENTATION OF NATURAL RESOURCES INVENTORY AND MONITORING | |
|---|---|
| **Archaeological Resources Protection Act 1979** | |
| **Clean Air Act** (42 USC 7401-7671 et seq, 1963, as amended in 1990) | Establishes a nationwide program for the prevention and control of air pollution and establishes National Ambient Air Quality Standards. Under the Prevention of Significant Deterioration provisions, the act requires federal officials responsible for the management of Class I Areas (national parks and wilderness areas) to protect the air quality related values of each area and to consult with permitting authorities regarding possible adverse impacts from new or modified emitting facilities. The act establishes specific programs that provide special protection for air resources and air quality related values associated with NPS units. The EPA has been charged with implementing this act. |
| **Clean Air Act** (42 USC 7401 et seq., 1963, amended 1977 and 1991) | |
| **Clean Water Act of 1972** (33 USC 1251-1376) | The Clean Water Act, passed in 1972 as amendments to the Federal Water Pollution Control Act, and significantly amended in 1977 and 1987, was designed to restore and maintain the integrity of the nation's water. It furthers the objectives of restoring and maintaining the chemical, physical and biological integrity of the nation's waters and of eliminating the discharge of pollutants into navigable waters by 1985. Establishes effluent limitation for new and existing industrial discharge into U.S. waters. Authorizes states to substitute their own water quality management plans developed under S208 of the act for federal controls. Provides an enforcement procedure for water pollution abatement. Requires conformance to permit required under S404 for actions that may result in discharge of dredged or fill material into a tributary to, wetland, or associated water source for a navigable river. |
| **Clean Water Act** (33 USC 1251-1376) | |
| **Clean Water Act** (33 USC 125 et seq.) | |
| **Clean Water Act 1972** amended 1977, 1987 | |
| **Coastal Zone Management Act** (1972) | |
| **Endangered Species Act** (16 USC 1531 et.seq., 1973, amended in 1982) | The purposes of the ESA include providing "a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved. According to the ESA 'all federal departments and agencies shall seek to conserve endangered species and threatened species' and '[e]ach federal agency shall…insure that any action authorized, funded, or carried out by such agency…is not likely to jeopardize the continued existence of any endangered species or threatened species.' The USFWS (non-marine species) and the National Marine Fisheries Service (NMFS) (marine species, including anadromous fish and marine mammals) administers the ESA. The effects of any agency action that may affect endangered, threatened, or proposed species must be evaluated in consultation with either the USFWS or NMFS, as appropriate. |
| **Environmental Quality Improvement Act of 1970** (42 U.S.C. 56 § 4371) | Directs all Federal agencies, whose activities may affect the environment, to implement policies established under existing law to protect the environment. |
| **Federal Cave Resources Protection Act 1988** | |
| **Fish and Wildlife Act** (16 USCA 742a et.seq., 1956) | |
| **Fish and Wildlife Coordination Acts** (16 USC 661 et seq., 1958, 1980) | |
| **Forest and Rangeland Renewable Resources Planning Act of 1974** (16 U.S.C. 36 § 1642) | Mandates that the Secretary of Agriculture inventory and monitor renewable natural resources in National Forests, and has been cited as congressional authorization for the inventory and monitoring of natural resources on all federal lands. While this is not specifically directed in the act it is perhaps indicative of a national will to account for and manage the nation's natural heritage in manner that sustains these resources in perpetuity. |
| **Forest and Rangeland Renewable Resources Planning Acts** (1974, 1976) | |

| SUMMARY OF LEGISLATION, NATIONAL PARK SERVICE POLICY, AND GUIDANCE RELEVANT TO DEVELOPMENT AND IMPLEMENTATION OF NATURAL RESOURCES INVENTORY AND MONITORING | |
|---|---|
| **General Authorities Act of 1970** (16 USC 1a-1—1a-8 (1988), 84 Stat. 825, Pub. L. 91-383 | The General Authorities Act amends the Organic Act to unite individual parks into the 'National Park System'. The act states that areas of the National Park System, "though distinct in character, are united through their inter-related purposes and resources into one national park system as cumulative expressions of a single national heritage; that individually and collectively, these areas derive increased national dignity and recognition of their superb environmental quality through their inclusion jointly with each other in one national park system preserved and managed for the benefit and inspiration of all the people of the United States…" |
| **Government Performance and Results Act** (1993) (GPRA) | Requires the NPS to set goals (strategic and annual performance plans) and report results (annual performance reports). The NPS Strategic Plan contains four GPRA goal categories: park resources, park visitors, external partnership programs, and organizational effectiveness. In 1997, the NPS published its first GPRA-style strategic plan, focused on measurable outcomes or quantifiable results. |
| **Migratory Bird Treaty Act** (1974) | |
| **Mining in the Parks Act** (1976) | |
| **National Environmental Policy Act of 1969** (42 USC 4321-4370) | The purposes of NEPA include encouraging 'harmony between [humans] and their environment and promote efforts which will prevent or eliminate damage to the environment… and stimulate the health and welfare of [humanity].' NEPA requires a systematic analysis of major federal actions that includes a consideration of all reasonable alternatives as well as an analysis of short-term and long-term, irretrievable, irreversible, and unavoidable impacts. Within NEPA the environment includes natural, historical, cultural, and human dimensions. Within the NPS emphasis is on minimizing negative impacts and preventing "impairment" of park resources as described and interpreted in the NPS Organic Act. The results of evaluations conducted under NEPA are presented to the public, federal agencies, and public officials in document format (e.g. Environmental Assessments and Environmental Impact Statements) for consideration prior to taking official action or making official decisions. |
| **National Historic Preservation Act 1966** | |
| **National Park Service Organic Act** (1916)(16 USC 1 et seq. [1988]). | The 1916 (August 25th) National Park Service Organic Act is the core of park service authority and the definitive statement of the purposes of the parks and of the National Park Service mission. The act establishes the purpose of national parks: "…. 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 the enjoyment of future generations." |
| **National Parks Omnibus Management Act** (1998) (P.L. 105-391) | Requires Secretary of Interior to continually improve NPS' ability to provide state-of-the-art management, protection, and interpretation of and research on NPS resources. Secretary shall assure the full and proper utilization of the results of scientific study for park management decisions. In each case where an NPS action may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered. The trend in NPS resource conditions shall be a significant factor in superintendent's annual performance evaluations. Section 5939 states that the purpose of this legislation is to:<br>(1) More effectively achieve the mission of the National Park Service;<br>(2) Enhance management and protection of national park resources by providing clear authority and direction for the conduct of scientific study in the National Park System and to use the information gathered for management purposes;<br>(3) Ensure appropriate documentation of resource conditions in the National Park System;<br>(4) Encourage others to use the National Park System for study to the benefit of park management as well as broader scientific value, and<br>(5) Encourage the publication and dissemination of information derived from studies in the National Park System. |
| **Natural Resource Protection Act** (1990) | |
| **Redwood National Park Act** (16 USC 79a-79q (1978), 82 Stat. 931, Pub. L. 90-545 | This act includes both park-specific and system-wide provisions. This act reasserts system-wide protection standards for the National Park System. This act qualifies the provision that park protection and management "shall not be exercised in derogation of the values and purposes for which these areas have been established" by adding "except as may have been or shall be directed and specifically provided for by Congress." Thus, specific provisions in a park's enabling legislation allow park managers to permit activities such as hunting and grazing. |

| SUMMARY OF LEGISLATION, NATIONAL PARK SERVICE POLICY, AND GUIDANCE RELEVANT TO DEVELOPMENT AND IMPLEMENTATION OF NATURAL RESOURCES INVENTORY AND MONITORING | |
|---|---|
| **Taylor Grazing Act** (1934) | |
| **Wild and Scenic Rivers Act** (1968) | |
| **Wilderness Act** (1964) (16 USC 1131 et seq.) (PL 88-577). | Establishes the National Wilderness Preservation System. In this act, wilderness is defined by its lack of noticeable human modification or presence; it is a place where the landscape is affected primarily by the forces of nature and where humans are visitors who do not remain. Wilderness Areas are designated by Congress and are composed of existing federal lands that have retained a wilderness character and meet the criteria found in the act. Federal officials are required to manage Wilderness Areas in a manner conducive to retention of their wilderness character and must consider the effect upon wilderness attributes from management activities on adjacent lands. The Wilderness Act of 1964 protects congressionally designated wilderness areas from roads, dams, and other permanent structures; from timber cutting and the operation of motorized vehicles and equipment, and, since 1984, from new mining claims and mineral leasing.<br>**NPS Management Policies (2001) §4.3.3 and 6.3 refer to this Act.** |

| EXECUTIVE ORDERS | |
|---|---|
| **Executive Order 11900** (Protection of Wetlands) | |
| **Executive Order 13112 on Invasive Species** | This executive order was signed into law on February 3, 1999, to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause. Among other things, this Executive Order It established the National Invasive Species Council and required the preparation of a National Invasive Species Management Plan to recommend specific, performance-oriented goals and objectives and specific measures of success for Federal agency efforts concerning invasive species. |
| **Executive Order No. 13112: Invasive Species** | This Executive Order prevents the introduction of invasive species and directs federal agencies to not authorize, fund, or carryout actions that it believes are likely to cause or promote the introduction or spread of invasive species. |
| Federal Compliance with Pollution Control Standards Executive Order 12088 | |
| **Floodplain Management** (Executive Order 11988) | Executive Order 11988 was enacted May 24, 1977. It requires all federal agencies to "reduce the risk of flood loss…minimize the impacts of floods on human safety, health and welfare, and…restore and preserve the natural and beneficial values served by flood plains." To the extent possible, park facilities, such as campgrounds and rest areas, should be located outside floodplain areas. Executive Order 11988 is implemented in the National Park Service through Floodplain Management Guidelines (National Park Service, 1993b). It is the policy of the National Park Service to 1) restore and preserve natural floodplain values; 2) to the extent possible, avoid environmental impacts to the floodplain by discouraging floodplain development; 3) minimize the risks to life and property when structures and facilities must be located on a floodplain; and, 4) encourage nonstructural over structural methods of flood hazard mitigation. |
| **Off-Road Vehicle Use** (Executive Orders 11644 and 11989) | Executive Order 11644, enacted February 8, 1972 and amended by Executive Order 11989 on May 24, 1977, regulates off-road vehicle use. If the enabling legislation allows the use of off-road vehicles, NPS is required to designate specific areas for off-road vehicle use. These areas must be "located to minimize damage to soil, watershed, vegetation, or other resources" (Section (3)(a)(1)). If it is determined that such use is adverse to resources, the NPS is to immediately close such areas or trails until the impacts have been corrected. |
| **Protection and Enhancement of Environmental Quality Executive Order 11514** | |
| **Protection of Wetlands** (Executive Order 11990) | Executive Order 11990 was enacted May 24, 1977. It requires all federal agencies to "minimize the destruction, loss, or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands". Unless no practical alternative exists, federal agencies must avoid any activities that have the potential to adversely affect wetland ecosystem integrity. NPS guidance pertaining to this Executive Order is stated in Floodplain and Wetland Protection Guidelines (National Park Service, 1980). |

| SERVICEWIDE (NPS) GOALS AND POLICY: NATURAL RESOURCES AND MONITORING | |
|---|---|
| **Government Performance and Results Act (1993)** | Goal Category I: Preserve Park Resources<br>I.b. The National Park Service contributes to knowledge about natural…resources and associated values; management decisions about resources…are based on adequate scholarly and scientific information.<br>Ib1. Natural Resource Inventories. Acquire or develop 434 of the 2,287 outstanding data sets identified in 1997 of basic natural resource inventories of parks<br>Ib3. Identify Vital Signs for Natural Resource Monitoring. |
| **NPS Management Policies (2001) (NPS Directives System) § 4 Natural Resource Management.** | This is the basic NPS servicewide policy document. It is the highest of three levels of guidance documents in the NPS Directives System. The Directives System is designed to provide NPS management and staff with clear and continuously updated information on NPS policy and required and/or recommended actions, as well as any other information that will help them manage parks and programs effectively<br>States the NPS "will strive to understand, maintain, restore, and protect the inherent integrity of the natural resources, processes, systems, and values of the parks<br>§ 4.1.2. Natural Resource Information.<br>§ 4.2.1. NPS-conducted or –sponsored Inventory, Monitoring, and Research Policies.<br>• "Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.<br>• Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.<br>• Use qualitative and quantitative techniques to monitor key aspects of resources and processes (i.e., "vital signs") at regular intervals.<br>• Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.<br>• Use the resulting information to maintain—and, where necessary, restore—the integrity of natural systems…"<br>§ 4.3.7. World Heritage Sites. "Once an area is designated a world heritage site, the Service will recognize the designation in public information and interpretive programs. Designation as a World Heritage Site will not alter the purposes for which the parks were established, change the management requirements, or reduce NPS jurisdiction over parks." |
| **NPS Directors Orders** | Second level of NPS Directives System. Directors Orders serve a vehicle to clarify or supplement Management Policies to meet the needs of NPS managers.<br>Relevant Directors Orders:<br>DO-2.1 Resource Management Planning<br>DO-12 Environmental Impact Assessment<br>DO-14 Resource Damage Assessment & Restoration<br>DO-24 Museum Collections Management<br>DO-41 Wilderness Preservation & Management<br>DO-47 Sound Preservation & Noise Management<br>DO-77 Natural Resource Protection |
| **NPS Handbooks and Reference Manuals** | This is the third tier in the NPS Directives System. These documents are issued by Associate Directors. These documents provide NPS field employees with a compilation of legal references, operating policies, standards, procedures, general information, recommendations and examples to assist them in carrying out Management Policies and Director's Orders. Level 3 documents may not impose any new servicewide requirements, unless the Director has specifically authorized them to do so.<br>Relevant Handbooks and Reference Manuals:<br>NPS-75 Natural Resources Inventory & Monitoring<br>NPS-77 Natural Resources Management Guidelines<br>NPS Guide to Federal Advisory Committee Act |
| **On-line sources of Information and Websites** | Monitoring Natural Resources in our National Parks, http://science.nature.nps.gov/im/monitor<br>Summary of Legislation, National park Service Policy, and Guidance Relevant to Development and Implementation of Natural Resources Monitoring in National Parks: http://science.nature.nps.gov/im/monitor/LawsPolicy.htm |

## PARK SPECIFIC SUMMARY OF LEGISLATION, INCLUDING SPECIAL DESIGNATIONS

### YOSEMITE NATIONAL PARK: LEGISLATION

| | |
|---|---|
| **Yosemite National Park Enabling Legislation Act of June 30, 1864** | Authorizes a grant to California for the "Yosemite Valley," and for land embracing the "Mariposa Big Tree Grove." This tract was "to be held for public use, resort, and recreation" by the state of California, and to "be inalienable for all time. |
| **Act Of Congress, October 1, 1890** (26 Stat., 650) | Establishes Yosemite National Park as a "forest reservation", excluding Yosemite Valley and the Mariposa Big Tree Grove. |
| **Act of Congress, February 7, 1905** (33 Stat. 702) | Excludes certain lands from Yosemite National Park and includes said lands in the Sierra Forest Reserve. |
| **Act of the Legislature of the State of California, Approved March 3, 1905** | Sec. 1. "The State of California does hereby recede and regrant unto the United States of America the 'cleft' or 'gorge' in the granite peak of the Sierra Nevada Mountains, situated in the county of Mariposa, State of California, and the headwaters of the Merced River, and known as the Yosemite Valley" … and "Sec. 2. The State of California does hereby recede and regrant unto the United States of America the tracts embracing what is known as the 'Mariposa Big Tree Grove…" |
| **Joint Resolution of Congress, June 11, 1906** (34 Stat. 831) | Accepts the 1905 recession by the State of California of the Yosemite Valley Grant and the Mariposa Big Tree Grove. |
| **Act of Congress, December 19, 1913** (38 Stat. 242) | Grants certain lands and rights-of-way within Hetch Hetchy Valley and Lake Eleanor Basin of Yosemite National Park to the City and County of San Francisco for municipal water supply and hydroelectric power development. |
| **Act of Congress, July 23, 1914** (38 Stat. 554) | Authorizes the leasing of lands within Yosemite National Park for business transactions under terms and conditions determined by the Secretary of the Interior. |
| **Act of Legislature of California, April 15, 1919** (Amendment to the California Code) | Cedes to the United States exclusive jurisdiction of Yosemite National Park. |
| **Act of Congress, June 2, 1920** | Accepts cession by California of exclusive jurisdiction over lands embraced within Yosemite National Park. |
| **Act of Congress, May 28, 1928** (45 Stat. 787) | Authorizes the acquisition of 547 hectares (1,350 acres) of land in exchange for 409 hectares (1,010 acres) of land within Yosemite National Park. |
| **Act of Congress, March 2, 1929** (45 Stat. 1486) | Provides for the preservation and consolidation of 4,846 hectares (11,970 acres) of non-federal land to be added to Yosemite National Park by Presidential Proclamation. |
| **Presidential Proclamation No. 1904, April 14, 1930** | Extends the western boundary of the Park to include non-federal timber stands near the Big Oak Flat road. |
| **Act of Congress, February 14, 1931** (46 Stat. 1115 and 1154) | Provides for the withdrawal of 2,293 hectares (5,664 acres) from National Forests to be adds to Yosemite National park by Presidential Proclamation. |
| **Presidential Proclamation No. 2005, August 13, 1932** (47 Stat. 2527) | Extends the southern boundary of the Park to include the Wawona area, by 3,556 hectares (8,784 acres). |
| **Act of Congress, July 9, 1937** (50 Stat. 485) | Provides for the acquisition of 2,769 hectares (6,840 acres) non-federal land to be added to Yosemite National Park by Presidential Proclamation. |
| **Presidential Proclamation No. 7898, May 26, 1938** (50 Stat. 485) | Extends the western boundary of the Park to include non-federal lands near the Tioga Road. |
| **Establishment of an Administrative site for Yosemite National Park 16 USC 47-1** | "(a) Establishment of …" an administrative site for Yosemite National Park. |
| **Act to Establish a Redwood National Park in the State of California, and for Other Purposes 1978** (92 Stat.163) | Enhancing the NPS Organic Act, the Redwood Act of 1978 reaffirmed the primary purpose of the National Park Service as, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress." (16 USC 1a-1 1978). |

| Yosemite: Special Designations | |
|---|---|
| **California Wilderness Act of 1984** (PL 98-425) | In 1984, Congress officially included most of Yosemite National Park in the National Wilderness Preservation System and named it the Yosemite Wilderness. Many other California wilderness areas were established or expanded with the passage of this act. Inclusion of an area in the National Wilderness Preservation System does not change the jurisdictional responsibility for the land – the National Park Service continues to manage the Yosemite Wilderness under the additional requirements for the Wilderness Act of 1964.<br><br>In addition to the designation of wilderness within Yosemite, the California Wilderness Act of 1984 (PL 98-425) designated 83 miles of the Tuolumne River as a Wild and Scenic River; 54 miles are within Yosemite National Park |
| **Wild and Scenic Rivers Act of 1968** as amended (PL 90-542; 16 USC 12371-1287 ? ). | In 1987, an amendment to this Act designated 43 miles of the main stem of the Merced River in Yosemite National Park and 4 miles within the El Portal Administrative Site a Wild and Scenic River. The amendment also designated 25 miles of the South Fork of the Merced within Yosemite National Park. This Act identified distinguished rivers of the nation that possess remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values; preserves the rivers' free-flowing condition; and protects their local environments. NPS Management Policies (2001) §4.3.4.<br><br>In addition to the designation of wilderness within Yosemite, the California Wilderness Act of 1984 (PL 98-425) designated 83 miles of the Tuolumne River as a Wild and Scenic River; 54 miles are within Yosemite National Park.<br><br>Section (5)(d)(I) of the Wild and Scenic Rivers Act states that "[n]o management actions may be taken that could adversely affect the values that qualify a river for inclusion in the National Wild and Scenic Rivers System. |
| **World Heritage Site** (Inscribed 02 November 1984) | Yosemite National Park meets at least two of the four criteria requirements to qualify for the World Heritage List of universally significant natural areas.<br><br>(i) An outstanding example representing the major stages of the earth's evolutionary history.<br>(ii) Contains unique, rare or superlative natural phenomena, formations or features or areas of exceptional natural beauty:<br><br>"Yosemite Valley and the Mariposa Grove of giant sequoias have the honorable distinction of being the first scenic natural areas to have been set aside by a national government for public benefit and enjoyment."<br><br>See also, NPS Management Policies, § 4.3.7. World Heritage Sites |

## PARK SPECIFIC SUMMARY OF LEGISLATION, INCLUDING SPECIAL DESIGNATIONS

### SEQUOIA & KINGS CANYON NATIONAL PARKS: LEGISLATION

| | |
|---|---|
| **September 25, 1890:** (26 Stat. 478, 16 USC 41) | Sequoia National Park established including only the drainage of the South Fork of the Kaweah River—Garfield Grove and Hockett Meadow |
| **October 1, 1890**: (26 Stat. 650) | General Grant National Park established. Sequoia boundary modified to include Giant Forest and its surroundings. |
| **1907** | Permit granted to construct Kaweah No. 3 hydroelectric plant |
| **May 1913** | 50-year permit granted by Secretary of Interior for operation of Kaweah No. 3 |
| **July 3, 1926**: 44 Stat. 818 | Sequoia NP major expansion to Sierra Nevada crest, adding Kern Canyon and Mt. Whitney areas to park. Mineral King Valley is excluded and declared Sequoia National Game Refuge. |
| **March 4, 1940** (54 Stat. 41, 16 USC 80a) | Kings Canyon National Park passed by Congress and boundary is expanded to approximate present condition. |
| **June 21, 1940**: (54 Stat. 2710) | Presidential proclamation establishing Kings Canyon NP adds land in Redwood Canyon ~10,000 acres) to Kings Canyon National Park |
| **December 21, 1943**: (57 Stat. 606) | Authorize acquisition of land now used for Buckeye Housing Area for addition to Sequoia NP, including land exchanges with Southern California Edison. |
| **July 21, 1949** | Sequoia NP boundary change pursuant to 1943 statute. |
| **October 19, 1951** | Sequoia NP boundary change pursuant to 1943 statute. |
| **August 14, 1958**: (P. L. 85-648,72 Stat. 604) | Transfers 10 acres of Sequoia NP(Cabin Cove) as part of Sequoia National Game Refuge, transfers and Summit Meadow to Sequoia National Forest . (72 Stat. 616) Small land exchange between Kings Canyon NP and Sequoia NF. (P.L. 85-666, 72 Stat. 617) adds ~210 acres to Kings Canyon NP at Big Stump. |
| **June 21, 1963**: (P.L 88-47) | Congress directs Secretary of Interior to permit Kaweah No. 3 (power station and associated flumes) |
| **August 6, 1965**: (P. L 89-111, 79 Stat 446) | Tehipite Valley (2659 ac) and floor of Kings Canyon (2879 ac) transferred to Kings Canyon NP from Sierra NF and Sequoia NF, respectively. |
| **November 10, 1978**: (P.L. 95-625) | Mineral King Valley (Sequoia National Game Refuge) added to Sequoia NP |
| **June 19, 1986:** (P.L. 99-338) | 10-year permit granted by Secretary of Interior for operation of Kaweah No. 3 |
| **December 28, 2000**: (P.L. 106-574, 16 USC 45(g) | Secretary of Interior instructed to acquire Dillonwood; boundary change to be automatic. |
| **December 5, 2001** | Took possession of Dillonwood. |

### SEQUOIA & KINGS CANYON NATIONAL PARKS: SPECIAL DESIGNATIONS

| | |
|---|---|
| **Biosphere Reserve** (Designated 1976) | This biosphere reserve comprises Sequoia and Kings Canyon National Parks. From west to east, the two adjacent parks extend from the foothills of the San Joaquin Valley to the crest of the Sierra Nevada and contain the highest parts of that range. Pleistocene glaciers left an abrupt topography of granite carved canyons and domes and hundreds of glacial lakes.<br><br>The most notable vegetation is forests of giant sequoia (*Sequoiadendron giganteum*). Oak woodland (*Quercus douglasii, Q. wislizenii*) and chaparral with *Adenostoma fasciculatum, Arctostaphylos viscida* characterize the lower elevations. Mixed conifer forest with Colorado white fir (*Abies concolor*), red fir (*A. magnifica*), western yellow pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*) and lodgepole pine (*P. contorta*) forests and montane meadows occupy the middle elevations. Subalpine forests with foxtail pine (*P. balfouriana, P. albicaulis*) and meadows, krummholz, and alpine ecosystems typify the higher elevations.<br><br>In addition to their natural diversity, the parks also host a unique cultural and historical record. Archeological sites date back at least five thousand years, indicating the presence of Native American peoples throughout the Sierra Nevada. Past herding of sheep (1850-1900) and cattle (1850-1940) has resulted in significant changes in the species composition and extent of upland and foothill vegetation. Fire suppression during the 20th century has interrupted successional patterns. Air pollution from outside the biosphere reserve affects several prominent tree species. Recreational impact is locally acute. Sequoia National Park contains a number of visitor centers, campsites and supply facilities. |

## PARK SPECIFIC SUMMARY OF LEGISLATION, INCLUDING SPECIAL DESIGNATIONS

### SEQUOIA & KINGS CANYON NATIONAL PARKS: SPECIAL DESIGNATIONS

| | |
|---|---|
| **November 3, 1987** (P.L. 100-150, 101 Stat. 881) Wild and Scenic Rivers Act (16 USC 1274(a) | Amended to add Middle Fork and South Fork of Kings River, including all park segments. |
| **November 24, 1987**: (P.L 100-174 Wild and Scenic Rivers Act (16 USC 1274(a) | Amended to add North Fork Kern River, including all park portions. |
| **California Wilderness Act** (1984) September 28, 1984 (P.L. 94-425, 98 Stat. 1619) | California Wilderness Act establishes Sequoia/Kings Canyon Wilderness. Transfers Jennie Lake Addition to Kings Canyon NP |

### DEVILS POSTPILE NATIONAL MONUMENT: PROCLAMATION

| | |
|---|---|
| **July 6, 1911**<br>**Presidential Proclamation No. 1166**<br>**Wm. H. Taft** | Whereas the natural formations known as the Devil Postpile and Rainbow Falls, within the Sierra National Forest, in the state of California, are of scientific interest, and it appears that the public interests will be promoted by reserving said formations as a National Monument. Now, therefore, I, William H. Taft, President of the United States of America, by virtue of the power in me vested by section two of the Act of Congress approved June 8th, 1906, entitled "An Act for the Preservation of American Antiquities," do proclaim that there are herby reserved from all forms of appropriation under the public land laws, subject to all prior valid adverse claims, and set apart as a National Monument, all the tracts of land in the State of California shown as Devil Postpile National Monument on the diagram forming a part thereof.<br>The reservation made by this proclamation is not intended to prevent the use of the lands for Forest purposes under the proclamation establishing the Sierra National Forest. The two reservations shall both be effective on the land withdrawn, but the National Monument hereby established shall be the dominant reservation and any use of the land which interferes with its preservation or protection as a National Monument is hereby forbidden.<br>Warning is hereby given to all unauthorized persons not to appropriate, injure, remove, or destroy any feature of this National Monument, or to locate or settle upon any of the lands reserved by this proclamation. |

### DEVILS POSTPILE NATIONAL MONUMENT: SEPCIAL DESIGNATIONS

| | |
|---|---|
| **California Wilderness Act** (1984) September 28, 1984 (P.L. 94-425, 98 Stat. 1619) | Established John Muir Wilderness on Inyo National Forest and in Devils Postpile National Monument. |

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix B: Biology, Ecology, Landscape, and Ecosytem Processes in Sierra Nevada Network Parks*

Natural Resource Report NPS/SIEN/NRR—2008/072

Linda S. Mutch
Sierra Nevada Network, Sequoia & Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Meryl Goldin Rose
Sierra Nevada Network Inventory & Monitoring Program
Yosemite Field Station
P.O. Box 700, El Portal, California 95318

Andrea M. Heard
Sierra Nevada Network, Sequoia & Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Rosamonde R. Cook, Ph. D.
528 Spruce Street
Riverside, CA 92507

Gary L. Entsminger
Acquired Intelligence, Inc.
23625 V66 Trail
Montrose, CO 81401

With Contributions from:
Tony Caprio, Laura Clor, Annie Esperanza, Sandy Graban, Liz van Mantgem.

Layout, design and illlustration Figure B–2, page 6: Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Mutch, L. S., Goldin Rose, M., Heard, A. M., Cook, R. R., and Entsminger, G.L. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix B. Natural history, biology, ecology, ecosystems, and landscapes of the Sierra Nevada Network parks. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Table of Contents


Part I. Biology, Ecology, Ecosystems, and Landscape Processes
of Sierra Nevada Parks ..... 15
Physical Setting ..... 16
Climate ..... 16
Geology & Soils ..... 16
Air Resources ..... 18
Water Resources ..... 18
Fire: A Key Process ..... 19
Plant and Animal Diversity ..... 21

Part II. Sierra Nevada Network: The Parks ..... 25
Devils Postpile National Monument ..... 25
Purpose and Significance ..... 25
Description of Resource Values ..... 26
Visitation ..... 28
Facilities ..... 28
Sequoia and Kings Canyon National Parks ..... 29
Purpose and Significance ..... 29
Description of Resource Values ..... 30
Yosemite National Park ..... 32
Purpose and Significance ..... 32
Description of Resource Values ..... 33
Overview of Biologicl Diversity, Ecological Integrity and Resource Issues ..... 35
References ..... 41

## Figures

Figure B-1. Sierra Nevada Network parks in regional context ..... 15
Figure B-2. Sierra Nevada physical setting ..... 16
Figure B-3. Watersheds in Sierra Nevada Network parks ..... 19
Figure B-4. Mean fire-return intervals for major vegetation or cover classes in Sequoia and Kings Canyon National Parks ..... 22
Figure B-5. Sierra Nevada vegetation zones along west to east gradient ..... 23
Figure B-6. Devils Postpile National Monument and surrounding area ..... 25
Figure B-7. Sequoia and Kings Canyon National Parks ..... 30
Figure B-8. Yosemite National Park ..... 33

## Tables

Table B-1. Mean and maximum fire return intervals for major vegetation classes in Sierra Nevada parks. ..... 21
Table B-2. Vascular plant species documented in Sierra Nevada parks. ..... 24
Table B-3. Vertebrate species documented in Sierra Nevada parks ..... 24

Sierra Nevada Network parks lie within the Sierra Nevada, the highest and most continuous mountain range in California. The range runs 692 km from north to south, is up to 113 km wide, and encompasses almost 75,520 sq. km. The range is flanked by California's Central Valley on the west and the arid western edge of the Great Basin on the east (Figure B–1).

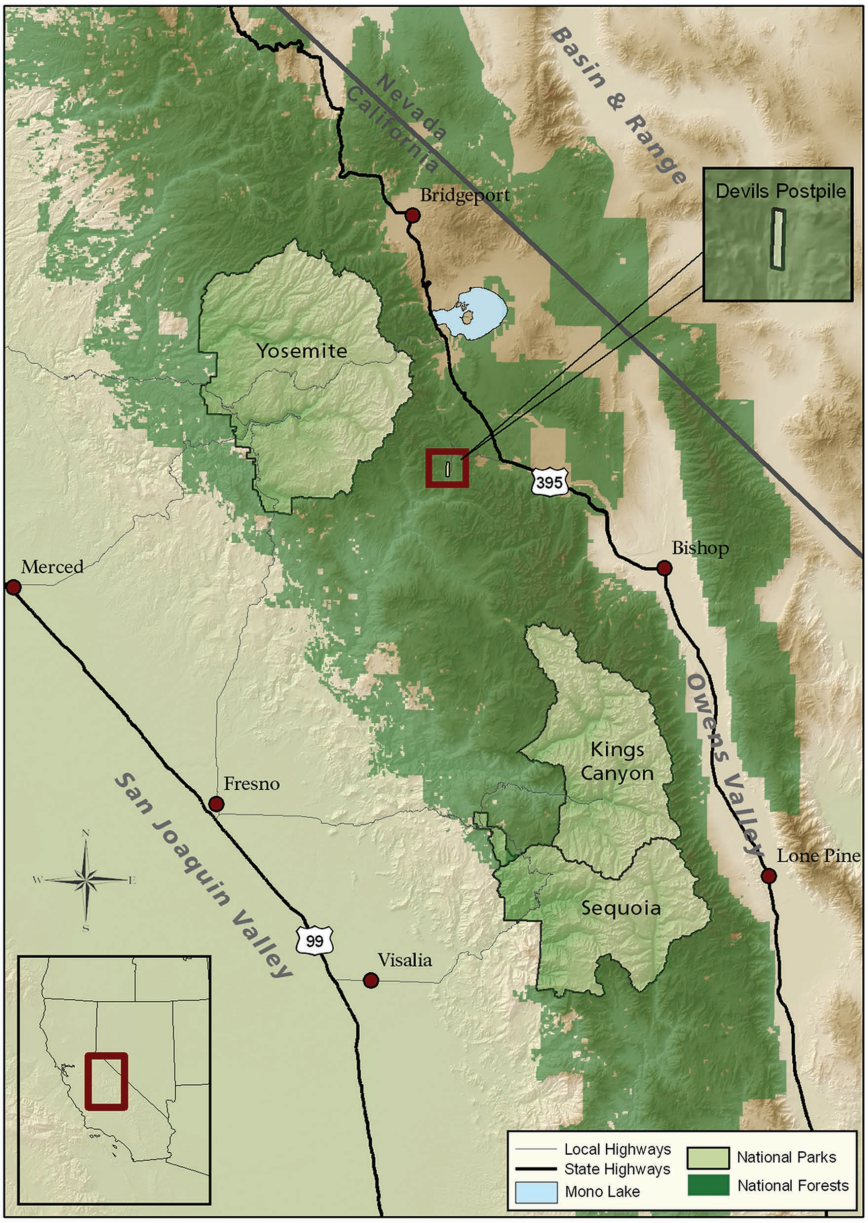
Humans have been part of Sierra Nevada ecosystems for at least 9,000 years B.P. (Roper Wickstrom 1992). Numerous, distinct American Indian groups were widely distributed throughout the region well before settlement by Euramericans in the mid-19th century. Although the record is incomplete, archaeological evidence indicates that, prior to the 1850s, the American Indian population in the Sierra Nevada may have been as large as 90,000 to 100,000 people (Anderson and Moratto 1996).

Settlement patterns and resource use have historically reflected the export value of Sierra Nevada resources as commodities. The foothills became a focus of early attention for "Mother Lode" gold deposits, timber, water, and agriculture. An estimated 150,000-175,000 Euramericans moved into the Sierra Nevada from 1848 to 1860. The population in 1970 was about 300,000, and by 1990, over 650,000 people were living in the Sierra. About 70% of the current population is located on the west-side foothills, with other concentrations in the vicinities of the main Sierran highways. Projections suggest that the Sierra Nevada population will grow between 1.5 and 2.4 million residents by 2040 (SNEP 1996a).

The following sections contain an overview of the physical environment, the important role of fire, biological diversity and the major stressors and management issues for the Sierra Nevada region and parks.

For readers who wish additional information about the larger Sierra Nevada region, see Sierra Nevada Ecosystem Project (SNEP), a detailed report requested by Congress in the Conference Report for Interior and Related Agencies in 1993 Appropriation Act (H.R. 5503), which authorized funds for a "scientific review of the remaining old growth in the national forests of the Sierra Nevada. . ., and for a study of the entire Sierra Nevada ecosystem by an independent panel of scientists, with expertise in diverse areas related to this issue" (SNEP 1996b). The report is a four-volume scientific assessment by an interdisciplinary team of scientists from land management agencies (primarily National Park Service and US Forest Service), universities, and private consulting groups. SNEP highlights what is known about physical, biological, ecological, social and institutional

**Figure B–1.** Sierra Nevada Network parks in the context of the larger region: Central Valley and Pacific Ocean to the west, and Great Basin to the east.



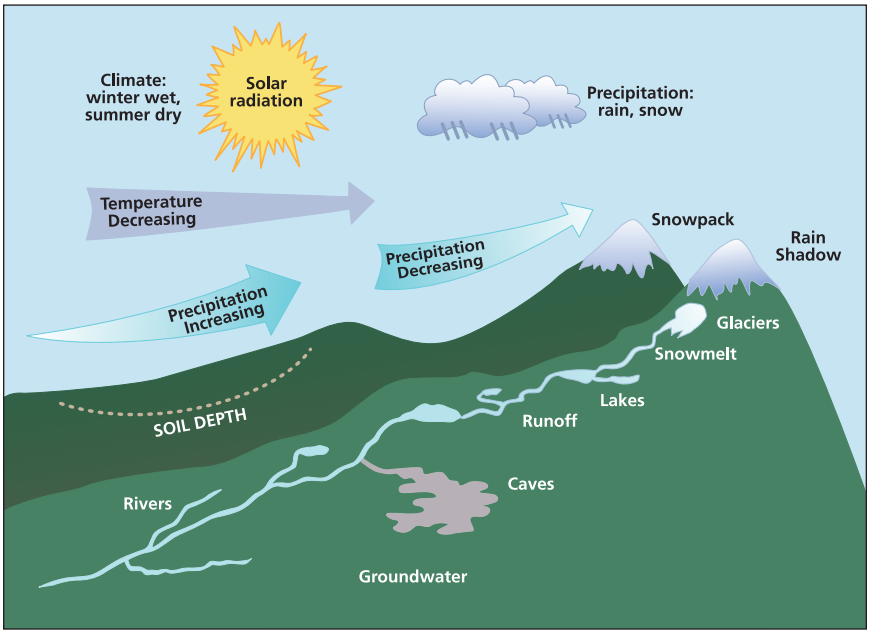



**Figure B–2.** The Sierra Nevada physical setting illustrates the elevational gradient from the Central Valley and foothills (left side of image), up to the Sierra Nevada crest, and dropping back down more steeply along the east slope (right side of image). Climatic, geologic, and hydrologic processes and features change along this gradient.

conditions for the Sierra Nevada region and presents individual and collective judgments about what this knowledge means for protecting the health and sustainability of Sierra Nevada ecosystems while providing resources to meet human needs.

## Physical Setting

The Sierra Nevada is a tilt block asymmetric mountain range with a short, steep east escarpment. The western flank has a longer and gentler slope in Yosemite and the northern Sierra Nevada. Farther south, in Sequoia National Park and elsewhere in the southern Sierra Nevada, the western flank is much steeper, rising from near sea level to 4,818 meters in less than 100 kilometers. This striking elevational gradient characterizes the physical environment in the three large network parks (YOSE, SEQU, KICA) and creates coincident gradients in climate that drive the distribution of plants and animals. Climatic, geologic, and hydrologic processes have dramatic effects in the Sierra Nevada (Figure B–2): concomitantly, changes in these processes have dramatic effects on Sierra Nevada ecosystems.

## Climate

Strong climatic gradients develop with changing elevation in the Sierra Nevada, from west to east. Low to mid-elevations have a Mediterranean climate, characterized by hot, dry summers and cool, wet winters. Higher elevations are dominated by a microthermal (or Boreal) climate, characterized by having average temperatures of below -3°C during the coldest month. As a result, a steep temperature gradient parallels the elevation gradient; on average, each 100 m gain in elevation results in a 0.6 C° drop in air temperature. This lapse rate varies locally according to factors such as air speed, relative humidity, slope aspect, insolation, and vegetation cover (Stephenson 1988), but the general pattern holds true as one climbs from the hot lowlands to the alpine crest.

The west slope of the Sierra receives between 50 and 200 cm of rainfall each year, depending on elevation. Above 2100 m on the western slope, about 50% of precipitation falls as snow (Stephenson 1988), creating a significant snowpack in the montane and subalpine elevations. Just as mean temperature decreases with increasing elevation, so does the moisture-holding capacity of air. By the time winter storms reach the alpine, much of the moisture has been lost from the clouds and the amount of snow accumulating on the ground begins to decline with increasing elevation. East of the crest, the mountains create a rain shadow with significantly less moisture falling throughout the season. Precipitation also increases with latitude, due to Pacific jet stream position and subtropical high pressure cells. Across all elevations and latitudes, nearly 70% of precipitation falls from December through March and only about 4% from June through September (Stephenson 1988).

Climatic forces are a major driver of Sierra Nevada ecosystems. Current patterns of vegetation, water dynamics, and animal distribution in the Sierra are determined largely by cumulative effects of past and present climates.

## Geology & Soils

The Sierra Nevada batholith is part of a more or less continuous belt of

plutonic rocks that extends from the Mojave Desert to northwestern Nevada (Bateman et al. 1963). These granitic magmas intruded into preexisting metasedimentary and metavolcanic country rocks from ~215- 70 million years ago, and were subsequently uplifted and tilted to the west, giving the range its asymmetric geometry with a short, steep east escarpment and a longer and gentler west slope (Whitney 1880, Lindgren 1911, Matthes 1960). Metamorphic units are still present as isolated roof pendants near the Sierra crest (Huber et al. 1989). With the onset of uplift, the erosive power of major streams was intensified due to their increased gradients, resulting in greater rates of incision and rolling hills that gave way to higher relief mountains with deep canyons cutting into the range's west flank (Huber 1987).

On the eastern flank of the mountains, volcanic activity at ~100 thousand years ago sent a lava flow into a valley, now designated Devil's Postpile NM, which cooled uniformly, contracted, and fractured into hexagonal columns. At ~10 thousand years ago, this formation was overridden by glaciers, exposing the columns. Evidence of the glacier—polish and scratches from glacial ice—remains atop the postpile (Clow and Collum 1986).

Several glacial periods in the Sierra Nevada, beginning at ~1 million years ago and lasting until ~10 thousand years ago, periodically covered much of the higher elevations of the Sierra Nevada parks and sent glaciers down many of the valleys (Yount and La Pointe 1997). Glacial ice quarried and transported vast volumes of rubble, which scoured and eroded the landscape. Small quantities of this debris accumulated along the margins of the glaciers and in widely distributed, hummocky piles called moraines. Landforms resulting from glaciation include U-shaped canyons, jagged peaks, rounded domes, waterfalls, and moraines. Granite that has been highly polished by glaciers is common in the parks and provides further evidence of glaciation. The innumerable natural lakes in the high Sierra Nevada are the result of glacial activity forming their basins. These lakes are transitory; eventually they will be filled with sediment and become meadows. Many lakes in the parks already have undergone this transformation (Huber 1987).

Sequoia and Kings Canyon National Parks contain more than 200 named caves (Despain 2003). The caves occur at elevations from 488 to 3,048 m, and include the longest cave in California, Lilburn Cave, with nearly 32 km of surveyed passage. Lilburn is a very complex maze cave with beautiful blue- and white-banded marble. Crystal Cave, developed with lights and trails at the end of the Great Depression, is one of the area's most popular tourist destinations. The caves provide unique habitats for animals, including bats, salamanders, small mammals, and invertebrates, some of which are endemic to specific caves (Despain 2003).

Soil and water chemistry characteristics in the Sierra Nevada are largely geologically controlled. Because the Sierra Nevada is underlain by mostly granitic rocks, soils that derive from these foundations are poorly developed, rocky, and generally low in fertility. Soils are thin due to recent glaciation, but tend to be thicker where not glaciated. In general, soil depth decreases with increasing elevation; deep alluvial soils of the Central Valley give way to shallow, decomposed granites and barren rock outcrops in alpine environments (Taskey 1995).

River basins are often underlain by surficial deposits, which are primarily glacial tills that occur in valley bottoms as lateral and recessional moraines, and are probably derived from the granitic bedrock present at higher elevations (Huber 1987, Bateman 1992). Stream water concentrations of chemical constituents such as cations, alkalinity, and silica tend to be higher in catchments with a high percentage of surficial cover (Clow et al. 1996), reflecting the importance of glacial till in controlling water chemistry. Bedrock geology across the Sierra Nevada is dominated by granitic intrusive rocks of fairly uniform composition (Huber 1987, Bateman 1992); however, slight variations in bedrock composition are reflected in the chemistry of surface

waters. For example, according to Clow et al. (1996), streams of Yosemite in the upper Merced River basin that drain granite and light-colored granodiorite terranes have relatively low Ca:Na ratios, while streams that drain dark-colored granodiorites and tonalites tend to have higher ratios. These few preceding examples exhibit how the fundamental ecosystem building blocks of water and soils are inextricably linked to the underlying geology in the Sierra Nevada.

## Air Resources

Kings Canyon, Sequoia, and Yosemite National Parks are designated Class I air sheds under the Clean Air Act (1977 amendment). As such, the parks are afforded the greatest degree of air quality protection, and the National Park Service is required to do all it can to ensure that air quality related values are not adversely affected by air pollutants. Devils Postpile National Monument is designated a Class II air shed. There is still a mandate to protect Class II air sheds; however, it is not as stringent compared to Class I air sheds. Despite these designations, air quality in the Sierra Nevada is impaired, threatening natural resources, human health, and visitor experiences *(See section 1.7, Sierra Nevada Ecosystem Stressors in Vital Signs Monitoring Plan, and also Appendix C)*.

In addition to air quality, Sierra Nevada parks contain other air resources, including night sky and natural soundscapes that are intrinsic elements of the environment (just as water and wildlife are intrinsic values). Night sky visibility is an important aesthetic value of wilderness and its protection has been added to the responsibilities of National Park Service managers. Light pollution is not confined to cities. Excessive glare, urban sky glow, and poorly designed lighting threaten dark skies in the Sierra Nevada. Natural soundscapes are inherent components of "the scenery and the natural and historic objects and the wild life" and are protected by the National Park Service's Organic Act. They are vital to the natural functioning of many parks and may provide valuable indicators of ecosystem condition (National Park Service 2001).

## Water Resources

SIEN parks span seven major watersheds: Tuolumne, Merced, San Joaquin, Kings, Kaweah, Kern and Tule (Figure B–3). Runoff from these watersheds drains into the San Francisco Bay/Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south. Yosemite, Sequoia, and Kings Canyon parks contain most of the headwater streams. Devils Postpile National Monument is located within the upper Middle Fork of the San Joaquin watershed. The headwaters of the Middle Fork of the San Joaquin begin 14.1 km upstream of the monument at Thousand Island Lake. The watershed area above the monument is managed by Inyo National Forest. The Sierra Nevada parks protect a diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs and karst springs.

Water dynamics in the Sierra Nevada are a critical component of both the parks' ecosystems and the larger California water infrastructure. The snow pack acts as a temporary reservoir, storing water that will be released during the warmer and drier months. Peak runoff typically occurs late May to early June. Water is captured and stored for summer use in a series of reservoirs in the Sierra foothills. Reservoirs are primarily located downstream of park boundaries, although there are exceptions, including Hetch Hetchy and Lake Eleanor in Yosemite and four small dams in Sequoia.

Sierra Nevada ecosystems produce approximately $2,200,000,000 in annual revenue. Water accounts for more than 60% of these dollars (SNEP 1996b). Primary uses include irrigated agriculture, domestic water supplies, hydroelectric power, recreation and tourism. Water resources and associated aquatic and riparian habitats also have high ecological value. Approximately 21% of vertebrates and 17% of plants in the Sierra Nevada are associated with aquatic habitats (SNEP 1996b).

The California Water Resources Control Board (WRCB) 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 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. Sierra Nevada Network 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 under the Clean Water Act. Sierra Nevada Network parks do not have any Outstanding Natural Resource Waters, but waters in national parks are strong candidates for this designation.

There are four Wild and Scenic Rivers in the parks—the Middle and South Forks of the Kings River (98.5 km) and the North Fork of the Kern River (46.5 km) in Sequoia and Kings Canyon, and the Merced (130.0 km) and Tuolumne (87.0 km) rivers in Yosemite.

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




**Figure B–3.** Watersheds in Sierra Nevada Network parks.

Sequoia, Kings Canyon and Yosemite protect some of the least altered aquatic ecosystems in the Sierra Nevada.

*See Appendix D for a more detailed description of Sierra Nevada water resources.*

## Fire: A Key Process

Fire has played a pivotal role in shaping ecosystems and landscapes in the Sierra Nevada for many millennia (Davis and Moratto 1988, Smith and Anderson 1992, SNEP 1996a, Anderson and Smith 1997). It affects numerous aspects of ecosystem dynamics such as soil and nutrient cycling, decomposition, succession, vegetation structure and composition, biodiversity, insect outbreaks, and hydrology (Kilgore 1973, SNEP 1996a). Historically, fire frequency, size, intensity, and severity varied spatially and temporally across the landscape depending on number of ignitions, climate, elevation, topography,

vegetation, fuels, and edaphic conditions (Skinner and Chang 1996). Fires were common, often burning for months and reaching large sizes.

Periodic fires performed many ecological functions within Sierran ecosystems prior to Euramerican settlement. Frequent surface fires in many vegetation types minimized fuel accumulation while their variable nature helped create diverse landscapes and forest conditions (Stephenson et al. 1991, SNEP 1996a). Fires tended to be low to moderately severe, with highseverity portions (intense enough to kill most large trees) generally restricted to localized areas of a fraction of an acre to a few acres. Extensive research in mixed-conifer forests has shown that low intensity surface fires were common and tended to keep the forests open (Biswell 1961, Hartesveldt and Harvey 1967, Weaver 1967, Kilgore 1971, 1972, Weaver 1974, Harvey et al. 1980).

Many species and most plant communities show clear evidence of adaptation to recurring fire, indicating that fire occurred regularly and frequently, particularly in the chaparral and mixedconifer communities, where many plant species have life history attributes tied to fire for reproduction or as a means of competing with other biota. Fire damaged or killed some plants, setting the stage for regeneration and vegetation succession. Many plants evolved fire-adapted traits, such as thick bark, and fire-stimulated flowering, sprouting, seed release, and/or germination (Chang 1996). Fire influenced soil and forest floor processes and organisms by consuming organic matter and inducing thermal and chemical changes. It also affected the dynamics of biomass accumulation and nutrient cycling at a variety of spatial scales. These effects in turn influenced habitats and the distribution and occurrence of many species.

Fire regimes are defined according to specific variables including frequency, severity, season, duration, magnitude, spatial distribution, and type of fire (Gill 1975, Heinselman 1981). These characteristics may vary through time and across the landscape in response to climatic variation, number of lightning ignitions, topography, vegetation, historic events, and cultural practices (SNEP 1996a). Fire regime types for major Sierra Nevada plant communities vary from shortinterval, low-intensity surface fires in ponderosa pine and blue oak woodland to long-interval, variable intensity fires that occur in lodgepole pine forests and include numerous other fire regimes in diverse vegetation types of the Sierra Nevada.

Variation in fir frequency exists locally and at large scales, and is affected by site productivity, potential for ignition, and other factors. General patterns of pre-Euramerican fire frequencies are apparent at several scales in the parks. Differences in average fire frequency are also apparent in different vegetation types (Table B- 1 and Figure B- 4). On the west slope of the Sierra, frequencies were reconstructed using fire-scarred trees. Data show an inverse relationship between number of fires and elevation (Caprio and Swetnam 1995, Swetnam et al. 1998, Caprio 2000).

Short-term climatic variation had a significant impact on past burn patterns and fire severity. Historically, on the west slope of the Sierra Nevada, specific fire years have been identified (years in which fires have been recorded at sites throughout the southern Sierra Nevada). These usually occurred during dry years (Brown et al. 1992, Swetnam et al. 1992, Swetnam 1993, Swetnam et al. 1998). Analysis of millennial-length fire histories from giant sequoias also document long-term variation (1,000-2,000 years) in the fire regime associated with climatic fluctuations (Swetnam 1993). These data suggest more frequent but smaller fires occurred during the Medieval Warm Period (A.D. 1000 - 1300) and fewer larger fires during cooler periods (A.D. 500 - 1000 and after A.D. 1300). These fluctuations indicate that characteristics of fire regimes are dynamic over long time periods.

Although fire regime characteristics may vary through time and across the landscape, from the late 1890s through the 1960s, Sierra Nevada park and

**Table B- 1.** Mean and maximum fire return intervals for major vegetation classes in Sierra Nevada Parks. The table also includes quality of the knowledge used to calculate or estimate fire return intervals and sources used to obtain this information.

| VEGETATION CLASS | MEAN (MAX) FIRE INTERVAL-YEARS | KNOWLEDGE | REFERENCE |
|---|---|---|---|
| **Very Low Fire Frequency** | | | |
| Lodgepole Pine | 102 (163) | v. poor | 5, 6,18 |
| Subalpine Conifer | 187 (508) | poor | 5, 9 |
| **Low Fire Frequency** | | | |
| Red Fir Mixed-conifer | 30 (50) | poor | 1, 4, 5 |
| Xeric Mixed-conifer | 30 (50) | v. poor | 5, 7, 8, 17 |
| Montane Chaparral | 30 (75) | estimated | 12 |
| Meadow | 40 (65) | estimated | 8 |
| Foothills Chaparral | 30 (60) | estimated | 12 |
| **Moderate Fire Frequency** | | | |
| Foothills Hardwood & Grassland | 10 (17) | v. poor | 5, 10, 11 |
| Mid-elevation Hardwood | 7 (23) | v. poor | 3, 19 |
| **High Fire Frequency** | | | |
| White Fir Mixed-conifer | 10 (16) | good | 1, 2 |
| Giant Sequoia | 10 (16) | good | 13, 14, 15 |
| **High Fire Frequency** | | | |
| Ponderosa Mixed-conifer | 4 (6) | good | 1, 2, 3, 16, 17 |

Notes: Data are prior to 1860 (1870 for subalpine conifer). Primary source(s) also listed in References. Fire frequency regime classes for each major vegetation class are based on mean maximum fire-return intervals (i.e., average of the longest fire-return intervals). Frequency classes were used to reconstruct fire frequency regimes spatially across the parks.

national forest personnel attempted to suppress all fires, and these efforts met with a fair degree of success. Consequently, numerous ecosystems that had evolved with frequent fires have since experienced prolonged periods without fire (Swetnam et al. 1992, Swetnam 1993, Caprio and Graber 2000, Caprio et al. 2002, Caprio and Lineback 2002). This change in fire regime has severely modified ecosystems. See Appendix F, *"Conceptual Models"*—Stressors.

1(Caprio and Swetnam 1993, 1994, Caprio and Swetnam 1995); 2 (Kilgore and Taylor 1979); 3 (Stephens 1997) unpublished data in (Skinner and Chang 1996); 4 (Pitcher 1981, 1987); 5 Caprio unpublished data 2000 ; 6 (Keifer 1991); 7 Taylor, unpublished data in (Skinner and Chang 1996); 8 Skinner, unpublished data in Skinner and Chang 1996; 9 Caprio, Mutch, and Stephenson unpublished data ; 10 (Mensing 1992); 11 (McClaren and Bartolome 1989); 12 (SNEP 1996a); 13 (Swetnam et al. 1990); 14 (Swetnam et al. 1992); 15 (Swetnam 1993); 16 (Warner 1980); 17 (McBride and Jacobs 1980); 18 (Sheppard 1984); 19 (Stephens 1997).

## Plant and Animal Diversity

The striking elevational gradient and topographic variability in the Sierra Nevada result in a high diversity of habitats for plants and animals. Sequoia, Kings Canyon and Yosemite National Parks, the largest and least fragmented habitat blocks in the Sierra Nevada, are recognized for their importance in protecting the long-term survival of certain species and the overall biodiversity of vegetation and wildlife in the region (SNEP 1996a).

The parks' vegetation can be categorized broadly into the following vegetation zones: oak woodland, chaparral scrubland, lower montane, upper montane, subalpine, and alpine. Vegetation changes dramatically along west-east elevation gradients from the lowest elevation oak woodlands up to ancient foxtail pines and western juniper, krumholz whitebark pine, and alpine perennial herbs at the highest elevations.

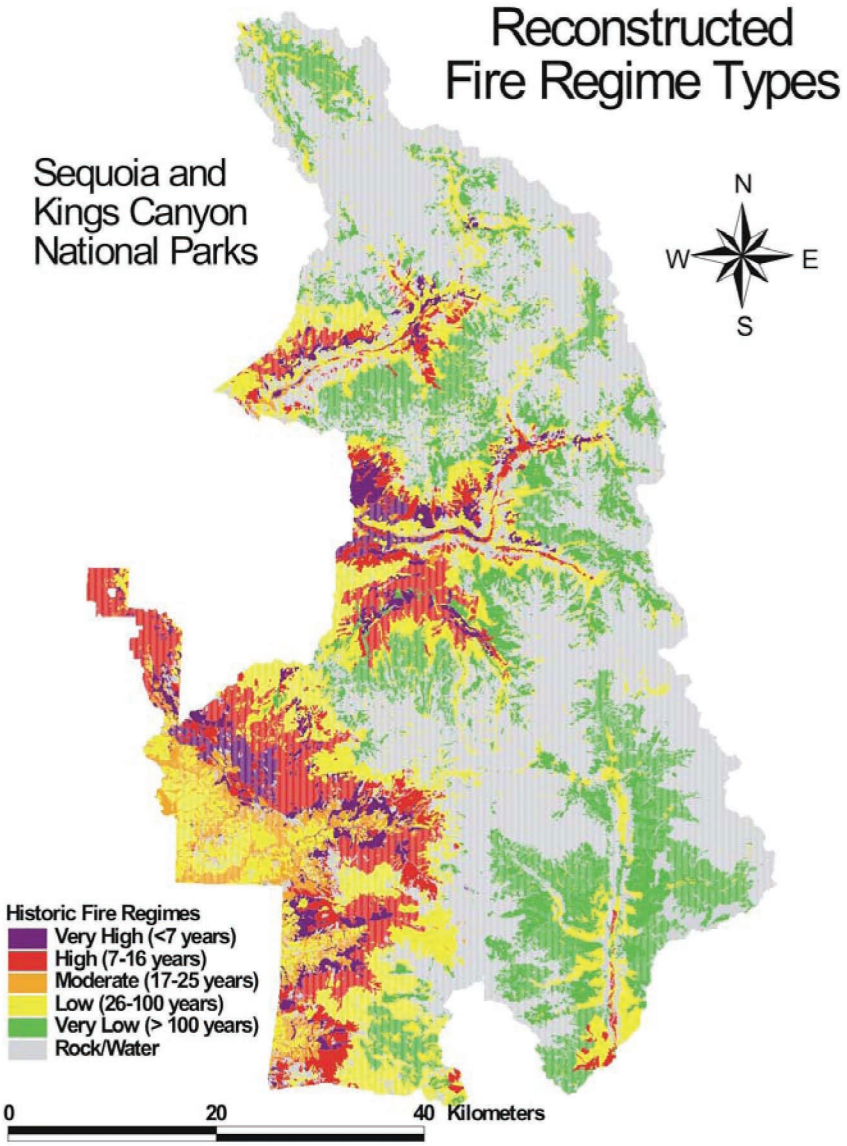



**Figure B–4**. Mean fire-return intervals (i.e., historic fire regimes), or mean time between fires, for different vegetation or cover classes in Sequoia and Kings Canyon National Parks (Caprio and Lineback 2002). Sources used to construct these fire regime types are summarized above in Table 1-3. A similar map exists for Yosemite National Park (van Wagtendonk et al. 2002).

While the parks' eastern boundaries are along the Sierra Nevada crest, some areas have plant communities showing a mix of west and east slope affinities, such as Devils Postpile National Monument (Arnett and Haultain 2004). Sparse forests on the upper east slope of the Sierra Nevada grade into semi-arid Great Basin scrublands in the mountains' rain shadow (Figure B- 5).

In its entirety, the Sierra Nevada region supports over 3,500 native vascular plant species, comprising half of the approximately 7,000 vascular plant species in California. Sierra Nevada parks support more than 20% of this California total.

All parks have had vegetation inventories done that are of value as baseline data for long-term monitoring. These include vegetation maps, Natural Resource Inventories in the 1990s in Sequoia, Kings Canyon, and Yosemite (Graber et al. 1993), a vascular plant inventory in Devils Postpile (Arnett and Haultain 2004), and rare plant surveys for individual park units (in progress, and Moore 2006).

In its entirety, the Sierra Nevada region supports over 3,500 native vascular plant species, comprising half of the approximately 7,000 vascular plant species in California. Sierra Nevada parks support more than 20% of this California total. DEPO data (Arnett and Haultain 2004), SEKI data (Norris and Brennan 1982, Stokes 2003); YOSE data (Botti 2001, Gerlach et al. 2002, Johnson 2003, Moore 2003, Stokes 2003 )(Table B- 2).

Bryophyte collections have been made in all Network parks (Steen 1988, Norris and Shevock 2004b, a, Shevock In progress). Surveys have documented 350 moss species in the southern Sierra Nevada region; 300+ species are estimated to occur in the central Sierra Nevada region (Shevock 2002). Lichen surveys have been limited (Smith 1980, Wetmore 1986); however, estimates suggest approximately 250 macrolichen and a similar number of crustose species could occur in Sierra Nevada parks (Neitlich 2004).

Table B- 3 lists vertebrate species documented in Sierra Nevada parks. The Sierra Nevada range includes about two-thirds of the bird and mammal species and about half the amphibians and reptiles in the state of California (Graber 1996), and supports over 280 native vertebrates, including fishes. Approximately 300 terrestrial vertebrate species use the Sierra Nevada as a significant part of their range; another 100 species use the Sierra Nevada as a minor part of more extensive home ranges: of 401 terrestrial species (not including fishes) documented for the Sierra Nevada, 232 are birds, 112 are mammals, 32 are reptiles, and 25 are amphibians (Graber 1996).

The foothills of the parks become

increasingly important as similar areas outside park boundaries succumb to heavy grazing and residential development. Most plant communities in the parks are comprised of native plant species, but foothill woodlands are dominated by non-native annual grasses introduced to California during the mid 19th century. Low elevation chaparral communities are dominated by dense thickets of thick-leaved shrubs. Many of these shrubs exhibit adaptations to fire and drought, both of which strongly influence the foothill environment. Particularly important resources to wildlife in these areas include blue oak (*Quercus douglasii*) acorns and chaparral shrub berries (especially manzanita) as well as other forage and cover.

Sierra Nevada montane forests form some of the most extensive stands of old growth mixed-species coniferous forest remaining in the United States. These mixed-coniferous forests support a remarkable diversity of tree species: ponderosa pine (*Pinus ponderosa*), incense-cedar (*Calocedrus decurrens*), white fir (Abies concolor), red fir (*Abies magnifica*), sugar pine (*Pinus lambertiana*), and giant sequoia (*Sequoiadendron giganteum*).

Giant sequoias occur naturally only in the Sierra Nevada, where they are found in approximately 75 separate groves. The 42 named groves in Kings Canyon, Sequoia, and Yosemite contain roughly one-third of all naturally occurring sequoia trees.

As one moves higher in elevation to the upper montane zone, mixed-coniferous forest is replaced by nearly pure stands of red fir and lodgepole pine (*Pinus contorta*), with some Jeffrey pine (*Pinus jeffreyi*), and western juniper (*Juniperus occidentalis*). Lodgepole pines tend to occur in moist lowlands, as well as in drier sites on benches and ridges. Animal diversity is at a maximum in lower and upper montane forest habitats, due to the relatively mild climate, and the mixture of habitat types and plant species present.

In the subalpine zone, western white pine (*Pinus monticola*), mountain hemlock (*Tsuga mertensiana*), lodgepole pine (*Pinus contorta*), foxtail pine (*Pinus balfouriana*), and stands of whitebark pine (*Pinus albicaulis*) intermix with subalpine meadows and lakes. In rocky alpine areas, where very short growing seasons and harsh winter conditions exist, trees give way to low-growing, perennial herbs. Plants often form ground-hugging mats or hummocks as a result of warmer temperatures closer to the surface. Winter snow provides insulation from extreme low temperatures and desiccating winds. Although exposed granite outcroppings, talus slopes, and boulder fields dominate this zone, these rocky habitats support a surprisingly rich flora.

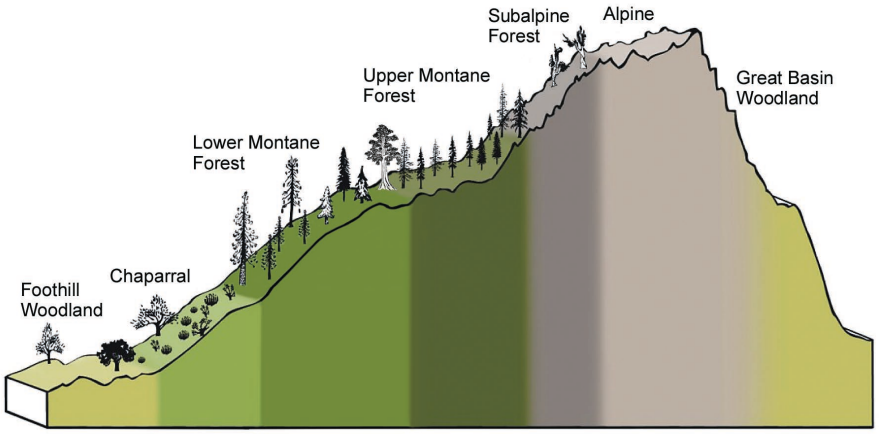
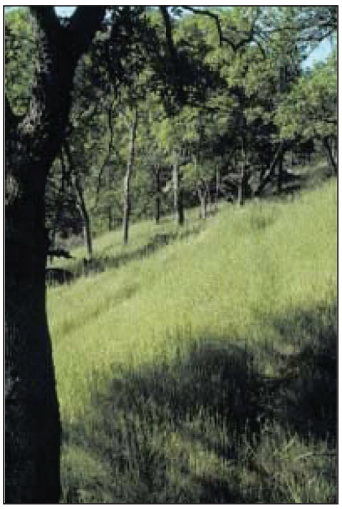



**Figure B–5.** Sierra Nevada vegetation zones along its west-to-east elevation gradient, from the Central Valley and foothills, up to the Sierra Nevada crest, and down its east slope. The diverse topography results in high diversity of plants and animals. Illustration by Justin Hofman.



Blue oak woodland

Clark's Nutcrackers are specialized for feeding on large pine seeds. Its behavior, annual cycle, and even its morphology are closely tied to this diet and thereby closely tied to subalpine white pine forests. Alpine talus fields are inhabited by pikas, marmots, voles, mice, shrews; endangered toads, many diverse invertebrate assemblages, and various other types of animals. Scattered bands of Sierra bighorn sheep (a federally endangered species), can still be found in some of the highest and most remote areas along the crest.

Meadows and wetlands, while occupying a small fraction of the land area in the Sierra Nevada, are a key ecosystem element in the Sierra Nevada. Meadows are extremely productive ecosystems, and provide critical breeding and

**Table B-2.** Vascular plant species documented in Sierra Nevada parks.

| | DEPO | SEKI | YOSE |
|---|---|---|---|
| **Vascular Plant Taxa** | 380 | 1,494 | 1,561 |
| **Special Status spp.** | 0 | 138 | 160 |
| **Non-native spp.** | 8 | 2151 | 1602 |

Data source: NPSpecies (https://science1.nature.nps.gov)
[1] Of these, 100 species do not occur in YOSE.
[2] Of these, 45 species do not occur in SEKI.

**Table B-3.** Vertebrate species documented in Sierra Nevada parks.

| | DEPO | SEKI | YOSE |
|---|---|---|---|
| **Birds** | 118 | 220 | 283 |
| **Mammals** | 35 | 91 | 88 |
| **Amphibians** | 1 | 13 | 13 |
| **Reptiles** | 8 | 26 | 23 |
| **Fishes** | 5 | 19 | 11 |

Data source: Data source: NPSpecies (https://science1.nature.nps.gov)



Red fir forest

foraging habitat for a suite of animal species in the Sierra Nevada. Recent work demonstrated the importance of Sierra Nevada meadows as breeding grounds for invertebrates, which form the energetic basis of many food chains (Holmquist and Schmidt-Gengenbach 2005). Many insects breed in meadows, and then disperse into adjacent forests and woodlands as the season progresses, where they are important as food sources and as pollinators. Dozens of bird species, including the federally endangered Willow Flycatcher and the state-listed Great Grey Owl, use meadows for foraging, nesting, or both. Mule deer take advantage of the cover provided by montane meadow vegetation by hiding their fawns under the dense herbaceous canopy. Small mammals, such as ground squirrels, pocket gophers, and voles, feed on both above and below ground meadow vegetation. Animals such as frogs, toads, and shrews frequent the moist vegetation edging stream channels.

Aquatic systems (lakes, ponds, streams and rivers) are some of the most biologically impaired systems in the Sierra Nevada. While altered hydrology (diversions, dams) plays a lesser role impacting aquatic life in the parks compared to outside the parks, they are locally important in some developed areas and at Hetch-Hetchy Reservoir in Yosemite. The introductions of nonnative fish to Sierra Nevada lakes and bull frogs to lower elevation lakes and stream courses have had devastating effects on native biota. Foothill yellow-legged frogs are extirpated, and mountain yellow-legged frogs and Yosemite toad are warranted (but currently precluded) for federal listing as endangered. In addition to feeding on tadpoles, non-native fish have altered invertebrate community composition (Stoddard 1987, Matthews et al. 2002), affecting food sources for other animals such as aquatic snakes and Pacific tree frogs (Matthews et al. 2002) and birds (Knapp et al. 2005).

The parks support a large number of special status, rare, or endemic species (NPSpecies (https://science1.nature.nps.gov). Rare local geologic formations and the unique soils derived from them have led to the evolution of ensembles of plant species restricted to these habitats. These include limestone outcrops in Sequoia and Kings Canyon National Parks and a unique contact zone of metamorphic and granitic rock in the El Portal area of Yosemite National Park,

where several state-listed taxa are found (Moore 2003). Karst environments have recently been shown to harbor assemblages of rare and endemic invertebrates (Despain 2003, Krejca in progress) as well as providing roosting sites for bat colonies. Seventeen species of bats are documented for Sierra Nevada parks, nine of which are either Federal Species of Concern or California Species of Special Concern (Pierson et al. 2001, Pierson and Rainey 2003).

While Sierra Nevada parks offer important protected habitats for a diverse assemblage of plants and animals, from direct pressures of habitat fragmentation and use (e.g., development, logging, mining, extensive water diversions, and other human impacts), they do not protect park resources from the larger-scale stressors of air anthropogenic climate change, air pollution, altered fire regimes, and invasive non-native species.

## Devils Postpile National Monument

### *Purpose and Significance*

Devils Postpile National Monument was established to preserve "the natural formations known as the Devils Postpile and Rainbow Falls" for both scientific interest and for public inspiration and interpretation (NPS 1982). Devils Postpile is a dramatic mass of columnar-jointed basalt—the remnants of lava that flowed down the valley of the Middle Fork San Joaquin River less than 100,000 years ago. Approximately 20,000 years ago, a glacier overrode the fractured lava mass, exposing a wall of columns 18 meters high and resembling a giant pipe organ. Rainbow Falls, along the Middle Fork of the San Joaquin River, is a spectacular waterfall that drops 31 m (101 feet) over a volcanic cliff.

Yosemite National Park once administered the Devils Postpile area. In 1905, more than 1,295 square kilometers (500 square miles) were withdrawn from Yosemite National Park in the Minaret Range and the Devils Postpile area and returned to public domain. Only 324 hectares (800 acres) were returned to protected status as Devils Postpile National Monument in 1911 by Presidential Proclamation No. 1166 (under President William Howard Taft). Please see Appendix A for the citation which contains additional details about this proclamation.

Devils Postpile National Monument is located high on the western slope of the Sierra Nevada in Madera County, California, near the headwaters of the Middle Fork of the San Joaquin River (Figure B- 6). Elevations within Devils Postpile range from 2,200 m to 2,500 m (7200-8200 feet). It is surrounded on all sides by the Inyo National Forest, and so comprises a small natural area within a much larger contiguous complex of federal public lands extending over a vast area of the eastern and western slopes of the Sierra Nevada range. Three-quarters of Devils Postpile is included within Ansel Adams Wilderness; this Wilderness extends into Inyo National Forest lands west of Devils Postpile. Ten kilometers (6 miles) to the east, and closely allied economically, is the resort town of Mammoth Lakes and the Mammoth Mountain ski complex.

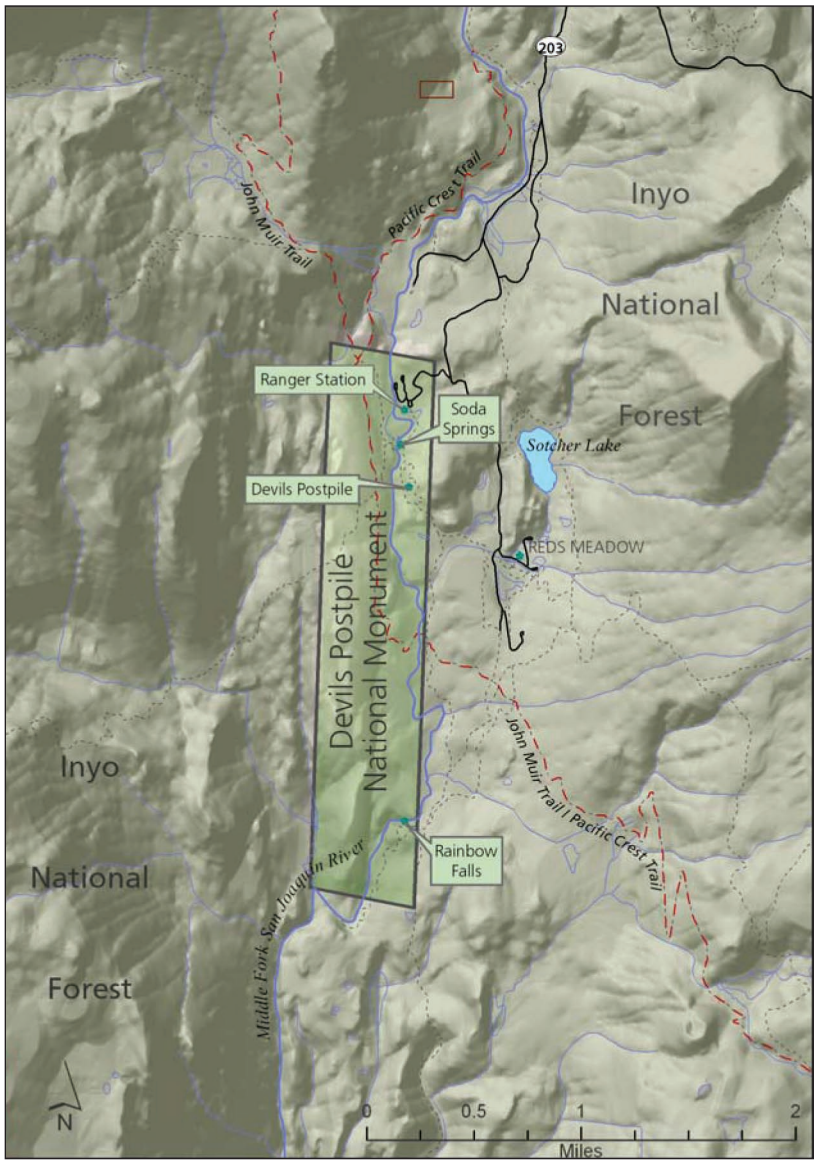



**Figure B- 6.** Devils Postpile National Monument and surrounding area.

### *Description of Resource Values*

*A country of wonderful contrasts.*
*Hot desertsbounded by snow-laden mountains, cinders and*
*ashes scattered on glacier-polished pavements,*
*frost and fire working together in the making of beauty.*

–John Muir

As is evident from the basalt columns of Devils Postpile National Monument and glacial polish on the tops of the "postpile columns", the landscape of Devils Postpile National Monument was shaped by volcanism and ice. While glaciers are long gone from the Middle Fork of the San Joaquin drainage, volcanic influence is still strong within the Devils Postpile/ Mammoth Lakes region. The region's soils have high concentrations of ash and tephra, and it is difficult to locate an area within the Devils Postpile not covered by pumice. The pumice indicates post-glacial volcanic activity in the Inyo/ Mono Craters and Long Valley Caldera complex, and it plays an important role in the area's phytogeography and vegetation development.

On slopes underlain by basalt and andesite, where the water table is low and percolation is high, a sparse conifer forest typically exists. Here, pines and firs contribute little organic matter towards extensive soil formation. Instead, the soils remain barren with a paucity of litter and insufficient moisture to enhance soil formation. It is common, on steeper slopes, to see bare rock with few plants. What plants exist often creep downhill with the soil, further inhibiting soil development.

There continues to be volcanic activity in the Long Valley area, just west of Devils Postpile (Huber and Eckhardt 2002):

- Carbon dioxide gas has recently killed many trees at adjacent Mammoth Mountain
- Swarms of earthquakes occurred in the 1980s and 1990s, several of which dislodged postpile column pieces with Devils Postpile National Monument
- Numerous hotsprings are present in the region
- Pumice is young and widespread.

Further, future volcanic activity has the potential to dramatically change the landscape in and surrounding Devils Postpile National Monument. Based on the frequency of eruptions along the Mono-Inyo Crates volcanic chain in the past 5,000 years, the probability of an eruption occurring in any given year is somewhat less than one percent per year or roughly one chance in a few hundred in any given year. This is comparable to the annual chance of a magnitude 8 earthquake (like the Great 1906 San Francisco Earthquake) along the San Andreas Fault in coastal California or of an eruption from one of the more active Cascade Range volcanoes in the Pacific Northwest, such as Mount Rainier in Washington or Mount Shasta in California.

Increased volcanic unrest (including earthquake swarms, ground deformation, and $CO_2$ gas emissions) in the Long Valley area since 1980 increases the chance of an eruption occurring in the near future, but scientists still lack adequate data to reliably calculate by how much. Volcanic unrest in some other large volcanic systems has persisted for decades or even centuries without leading to an eruption. But since volcanic unrest can escalate to an eruption quickly–in a few weeks, days, or less–USGS scientists continue to monitor the activity closely (http://lvo.wr.usgs.gov/hazards/index.html).

The Middle Fork of the San Joaquin River, which flows through Devils Postpile, is a Wild Trout River. Although the river was designated a 'Wild Trout River' due to its trout populations, highly valued by the recreational fishing community, none of the fish species are native to the river.

The river changes in character many times throughout its journey through Devils Postpile: from a series of broad low-gradient meanders, to scattered pools and fastflowing rapids, cascades, and falls. South of Devils Postpile, the river continues on to race through a narrow granite gorge south of "Lost Camp" and towards Mammoth Pool (the first man-made obstruction on the San Joaquin River). Three small creeks enter the river within or near Devils Postpile National Monument: King Creek, Boundary Creek, and an unnamed creek from Red's Meadow (to the east).

Although the San Joaquin River drains the length of Devils Postpile into the San Joaquin Valley to the west, the Ritter Range west of Devils Postpile is higher in elevation. As a consequence, biological communities contained within have east-slope as well as westslope affinities. The principal vegetation is montane forest, mostly dominated by red fir or lodgepole pine. Along the San Joaquin River, typical montane riparian vegetation dominates, represented by quaking aspen, black cottonwood, alder, and willows. A recent vascular plant inventory of Devils Postpile documented 360 taxa, a 113 percent increase from the 169 taxa documented previously (Arnett and Haultain 2004).

A number of meadows of various subtypes can be located within Devils Postpile. Dry meadows, where seeps or intermittent drainages occur, form shallow meadows occupied by sedges and grasses. In dry years these may not even "green up" after the snow melt. A few larger meadows occur in the southern monument region that are regularly wet and occupied by sedges, mannagrass, wildryes and other grasses. Some of these southern meadows are bordered with quaking aspen.

Soda Springs Meadow is the largest meadow within Devils Postpile. The large meadow is divided by the San Joaquin River and appears to be formed by classic fluvial events. The soda spring for which this meadow is named is at the southern edge of the meadow.

Totally submerged in the June snowmelt, the soda spring gradually becomes more accessible by July. Iron in the water oxidizes to reddish-brown and clearly marks the spring's location. The spring provides a continuous flow of carbonated water throughout the year.

A total of 143 vertebrates have been documented for Devils Postpile (Pierson and Rainey 2002, Gates and Heath 2003, Siegel and Wilkerson 2003, Werner 2004). The animals most frequently observed are birds, small diurnal mammals, and invertebrates. The most frequently seen birds include the Steller's jay, the western tanager, dark-eyed juncos, and hairy woodpeckers. Common mammals within Devils Postpile include the golden mantled ground squirrel, the lodgepole chipmunk, chickaree, and Belding ground squirrels. Porcupines, coyotes, long-tailed weasels, martins, and marmots are occasionally sighted. Mule deer visit Soda Springs Meadow in the evening and early morning hours. Black bears are frequently seen within Devils Postpile boundaries. During August of 2001, a survey of bats was conducted and ten species of bats were newly documented (Pierson and Rainey 2002), six of which are species of special concern.

Because of the cold climate, there are few known species of reptiles and amphibians within Devils Postpile. The Middle Fork of the San Joaquin has four nonnative species of trout, golden trout, rainbow trout, brown trout and brook trout. Many places throughout the Sierra Nevada, including Starkweather and Sotcher Lakes in the Reds Meadows area, are stocked with fish. Devils Postpile has not been stocked with fish since 1995.

The vegetation and wildlife in Devils Postpile are adapted to periodic fire, and evidence of past fires can be found in charcoal and fire scars left on some trees. Fire history and forest age structure studies are currently being conducted (Caprio, in progress). Fire history studies in similar forests in other areas of the Sierra Nevada have shown fires in lodgepole pine forests occurred an average of every 150 years and more frequently in lower elevation mixed

conifer forests. The Rainbow Fire burned approximately two-thirds of Devils Postpile in 1992; the most severe burning occurred in the southeast portion. In some areas, tree mortality was high and seedlings have not re-established due to long distances to living trees. In other areas the fire crept along the forest floor, occasionally burning into trees—in these areas, re-establishment of seedlings has been more rapid.

Evidence of prehistoric human use of Devils Pospile has been documented, with several prehistoric sites identified based on the presence of tools, points, and chips. It is considered likely that this area was a locale for seasonal hunting and fishing camps used by Northern Paiute and/or Northfork Mono groups. However, the archeological sites are modest in size. Materials and analyses conducted thus far have not provided the basis for definitive conclusions about the people using the area and the nature of their use.

Historic uses of the area date from the 19th century. A toll road known as the French Trail, was developed in 1879-80 to connect the mining enterprises at Mammoth to the east with the Central Valley to the west. It passed through Reds Meadow, crossed the river and then continued up King Creek. Miners are also thought to have maintained camps in the area at this time and worked nearby mines. Some evidence also suggests late 19th century sheepherder camps within Devils Postpile. The remnants of "Postpile Joe's" trapper cabin dating from the early 20th century can still be seen.

An archeological survey within Devils Postpile was conducted in 1994, following the Rainbow fire. All existing structures, including the rustic ranger station, have been evaluated for historic significance, but were found not eligible for the National Register.

### *Visitation*

The primary period of public use for the area is in mid-June to the end of September, after the snow has melted and the road has become accessible to motor vehicles. Generally, the season extends from mid-June through October, but can vary depending on snowpack. Several hundred visitors also arrive in the winter by snowmobile and crosscountry ski. This type of winter use is steadily growing.

Summer visitors arrive primarily by shuttle bus. Visit by private vehicle is not controlled in the spring or fall when the shuttle is not in operation. Visitor use has averaged 143,868 per year over the last three years. Daily visitor loads during the peak period average 2,000. The average length of stay for day users is estimated at four to five hours. Most campers stay an average of two and one half days.

Devils Postpile serves as a trailhead for backpackers using the Pacific Crest and John Muir Trails. These visitors leave their vehicles in the parking lot near the ranger station and spend an average of three days in the backcountry before returning to claim their vehicles. Horseback riders from the Reds Meadow Pack Station and long-distance hikers also pass through Devils Postpile on their way to the backcountry. Approximately 1500 horseback riders use Devils Postpile yearly, with about 1200 taking day trips to Rainbow Falls.

### *Facilities*

Access to Devils Postpile headquarters area is provided by a variable width paved road of approximately 0.34 miles. The narrower sections of the road can be problematic for larger vehicles, including the shuttle buses. The remainder of the park is accessible only by trails.

Unpaved parking accommodating approximately 60 cars is provided at the headquarters area for day visitors and long distance trail users. An additional unpaved parking lot on Forest Service land serves as a trailhead for day hikes to Rainbow Falls and also for long distance trail users. Parking can be a significant problem, particularly when substantial numbers of backpacker vehicles are parked in the area and numerous private vehicles arrive after the shuttle operations have ended for the day. There are about five miles of unpaved trails in Devils Postpile, and two trail bridges across the Middle Fork San Joaquin River. One campground

within Devils Postpile provides 21 sites for overnight visitors, and five additional campgrounds are on USFS land within several miles of its boundary.

A small ranger station of approximately 420 square feet provides multiple duty as a minivisitor center, curatorial storage site, and park office. The building was originally located in Yosemite National Park and was moved to Devils Postpile in about 1946.

An administrative area is located near the ranger station, but out of the visitor circulation pattern. Five small, rustic wood-frame cabins provide housing for park employees. A small maintenance building provides some storage and workspace. A fire cache houses fire equipment.

## Sequoia and Kings Canyon National Parks

### *Purpose and Significance*

Sequoia and Kings Canyon National Parks protect a variety of landscapes, and biological and cultural resources, in the southern Sierra Nevada of California (Figure B–7). Though juxtaposed, they are two separate national parks created by acts of Congress fifty years apart. Today, both parks are administered as a single unit.

Established September 25, 1890, Sequoia National Park is the second oldest national park in the United States. The campaign to create Sequoia–initiated and executed by San Joaquin Valley residents–focused on the scenic and inspirational values of the region's giant sequoia (California Big Tree *Sequoiadendron giganteum*) groves. The park's original boundaries were drawn to protect what local supporters believed were the largest and best of the unclaimed sequoia groves remaining in the world. One week later, under circumstances that have never been fully explained, Congress tripled the size of the new park, adding to it several sequoia groves already under the nominal control of logging enterprises. Eventually these groves were all preserved. Because the two acts of 1890 established boundaries along section lines, Sequoia National Park included not only giant sequoia forestlands but also considerable tracts comprising both the foothills and High Sierra. The October 1, 1890, act also created four-square-mile General Grant National Park to protect the General Grant Tree and immediately surrounding forest. Since 1890, Sequoia National Park has undergone two major enlargements, both of which added High Sierra lands to the park.

In 1926, Congress added what is known as the Great Western Divide, Kern headwaters, and Sierra Crest regions. This enlargement, which more than doubled the park's acreage, made it clear that Sequoia National Park would not only be a forest park, but also a superlative alpine park. Included within the enlargement areas was Mt. Whitney, the highest mountain in the contiguous United States. In 1978 Congress again enlarged Sequoia National Park, this time adding Mineral King area to park boundaries, previously a part of Sequoia National Forest. Alpine and subalpine in character, Mineral King basin had been proposed by the Forest Service for development as a major downhill ski resort.

Congress added this basin to Sequoia National Park with specific instructions that it be preserved "undeveloped." Please see Appendix A for additional details on legislation and special designations for Sequoia and Kings Canyon National Parks.

Today, the best known and most appreciated features of Sequoia National Park remain the sequoia groves and high country. In recent years, however, a new appreciation has developed which suggests that the park's "buffer lands" are far more important than previously thought, and that the park's greatest value is in its wholeness. These themes are explored in more detail below.

The small General Grant National Park existed unchanged for fifty years. In 1940, however, responding 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, Kings Canyon National

Park featured 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 duality was readily apparent from the beginning. In 1940, as a political compromise, the "floors" of the parks two great glacial canyons—Kings Canyon and Tehipite Valley—were left outside its boundaries as possible reservoir sites—this situation was rectified in 1965 when Congress added them to the park.

### *Description of Resource Values*

*Excerpted from NPS (1999): Resources Management Plan, Sequoia and Kings Canyon National Parks*

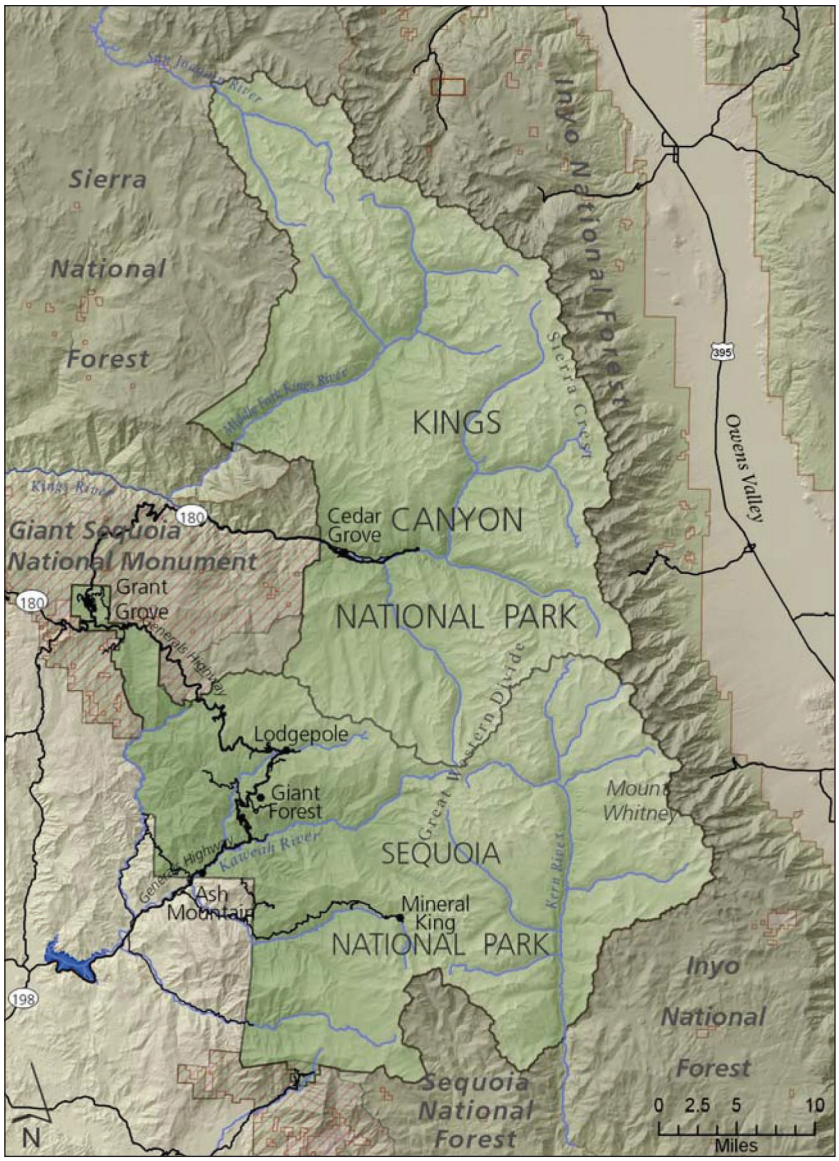



**Figure B–7.** Sequoia and Kings Canyon National Parks.

Sequoia and Kings Canyon National Parks contain resources of geological, biological, cultural, and sociological value. In addition to national park status, the two reservations have also been designated as a unit of the International Biosphere Preserve Program. In addition, 85% of land within the parks is designated wilderness.

The geological significance of the parks results primarily from the composition and structure of the Sierra Nevada, the highest mountain range in the 48 contiguous states. Geological resources include river-cut canyons more than a mile deep, extensive and spectacular examples of glacial erosion including hundreds of alpine lakes, and several superlative examples of glacially eroded canyons. The most famous of these–Kings Canyon–was once described by John Muir as a "rival of the Yosemite." Within these canyons flows the largest remaining undammed rivers in the Sierra Nevada. Igneous rocks of Mesozoic origins underlie the majority of the two parks, but extensive bands of Paleozoic metamorphic beds also occur. Within the latter, beds of marble are common, as are caves.

The two parks contain over 200 known karst features. Several major cave systems have been located, including Lilburn Cave, which is the most extensive in California (over 17 miles of measured passages). The two parks contain some of the wildest and leastimpacted caves in the United States.

Sequoia and Kings Canyon National Parks also contain biological resources of the great significance. Congress created Sequoia and General Grant National Parks in 1890 expressly to protect the giant sequoia. The General Sherman Tree, growing in Sequoia National Park's Giant Forest, is generally recognized as the largest sequoia and largest living tree on earth. Three other trees in the Giant Forest, and General Grant Tree in Kings Canyon National Park, comprise the list of the world's five largest single organisms (excluding giant fungus, aspen clones, and barrier reefs).

Sequoia trees do not grow continuously through the mixed-conifer forest belt, but rather in geographically limited

areas called groves. In the Sierra Nevada, the only present natural home of the sequoias, trees grow in 75 separate groves. While only thirty-seven of these groves are within the two parks, these groves contain more than 65% of all naturally occurring sequoias.

The biological resources of the two parks are not limited to giant sequoia. Extensive tracts of Sierran mixed-conifer forest surround sequoia groves. This forest belt, which generally clothes the mountains at altitudes between 5,000 and 9,000 feet (1,524 and 2,743 m), covers much of the southern Sierra. On surrounding lands, however, the great majority of this forest zone is being managed for multiple use. As a result, Sequoia and Kings Canyon National Parks now contain the largest remaining old growth forest in the southern Sierra. This forest is a very significant resource because its largely pristine nature gives it both a high recreational value and a critical scientific value. Below the conifer forest, in the western portions of the Sierra, are various plant communities and environments that together constitute the foothill region. Kings Canyon contains very little land within this natural zone; but, in Sequoia National Park, lower canyons of several forks of the Kaweah River include extensive foothill lands. This environment, typified by blue oak savanna, chaparral, and oak woodland, covers much of lowland Central California outside the parks. However, very little of this non-park land is receiving any protection. In the Southern Sierra Nevada, the foothill lands of Sequoia National Park are the only foothill tracts currently designated for long-term preservation.

The remainder of Sequoia and Kings Canyon National Parks, most of it above 9,000 feet (2,743 m) elevation, can be described as "high Sierra." This environment, which covers nearly as much acreage as the other environments combined, is a spectacular land of rugged, ice-sculptured alpine ridges and sparsely wooded lake-jeweled basins. As the heart of the largest wilderness area in California, these lands are of very high recreational and scientific significance.

Preservation of native wildlife within the two parks results naturally from habitat protection that the parks provide and adds yet another level of biological significance. While wildlife found within the parks does not differ significantly from that found naturally on surrounding lands, those lands are mostly undergoing profound change. As a result, the wildlife protection function of the parks is becoming increasingly important. Regional survival of a number of species may ultimately be largely dependent upon the protection the parks provide.

In addition to rich natural diversity, the parks preserve unique cultural and historical records. Eighteen sites or structures within the parks have been listed on the National Register of Historic Places; another six are formally determined to be eligible. Known sites include 312 prehistoric and 110 historic. Site types include prehistoric villages, bedrock mortars and basins, rock art panels, campsites, hunting blinds, cattle and sheep camps, logging camps, sawmills, mines, dams, ranger stations, and CCC-era buildings and structures. The archeological evidence dates back at least five thousand years and indicates a wide-ranging presence throughout the Sierra Nevada of Native American peoples. Local logging, mining, and hydroelectric enterprises, closely related to the formation of the parks, illustrate a particular current of Western settlement and industry. Of the former, the Kaweah Colony, a Bay Area utopian collective which sought to log the sequoias, is unique in representing at once the confidence of industry and the idealism of the early labor movement. Finally, the historical primacy of Sequoia National Park and its unique course of development provide an invaluable and specifically shaded account of the emergence of the preservation ethic and evolution of the National Park Service.

At present, collections contain approximately 320,000 items. Of these, some 250,000 comprise the parks' archives: 46,000 items are included in the history collection, 12,000 in biology, and 11,000 in archeology. Smaller collections include geology (consisting of around

400 items), ethnology (some 100 items), and paleontology (consisting of 20 examples of fossilized sequoia wood).

The collection contains material from the disciplines of archeology, ethnology, and history and includes documentary material, photographs, fine art, and historic objects.

The sociological values and significance of Sequoia and Kings Canyon National Parks result directly from the quality of natural and cultural resources. The preeminent value of all the parks' resources is that they remain relatively unaffected by modern humans; or in the case of the parks' cultural resources, tell of the historical relationship between humanity and the natural environment. In all descriptions of the parks' resource values, the words "wild" and "natural" appear repeatedly. The value to humanity of the parks' many natural environments is greatly enhanced by their largely unimpaired nature. Both visitors and scientists come to the parks seeking a natural environment unaffected by modern humans. Recent legislation, including the 1978 Mineral King addition to Sequoia, the California Wilderness Act of 1984, the Chimney Rock Wilderness addition, and the addition of the Kings and Kern Rivers to the Federal Wild and Scenic River System, reinforces this theme. The ultimate value of the parks' archaeological resources derives from their ability to help modern humans understand early human's relationship to the natural world.

## Yosemite National Park

### *Purpose and Significance*

In 1864, Yosemite Valley and the Mariposa Grove of Big Trees were granted by Act of the U.S. Congress to the State of California for "public use, resort and recreation," and to "be inalienable for all time." Thus, the significance of the area was recognized well before establishment of Yosemite National Park and nearly eight years before Yellowstone was set aside as the world's first national park. Landscape architect Frederick Law Olmsted, designer of New York City's Central Park, provided early direction in managing the Yosemite Grant and saw it as a museum of natural science and native species, and a field of study for art.

In 1906, Congress accepted transfer of the Grant back to the United States, adding it to Yosemite National Park, which had been established in 1890 "to preserve from injury all timber, mineral deposits, natural curiosities or wonders within the park area and to retain them in their natural condition." Several changes to the park boundary were made over the years. In 1984, Yosemite was designated a World Heritage Site.

Approximately 94% of Yosemite's acreage is designated Wilderness. Portions of the Tuolumne River (including the Dana and Lyell Forks), and the main stem and South Fork of the Merced River, are designated National Wild and Scenic Rivers. El Portal Administrative Site west of the park (approximately 566 hectares / 1,400 acres) was established by Act of Congress in 1958, for the purpose of relocating park facilities from within the core park boundary. U.S. Forest Service lands surround the park, and are divided into three national forests: Stanislaus, Toiyabe-Inyo, and Sierra. Please see Appendix A for additional details on legislation and special designations for Yosemite National Park.

The park's exceptional geological, biological, and scenic resources are contained within 308,075 hectares (761,266 acres / 1,189 square miles / 3,079 square km) of scenic wildland, parts of which were first set aside in 1864 (Figure B- 8). Yosemite preserves a portion of the western slope of the central Sierra Nevada.

The region's beauty incited a profound human response that compelled John Muir and others to form the Sierra Club (one of the first private conservation organizations) and prepared the world for the idea of, and desire for, a "national park." This, in itself, is a profound legacy for the world.

> *Nowhere will you see the majestic operations of nature more clearly revealed beside the frailest, most gentle*

*and peaceful things. Nearly all the park is a profound solitude. Yet it is full of charming company, full of God's thoughts, a place of peace and safety amid the most exalted grandeur and eager enthusiastic action, a new song, a place of beginnings abounding in first lessons on life, mountain-building, eternal, invincible, unbreakable order; with sermons in stones, storms, trees, flowers, and animals brimful of humanity.*

(Muir 1901)

Frederick Law Olmsted, considered to be America's premier landscape architect, aided this quest for a "public park" through his preliminary report on the Yosemite Valley and the Mariposa Big Tree Grove. This report encapsulated the character and value of the Yosemite region:

*No photograph or series of photographs, no painting ever prepare a visitor so that he is not taken by surprise, for could the scenes be faithfully represented the visitor is affected not only by that upon which his eye is at any moment fixed, but by all that with which on every side is associated, and of which it is seen only as an inherent part.*

*[T]he union of deepest sublimity with the deepest beauty of nature, not in one feature or another, not in one part of scene or another, not in any landscape that can be framed by itself, but all around and wherever the visitor goes, constitutes the 'Yo Semite', the greatest glory of nature.*

(Olmstead 1865)

### *Description of Resource Values*

Yosemite's landscape comprises a wide range of elevations, from its semi-arid foothills to its snowcapped crests—from 610 meters in El Portal, to 3,998 meters in height at Mount Lyell (range 2,000 to 13,123 feet). The park can be further divided into five major vegetative zones: chaparral/oak woodland, lower montane, upper montane, subalpine, and alpine. In addition to these impressive ecosystems, it includes three groves of Giant Sequoias and glacier-carved Yosemite Valley–with its abundance of waterfalls, cliffs, and extraordinary rock formations.

The climate of Yosemite, like the entire central Sierra Nevada, is Mediterranean—hot, dry summers and cool, moist winters. The foothills and lower slopes are semiarid, and the higher peaks and crests are also relatively dry; the majority of rain and snow falls at the middle elevations between approximately 1,220 and 2,743 meters (4,000 to 9,000 feet).

Dotted in among the forests, meadows, and broad expanses of rock are over 3,000 water bodies—each a reminder of the glaciers that gourged many basins in their slow, powerful journey. These sparkling jewels are located in the upper reaches of canyons and glacial amphitheatres around the peaks,




**Figure B–8.** Yosemite National Park.

primarily in the subalpine and alpine regions. Glacial meadows are spread over the filled-in basins of vanished lakes. In the Park's high country, the most extensive and well known meadows are the Tuolumne Meadows.

Tuolumne Meadows is the largest subalpine meadow complex in the Sierra. In general, however, Yosemite is heavily forested. The size of individual trees and the diversity of species is due to climatic variation and topography that influence distribution of soils and moisture. The Park contains three giant Sequoia (*Sequoiadendron giganteum*) groves, though they do not compare to the number and grandeur of those found in Sequoia and Kings Canyon National Parks.

The geology of Yosemite is characterized by granitic rocks and remnants of older rock (Huber 1989), formed during three intrusions dating from 200 to 85 millions years ago.

In the early Tertiary period, 40 to 60 million years ago, the geologic environment of the Sierra Nevada region was lower in elevation, with a gently rolling upland surface. The Merced River flowed at a gentle gradient westward through a broad river valley.

About 10 million years ago, the Sierra Nevada was uplifted and then tilted to form its relatively gentle western slopes and the more dramatic, steep eastern slopes. The uplift increased the flow gradients, resulting in deep, narrow canyons.

Subsequent uplifting and erosion created the two major drainage basins: Merced and Tuolumne, both National Wild and Scenic Rivers. The Merced watershed begins in the Park's southern peaks, primarily in the Clark range. The South Fork of the Merced flows through the area of Wawona (a Miwok word which means "big tree", referring to the giant Sequoia), uniting with the main stem west of the Park boundary. The main stem of the Merced, growing from numerous tributaries, fills up lake basins such as Washburn Lake and Merced Lake before running through Yosemite Valley and the steep downstream Merced Canyon. The Park's largest river, the Tuolumne, drains the entire northern portion of the Park. Originating at Mount Lyell glacier (the second largest extant glacier in the Sierra Nevada), the Tuolumne flows through Lyell Canyon, Tuolumne Meadows, Glen Aulin, the Grand Canyon of the Tuolumne, and finally merges with the water of the Hetch Hetchy reservoir on the Park's western boundary (an artificial lake impounded by a dam, part of San Francisco's water supply). Mount Lyell, the highest peak in Yosemite (3,998 meters /13,123 feet), occupies the apex of the range and drains into both Tuolumne and Merced watersheds.

About 1 million years ago, snow and ice accumulated, forming glaciers at the higher alpine elevations that began to move westward down the river valleys. The whole Sierra Nevada range was, at one time, covered with glaciers that furrowed canyons 610 to 1,829 meters (2,000 to 6,000 feet) deep. Ice thickness within Yosemite Valley may have reached 4,000 feet (1,219 meters) during the early glacial episode. Downslope movement of the ice masses cut and sculpted the U-shaped valley evident today. After the last glacier receded from the valley about 15,000 years ago, a lake referred to as Lake Yosemite was formed behind a "dam" of depositional materials left behind. More than 1,000 feet (914 meters) of glacial and stream sediments now comprise the floor of Yosemite Valley, covering glacially disturbed granitic rock (Huber 1989).

Such glacial action resulted in the final stripping of the metamorphic overlayer, leaving behind textbook-perfect glacial features for which Yosemite is known: domes, moraines, sheer rock walls, and hanging valleys. An equally rare and striking glacial phenomenon is "glacial polish" or "pavement." The glacial pavements are so young that erosive weathering has barely marred their brilliant beauty.

> *"... Every peak, ridge, dome, canyon, lake basin, garden, forest, and stream testifies to the existence and modes of action of ... scenerymaking ice"*
>
> (Muir, undated)

Yosemite Valley is the "world's most renowned example of a [glacially carved]

valley" (Hill 1975), itself a single feature of beauty and fame that dramatically displays the varied rock forms created by glaciers. In no other canyon or valley is "magnitude, beauty, and accessibility so ideally combined as in Yosemite" (California Geological Survey 1869). Eight different granitic rock types occur in Yosemite Valley alone.

However, Yosemite Valley is not the only valley of note within the Park. A dozen miles to the north is the Grand Canyon of the Tuolumne River—a prodigious gash which exceeds Yosemite Valley in length and depth—which opens into Hetch Hetchy Valley.

A feature not restricted to Yosemite Valley—although many of the largest ones occur there—are great granite domes. Domes are rare on this planet and "the Yosemite region contains a greater and more varied assemblage of [domes and related] distinctive forms than any other area of similar extent in the Sierra Nevada or, perhaps, on Earth" (Matthes 1950).

However impressive Yosemite's geologic features are, the Park's waterfalls are often the natural feature most remembered by those who visit. There are two types of falls in Yosemite—those that leap free pouring from the lips of hanging valleys, and those that cascade in stair-step fashion in a canyon. "No where in the world are there waterfalls of such variety within a single area as those that leap into Yosemite Valley in the spring and early summer" (Schaffer 1978). The "waterfalls of the Yosemite region are relatively slender, resembling shimmering veils of ribbons fluttering from the cliffs" (Matthes 1950). Among Yosemite's waterfalls are some of the tallest and most spectacular of the "free-leaping" type which is relatively rare in nature. Yosemite has two of the world's ten tallest-known waterfalls (Yosemite and Ribbon Falls). Angel Falls in Venezuela at 979 meters (3,212 feet) is the tallest in the world; Yosemite Falls, at 739 meters (2,425 feet), is the tallest in the park.

### *Overview of Biological Diversity, Ecological Integrity, and Resource Issues*

Humans have lived and sustained themselves in the region for at least 9,000 years and are part of the Sierra Nevada ecosystem. Indigenous populations were widely distributed throughout the area at the time of Euro-American immigrations. Archeological evidence indicates that for more than 3,000 years American Indians practiced localized burning, harvesting, pruning, irrigation, and vegetation thinning. Immigration of Euro-American settlers in the mid-1800s began a period of increasingly intense resource use and settlement (SNEP 1996). As in Sequoia and Kings Canyon National Parks, Yosemite fire history studies document a decline in frequent, widespread fires by the mid 1800s (Swetnam 1993, Swetnam et al. 1998). This disruption of fire regime was concommitant to introduction of large numbers of sheep and other livestock into higher elevation forests of the Sierra Nevada during and following the drought of the early 1860s (Swetnam et al. 1998).

Still, Yosemite National Park remains one of the largest and least-fragmented habitat blocks in the Sierra Nevada, and supports a diverse and abundant assemblage of plants and wildlife. As stated above, "[f]ew areas in the United States have more variety of native flora and fauna than the Sierra slopes" (Shaffer 1978). Its importance in protecting the long-term survival of certain species and overall biodiversity of vegetation and wildlife in the Sierra Nevada was recognized in congressional reports prepared as part of the Sierra Nevada Ecosystem Project (SNEP 1996). Yosemite possesses five of the seven recognized life-zones that occur in the United States. "Few areas in the United States have more variety of native flora and fauna than the Sierra slopes" (Shaffer 1978).

Today, most plant communities in Yosemite and other national park units within the Sierra Nevada Network are fairly intact as compared to similar non-Wilderness areas outside park boundaries. Much of this "pristine" quality can be attributed to relatively low levels of historic and/or recent human-caused alteration, and lack of disruption of natural processes. Notable exception to this is the displacement by introduced

Eurasian species of the native herbaceous understory of the meadows of Yosemite Valley and foothill savannas and woodlands of Sequoia National Park. However, impacts to plant communities, species, and individuals can be found throughout all parks. Past logging and grazing continue to affect hydrology and soils, and thus vegetation, in many areas of the parks, including parts of both subalpine and alpine environments.

The park's ecosystems depend upon dynamic natural processes. There exist everchanging environments resulting from the presence or absence of fire, alterations in watersheds, and variations in climate.

More recent manipulations of the environment have resulted in alterations in vegetation in many locales. These forcing agents include suppression of natural fire frequencies, local water diversions or water impoundments, and development of infrastructure throughout non-Wilderness portions of the parks. In addition, changes in these natural processes of fire and flooding have resulted in changes in effects of re-introduced fire or floods, including sometimes greater fire intensities and severities in all parks, and depth of flooding, scour, and depositional patterns in Yosemite. Finally, the level of recreational use today in the most popular areas of the parks, although quite localized, has led to trampling, loss of vegetative cover, and increased susceptibility to the introduction of non-native plant species. The latter are brought in on vehicles, in construction and maintenance materials, as well as on the feet and hooves of visitors and their animals. All of these factors have lead to identification of management issues requiring far better inventory and monitoring data than presently exist.

Riparian and wetland areas contain important plant and animal habitat, yet they receive levels of recreational use out of proportion to their occurrence. Trampling and streambank damage associated with this use introduce disturbance factors that favor exotic plant establishment in areas especially susceptible to non-native intruders, further degrading this critical ecotonal habitat between aquatic and upland terrain.

In some park habitats—particularly chaparral, hardwood forest and woodland, and mixed-conifer—a long history of fire suppression has affected the natural structure and succession of plant communities, which has in turn affected habitat quality for both plants and wildlife. In some cases, this has also led to fires of unnaturally high intensity, which have drastically altered habitats for many years to come. In others, gaps that would otherwise form in conifer forest from natural fires (and thereby provide habitat for "forage" species) have been greatly reduced. Decades of fire suppression disrupted competitive balance between non-native and native plant species, and jeopardized the viability of some fire-dependent species. Yosemite National Park has used prescribed fire since 1970 and monitored lightning-ignited fires since 1972 to reduce fuels and return fire to the landscape (van Wagtendonk 1977). Fire is a profoundly important ecological process in these systems, but both prescribed and wildland fires can create conditions that promote exotic plant establishment. On the other hand, fire suppression activities contribute to introduction of exotic plant propagules while creating conditions for their establishment.

Air pollution, especially in the southern Sierra Nevada, has affected vitality of some plant species studied, and may be extensively altering competitive balance and overall productivity of some plant communities. Global climate change, if it takes place as predicted, is expected to lead to striking changes in distribution, persistence, and character of many plant communities throughout their range.

### *Vegetation*

Major vegetation zones in Yosemite form readily apparent, large-scale, north-south elevational bands along the axis of the Sierra Nevada. Major east-west watersheds that dissect the park into steep canyons form a secondary pattern of vegetation. Yosemite National Park supports five major vegetation

zones: chaparral/oak woodland, lower montane, upper montane, subalpine, and alpine. The park is rich in plant diversity. Of California's 7,000 plant species, about 50% occur in the Sierra Nevada—more than 20% within Yosemite alone.

To date, 1,561 plant taxa are thought to occur within park boundaries. Documented records of, or suitable habitat for, approximately 164 special-status plant species exist in the park. As a group, Sierra Nevada plants are most at risk where habitat has been reduced or altered. In some areas, rare local geologic formations and associated unique soils have led to evolution of ensembles of plant species restricted to these uncommon habitats. This is true in the El Portal area, where a number of state-listed rare species are sustained in a unique contact zone of metamorphic and granitic rock.

Although moderately extensive plot networks in Kings Canyon, Sequoia, and Yosemite have provided good information on distribution and habitat affinities of common species of plants, little is known regarding distribution of rare and special-status plant species (beyond some opportunistic surveys conducted during the 1980s and some work currently being conducted). Information on current population trends is non-existent, making impossible any comparisons of such information to trends on adjacent lands with differing management strategies.

Little-to-nothing is known about the diversity, distribution, and abundance of nonvascular plants within the park.

### *Wildlife*

Wildlife populations in Sierra Nevada Network parks, as a whole, are thought to be relatively intact compared to other areas of the Sierra Nevada where human activities such as hunting, logging, grazing, fire suppression, and extensive development have led to widespread degradation, particularly in lower elevations outside designated wilderness.

In the parks, however, some human activities and development have affected wildlife and habitats. The most notable example is the inundation of Hetch Hetchy Valley by construction of O'Shaughnessy Dam across the Tuolumne River in Yosemite, destroying riparian, oak woodland, and wetland habitats that comprised a substantial portion of all bottomland winter habitat in that park. Similar habitats survive in Yosemite Valley, but roads and dense development in the east end of the Valley have eliminated or fragmented them; high levels of human activity from millions of visitors result in disturbance to wildlife. In Kings Canyon, Sequoia, and Yosemite, local areas of montane to subalpine habitats have been developed in ways detrimental to some native animals, but these represent a relatively minor proportion of available habitat.

To date, faunal composition of Yosemite is as follows:

- 82 native mammals (seventeen of those are bats—nine of which are either federal "Species of Concern" or State "Species of Special Concern").
- 273 birds (1 is listed as federally threatened; 13 are either federal "Species of Concern" or State "Species of Special Concern")
- 24 reptiles (2 are both federal "Species of Concern" and State "Species of Special Concern")
- 14 amphibians (5 are both federal "Species of Concern" and State "Species of Special Concern")
- 15 fish species (five of which are non-native)

For some species we know the reason(s) for decline; for others, we do not. For example, Pacific fishers (*Martes pennanti pacifica*) are present in very low numbers in the park.

Road-kills and low numbers of an important prey species (porcupine, *Erethizon dorsatum*) may be explanations, but not enough information exists to determine causative factors. Bighorn sheep (*Ovis canadensis sierrae*) (State-endangered; being considered for federal listing) formerly populated the Sierra crest, but have been reduced to several remnant populations—none of which regularly occur in Yosemite. Reasons for their initial decline are unknown, though

today they are frequently depredated by mountain lions. Grizzly bears (*Ursus horribilis*) once occurred in the park, but were extirpated from the state by the early 20th century. Black bears (*Ursus americanus*) are abundant in the park and are often involved in conflicts with humans that result in property damage, injuries to humans, and the necessity of euthanizing black bears that present a clear threat.

Introduction of non-native species has affected some native wildlife species in the parks. Introduction of several species of salmon fish to high-elevation lakes and streams that were naturally fishless radically altered faunal communities of those waters and is suspected to be the primary cause of disappearance of mountain yellow-legged frogs (*Rana muscosa*) from wide areas of its former range throughout the Sierra Nevada.

Population declines of Yosemite toads (*Bufo canorus*)—and complete disappearance of foothill yellow-legged frogs (*Rana boylei*)—may also be at least partially due to nonnative species. Bullfrogs (*Rana catesbeiana*) are present in Yosemite Valley, several lakes in the north part of Yosemite, and some foothill portions of Sequoia where foothill yellow-legged frogs, or California red-legged frogs (*Rana aurora draytoni*), a federal Threatened species, once existed. Bullfrogs also prey on western pond turtles found in Sequoia. Brown-headed cowbirds (*Molothrus ater*), recent arrivals in the Sierra Nevada, flourish at stables, campgrounds, and residential areas of the parks, affecting native bird species through nest parasitism.

Other adverse effects on park wildlife originate outside park boundaries. For example, Willow Flycatchers (*Empidonax traillii*), a federal Threatened species, have become recently rare in the parks, although their favored habitat, meadows with willow thickets, is largely intact. Sierra-wide decimation of Willow Flycatchers, primarily from grazing and clearing of habitat—and perhaps cowbird parasitism—has affected numbers of this species in the parks as well by reducing regional population size to such a low number that it is difficult for park populations to be self-sustaining. Such regional effects on habitat likely affect a wide range of species in parks that are migratory or rely on immigration of individuals from adjacent areas.

One federal Endangered invertebrate is known to occur within the park (Valley elderberry longhorn beetle (Desmocerus californicus). Little-to-nothing is known about the diversity, distribution, and abundance of most other invertebrates within Yosemite.

### *Facilities*

Yosemite National Park has major developed areas in Yosemite Valley, Wawona, and Tuoloumne Meadows. Smaller developed areas include Aspen Meadows, Crane Flat, Hodgdon Meadow, Foresta, White Wolf, Porcupine Flat, Tioga Pass, Hetch Hetchy, South Entrance, Arch Rock and Glacier Point. Development zones, managed to provide roads and facilities to serve visitors and the management of the park, comprise approximately 13,000 acres, or 1.7% of the park. El Portal and Yosemite West abut the park.

In Yosemite Valley are Yosemite Village, Yosemite Lodge/Camp 4, Ahwahnee, Curry Village, Housekeeping Camp, the Campground complex, and Happy Isles. North and Southside Drives run from the west end of the valley at Pohono, east and looping to connect all developed areas in the east end of the valley. Infrastructure follows similar paths, and in some instances contributes to such problems as the draining of meadows.

Wawona is located along the South Entrance Road. This community of approximately 300 homes and vacation homes is served by a network of roads that branch from the Chilnualna Falls Road, which parallels a reach of the South Fork of the Merced River. Wawona Hotel and Pioneer Village are the major visitor services.

Tuolumne Meadows includes Tuolumne Lodge, Tuolumne Meadows Campground, parking and logistical support facilities for various day and overnight visitor activities. The Tioga

Road follows the edge of Tuolumne Meadows, a fragile subalpine meadow, and in some locations contributes to conifer invasion and other impacts.

There are four main park entrances, each serving a major road corridor: Tioga Pass, along the Tioga Road; Big Oak Flat, along the Big Oak Flat Road; Arch Rock, along the All- Weather Highway from El Portal; and the South Entrance, along the south entrance road (Mariposa Grove Road and the Glacier Point Road begin along this road).

# References


Anderson, M. K., and M. J. Moratto. 1996. Native-American land use practices and ecological impacts. Sierra Nevada Ecosystem Project Report to Congress, Vol II. Assesments and Scientific Basis for Management Options Davis: University of California Centers for Water and Wildland Resources.

Anderson, R. S., and S. J. Smith. 1997. Sedimentary record of fire in montane meadows, Sierra Nevada, California, USA: A preliminary assessment. Pages 313-327 *In* J. S. Clark, H. Cachier, J. G. Goldammer, and B. Stocks, editors. Sediment Records of Biomass Burning and Global Change. NATA ASI series, Springer-Verlag, Berlin.

Arnett, M., and S. Haultain. 2004. Vascular plants of Devils Postpile National Monument, Final report to Sierra Nevada Inventory & Monitoring program. National Park Service, Three Rivers, CA.

Bateman, P. C. 1992. Plutonism in the central part of the Sierra Nevada batholith, California. U.S. Geological Survey Paper 1483.

Bateman, P. C., L. D. Clark, N. K. Huber, J. G. Moore, and C. D. Rinehart. 1963. The Sierra Nevada batholith: A synthesis of recent work across the central part. U.S. Geological Survey Paper 414-D.

Biswell, H. H. 1961. The big trees and fire. *National Parks Magazine* **35**:11-14.

Brown, P. M., M. K. Hughes, C. H. Baisan, T. W. Swetnam, and A. C. Caprio. 1992. Giant sequoia ring width chronologies from the central Sierra Nevada, California. *Tree-Ring Bulletin* **52**:1-14.

Caprio, A. C. 2000. Analysis done at Sequoia and Kings Canyon National Parks.

Caprio, A. C., C. Conover, M. Keifer, and P. Lineback. 2002. Fire management and GIS: A framework for identifying and prioritizing fire planning needs. N. G. Sugihara and M. E. Morales. Proceedings of the symposium: Fire in California ecosystems: Integrating ecology, prevention and management, San Diego, CA, Nov. 17-20, 1997. Vol. 1.

Caprio, A. C., and D. M. Graber. 2000. Returning fire to the mountains: Can we successfully restore the ecological role of pre-Euroamerican fire regimes to the Sierra Nevada? D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin. Proceedings: Wilderness Science in a Time of Change. Wilderness Ecosystems, Threats, and Management, Missoula, MT and Ogden, UT, May 23-27, 1999. Vol. RMRS-P-15-VOL-5.

Caprio, A. C., and P. Lineback. 2002. Pre-twentieth century fire history of Sequoia and Kings Canyon National Parks: A review and evaluation of our knowledge. N. G. Sugihara, M. E. Morales, and T. J. Morales. Proceedings of the Symposium: Fire in California Ecosystems: Integrating Ecology, Prevention and Management, San Diego, CA, Nov.17-20, 1997. Vol. 1.

Caprio, A. C., and T. W. Swetnam. 1993. Fire history and fire climatology in the southern and central Sierra Nevada: Progress Report 1992/93 to National Park Service Global Change Program, Southern and Central Sierra Nevada Biogeographical Area. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

Caprio, A. C., and T. W. Swetnam. 1994. Fire history and fire climatology in the southern and central Sierra Nevada: Progress Report 1993/94 to National Park Service Global Change Program, Southern and Central Sierra Nevada Biogeographical Area. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

Caprio, A. C., and T. W. Swetnam. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. Pages 173-179 *In* J. K. Brown, R. W. Mutch, C. W. Spoon, and R. H. Wakimoto, editors. Proceedings of a Symposium on Fire in Wilderness and Park Management. USDA Forest Service Gen. Tech. Rep. INT-GRT-320.

Chang, C. 1996. Ecosystem responses to fire and variations in fire regimes. Pages 1071- 1099 *In* Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildlands Resources, Davis, CA.

Clow, D. W., and K. R. Collum. 1986. Geology of the volcanic rocks at Devils Postpile, California. *Journal of Natural Sciences* **1**:18-21.

Clow, D. W., M. A. Mast, and D. H. Campbell. 1996. Controls on surface water chemistry in the upper Merced River basin, Yosemite National Park, California. *Hydrological Processes* **10**:727-746.

Davis, O. K., and M. J. Moratto. 1988. Evidence for a warm dry early Holocene in the western Sierra Nevada of California: Pollen and plant macrofossil analysis of Dinkey and Exchequer Meadows. *Madrono* **35**:132-149.

Despain, J. 2003. Hidden beneath the mountains: The caves of Sequoia and Kings Canyon National Parks. Cave Research Foundation, Inc., Dayton, OH.

Gill, A. M. 1975. Fire and the Australian flora: A review. *Australian Forestry* **38**:4-25.

Graber, D. M. 1996. Status of terrestrial vertebrates. Pages 709-734 *In* Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis, CA.

Graber, D. M., S. A. Haultain, J. E. Fessenden, S. D. Veirs, T. J. Stohlgren, and C. M. Schonewald-Cox. 1993. Conducting a biological survey: A case study from Sequoia and Kings Canyon National Parks. Fourth Conference on Research in California's National Parks: National Park Service.

Hartesveldt, R. J., and H. T. Harvey. 1967. The fire ecology of sequoia regeneration. Tall Timbers Fire Ecology Conference Proceedings. Vol. 7.

Harvey, H. T., H. S. Shellhammer, and R. E. Stecker. 1980. Giant Sequoia Ecology: Fire and Reproduction. Scientific Monograph Series USDI NPS, Washington, D.C.

Heinselman, M. L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. Pages 7-57 *In* T. M. Mooney, T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners, editors. Proceedings of the conference: Fire regimes and ecosystem properties. USDA Forest Service, Honolulu, HI.

Holmquist, J. G., and J. M. Schmidt-Gengenbach. 2005. Interim report: A pilot study on the efficacy of invertebrates as indicators of meadow change in Sierra Nevada Network parks. White Mountain Research Institute, University of California.

Huber, N. K. 1987. The geologic story of Yosemite National Park. USGS Bulletin 1595.

Huber, N. K., P. C. Bateman, and C. Wahrhaftig. 1989. Geologic map of Yosemite National Park and vicinity, California. USGS Map I-1874.

Kattelmann, R. 1996. Hydrology and Water Resources. In Sierra Nevada Ecosystem Project, Davis, CA.

Keifer, M. 1991. Age structure and fire disturbance in southern Sierra Nevada subalpine forests. MS Thesis. University of Arizona, Tucson, AZ.

Kilgore, B. M. 1971. The role of fire in managing red fir forests. *Transcript North America Wildlife Natural Research Conference* **35**:405-416.

Kilgore, B. M. 1972. Fire's role in a Sequoia Forest. *Naturalist* **23**:26-37.

Kilgore, B. M. 1973. The ecological role of fire in Sierran conifer forests: Its application to national park management. *Quaternary Research* **3**:496-513.

Kilgore, B. M., and D. Taylor. 1979. Fire history of a sequoia mixed-conifer forest. *Ecology* **60**:129-142.

Knapp, R. A., C. P. Hawkings, J. Ladau, and J. G. McClory. 2005. Fauna of Yosemite National Park lakes has low resistance but high resilience to fish introductions. *Ecological Applications* **15**:835-847.

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

Lindgren, W. 1911. The tertiary gravels of the Sierra Nevada of California. U.S. Geological Survey Professional Paper 73.

Matthes, F. E. 1960. Reconnaissance of the geomorphology and glacial geology of the San Joaquin basin, Sierra Nevada, California. U.S. Geological Survey Professional Paper 329.

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

McBride, J. R., and D. F. Jacobs. 1980. Land use and fire history in the mountains of southern California. M. A. Stokes and J. H. Dieterich. Fire History Workshop, Tucson, AZ. Vol. GTR-RM.

McClaren, M. P., and J. W. Bartolome. 1989. Fire-related recruitment in stagnant *Quercus douglasii* populations. *Canadian Journal of Forest Research* **19**:580-585.

Mensing, S. A. 1992. The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California. *Madrono* **39**:36-46.

Moore, P. 2003. Special status vascular plant list for Yosemite National Park: Interim Report. WERC-USGS Yosemite Field Station report to Sierra Nevada Network Inventory and Monitoring Program.

National Park Service. 2001. Director's Order #47: Soundscape preservation and noise management. National Park Service.

Neitlich, P. 2004. Personal communication (NPS Ecologist/Lichen Specialist, Alaska Region).

Norris, D. H., and D. A. Brennan. 1982. Sensitive plant species of Sequoia and Kings Canyon National Parks. Co-operative National Park Resources Study Technical Report No. 8.

Norris, D. H., and J. R. Shevock. 2004a. Contributions toward a bryoflora of California I: A specimen-based catalogue of mosses. *Madrono* **51**:1-131.

Norris, D. H., and J. R. Shevock. 2004b. Contributions toward a bryoflora of California II: A key to the mosses. *Madrono* **51**:132-269.

Pierson, E. D., and W. E. Rainey. 2003. Inventory of bat species in Kings Canyon and Sequoia National Parks. Report on 2002 surveys to Sierra Nevada Network Inventory and Monitoring Program, Berkeley, CA.

Pierson, E. D., W. E. Rainey, and C. J. Corben. 2001. Seasonal patterns of bat distribution along an altitudinal gradient in the Sierra Nevada. Report to California State University at Sacramento Foundation, Yosemite Association and Yosemite Fund.

Pitcher, D. 1981. The ecological effects of fire on stand structure and fuel dynamics in red fire forests of Mineral King, Sequoia National Park, California. M.S. Thesis. UC Berkeley.

Pitcher, D. 1987. Fire history and age structure in red fir forests of Sequoia National Park, California. *Canadian Journal of Forest Research* **17**:582-587.

Roper Wickstrom, K. C. 1992. A study of high altitude obsidian distribution in the southern Sierra Nevada, California. Sonoma State University, Petaluma, CA.

Sheppard, P. R. 1984. Fire regime of the lodgepole pine (*Pinus contorta* var. *murrayana*) forests of the Mt. San Jacinto State Park Wilderness, California. M.S. Thesis. Cornell University, Ithaca, NY.

Shevock, J. R. 2002. Personal communication. (California CESU coordinator, bryologist).

Shevock, J. R. In progress. Sierra Nevada Bryophyte Inventory.

Skinner, C. N., and C. Chang. 1996. Fire regimes, past and present. Sierra Nevada ecosystem project, final report to congress: Status of the Sierra Nevada, vol. II, assessments and scientific basis for management options.

Smith, D. W. 1980. A taxonomic survey of the macrolichens of Sequoia and Kings Canyon National Parks. San Francisco State University.

Smith, S. J., and R. S. Anderson. 1992. Late Wisconsin paleoecologic record from Swamp Lake, Yosemite National Park, California. *Quaternary Research* **38**:91–102.

SNEP. 1996a. Sierra Nevada Ecosystem Project: Final Report to Congress. 36 & 37, University of California, Center for Water and Wildlands Resources, Davis, California, USA.

SNEP. 1996b. Sierra Nevada Ecosystem Project: Final Report to Congress—Summary. University of California, Centers for Water and Wildland Resources, Davis, CA.

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

Steen, A. J. 1988. Contributions to the bryophyte flora of Sequoia and Kings Canyon National Parks No. 2, including all species determined to date. National Park Service.

Stephens, S. L. 1997. Fire history of a mixed conifer oak-pine forest in the foothills of the Sierra Nevada, El Dorado County, California. N. H. Pillsbury, J. Verner, and W. D. Tietje. Proceedings of a Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, San Luis Obispo, CA, March 19-22, 1996. Vol. PSW-GTR-160.

Stephenson, N. L. 1988. Climatic control of vegetation distribution: The role of the water balance with examples from North America and Sequoia National Park, California. Dissertation. Cornell University, Ithaca, NY.

Stephenson, N. L., D. J. Parsons, and T. W. Swetnam. 1991. Natural fire to the sequoiamixed conifer forest: Should intense fire play a role. Poceedings 17th Tall Timbers Fire Ecology Conference: High Intensity Fire in Wildlands: Management Challenges and Options, Tall Timbers Research Station, Tallahassee, Florida, May 18-21, 1989.

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

Stokes, J. a. 2003. Special-status vascular plant lists and survey strategy for the Sierra Nevada Network Parks. Prepared for Sequoia and Kings Canyon National Parks. J&S 00-430, Sacramento, CA.

Swetnam, T. W. 1993. Fire history and climate-change in Giant Sequoia Groves. *Science* **262**:885-889.

Swetnam, T. W., C. H. Baisan, A. C. Caprio, R. Touchan, and P. M. Brown. 1992. Treering reconstruction of giant sequoia fire regimes. Final report to Sequoia, Kings Canyon and Yosemite National Parks Laboratory of Tree-Ring Research, Tucson, AZ.

Swetnam, T. W., C. H. Baisan, K. Morino, and A. C. Caprio. 1998. Fire history along elevational transects in the Sierra Nevada, California. Final report to Sierra Nevada Global Change Research Program Sequoia and Kings Canyon National Parks, USGS BRD Sequioa and Kings Canyon, and Yosemite Field Stations.

Swetnam, T. W., R. Touchan, C. H. Baisan, A. C. Caprio, and P. M. Brown. 1990. Giant sequoia fire history in Mariposa Grove, Yosemite National Park. Yosemite Centennial Symposium: Natural Areas and Yosemite, Prospects for the Future, Concord, CA, 1991.

Taskey, R. D. 1995. Soil Survey of High Sierra area, California. U.S. Department of Agriculture, USFS, Pacific Southwest Research Station, CA.

van Wagtendonk, J. W., K. A. van Wagtendonk, J. B. Meyer, and K. J. Paintner. 2002. The use of geographic information for fire management planning in Yosemite National Park. *The George Wright Forum* **19**:19-39.

Warner, T. E. 1980. Vegetation management plan for the Grant Tree area. Sequoia and Kings Canyon National Parks Management Report.

Weaver, H. 1967. Fire and its relationship to ponderosa pine. Proc. Tall Timbers Fire Ecology Conference. Vol. 7.

Weaver, H. 1974. Effects of fire on temperate forests: Western United States. Pages 542 *In* T. T. Kozlowski and C. E. Ahlgren, editors. Fire and Ecosystems. Academic Press.

Wetmore, C. M. 1986. Lichens and air quality in Sequoia and Kings Canyon National Parks. Contract No. CX 0001-2-0034, Denver, CO.

Whitney, J. D. 1880. The auriferous gravels of the Sierra Nevada of California. Harvard College Musuem of Comparative Zoology Memoir **6**.

Yount, J., and D. D. La Pointe. 1997. Glaciation, Faulting, and Volcanism in the Southern Lake Tahoe Basin. Pages 34-56 *In* B. Dillet, L. Ames, L. Gaskin, and W. Kortemeier, editors. Where the Sierra Nevada Meets the Basin and Range.

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix C: Air Quality Synthesis*

Natural Resource Report NPS/SIEN/NRR—2008/072

Annie Esperanza, Air Quality Specialist
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Liz van Mantgem, Physical Sciences Technician,
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Layout and design: Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Esperanza, A., and van Mantgem, L. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix C. Air quality synthesis for Sierra Nevada Network parks. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Contents

List of Figures ..... 48
List of Tables ..... 48
General Description of Air Pollution ..... 49
Criteria Pollutants: Description and Issues ..... 52
- Carbon Dioxide ..... 52
- Nitrogen Dioxide ..... 52
- Ozone ..... 52
- Particulate Matter ..... 53
- Sulfur Dioxide ..... 53

Attainment ..... 53
Air Quality in Sierra Nevada Parks ..... 54
- Emissions ..... 54
- Ozone ..... 55
- Nitrogen and Sulfur Deposition ..... 56
- Particulate Matter/Visibility ..... 58
- Contaminants ..... 59

Air Resources Division of the National Park Service ..... 61
Long-term Monitoring Programs ..... 61
- National Atmospheric Deposition Program/National Trends Network ..... 63
- Interagency Monitoring of Protected Visual Environments ..... 63
- Clean Air Status and Trends Network ..... 64
- Light Pollution ..... 64
- Natural Soundscapes ..... 64

Monitoring and Research Needs ..... 65
- Data Acquisition and Analysis, Monitoring ..... 65
- Wet and Dry Deposition ..... 65
- Ozone ..... 65
- Particulate Matter/Visibility ..... 66
- Natural Soundscapes ..... 66
- Dark Sky ..... 66

Literature Cited ..... 67

## Figures

Figure C-1. Ozone exceedance chart ..... 56
Figure C-2. Total Annual Wet Deposition (NADP) ..... 57
Figure C-3. Fine aerosol mass proportions..... 59
Figure C-4. Regional visibility measured in deciviews,1996 to 1998 ..... 60
Figure C-5. Air quality monitoring sites..... 62

## Tables

Table C-1. National and California Ambient Air Quality Standards..... 51
Table C-2. Attainment status for criteria air pollutants in SIEN parks..... 54
Table C-3. Target dates for attainment (as of 17 May 2004)..... 54
Table C-4. Bio-indicator plant species..... 56
Table C-5. Air monitoring stations ..... 63

# General Description of Air Pollution

Air pollution is currently recognized as one of the most significant threats to natural resources of the Sierra Nevada. A description of these threats can be found in the main body of this Monitoring Plan (section 1.9.5).

Sources of air pollutants are local, regional, and in some instances, global. The National Park Service (NPS), in cooperation with state and other federal agencies, is making concerted efforts to reduce resource damage caused by air pollution. This is done by an intensive monitoring program, support for research, identifying and seizing opportunities to participate in decisions being made by regulatory groups, and expanding the education of park visitors and those concerned about the future of Sierra Nevada parks.

Kings Canyon, Sequoia, and Yosemite National Parks are designated Class I air sheds under the Clean Air Act (1977 amendment). As such, the parks are afforded the greatest degree of air quality protection under the Clean Air Act, and the National Park Service is required to do all it can to ensure that air quality related values are not adversely affected by air pollutants. This includes participation in the review of permits of those sources whose emissions will potentially affect the parks. Devils Postpile National Monument, the fourth NPS unit in the Sierra Nevada Network (SIEN), is listed as a Class II air shed, which still has a mandate to protect air quality, but it is not as stringent as that required for parks with Class I air sheds.

Air pollution impairs visibility and injures plant and animal life. The once vast panoramas from vista points in the parks looking westward are now highly obscured by regional haze. Plant species differ in their sensitivity to pollutants; there are numerous species within SIEN parks that are damaged by air pollutants. For example, studies have shown that Jeffrey and ponderosa pines are especially sensitive to ozone (Duriscoe and Stolte 1989). Ozone-related effects include foliar damage, reduced needle retention, and reduced growth. Giant sequoia seedlings show needle damage at current ozone levels. Acid deposition has been found to affect the chemical composition of lakes and streams within the parks, which can harm aquatic life. Contaminants used in the nearby San Joaquin Valley are found in rain and snow samples within the parks, raising concern over potential impacts to both aquatic and terrestrial wildlife.

The San Joaquin Valley, west of the Sierra Nevada parks, is a trap for air pollutants originating in the Valley as well as from pollutants from cities along the central California coast. These pollutants are carried in prevailing winds. Southward wind patterns carry pollutants through the Valley until reaching the mountains (Tehachapi Range) at the southern end of the basin, causing an eddy of air to form in the vicinity of Visalia and Fresno, just west of the southern Sierra Nevada. Frequent inversions trap the Valley air at night. Rising daytime air currents subsequently carry these trapped pollutants into the Sierra Nevada, resulting in some of the worst air quality found in any NPS unit in the country (Cahill et al.1996). This movement of polluted air into the Sierra occurs daily during summer months. The airflow pattern transports air pollutants to all the SIEN parks; the highest pollutant levels occur in Sequoia and Kings Canyon—lower, but not insignificant, levels occur in Yosemite and Devils Postpile.

Automobiles are one of the major sources of pollutants in the San Joaquin Valley, contributing much of the particulates, carbon monoxide, nitrogen oxides, and hydrocarbons annually emitted. The latter two constituents are precursors in the formation of ozone. Other sources of pollution include agricultural activities (e.g., plowing, diesel generators, off-road vehicles), power generation, petroleum production, and other industrial emissions.

Emissions within the parks include motorized vehicles, whose numbers are greatest in the summer when visitation is at its highest. Smoke emissions are another source found within park boundaries. Fires from prescribed burns,

wildfires, and campfires all produce varying levels of particulate matter and chemical precursors to ozone with varying but largely localized air quality impacts. During winter months, most in-park emissions are from wood used for heating; however, emissions are typically minimal due to low visitation and a smaller number of in-park residents. Still, a vast majority of air pollutants found in the parks are generated outside park boundaries.

There are also air-related health concerns in SIEN parks. Increased levels of ozone and particulate matter pose a threat to human health. The U.S. Environmental Protection Agency (USEPA) has established National Ambient Air Quality Standards (NAAQS) for each of six "criteria" pollutants, to protect the public from the health hazards associated with air pollution. These six criteria pollutants are: carbon monoxide (CO), ozone ($O_3$), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), particulate matter less than 10 micrometers ns in diameter (PM10), particulate matter less than 2.5 micrometers, and lead (Pb) (Table C-1). The state of California has adopted additional air quality standards for sulfates, hydrogen sulfide, vinyl chloride, and visibility-reducing particulates. Ozone may pose a risk to animal health as well.

**Table C-1.** National and California Ambient Air Quality Standards

| POLLUTANT | AVERAGING TIME | FEDERAL PRIMARY STANDARDS | CALIFORNIA STANDARDS |
|---|---|---|---|
| **PARTICULATE MATTER (PM10)** | | | |
| | Annual Arithmetic Mean | 50 ug/m3 | 20 ug/m3 |
| | Annual Geometric Mean | | 30ug/m3 |
| | 24-hour | 150 ug/m3 | 50 ug/m3 |
| | 1-hour | — | |
| **PARTICULATE MATTER (PM2.5)** | | | |
| | Annual Arithmetic Mean | 15 ug/m3 | 12 ug/m3 |
| | Annual Geometric Mean | — | |
| | 24-hour | 35 ug/m3 | |
| | 1-hour | | |
| **SULFUR DIOXIDE ($SO_2$)** | | | |
| | Annual | 80 ug/m3 (0.03ppm) | — |
| | 24-hour | 365 ug/m3 (0.14 ppm) | 105 ug/m3 (0.04 ppm) |
| | 3-hour | | |
| | 1-hour | — | 655 ug/m3 (0.25 ppm) |
| **NITROGEN DIOXIDE ($NO_2$)** | | | |
| | Annual | 100 ug/m3 (0.053 ppm) | — |
| | 1-hour | — | 470 ug/m3 (0.25 ppm) |
| **OZONE ($O_3$)** | | | |
| | 8-hour | 0.08 ppm | — |
| | 1-hour | 0.12 ppm (235 ug/m3) | 0.09 ppm (180 ug/m3) |
| **CARBON MONOXIDE (CO)** | | | |
| | 8-hour | 9 ppm (10 mg/m3) | 9.0 ppm (10 ug/m3) |
| | 1-hour | 35 ppm (40 mg/m3) | 20 ppm (23 ug/m3) |
| **SULFATES** | | | |
| | 24-hour | — | 25 ug/m3 |
| **LEAD** | | | |
| | Calendar Quarter | 1.5 ug/m3 | — |
| | 30-day average | — | 1.5 ug/m3 |
| **HYDROGEN SULFIDE** | | | |
| | 1-hour | — | 0.03 ppm (42 ug/m3) |
| **VINYL CHLORIDE (CHLOROETHENE)** | | | |
| | 24-hour | — | 0.010 ppm (26 ug/m3) |

ug/m3 = micrograms per cubic meter
ppm = parts per million
--- = no standard exists for that pollutant and/or averaging time

## Criteria Pollutants: Description and Issues

Air pollutants which are determined to have a detrimental effect on human health are called criteria pollutants.

### *Carbon Monoxide*

Carbon monoxide (CO) is a colorless, odorless and poisonous gas produced by incomplete burning of carbon in fuels. When CO enters the bloodstream, it reduces the delivery of oxygen to the body's organs and tissues. Health threats are most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Exposure to elevated CO levels can cause impairment of visual perception, manual dexterity, learning ability, and performance of complex tasks.

Seventy-seven percent of the nationwide CO emissions are from transportation sources. The largest emissions contribution comes from highway motor vehicles. Thus, focus of CO monitoring has been on traffic-oriented sites in urban areas where the main source of CO is motor vehicle exhaust. Other major CO sources are wood-burning stoves, incinerators and industrial sources. The National Ambient Air Quality Standard (NAAQS) for carbon monoxide is a 9 ppm, eight-hour, non-overlapping average, not to be exceeded more than once per year. An area meets the carbon monoxide NAAQS if no more than one eight-hour value per year exceeds the 9 ppm threshold. To be in attainment, an area must: (1) meet the NAAQS for two consecutive years, and (2) carry out air quality monitoring during this entire time period. Air quality carbon monoxide value is estimated using EPA guidance for calculating design values (Laxton Memorandum, June 18, 1990).

### *Nitrogen Dioxide*

Nitrogen dioxide ($NO_2$) is a brownish gas produced by high-temperature combustion that is present at elevated levels in all urban environments. At very high concentrations that occur only in the most severely polluted urban areas, $NO_2$ can irritate lungs, cause bronchitis and pneumonia, and lower resistance to respiratory infections. More commonly, nitrogen oxides become an important precursor both to ozone ($O_3$), acid rain, and nitrogen deposition, and affecting the ecology of both terrestrial and aquatic ecosystems.

The major mechanism for the formation of $NO_2$ in the atmosphere is the oxidation of the primary air pollutant nitric oxide (NO). Both of these oxides of nitrogen (or NOx) play a major role–together with volatile organic compounds (VOCs)–in atmospheric reactions that produce $O_3$ and PM2.5 (PM = particulate matter). NOx forms during any high temperature combustion. The two major emissions sources are transportation (i.e., cars and trucks) and stationary fuel-combustion sources, such as electric utility and industry boilers.

### *Ozone*

Ozone ($O_3$) is a photochemical oxidant and the major component of smog. While $O_3$ in upper atmosphere is beneficial to life by shielding earth from harmful ultraviolet radiation from the sun, high concentrations of $O_3$ at ground level are a major health and environmental concern. $O_3$ is not emitted directly into the air, but is formed through complex chemical reactions between precursor emissions of volatile organic compounds (VOC) and oxides of nitrogen (NOx) in the presence of sunlight. These reactions are stimulated by sunlight and temperature, so peak $O_3$ levels occur typically during the warmest, sunniest times of the year.

Both VOCs and NOx are emitted by transportation and industrial sources. VOCs are emitted from sources as diverse as autos, chemical manufacturing, dry cleaners, paint shops and other sources that use solvents. The reactivity of $O_3$ causes health problems because it damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants. Scientific evidence indicates that ambient levels of $O_3$ not only affect people with impaired respiratory systems, such as asthmatics, but healthy adults and children as well. Exposure to $O_3$ for several hours at relatively low concentrations has been found to significantly reduce lung function and induce respiratory inflammation

in normal, healthy people during exercise. This decrease in lung function is generally accompanied by symptoms including chest pain, coughing, sneezing, and pulmonary congestion.

### *Particulate Matter*

Air pollutants called particulate matter include dust, dirt, soot, smoke, and liquid droplets directly emitted into the air by sources such as factories, power plants, cars, construction activity, fires, and natural windblown dust. Particles formed in the atmosphere by condensation or the transformation of emitted gases such as sulfur dioxide ($SO_2$) and VOCs are also considered particulate matter. Another byproduct of atmospheric reactions is nitric acid ($HNO_3$), which combines with ammonia ($NH_3$) to produce a species of particulate matter (PM2.5) called ammonium nitrate ($NH_4NO_3$) .

Based on studies of human populations exposed to high concentrations of particles (sometimes in the presence of $SO_2$) and laboratory studies of animals and humans, there are major effects of concern for human health. These include effects on breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense systems against foreign materials, damage to lung tissue, carcinogenesis, and premature death. The major subgroups of the population that appear to be most sensitive to the effects of particulate matter include individuals with chronic obstructive pulmonary or cardiovascular disease or influenza, asthmatics, the elderly, and children. Particulate matter also soils and damages materials, and is a major cause of visibility impairment in the United States.

Annual and 24-hour National Ambient Air Quality Standards (NAAQS) for particulate matter were first set in 1971. Total suspended particulate (TSP) was the first indicator used to represent suspended particles in the ambient air. Since July of 1987, however, EPA has used–as an indicator–those particles with aerodynamic diameter smaller than 10 micrometers. Most recently, studies have found that even smaller diameter particles (less than 2.5 micrometers or PM2.5) are an even better indicator of health effects. These smaller particles are likely responsible for most adverse health effects from particulate matter because of their ability to infiltrate the thoracic or lower regions of the respiratory tract, and even pass through the alveolar tissue into the bloodstream.

### *Sulfur Dioxide*

High concentrations of sulfur dioxide ($SO_2$) affect breathing and may aggravate existing respiratory and cardiovascular disease. Sensitive populations include asthmatics, individuals with bronchitis or emphysema, children, and the elderly. $SO_2$ is also a primary contributor to acid deposition, or acid rain, which causes acidification of lakes and streams and can damage trees, crops, historic buildings, statues, etcetera. In addition, sulfur compounds in the air contribute to visibility impairment in large parts of the country. This is especially noticeable in national parks.

Ambient $SO_2$ results largely from stationary sources such as coal and oil combustion, steel mills, refineries, pulp and paper mills and from nonferrous smelters. There are three NAAQS for $SO_2$: an annual arithmetic mean of 0.03 ppm (80 ug/m3); a 24-hour level of 0.14 ppm (365 ug/m3); and a 3-hour level of 0.50 ppm (1300 ug/m3). The first two standards are primary (health-related) standards, while the 3-hour NAAQS is a secondary (welfare-related) standard. The annual mean standard is not to be exceeded, while the short-term standards are not to be exceeded more than once per year.

## Attainment

To reiterate, air pollutants determined to have a detrimental effect on human health are called criteria pollutants. Geographic areas are determined, by both national and California standards, as meeting or not meeting the health based standard for a specific air pollutant (e.g., ozone, PM10). An area may be in attainment for one pollutant and non-attainment area for others. The following tables describe attainment status for Sierra Nevada Network parks (Table C-2). Non-attainment status requires that the area produce a plan, with a targeted

**Table C-2.** Attainment status for criteria air pollutants in SIEN parks: Yosemite (YOSE)–Mountain Counties (Mariposa and Tuolumne) Air District; Sequoia & Kings Canyon National Parks (SEKI) and Devils Postpile National Monument (DEPO)–San Joaquin Valley Air District.

| POLLUTANT | FEDERAL | STATE |
|---|---|---|
| **YOSEMITE** | | |
| $O_3$ (1hr) | Attainment | Non-Attainment |
| $O_3$ (8hr) | Non-Attainment | — |
| CO | Attainment | Unclassifiable |
| PM10 | Attainment | Non-Attainment |
| PM2.5 | — | Unclassifiable |
| $SO_2$ | Attainment | Attainment |
| $NO_2$ | Attainment | Attainment |
| **SEQUOIA & KINGS CANYON AND DEVILS POSTPILE** | | |
| $O_3$ (1hr) | Non-Attainment/Extreme | Non-Attainment |
| $O_3$ (8hr) | Non-Attainment/Serious | — |
| CO | Attainment | Attainment |
| PM10 | Non-Attainment/Serious | Non-Attainment |
| PM2.5 | — | Non-Attainment |
| $SO_2$ | Attainment | Attainment |
| $NO_2$ | Attainment | Attainment |

**Table C-3.** Target dates for attainment (as of 17 May 2004).

| AIR DISTRICT | POLLUTANT | AVERAGING TIME | CLASSIFICATION | ATTAINMENT YEAR |
|---|---|---|---|---|
| SAN JOAQUIN VALLEY | Ozone | 1-hour | Extreme | 2010 |
| | Ozone | 8-hour | Serious | 2013 |
| | Particulate Matter (PM10) | | | |
| MARIPOSA/ TUOLUMNE | Ozone | 1-hour | *** | *** |
| | Ozone | 8-hour | Subpart 1 | 2009 |
| | Particulate Matter (PM10) | | | |

***no data available and/or no attainment classification

timeline, to reduce pollutant levels within the specified area and submit the plan to the appropriate level of government (state or federal) for approval.

## Air Quality in Sierra Nevada Parks

### *Emissions*

Devils Postpile and Sequoia and Kings Canyon are located within the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD). The SJVUAPCD is made up of eight counties (San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, and Kern) in the San Joaquin Valley. This air district is in non-attainment status for ozone and PM10 (Table C-2).

Yosemite lies within Mountain Counties' air district, comprising Tuolumne and Mariposa Counties. A small portion of southern YOSE is located in Madera County but the park is generally not regulated by the SJVUAPCD. Mountain Counties Air District also has non-attainment status for ozone and PM10 (Table C-2).

All SIEN parks are exposed to pollutants transported from the Valley as well as from other urban areas of California due to prevailing westerly winds. Approximately nine percent of the

state's thirty five million people live in San Joaquin Valley (SJV), and emission sources (e.g., industry, agriculture, and transportation) within SJV account for about 14 percent of total statewide emissions (Alexis et al. 1999).

Emissions in SJV derive from a number of moderate-sized urban areas, primarily located along the Highway 99 corridor. The other main travel corridor in SJV is US Interstate 5. Since 1980, population growth in the SJV has been more rapid than in other parts of California, partially offsetting effects of emission-control programs (Alexis et al. 1999). Air pollution sources found within parks include: automobiles, buses, construction activities, campfires, wood-burning stoves, natural and prescribed fire, and road dust.

Principal air pollutant species of concern to SIEN parks are ozone, ozone precursors (NOx and VOC's), particulate matter precursors, and particulate matter concentrations that decrease visibility and/or lead to acidic deposition. $SO_2$ emissions are not high in any SIEN parks. Air districts' target dates for ozone and PM10 standards attainment are shown in Table C-3.

Sequoia and Kings Canyon are located within Fresno and Tulare counties. No major point sources of emissions are located in Tulare County; major point sources are not numerous in Fresno County, nor in most other counties of the SJV. Within Fresno County, the closest sources that emit at least 100 tons/year of VOC, NOx, PM10, or $SO_2$ are located near Fresno and Kingsburg; three additional point sources are located in the western portion of the county. As of 1996, stationary sources accounted for 22% of ROG emissions, 34% of NOx emissions, and 4% of PM10 emissions in Fresno County (CARB, 1998b). In Tulare County, stationary sources accounted for 8% of ROG emissions, 11% of NOx emissions, and 5% of PM10 emissions in1996 (CARB, 1998b). In both Fresno and Tulare counties, mobile sources dominated NOx emissions, while area sources (road dust, construction, and farming operations) dominated PM emissions. Mobile sources accounted for 46% of VOC emissions in Fresno and 41% in Tulare Counties.

Yosemite is located within Madera, Mariposa, and Tuolumne counties. Major point sources are not numerous in these counties, nor in most other counties of the SJV or Mountain Counties air basins. Sources that emit at least 100 tons/yr of VOC, NOx, PM10, or $SO_2$ are located near Jamestown and Standard in Tuolumne County, and farther away, near Madera and Chowchilla in western Madera County; none are located within Mariposa County. As of 1996, stationary sources accounted for 12% of VOC emissions, 36% of NOx emissions, and 7% of PM10 emissions in Madera, Mariposa, and Tuolumne counties (CARB1998b). Mobile sources dominated NOx emissions, whereas area sources (road dust, construction, and farming operations) dominated PM emissions.

Devils Postpile is, technically, in SJVUAPCD, but is located at the extreme eastern edge of Madera County. It straddles the San Joaquin Valley (SJV) and Great Basin (GB) Air Basins. There are significant differences between the two air basins. One is size: the SJV is larger, comprising eight counties; the GB comprises three counties. We are concerned with both ozone and particulate matter in SJV; in GB, particulate matter is more prominent. Area wide sources are the main contributor of PM for both districts. Mobile sources are the most influential in contributing precursors of ozone in SJV. Monitoring near the monument provides air-related data that are relevant to DEPO.

### *Ozone*

Through monitoring and research at Sequoia, Kings Canyon and Yosemite, we know that ozone levels are consistently higher than background or natural levels. All three parks experience multiple days where ozone levels exceed the state and national health standard (for 8hr ozone). While elevated levels of ozone can be found at all of the Class I SIEN parks, levels are consistently and at times substantially higher at Sequoia and Kings Canyon. For example, in 2003 Sequoia and Kings

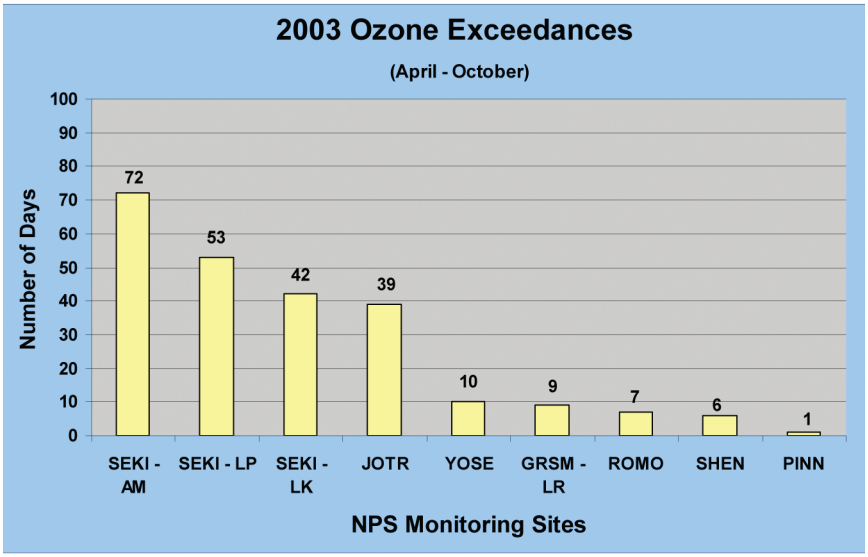



**Figure C-1.** Ozone Exceedance Chart

**Table C-4.** Bio-indicator plant species

| PARK | SCIENTIFIC NAME | COMMON NAME |
|---|---|---|
| SEKI,YOSE | *Apocynum androsaemifolium* | Spreading dogbane |
| SEKI,YOSE | *Artemisia douglasiana* | Mugwort |
| SEKI,YOSE | *Physocarpus capitatus* | Ninebark |
| SEKI,YOSE | *Pinus jeffreyi* | Jeffrey pine |
| SEKI,YOSE | *Pinus ponderosa* | Ponderosa pine |
| SEKI,YOSE | *Populus tremuloides* | Quaking aspen |
| SEKI,YOSE | *Rhus trilobata* | Skunkbush |
| SEKI,YOSE | *Salix scouleriana* | Scouler's willow |
| SEKI,YOSE | *Sambucus mexicana* | Blue elderberry |

Canyon exceeded the health standard for ozone (85 ppb 8 hr. average) 72 days, while Yosemite recorded 10 days above the standard (Figure C-1). These numbers of days exceeding health standards ranks Sequoia, Kings Canyon and Yosemite in the top 10 most ozone polluted parks in the country.

Ozone is a pollutant well known for producing foliar damage in ozone sensitive ponderosa and Jeffrey pines. Ozone damages photosynthetic cells in these pines. It impairs their ability to grow, and compete with other plants, and compromises their resistance to other forest stressors such as insects, pathogens, and drought. (James 1980, Miller 1983). Monitoring sensitive vegetation for ozone damage will help define the severity of impact to our resources. Potential bio-indicator plant species, plants with sensitivity to ozone pollution for the SIEN parks are listed in Table C-4 (NPS—Air Resources Division).

### *Nitrogen and Sulfur Deposition*

Although acidic deposition has been found to currently have less significant impact on Sierra Nevada resources, there are two seasonal pulses of acidity: (1) late summer rain, and (2) the onset of spring snowmelt. These pulses of relatively high acidity can lower pH below 5.35, making naturally basic waters acidic in an un-buffered ecosystem (i.e., not much vegetative cover, steep slopes, granite under-layer, not much soil) (Melack and Sickman et al. 1998). Recent research suggests that these high elevation systems are more resilient that originally believed (Melack and Sickman et al. 1998). Currently, these systems are able to buffer existing acidic events. Potential reactions of these systems to increased acidic deposition are not well understood. In forested ecosystems, summer wet deposition concentrations of $NO_3$ and $SO_4$ averaged two and five times higher, respectively, as compared with concentrations reported for remote areas of the world (Stohlgren and Parsons 1987).

Although we don't know the minimum concentrations of acid that may cause direct or indirect foliar damage to plant species in Sierra Nevada parks, Stohlgren and Parsons (1987) emphasized that acid concentrations are highest during the primary growing season and during periods of maximum drought stress. Both of these occur during the summer (Stohlgren and Parsons 1987; Williams and Melack 1991; Williams and Melack 1997b; Melack et al. 1998; Williams et al. 1995; Galloway et al. 1982; Stoddard 1994).

Wet deposition monitoring has provided a long term data set in Sequoia, Kings Canyon, and Yosemite, measuring constituents that are related to vehicle, agriculture, and other human activities which produce air pollutants. The data show that national parks in the West do not receive substantial amounts of wet SO4 deposition. On the other hand, levels of $NO_3$ and NH4 deposition appear high enough to fertilize terrestrial vegetation and cause euthrophication of aquatic systems. However, without site-specific totals or dry deposition

data to accompany the wet deposition data, a quantitative (i.e., determination of critical loads) approach remains improbable. Figure C-2 illustrates approximately the past 20 years of annual deposition of NO3, NH4, and SO4 for Sequoia, Kings Canyon, and Yosemite. These numbers do not provide a complete picture of N contribution from dry deposition in the parks: given their Mediterranean climate, almost half the year is dry. Therefore wet deposition values alone underestimate total deposition.

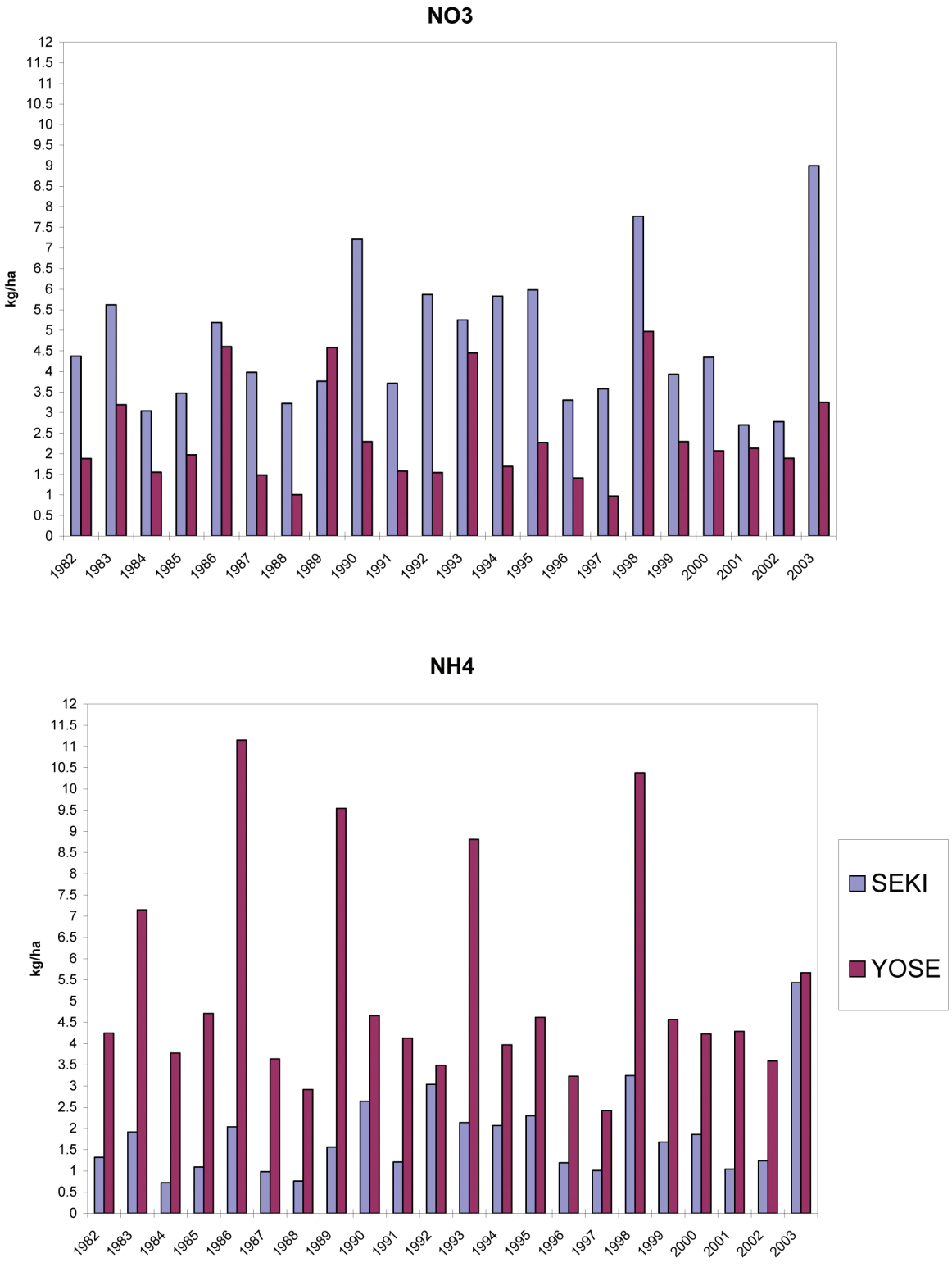



**Figure C-2.** Total Annual Wet Deposition (NADP), SEKI and YOSE, 1982–2003.

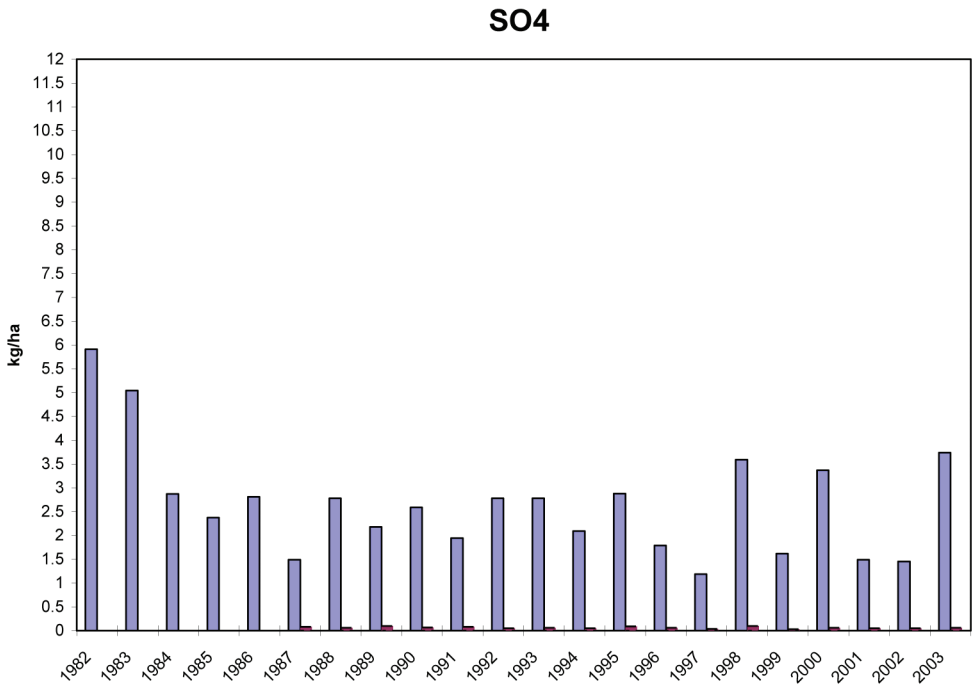



**Figure C-2.** Total Annual Wet Deposition (NADP), SEKI and YOSE, 1982–2003 (cont'd).

### *Particulate Matter/Visibility*

Changes in visibility at SIEN parks are largely due to organics, sulfates, and nitrates. Historically, visibility varies with patterns in weather, winds, and smoke from fires. The cleanest 20% of days probably approaches natural conditions (GCVTC 1996). Smoke from frequent fires is suspected to have reduced pre-settlement visibility below current levels during some summer months, however there are no quantitative records for comparison to more recent datasets. Long-term visibility trends fall into three categories: increases, decreases, and insignificant changes. The characterization of long-term trends can be a highly subjective exercise: slopes and their statistical significance can vary depending on the technique employed. Recently the IMPROVE aerosol network, initiated in March 1988, matured to a point where long-term trends of average ambient aerosol concentrations and reconstructed extinction can be assessed for sites with an eleven year period of record (CA Class I Parks 2001).

Because full IMPROVE aerosol monitoring was not initiated at Yosemite or Sequoia until March 1994, the current monitoring period is not considered long enough to adequately summarize long-term trends. Seasonal trends (1996 to 1998) show that fine aerosols rise in the summer and that organics make up the largest proportion of these aerosols (see Figure C-3 and also, http://vista.circa.colostate.edu.improve/Data/GraphicViewer/).

Other aerosol species observed include: sulfate, nitrate, elemental (light absorbing) carbon, and coarse particles (i.e., wind blown dust). Coarse particles tend to have geological origins and deposit close to their source. Fine particles are usually man-made or from fires, have the ability to transport great distances, and cause the greatest impairment to visibility. Of the fine particles, the organics and carbon are largely from fires or biogenic sources, while the sulfate and nitrate are from anthropogenic sources.

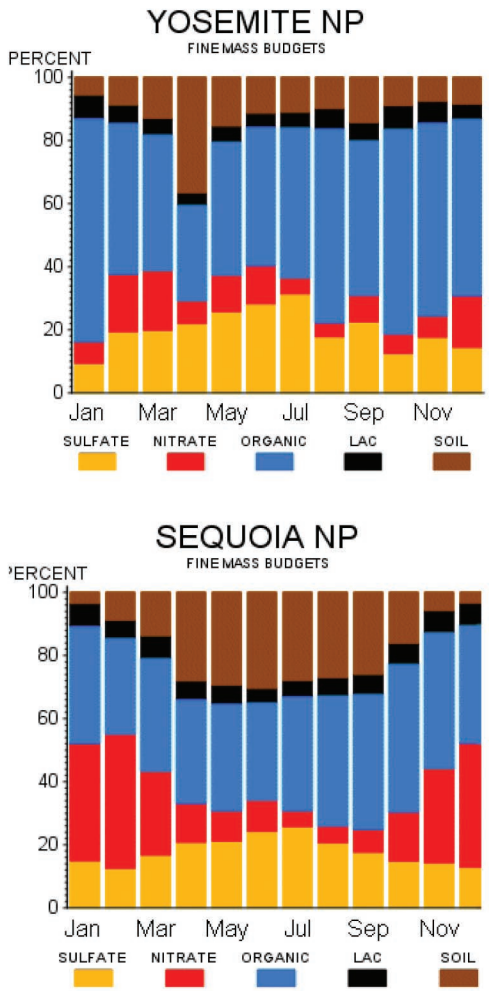



**Figure C-3.** Fine aerosol mass proportions for Yosemite and Sequoia National Park, 1996-1998. Light absorbing carbon noted as LAC, above.

In the Malm et al. (2000) IMPROVE report, eleven years of data were used to describe trends in particulate matter (specifically, PM2.5) pollution for Yosemite (CA Class I parks 2001). Aerosol species were associated with low, median, and high fine mass day categories, and then respective light extinctions and deciviews (relative haziness values) were calculated for each species. The report concluded that there was an insignificant change in visibility over time, meaning that there was neither an increasing nor a decreasing trend (Figure C-4). However, like Sequoia, seasonal trends within Yosemite show a significant rise in fine aerosols through the hot summer months, with organics making up the largest proportion of these aerosols—large regional fires are the most likely origin of these fine particles, although some sulfate increase has been recorded most recently (2007). Visibility diminishes with increased particulate matter pollution, so the IMPROVE network attempts to identify chemical species that significantly reduce visibility in our Parks.

By summarizing these data regionally and comparing them nationally, it becomes apparent that southern California visibility is similar to northern Massachusetts and southern Vermont in terms of average haziness in deciviews (Figure 3). However, approximately 11% of southern California's light absorption is caused by aerosols, while only 5.1% of New England's light absorption is caused by aerosols. This is a complicated observation considering the differences in average air moisture content between the two regions, as well as the variety of pollution species, all contributors to haze. The worst average visibility in the country is in the southeast, with visibility impairment values of 21 to 26 deciviews (lower numbers denote greater visibility).

### *Contaminants*

California pesticide-use data show that between 1991 and 2000, approximately 2 billion pounds of active ingredients were applied in the State (Pesticide Action Network). Pesticides, which are used extensively in California's heavily-farmed SJV, are of concern in the Sierra Nevada. Potential impacts depend on the degree to which a particular pesticide breaks down in the environment and the levels of toxicity of the breakdown products. The amount of pesticide use suggests that further study is warranted. Pesticides vary as to their levels of volatility. For example, in Fresno County, the estimated pesticide VOC emissions potential of 17.6 million pounds (8.8 thousand tons) is a substantial portion of the total VOC emissions of 39.4 thousand tons. However, California Department of Pesticide Regulation's (CDPR) estimate of VOC emissions potential exceeds that used in the CARB emissions inventory (CARB, 1998b) by a factor of two. It also should be noted that most ozone formation in the SJV is NOx,

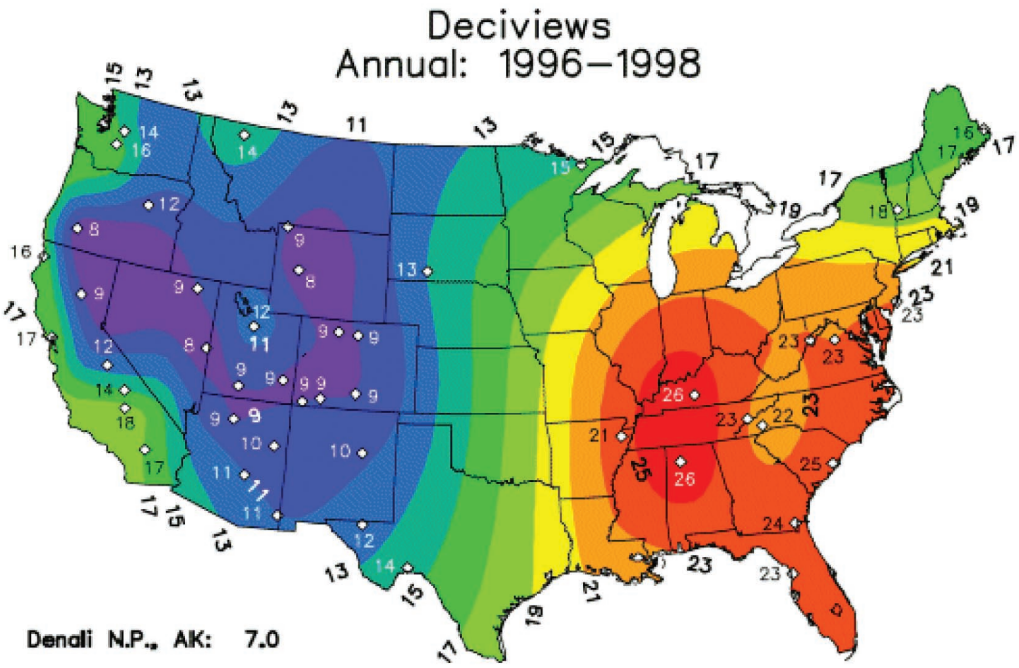



**Figure C-4.** Regional visibility measured in deciviews,1996 to 1998. Lower numbers denote greater visibility.

not VOC limited, so the increase from pesticides probably has little impact on actual ozone formation where that NOx limitation prevails. Some sites downwind however (i.e., in SEKI), may be less NOx limited due to degradation aging of the NOx plumes during transport (Blanchard, 2001; Luria, 1999, 2000)

Pesticides are of concern for their potential toxicity, not just their ozone-forming potential. Studies conducted in SEKI indicate that more commonly and heavily used pesticides in the SJV are transported into the Sierra Nevada (Zabik and Seiber 1993, LeNoir et al. 1999). Measurements made in Sequoia National Park, showed pesticides concentrations diminishing between Ash Mountain entrance station and Lower Kaweah (Zabik and Seiber 1993). This represents a decrease in concentration with both distance and elevation (relative to the San Joaquin valley floor). Pesticides applied to crops (that are intensively produced in the Central Valley) can volatilize under warm valley temperatures, subsequently be transported via upslope air movement, and then deposited in the cooler, high-elevation regions of Sequoia National Park (Zabik and Seiber 1993; LeNoir et al. 1999).

In 2002, SEKI was included in the Mercury Deposition Network (MDN), a network developed by the National Atmospheric Deposition Program (NADP). The sampler is co-located with the NADP sampler at Lower Kaweah in Sequoia National Park. This network investigates the local and regional transport and deposition of mercury. Mercury is known to contaminate aquatic ecosystems, and there are over 30 states which have fish consumption advisories due to mercury content. Atmospheric transport and deposition is the dominant pathway to aquatic ecosystems. This problem has greater attention in the eastern U.S., as reflected in both the number of sampling sites in the east, and mercury levels found in these states. Origin of mercury in the East is predominantly from coal burning industries. There also exists global transport of mercury in the atmosphere, whose source is wide and varied. Effects of mercury deposition vary by site as a result of differences in soil chemistry, water chemistry, the food web, etc. There is less information on mercury

deposition in California, and there are only 2 active MDN sites in California.

### Air Resources Division of the National Park Service

The National Park Service Air Resources Division (ARD) mission is to: "[p]reserve, protect, enhance, and understand air quality and other resources sensitive to air quality in the National Park System" (http://www2.nature.nps.gov/air/). In order to do this, a combination of both monitoring and research is necessary. Long-term monitoring data make it possible to plot and assess air pollution patterns and compare these patterns to other regions of the country. At the same time, research data are needed to answer more specific pollution questions concerning cause and effect and total deposition loads.

As part of the NPS ozone monitoring network, and by participating in the National Atmospheric Deposition Program (NADP), the Interagency Monitoring of Protected Visual Environments (IMPROVE), and the Clean Air Status & Trends Network (CASTNet), Sequoia & Kings Canyon and Yosemite National Parks contribute to the NPS effort to monitor air pollution in the form of wet deposition and dry deposition, as well as fine particulate matter and aerosols. All of these monitoring data are collected with relevant meteorological data, making the interpretation of the pollutant patterns more meaningful and comparable. Air-related research projects are mostly cooperative with the NPS in the role of facilitator, supplying information and resources to universities, private researchers, and other branches of state and federal government.

### Long-term Monitoring Programs

The National Park Service Air Resource Division (ARD) coordinates NPS air quality monitoring programs nationwide and contracts with a private consulting group called Air Resources Specialists (ARS) located in Fort Collins, Colorado Specifically, ARS provides technical support which enables NPS station operators to troubleshoot complicated monitoring equipment and provide for consistent operations. Their efforts contribute to generation of accurate and high quality data. The ARS group also helps NPS-ARD with data summaries and interpretation.

Both Yosemite and Sequoia & Kings Canyon operate year-round air monitoring sites, some dating back to the early 1980s (Figure C-5). Each site is unique in its array of monitoring equipment (described in Table C-5). Devils Postpile National Monument does not currently conduct any air monitoring within the boundaries of the monument, but monitoring work has been conducted in the surrounding area and is representative of air in the monument.

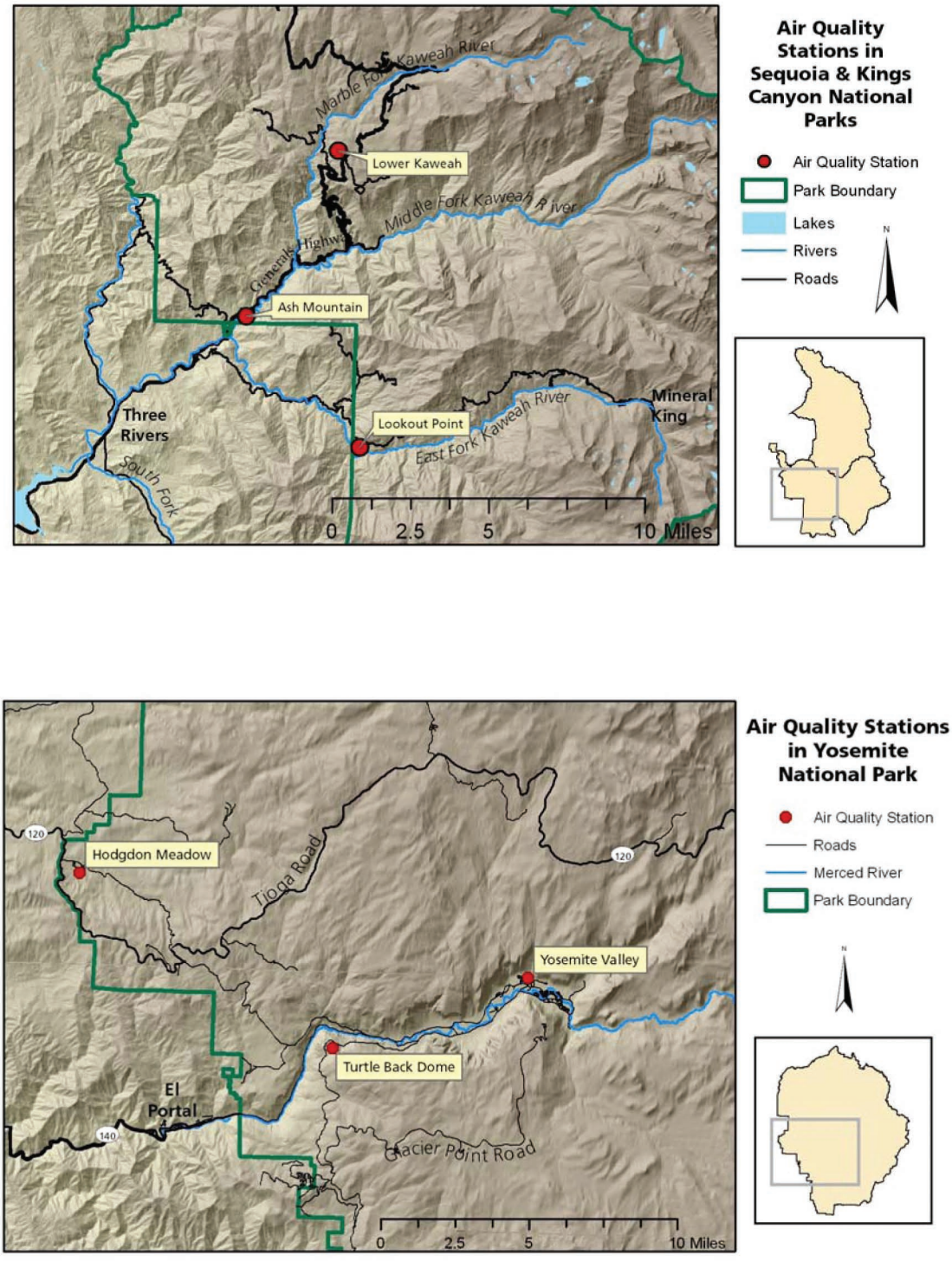



**Figure C-5.** Air quality monitoring sites in Sequoia & Kings Canyon and Yosemite National Parks.

**Table C-5.** Air monitoring stations

| PARK | SITE | TYPE | NETWORK** |
|---|---|---|---|
| **SEQUOIA** | Ash Mountain | Meteorology | NPS – ARD |
| | | Ozone | NPS – ARD |
| | | Particulate Matter | SEKI Fire |
| | | $PM_{2.5}$ and $PM_{10}$ | IMPROVE |
| | Lookout Point | Meteorology | NPS – ARD |
| | | Ozone | NPS – ARD |
| | | Dry deposition | CASTNet |
| | Lower Kaweah | Meteorology | NPS – ARD |
| | | Ozone | NPS – ARD |
| | | Wet deposition | NADP/NTN |
| | | Mercury | MDN |
| | | Webcam | NPS – ARD |
| **YOSEMITE** | Yosemite Valley | PM2.5 and PM10 | CARB |
| | | Meteorology | NPS – ARD |
| | | Ozone | NPS – ARD |
| | | $NO_X$ | NPS – ARD |
| | | CO | NPS – ARD |
| | Turtleback Dome | Meteorology | NPS – ARD |
| | | Ozone | NPS – ARD |
| | | Visibility | NPS – ARD |
| | | Webcam | YOSE Concession |
| | | Dry deposition | CASTNet |
| | | Particulate Matter | IMPROVE |
| | Hodgdon Meadow | Wet deposition | NADP/NTN |

** California Air Resources Board (CARB)
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)

### *National Atmospheric Deposition Program/National Trends Network*

(NADP/NTN) is a nationwide network of over 200 precipitation monitoring sites developed by the EPA. The NADP/NTN is a cooperative effort between many different groups, including the State Agricultural Experiment Stations, U.S. Geological Survey, U.S. Department of Agriculture, and numerous other governmental and private entities. Its purpose is to collect weekly rain, snow, or condensation samples and produce chemical data. The weekly water samples are sent to the Central Analytical Laboratory where they are analyzed for hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (such as calcium, magnesium, potassium and sodium (paraphrased from http://nadp.sws.uiuc.edu/nadpoverview.asp).

The NADP site within Giant Forest, Sequoia National Park, has been in operation since the early 1980's. The NADP site at Hodgden Meadows in Yosemite has been operating since 1981.

### *Interagency Monitoring of Protected Visual Environments*

Interagency Monitoring of Protected Visual Environments (IMPROVE) is a cooperative measurement effort comprising representatives from federal and regional-state organizations. It

aids the creation of federal and state implementation plans for the protection of visibility in Class I areas (156 national parks and wilderness areas) as stipulated in the 1977 amendments to the Clean Air Act .The objectives of IMPROVE are to:

1. Establish current visibility and aerosol conditions in mandatory class I areas
2. Identify chemical species and emission sources responsible for existing man-made visibility impairment
3. Document long-term trends for assessing progress towards the national visibility goal
4. Provide regional haze monitoring representing all visibility-protected federal class I areas where practical (in response to the enactment of the Regional Haze Rule)

IMPROVE has also been a key participant in visibility-related research, including the advancement of monitoring instrumentation, analysis techniques, visibility modeling, policy formulation and source attribution field studies (paraphrased from http://vista.circa.colostate.edu.improve/Overview/Overview.htm).

A full IMPROVE aerosol sampler (modules A, B, C, and D) began operation at Sequoia in March of 1994. The sampler is located near Park Headquarters at Ash Mountain, at the southwest entrance to Sequoia National Park. There has been a full IMPROVE aerosol sampler at Yosemite since March 1988, located at Turtleback Dome. In 2002, improvements to the Sequoia IMPROVE stations added a set of PM10 modules (E &F) at the Ash Mountain site.

### *Clean Air Status and Trends Network*

Clean Air Status and Trends Network (CASTNET) was developed by EPA to monitor dry deposition of gaseous pollutants. By design, monitoring site locations are predominantly rural to assess the relationship between regional pollution and changes in regional patterns in dry deposition. CASTNET also includes measurements of rural ozone and the chemical constituents of PM2.5 (fine particulate matter). Rural monitoring sites of CASTNET provide data where sensitive ecosystems are located and provide insight into natural background levels of pollutants where urban influences are minimal.

These data provide much-needed information to scientists and policy analysts to study and evaluate numerous environmental effects, particularly those caused by regional sources of emissions for which long range transport plays an important role. Measurements from these networks are also important for understanding non-ecological impacts of air pollution such as visibility impairment and damage to materials, particularly those of cultural and historical importance (paraphrased from http://www.epa.gov/castnet).

The CASTNet dry deposition monitoring site located at Lookout Point, within Sequoia National Park, began operating February 1997. The CASTNet site in Yosemite, on Turtleback dome, has been in operation since September 1995.

### *Light Pollution*

Light pollution is not confined to cities. Excessive glare, urban sky glow, and poor lighting threaten dark skies. Night sky visibility is an important aesthetic value of wilderness and its protection has been added to the responsibilities of NPS managers. The objectives of the night visibility monitoring program are to: (1) define the magnitude of night sky brightness, (2) identify short-term or seasonal impairments, (3) utilize monitoring data summaries for public education, and (4) help define limits of acceptable change for night sky visibility.

Dark sky monitoring sites were established in both Sequoia and Kings Canyon. Yosemite currently has one site with a second identified and monitoring began in September 2004.

### *Natural Soundscapes*

Biophony is the combined sound that living organisms produce in a given habitat. When habitat health is stable, indications are that there is a symbiotic and unique relationship between the creature voices denoted by both frequency and time niches discernible on audio spectrogram graphic displays with a high degree of discrimination and detail (Krause 2001). Manmade noise

can be harmfully disruptive and, as such, NPS has designated natural soundscapes as a resource, which means they must be protected (akin to "clean air"). The program is managed by the NPS-ARD and parks locally facilitate and conduct sound measurements.

In 2001, Sequoia National Park became the site of a natural soundscape monitoring pilot program. Dr.Bernie Krause and Dr. Stuart Gage collected recordings in different habitats at different seasons to test biophony as an indicator of habitat fitness.

## Monitoring and Research Needs

### *Data Acquisition and Analysis, Monitoring*

Current monitoring efforts need to continue. In addition to monitoring efforts, resources should also be devoted to acquiring and integrating existing data, and to analyze and present findings from the available datasets. Existing meteorological and air-quality data could be more extensively analyzed to better characterize patterns of transport of air pollutants (e.g., fine particulate), including the nature of upslope and downslope flows.

Better characterization of pollutant transport is also needed to support the parks' fire management programs, help discern origins of specific pollutants, and provide critical information to complement biological effects research.

Another research and monitoring gap is regarding the prevalence, concentration, and spatial distribution of the nitrogenous ozone precursors that can deposit to low productivity watersheds (discussed below) and change their N cycling regime, and the ecology that depends on it.

Additional efforts should be devoted to characterizing the ambient atmospheric levels of non-criteria air pollutants (e.g., pesticides and gaseous nitrogen) and comparing these levels with their concentrations in aquatic systems. This research effort would be enhanced by linking it to any ongoing studies of atmospheric transport and biological effects.

### *Wet and Dry Deposition*

Continued monitoring of wet and dry deposition is needed to provide estimates of spatial patterns and temporal variability of deposition. The long-term data records should be maintained by continuing wet-deposition monitoring at Giant Forest (NADP). Dry deposition monitoring should continue at Ash Mountain (IMPROVE), and Lookout Point (CASTNet). It is recommended that wet deposition monitoring be reinitiated at Ash Mountain in Sequoia National Park.

The long-term deposition record presently available lends itself to analyses of trends. The data should be analyzed to determine the statistical power of trend tests (i.e., the length of monitoring needed to detect trends and the levels of change that can be discerned within a specified time).

Increased input of nitrogen (i.e., $HNO_3$, $NH_4$, $NH_3$, $NO_3$) is recognized as an additional stressor to Sierra Nevada ecosystems. There are potential landscape-scale changes such as terrestrial fertilization and aquatic eutrophication due to increased nitrogen and phosphorus loading (Sickman et al. and Fenn et al.) Improved measurements of both wet and dry forms of nitrogen will give more accurate levels of nutrient loading to Sierra Nevada ecosystems

Additional benefit to understanding pollutant levels in the Sierra Nevada would be use of NOx analyzers. Co-location with ozone, wet deposition, and particulate matter would be useful to park management needs, including but not limited to fire operations, health advisories, and monitoring vegetation stressors. Retention of the NOx measurement recently moved to Turtleback Dome should be considered for these purposes, since it provides an indicator of the NOx transported from the Central Valley via the Merced River Canyon into Yosemite.

### *Ozone*

Continuous measurements of ozone are needed to provide estimates of spatial patterns and temporal variability. The long-term data records should

be maintained by continuing ozone monitoring at the existing sites at Giant Forest, Ash Mountain, and Lookout Point in Sequoia, and at Turtleback Dome in Yosemite. An ozone monitor was installed in Yosemite Valley to provide information to an ozone effects study in 2001. The study found significant differences in ozone levels between the Valley site and Turtleback Dome. With the high visitation found in the Valley, this site should be retained and added to the NPS ozone monitoring network.

Passive ozone monitors suggest that ozone levels vary significantly within Sierra Nevada parks. Additional efforts to characterize the spatial patterns of ozone concentrations should be supported. Summary statistics documenting violations of the state and federal ozone standards are also of interest. The use of existing passive sampler data should be continued to provide on-site data relevant for co-located ozone-injury vegetation plots. The value of previous ozone data collected with passive samplers should be assessed for developing calibrated spatial relationships relative to analyzers, so that large-scale ozone exposure in the park can be quantified. If the spatial distribution (especially variation in elevation) has not been sufficient, it is recommended that a one-time study with well-distributed passive samplers be used for spatial calibration.

### *Particulate Matter/Visibility*

IMPROVE aerosol monitoring should continue at Sequoia and Yosemite. As part of the IMPROVE Network expansion, the EPA and NPS have upgraded the aerosol sampler in Sequoia to include 2 additional modules for PM10. While the site at Ash Mountain (550 m) serves the purpose of measuring what PM is traveling into the park via the Kaweah River drainage, it inadequately represents the average elevation of the parks. An additional site has been proposed, to be located at a higher elevation (2,250 m). This new location may better represent conditions for the high elevation landscape that dominates the Sierra Nevada. Aerosol concentrations can vary at different elevations throughout the parks. Aerosol and optical monitoring at both high and low elevations would provide information concerning the extent and nature of visibility impairment at Sierra Nevada parks. Emissions from industrial processes and wildland fires also contribute to visibility impairment in all SIEN parks. In addition to monitoring for human health concerns, monitoring should be developed to identify carbon emissions from industrial processes and wildland fires.

Visibility as measured by transmissometers is being utilized in Yosemite. The transmissometer receiver is located on Turtleback Dome with the target transmitter at Foresta. Additional visibility data should be considered in high visitation areas where broad vistas are a hallmark for their respective parks to measure degradation or improvement.

### *Natural Soundscapes*

Natural sound monitoring should be developed for one or more of the SIEN parks. Co-location with a year round air monitoring site would be the most useful as sound levels could correspond with meteorology and various high air pollution events (e.g., high levels of particulate matter or ozone). It would also be logistically practical as the air monitoring sites are visited on a weekly basis.

### *Dark Sky*

The NPS Dark Sky monitoring program is widespread and growing. Yosemite, Sequoia and Kings Canyon have areas targeted for repeat dark sky photography. Comparisons should be made between natural dark sky and light pollution often found in developed areas. This would help in guiding park operations in types and location of light fixtures and could provide information useful to lighting policy and planning for local communities.

# LIterature Cited


Alexis A., P. Gaffney, C. Garcia, C. Nystrom, and R. Rood. 1999. The 1999 California Almanac of Emissions and Air Quality. California Air Resources Board. Sacramento, CA. 310 pp.

Blanchard, C.L. and D. Fairley. 2001. Spatial mapping of VOC and NOx-limitation of ozone formation in the Central Valley, *Atmospheric Environment*, **35**: 3861-3873.

Cahill, T.A., J.J. Carroll, D. Campbell, and T.E. Gill. 1996. Air quality. *In*: Status of the Sierra Nevada, Sierra Nevada Ecosystem Projects. Centers for Water and Wildland Resources, University of California, Davis. Pp. 1227-1261.

CARB. 1998b. Emission Inventory 1996. California Air Resources Board. Sacramento, CA.

Clean Air Status and Trends Network— http://www.epa.gov/castnet

Cooperative Institute for Research in the Atmosphere––http://vista.circa.colostate.edu.improve/Overview/Overview.htm and http://vista.circa.colostate.edu.improve/Data/GraphicViewer/

Fenn, M.E., R. Haeuger, G.S. Tonnesen, J.S. Baron, S. Grossman-Clark, D. Hope, D.A. Jaffe, S. Copeland, L. Geiser, H.M. Rueth, and J.O. Sickman. 2003. Nitrogen emission, deposition, and monitoring in the Western United States. *BioScience*, **53**: 4.

Fenn, M.E., J.S.Baron, E.B. Allen, H.M. Rueth, K.R. Nydick, L. Geiser, W.D. Bowman, J.O. Sickman, T. Meixner, D.W. Johnson, and P. Neitlich. 2003. Ecological effects of nitrogen deposition in the western United States. *BioScience*, **53**:4.

Galloway, J.N., G.E. Likens, W.C. Keene, and J.M. Miller. 1982. The composition of precipitation in remote areas of the world. *J. Geophys. Res.* **88**:10850-10864.

Grand Canyon Visibility Transport Commission (GCVTC), 1996, Proposed Recommendations of the Grand Canyon Visibility Transport Commission, Public Advisory Committee Final Report.

James R.L., F.W. Cobb, P.R. Miller, J.R. Parmeter Jr. 1980 Effects of oxidant air pollution on susceptibility of pine roots to Fomes annosus. *Phytopathology* **70**:560-563.

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. *Environ. Toxicol. Chem.* **18**(**12**):2715-2722.

Luria, M., R. J. Valente, R. L. Tanner, N. V. Gillani, R. E. Imhoff, S. F. Mueller, K. J. Olszyna, and J. F. Meagher. 1999. The evolution of photochemical smog in a power plant plume. *Atmospheric Environment* **33**:3023-3036.

Luria, M., R. L. Tanner, R. E. Imhoff, R. J. Valente, E. M. Bailey, and S. F. Mueller. 2000. Influence of natural hydrocarbons on ozone formation in an isolated power plant plume. *Journal of Geophysical Research-Atmospheres* **105**:9177-9188.

Miller, P.R. 1983. Ozone effects in the San Bernardino National Forest. In Proceedings: Air Pollution and the Froductivity of the Forest. Izaak Walton League and Penn State University, pp. 161-197.

Melack, J.M., J.O. Sickman, A. Leydecker, and D. Marrett. 1998. Comparative analyses of high-elevation lakes and catchments in the Sierra Nevada: susceptibility to acidification. Final Report, Contract A032-188, California Air Resources Board, Sacramento. 615 pp.

National Atmospheric Deposition Program— http://nadp.sws.uiuc.edu/nadpoverview.asp

National Park Service—http://www2.nature.nps.gov/air/ Pubs/index.htm

Sequoia and Kings Canyon National Park––http://www.nps.gov/seki/

Sickman, J.O., A. Leydecer, C.C.Y. Chan, C. Kendall, J.M. Melack, D.M. Lucero, J.P. Schimel 2003a. Mechanisms underlying export of nitrogen from high elevation catchments during seasonal transitions. *Biogeochemistry* **64**:1-24

Sickman, J.O, D. Clow, and J.M. Melack 2003b. Evidence for nutrient enrichment of high elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* **48**(5): 1885-1892.

Stoddard, J.L. 1994. Long-term changes in watershed retention of nitrogen: its causes and aquatic consequences. *In*: L.A. Baker, (ed.). Environmental Chemistry of Lakes and Reservoirs. Advances in Chemistry Series, No. 237, American Chemical Society, Washington, DC. pp. 223-284.

Stohlgren, T.J. and D.J. Parsons. 1987. Variation of wet deposition chemistry in Sequoia National Park, California. *Atmos. Environ.* **21**(6):1369-1374.

Sullivan, T.J., Peterson, D.L., and C.L. Blanchard. 2001. Assessment of Air Quality and Air Pollutant Impacts in Class I National Parks of California 377p.

Williams, M.W. and J.M. Melack. 1997b. 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., 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.

Yosemite National Park—http://www.nps.gov/yose/. Accessed: 2005.

Zabik, J.M. and J.N. Seiber. 1993. Atmospheric transport of organophosphate pesticides from California's Central Valley to the Sierra Nevada Mountains. *J. Environ. Qual.* **22**:80-90.

# Sierra Nevada Network Vital Signs Monitoring Plan

## *Appendix D: Evaluation of Existing Water Resources Information in the Sierra Nevada Network*

Natural Resource Report NPS/SIEN/NRR—2008/072

Andi Heard, Physical Scientist, Sierra Nevada Network
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

John D. Stednick, Professor
Colorado State University
Watershed Science Program,
Department of Earth Resources
Fort Collins, CO 80523-1482

Layout and design Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Heard, A. and J. D. Stednick. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix D. Evaluation of existing water resources information in the Sierra Nevada Network parks. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Contents


Introduction ..... 73
Purpose and Scope. ..... 74
Current and Emerging Aquatic Ecosystem Threat ..... 74
Methods and Approach ..... 79
Literature Review. ..... 79
Data Retrieval ..... 79
Trend Analyses.. ..... 80
Devils Postpile National Monument. ..... 81
Water Resources. ..... 81
Hydrologic and Water Quality Data sets ..... 81
Water Quantity. ..... 81
Water Quality ..... 82
Water Resources Monitoring. ..... 83
Local Water Resource Status and Issues ..... 83
Sequoia and Kings Canyon National Parks. ..... 85
History ..... 85
Water Resources. ..... 86
Hydrologic and Water Quality Datasets ..... 88
Water Resources Monitoring ..... 89
Long-term Monitoring in the Middle Fork of the Kaweah Watershed. ..... 89
East Fork of the Kaweah Watershed. ..... 90
South Fork of the Kings River. ..... 90
Drinking Water Monitoring ..... 90
Long-term USGS Gaging Stations ..... 90
Current Research Projects ..... 91
Local Water Resource Issues ..... 92
Yosemite National Park ..... 95
Water Resources. ..... 95
Hydrologic and Water Quality Datasets ..... 96
Water Resources Monitoring ..... 97
Current Research Projects ..... 98
Local Water Resource Issues ..... 98
Broad-scale Spatial Surveys. ..... 99
Time Series Plots and Trend Analyses ..... 101
Summary ..... 108
Acknowledgements ..... 108
Literature Cited. ..... 109
Addenda ..... 115

## Figures

Figure D-1: Sierra Nevada Network parks and watersheds ..... 78
Figure D-2: Representative mean annual hydrograph from the Merced River at Happy Isles in Yosemite National Park ..... 79
Figure D-3: Lakes, rivers, and streams in and near Devils Postpile National Monument ..... 83
Figure D-4: Mean monthly precipitation at low (Ash Mountain: 535 m) and middle (Atwell Mill: 1975 m) elevations ..... 90
Figure D-5: Lakes, rivers, and streams in Sequoia and Kings Canyon National Parks ..... 91
Figure D-6: Lakes, rivers, and streams in Yosemite National Park ..... 99
Figure D-7: ANC and sulfate time series plots ..... 107
Figure D-8: Ammonium and nitrate time series plots ..... 108
Figure D-9: Calcium and magnesium time series plots ..... 109
Figure D-10: Sodium and potassium time series plots ..... 110
Figure D-11: Phosphate and chloride time series plots ..... 111

## Tables

Table D-1. National and California Ambient Air Quality Standards ..... 84
Table D-2. Attainment status for criteria air pollutants in SIEN parks ..... 86
Table D-3. Target dates for attainment (as of 17 May 2004) ..... 92
Table D-4. Bio-indicator plant species ..... 93
Table D-5. Air monitoring stations ..... 100
Table D-6. Seasonal Kendall test results for Chamise Creek, Log Creek and Emerald Lake ..... 106

# Introduction

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

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

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

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




**Figure D-1.** Watersheds in Sierra Nevada Network parks.

## PURPOSE AND SCOPE

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

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

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

## CURRENT AND EMERGING AQUATIC ECOSYSTEM THREATS

The State Water Resources Control Board and nine Regional Water Quality Control Boards, under the Porter-Cologne Water Quality Control Act, are responsible for the protection and enhancement of California's

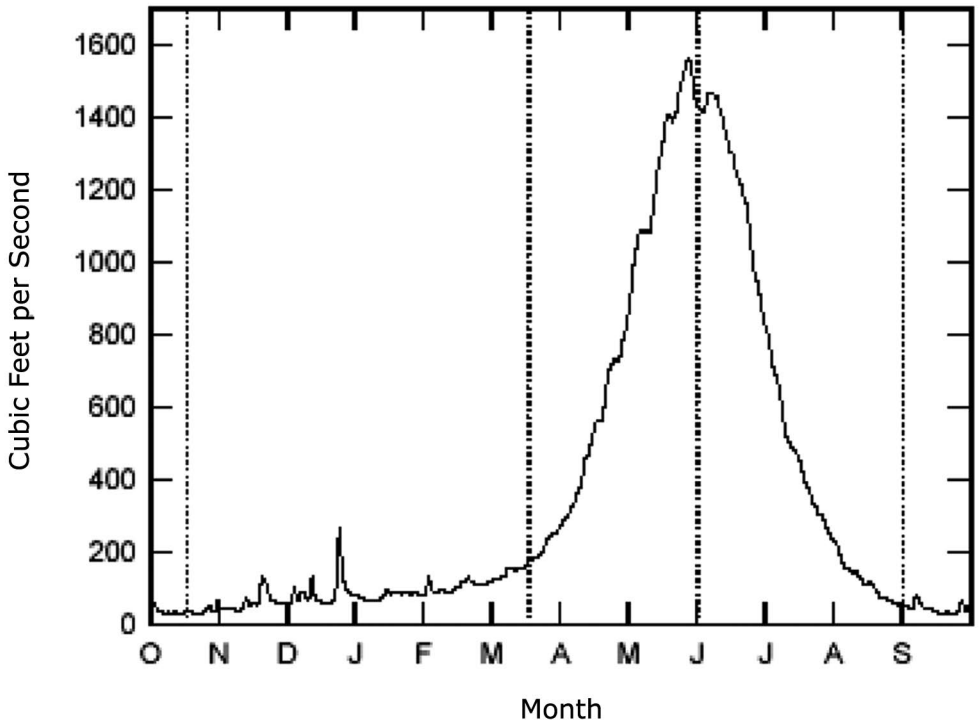



**Figure D-2:** Representative mean annual hydrograph from the Merced River at Happy Isles in Yosemite National Park. National Park Service- Water Resources Division plotted the hydrograph using a 72 year record (National Park Service 1998). Vertical lines divide the hydrograph into four seasons.

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

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

The Sierra Nevada national parks protect many lakes, streams and rivers with unaltered flow regimes and good to high water quality. However, the parks water resources are subjected to natural and anthropogenic disturbances that have the potential to modify the

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

Over 100 years of fire suppression polices have altered fire regimes in the Sierra Nevada Network parks. In general, fire frequencies have decreased and the potential for higher severity wildfires has increased (Swetnam 1993, Caprio and Lineback 1997, Caprio 2004). Potential effects on water resources from a lack of fire are reduced stream flows, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires have the potential to impair water resources. Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003). Deposition of ash particles in the surrounding landscape may contribute to increasing nutrient inputs to oligotrophic waters (Spencer et al. 2003).

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

The western slope of the central and southern Sierra Nevada is impacted by some of the worst air pollution in the United States (Cahill et al. 1996). Contaminants and nutrients, produced from agricultural, urban, and industrial sources in the San Francisco Bay Area and the Central Valley, are transported by air currents into the Sierra Nevada where they are deposited as wet or dry deposition. High elevation lakes and streams in the Sierra Nevada are oligotrophic, have a low buffering capacity, and sensitive to change from atmospheric deposition of nutrients, toxic substances, and acids. Increased nitrogen and phosphorous inputs are contributing to eutrophication, changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes (Goldman et al. 1993, Sickman et al. 2003). Pesticides from the adjacent Central Valley (LeNoir et al. 1999) and global sources (National Park Service Air Resources Division 2003) have been detected in Sierra Nevada streams and lakes at all elevations. The extent of the effects on aquatic ecosystems is largely unknown;

however, current research suggests that pesticides may be a threat to aquatic species, including declining amphibian populations (Sparling et al. 2001, Davidson and Shaffer 2002). At a recent water resources scoping meeting in Sequoia and Kings Canyon, participants identified atmospheric transport of contaminants into the parks as one of the top threats to aquatic resources. Episodic acidification from acid neutralizing capacity (ANC) depression during snowmelt and increased nitrate deposition is also a potential threat, although Sierra Nevada waters appear to be fairly resilient and able to buffer current and potentially increased inputs (Leydecker et al. 1999).

Global temperatures have increased over the last century. Climatologists and atmospheric scientists have attributed at least part of this increase to anthropogenic inputs of greenhouse gases (Houghton et al. 1996). Greenhouse gas concentrations and global temperatures are expected to continue to rise. It is predicted that even a modest temperature increase (2.5 °C) will significantly alter hydrologic processes. The most pronounced changes are earlier snowmelt runoff, reduced summer base flows and soil moisture, (Dettinger et al. 2004), a lower snowpack volume at mid-elevations (Knowles and Cayan 2001), and increased flooding, including rain-on-snow events. The water infrastructure in California was built under the assumption that the Sierra Nevada snowpack would act as a temporary reservoir for the State's water and release it slowly during the spring and early summer months. Changes in precipitation type and timing would result in longer and drier summers with less water available during the months it is most needed. Water quality would be threatened by increased flooding and erosion and lower summer flows. Prolonged summer drought would increase the potential for high severity wildfires, further threatening water quality.

# Methods and Approach

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

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

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

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

## LITERATURE REVIEW

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

## DATA RETRIEVAL

The Water Resources Division of the National Park Service did a thorough search for existing water quality data in all four network parks during the 1990s and results are available in the Baseline Water Quality Data Inventory and Analysis reports (National Park Service 1994, National Park Service 1997, National Park Service 1998). As part of this effort, they organized all the raw data in Visual dBase databases. The Water Resource Division also summarized the presence/absence and distribution of Servicewide Inventory and Monitoring Program "Level 1" water quality parameter groups. Four of these parameters (temperature, specific conductance, pH and dissolved oxygen) are considered 'core parameters' and will be monitored servicewide (National Park Service- Freshwater Workgroup Subcommittee 2002) (Table D-1). Gaging station locations with available metadata were identified. However, flow data associated with these sites were not included; only flow data associated with water quality samples were reported. The Baseline Water Quality Reports and associated databases were used as a starting point for identifying historic water data sets.

**Table D-1**: Level 1 water quality parameter groups. Bolded parameters are the core parameters that all the networks are required to monitor.

| LEVEL 1 WATER QUALITY PARAMETER GROUPS | |
|---|---|
| **Temperature** | Phosphate/Phosphorous |
| Toxic Elements | Alkalinity |
| **pH** | Chlorophyll |
| Clarity/Turbidity | Flow |
| **Conductivity** | Sulfates |
| Nitrate/Nitrogen | |
| **Dissolved Oxygen** | Bacteria |

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

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

Concurrently, an interagency agreement with the USGS-WRD was initiated to develop and populate a water quality geodatabase for the Sierra Nevada Network. USGS uploaded STORET and NWIS data to the SIEN geodatabase.

Additional data compiled as part of this report was also uploaded. The Sierra Nevada Network water quality geodatabase contains existing water quality data in one MS Access database.

## TREND ANALYSES

We selected long-term data sets that met specific criteria for temporal trend analyses. The data sets had to have a period of record greater than five years and a sample size greater than 50. Protocols, metadata and QA/QC reports needed to be well documented. Time series and box plots were used to further evaluate the quality of data and to identify any erroneous data points.

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

# Devils Postpile National Monument

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

## WATER RESOURCES

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

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

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

## HYDROLOGIC AND WATER QUALITY DATA SETS

### *Water Quantity*

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

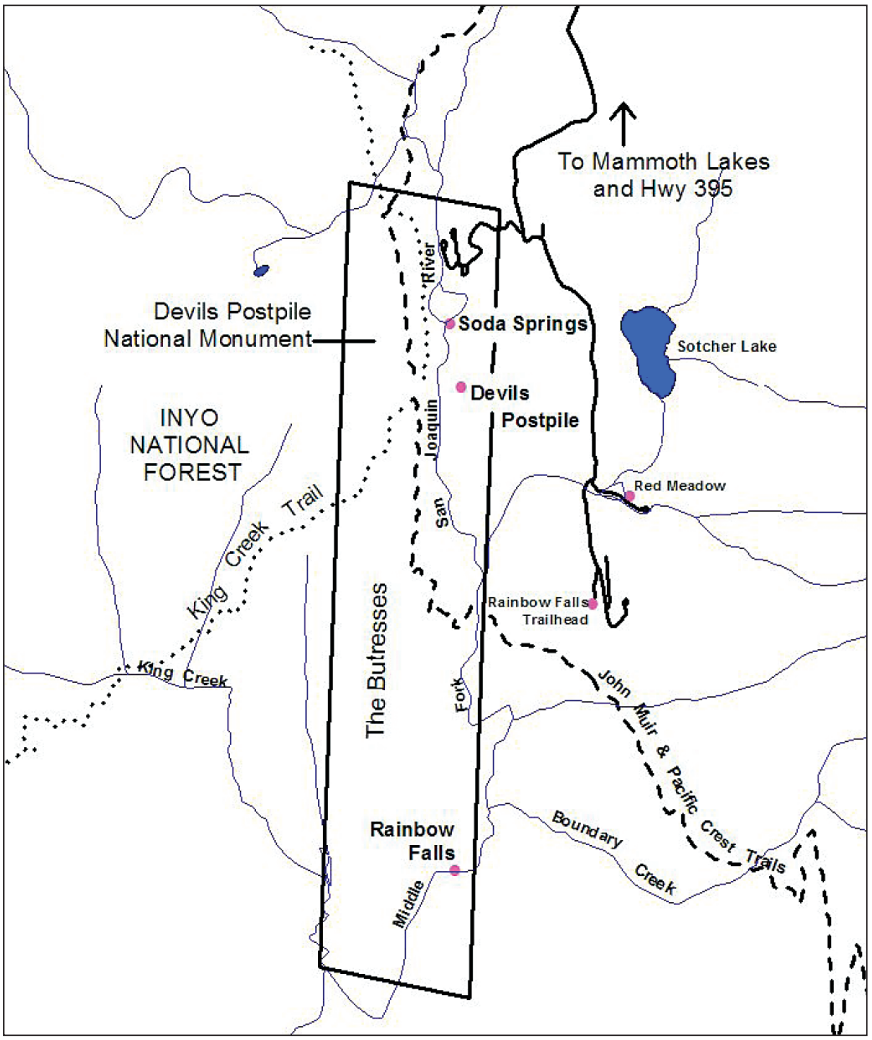



**Figure D-3**: Lakes, rivers, and streams in and near Devils Postpile National Monument.

**Table D-2:** Historical water quality data sets for Devils Postpile National Monument and upstream waters.

| HISTORICAL WATER QUALITY DATA: DEVIL'S POSTPILE NATIONAL MONUMENT | | | | |
|---|---|---|---|---|
| **DATA SET** | **Agency** | **Beg. Year** | **End Year** | **No. Records** |
| Horizon Report | NPS | 1980 | 1997 | 358 |
| STORET: Upper San Joaquin | EPA | 1980 | 1985 | 38 |
| Fishery and Riparian Resources Assessment | Fish & Game | 1994 | 1996 | |
| Water quality monitoring Inyo National Forest | UCLA/UCD | 1975 | 1975 | |

1921-1991 are available from NWIS Web (Addendum 2).

The first collection of stream flow data in the monument began in 1994. A staff gage was installed along the Middle Fork of the San Joaquin River near the Devils Postpile formation and a stage-discharge relationship developed. National Park Service rangers recorded staff gage measurements during routine patrols (Rowan et al. 1996).

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

### *Water Quality*

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

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

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

STORET Legacy contains water quality data for two additional sites in the upper San Joaquin that were not captured in the Baseline Water Quality Report. These sites were part of the National Uranium Resource Evaluation and are located upstream of the monument and

the Baseline Water Quality Report study area. There are 38 additional records associated with these sites. Modernized STORET does not contain any records for the upper watershed.

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

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

## WATER RESOURCES MONITORING

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

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

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

## LOCAL WATER RESOURCE STATUS AND ISSUES

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

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

The town of Mammoth Lakes is proposing to pump groundwater from

the San Joaquin Ridge. This action could reduce annual flows in the Middle Fork of the San Joaquin River in Devils Postpile, although impacts are unknown (National Park Service 2002a).

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

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

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

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

# Sequoia and Kings Canyon National Parks

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

## HISTORY

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

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

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

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

In 1935, the Secretary of the Interior, Harold Ickes, proposed a bill to establish Kings Canyon National Park. He designated the park as one of backcountry and wilderness uses, intending to maintain the park in its natural state. Though this proposal was met with a great deal of initial opposition, Ickes promoted the potential of a tourist magnet, and promised valley residents the necessary water allocation. Appeasing the dissidents of the powerful Kings River Water Association with water projects outside of the park, and with the withdrawal of Los Angeles's need for water due to the recently completed Boulder Dam on the Colorado River, Ickes was able to create legislation for the creation of the park. On March 4, 1940, Kings Canyon National Park was established when Franklin D Roosevelt signed the

bill, adding 450,000 acres of the Sierra Nevada to the National Park Service (Strong 1996).

## WATER RESOURCES

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

Mean annual precipitation is 92 cm at the middle elevations (National Atmospheric Deposition Program (NRSP-3)/National Trends Network 2004). Most of the precipitation falls during the winter months (Figure D-4).

The dominant precipitation types are rain at the low elevations and snow at the middle and high elevations.

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

Sequoia and Kings Canyon National Parks contain three Wild and Scenic

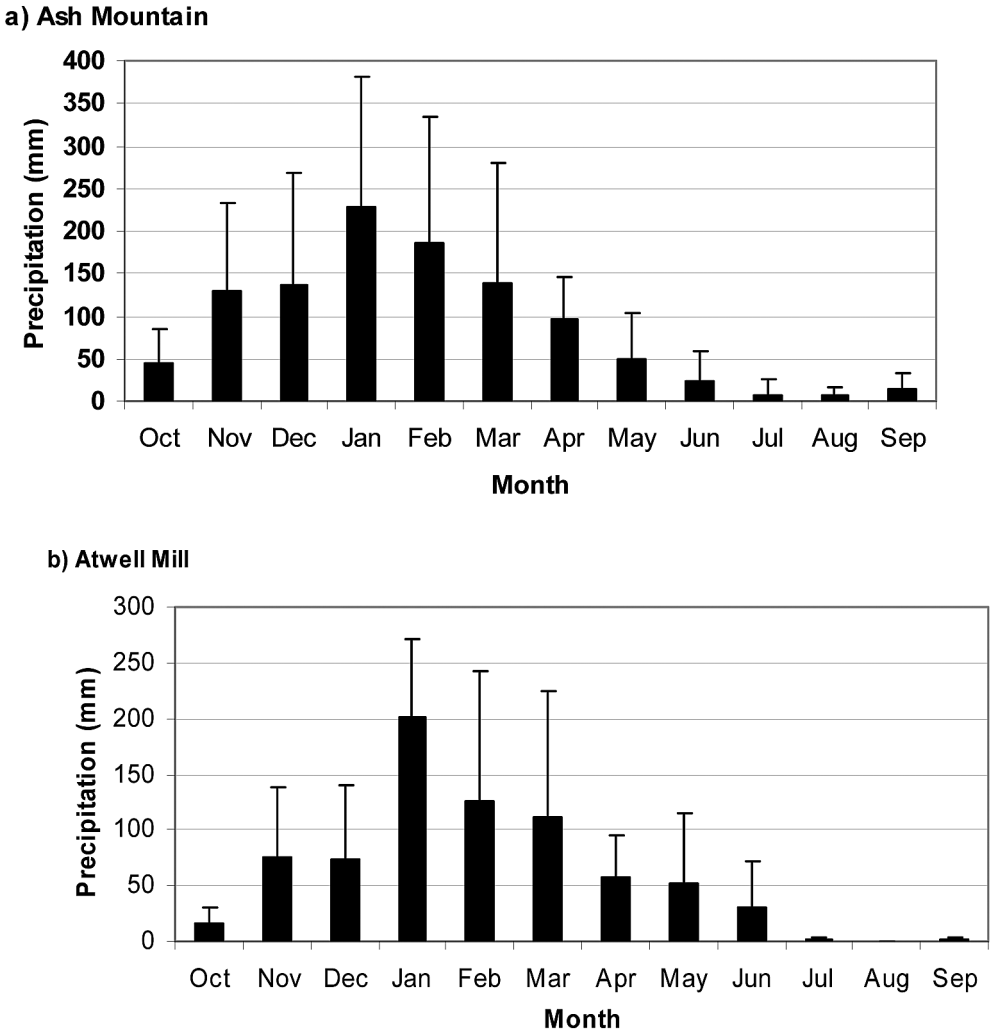



**Figure D-4:** Mean monthly precipitation at low (Ash Mountain: 535 m) and middle (Atwell Mill: 1975 m) elevations (Sequoia and Kings Canyon National Parks 2002a, U. S. Army Corps of Engineers 2002).

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

There are four large impoundments within the park boundary. All four were built on existing lakes in the upper East Fork of the Kaweah in the early 1900s

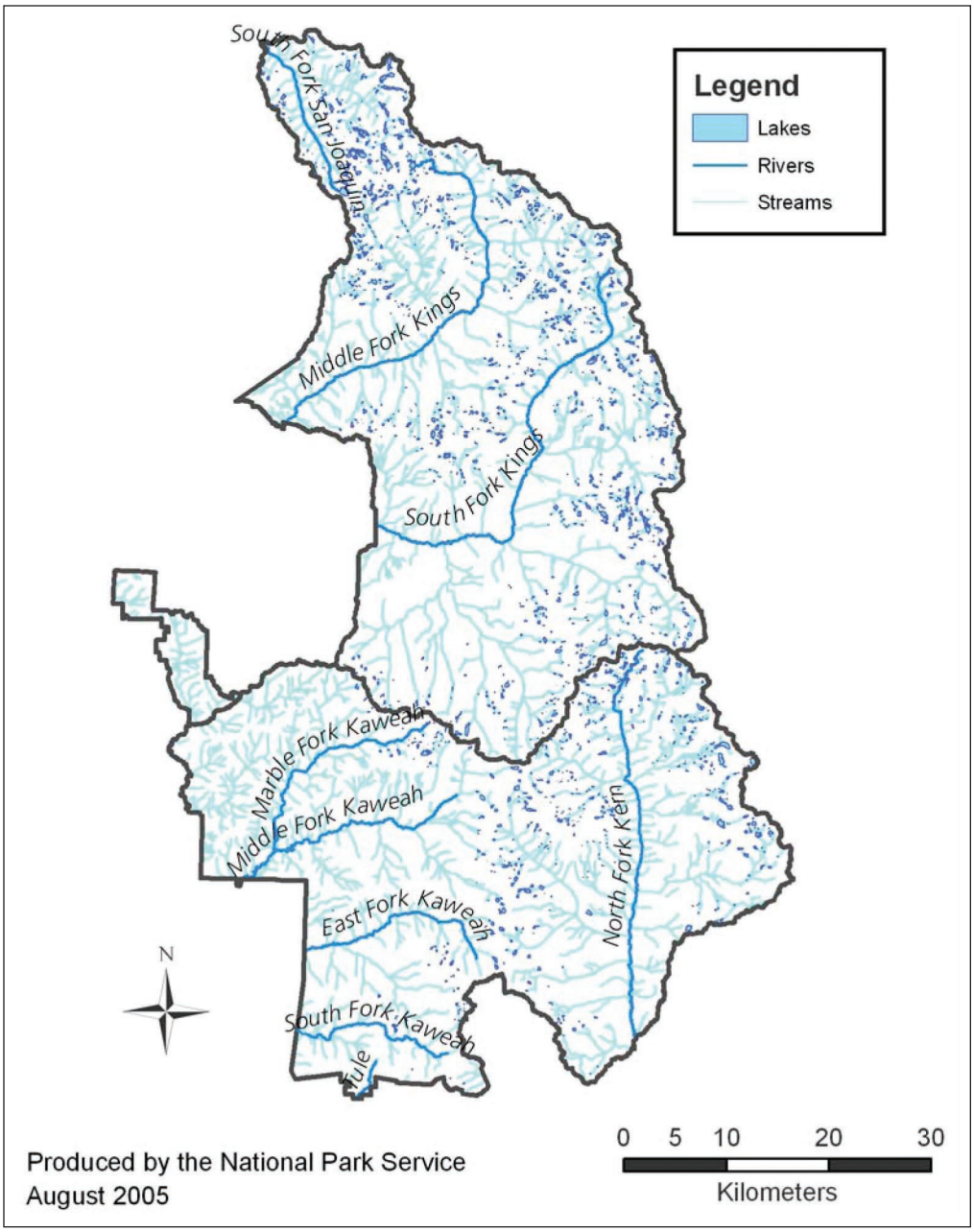



**Figure D-5**: Lakes, rivers, and streams in Sequoia and Kings Canyon National Parks.

and are currently operated by Southern California Edison. Numerous small impoundments also exist in small creeks primarily used for water supplies. There are at least 18 water diversions and seven wells within the park boundary. Most are small diversions for local water supplies, particularly in the Mineral King area. There are likely additional diversions and wells within the park associated with private in-holdings. Southern California Edison holds the water rights for the two largest diversions, located on the Middle Fork and Marble Fork of the Kaweah near Potwisha Campground (Addendum 1).

## HYDROLOGIC AND WATER QUALITY DATASETS

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

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

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

**Table D-3**. Water quality data sets compiled for Sequoia and Kings Canyon National Parks.

| WATER QUALITY DATA: SEQUOIA AND KINGS CANYON NATIONAL PARKS | | | | |
|---|---|---|---|---|
| **DATA SET** | **Agency** | **Beg. Year** | **End Year** | **No. Records** |
| Baseline Water Quality Data Inventory and Analysis Report | NPS | 1951 | 1994 | 66,040* |
| National Water Information System | USGS | 1960 | 1980 | 10,724* |
| Sequoia and Kings Canyon Watershed Program | NPS/USGS | 1983 | 2003 | 6,650 |
| Western Lakes Survey | USGS/EPA | 1999 | 1999 | |
| Lake Inflow chemistry (7 lakes study) | UCSB | 1983 | 2000 | 935 |
| Lake outflow chemistry (7 lakes study) | UCSB | 1986 | 2001 | 1,517 |
| Lake chemistry (7 lakes study) | UCSB | 1982 | 1995 | 1,144 |
| Marble Fork Kaweah (Tokopah and Potwisha) | UCSB | 1993 | 2000 | 890 |
| Emerald Lakes Outflow | UCSB | 1983 | 2001 | 199 |
| Sierra Episodes Study | UCSB | 1993 | 1994 | 340 |
| Amphibian/high elevation lake inventory | UCSB SNARL | 1999 | 2001 | |
| Surface Water Ambient Monitoring Program | RWQCB | 2002 | 2003 | 55 |

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

**Table D-4:** Long-term monitoring sites in Sequoia and Kings Canyon National Parks

| LONG-TERM MONITORING: SEQUOIA AND KINGS CANYON NATIONAL PARKS | | | |
|---|---|---|---|
| **SITE NAME** | **Period of Record** | **Water Quality** | **Flow** |
| Chamise Creek | 1985–2000, 2002–present | X | X |
| Tharp's Creek | 1984–2000, 2003–present | X | X |
| Log Creek | 1984–2000, 2003–present | X | X |
| Emerald Lake Outflow | 1984—present | X | X |
| Marble Fork Kaweah — above Tokopah | 1993—present | X | X |
| Topaz Lake Outflow | 1987—present | X | X |
| East Fork Kaweah — near Lookout Point | 1995—present | X | |
| Trauger's Creek | 1995—present | X | X |
| Deadwood Creek | 1995—present | X | X |
| Middle Fork Kaweah — at Potwisha | 1949—present | | X |
| Marble Fork Kaweah — at Potwisha | 1950—present | | X |
| East Fork Kaweah — near Three Rivers | 1952—present | | X |

identified during local searches in the park and with co-operating agencies (Table D-3).

## WATER RESOURCES MONITORING

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

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

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

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

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

### *East Fork of the Kaweah Watershed*

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

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

### *South Fork of the Kings River*

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

### *Drinking Water Monitoring*

The Sequoia and Kings Canyon Branch of Public Health monitors water quality for drinking water sources and wastewater discharge effluent. Currently, source water monitoring is conducted at approximately thirteen sites in the parks. Detailed source location data are not widely published for security reasons; however, more information can be obtained from the parks' Public Health Sanitarian. Front country drinking water sources are monitored for total coliform, escherichia coli (most probable number/100ml), general minerals, general physical and inorganic chemical parameters. Monitoring frequency is dependent on the classification of the water system and the source (National Park Service 1999, 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).

### *Long-term USGS Gaging Stations*

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

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

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

Outflow, Marble Fork Kaweah above Tokopah, Trauger's, and Deadwood. Continued operation of these eight research watersheds is dependent on research needs and funding.

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

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

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

## CURRENT RESEARCH PROJECTS

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

- Park staff members are continuing to monitor hydrology and stream chemistry in Tharp's and Log Creeks in order to study the effects of a prescribed fire re-burn in the Tharp's watershed.
- The park staff is also working with US Geological Survey- Biological Resources Division and UC Santa Barbara to summarize existing data and produce several publications addressing long-term research in the Tharp's and Log watersheds (Engle et al. 2008).
- Colorado State University investigated the effects of landscape scale prescribed burning on hydrology and stream chemistry in the East Fork of the Kaweah (Heard 2005).
- UC Berkley has a project in the East Fork of the Kaweah studying the effects of prescribed fire on aquatic macroinvertebrates, periphyton, channel morphology, hydrology, large woody debris, and riparian vegetation in headwater streams (Rogers in progress).

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

- The Environmental Protection Agency is studying the distribution of agricultural contaminants in relation to the decline of the mountain yellow legged frog (*Rana muscosa*) in Sequoia and Kings Canyon National Parks and the Sierra National Forest ( Bradford in progress).
- Texas A&M University and the U. S. Geological Survey are investigating the effects of pesticides on Pacific treefrog tadpoles along a north-south transect in the Sierra Nevada. Researchers translocated and placed tadpoles in chambers among sites located in Sequoia, Yosemite and Lassen National Parks (Sparling and Cowman 2003).
- The Western Airborne Contaminants Assessment Project (WACAP) is a cooperative effort between multiple agencies and universities to study persistent organic pollutants in western National Parks. Pear and Emerald lakes, in Sequoia National Park, were chosen as two of the WACAP sites (Landers et al. 2008).
- UC Santa Barbara is investigating biogeochemical and hydrological mechanisms that influence the extent of nitrogen-limitation in alpine and chaparral ecosystems. Their study has advanced our understanding of how increased nitrogen deposition and climate change will affect nitrogen cycling in these ecosystems (Melack et al. 2002, Miller et al. 2005, Miller et al. 2007, Miller et al. 2009).

Portland State University inventoried and mapped glaciers in Sequoia and Kings Canyon, Yosemite and the surrounding national forests (Basagic 2008). Information from this study will help managers understand how climate affects hydrologic processes in the Sierra Nevada.

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

Western Kentucky University and the National Park Service are measuring stream stage, conductivity, pH, and temperature in Tufa Falls Creek, located in the East Fork of the Kaweah watershed. This research will contribute to the overall understanding of the role of karst systems in global carbon budgets (Despain 2006).

## LOCAL WATER RESOURCE ISSUES

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

The State initiated the Surface Water Ambient Monitoring Program (SWAMP) in 1999 to assess California's waters. As part of this program, Regional Water Quality Control Boards (RWQCBs) are monitoring water quality to determine if waters should be listed as 303(d) waters. Due to the outstanding water quality, Sequoia and Kings Canyon National Parks do not have any water bodies that are listed (State Water Resources Control Board 2002). However, the South Fork of the Kings River near the park boundary was selected for preliminary monitoring of nutrients and pathogens. Preliminary results from SWAMP indicate that concentrations are low and the South Fork of the Kings will not be considered for 303(d) listing (P. Bufort, oral comm., 2003). The Central Valley RWQCB considers water quality in the parks to be good to excellent and suitable for all beneficial uses (California Regional Water Quality Control Board Central Valley Region 1995). In general, the Basin Plans and 305(b) report are primarily concerned with river segments below the foothill dams and groundwater in the Central Valley.

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

Water quantity can be a problem for the Grant Grove water supply, which consists of two wells and two springs. In addition, water rights for these sources may not be secured by the park.

Potential acid rock drainage from abandoned mines in the Mineral King area of Sequoia National Park could degrade water quality in the East Fork of the Kaweah. Impacts on water quality have been observed from one mine in the park. Impacts from other mines and cumulative impacts at a larger scale have not been quantified.

High concentrations of nutrients and bacteria from spray fields can move into receiving stream waters. Monitoring in streams near the Red Fir and former Giant Forest spray fields detected increased nutrient concentrations up to 3 km downstream of the sites (Sequoia and Kings Canyon National Parks 1999). There are a minimum of seven spray fields in the park.

There was expressed concern about the effects of pharmaceuticals on park waters. While effects maybe more pronounced in urban areas well

downstream of the park boundaries, there is currently no information on whether pharmaceuticals occur in the parks in sufficient concentrations to have chemical or biological effects on humans or ecosystems.

There are little data available on the impacts of the impoundments and diversions within the park. Since these structures alter flow regimes and have the potential to degrade water quality, park managers identified this as an area of high concern (see earlier Water Resources section and Addendum 1 for descriptions of the impoundments, diversions, and wells).

## WATER RESOURCES

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

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

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

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

The park contains two major impoundments: Hetch Hetchy (4.45 x 108 m3) and Lake Eleanor (3.34 x 107 m3). Hetch Hetchy, which impounds the Tuolumne River, was created in 1938 with the completion of O'Shaughnessy Dam. Hetch Hetchy Reservoir is part of the larger Hetch Hetchy Regional Water System that supplies drinking water to the City of San Francisco and irrigation water to the Central Valley. Lake Eleanor was created in 1918 and the water is used primarily for hydroelectric power. Cascades Dam, located on the Merced River downstream of Yosemite Valley since 1918, was recently removed and the river corridor restored. Numerous small dams and diversion are located throughout the park; most of these are associated with the High Sierra Camps.

The park also has numerous wells for drinking water sources. Most of the larger wells are located in the El Portal, Yosemite Valley, Crane Flat, White Wolf, Wawona,




**Figure D-6**: Lakes, rivers, and streams in Yosemite National Park.

and Tuolumne Meadows areas. There are additional research and monitoring wells located throughout the park, many associated with restoration projects.

## HYDROLOGIC AND WATER QUALITY DATASETS

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

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

The USGS-WRD queried Legacy and Modernized STORET and NWIS as part of the water quality database project. After the data were compared for duplicates and checked for data quality, 3,692 records from Legacy STORET and 40,107 records from NWIS were imported to the main water quality database. There were

**Table D-5**: Long-term monitoring sites in Yosemite

| LONG-TERM MONITORING SITES: YOSEMITE NATIONAL PARK | | | |
|---|---|---|---|
| **SITE NAME** | **Period of Record** | **Water Quality** | **Flow** |
| Big Creek Diversion nr Fish Camp | 1969–present | | X |
| Eleanor Creek near Hetch Hetchy | 1909–present | | X |
| Falls Creek near Hetch Hetchy | 1915–1983 | | X |
| Hetch Hetchy Reservoir | 1950s—present | X | |
| Lake Eleanor diversion tunnel | 1997—present | | X |
| Lake Eleantor Div to Cherry Lk near Hetch Hetchy | 1996—present | | X |
| M Tuolumne River at Oakland Rec Camp | 1916–2002 | | X |
| Merced River at Happy Isles Bridge near Yosemite | 1915—present | | X |
| Merced River at Pohono Bridge near Yoemite | 1916—present | | X |
| Merced Riverat Happy Isles | 1967—present | X | |
| Merced Riverat Happy Isles | 1915–present | | X |
| Merced River near Briceburg | 1966–1984 | X | |
| Merced River near Briceburg | 1965–1974, 1999–present | | X |
| SF MErced River at Wawona | 1955–1975 | | X |
| SF Merced River near El Portal | 1950–1975 | | X |
| SF Tuolumne River near Oakland Rec Camp | 1923–2002 | | X |
| Smoky Jack Creek trib near Yosemite Vilage | 1963–present | | X |
| Tenaya Creek near Yosemite Village | 1912–1958 | | X |
| Tuolumne River above Early Intake near Mather | 1943–present | | X |
| Tuolumne River below Early Intake near Mather | 1966–2004 | | X |
| Tuolumne River near Hetch Hetchy | 1910–2004 | | X |
| Tuolumne River at Tuolumne Meadows | 1973–1986 | X | |

zero records in Modernized STORET. Additional water quality datasets identified by the USGS and park staff include the US Geological Survey's Alpine Hydro Research Group data and UC Santa Barbara's seven lakes study.

## WATER RESOURCES MONITORING

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

The site with the longest period of water quality monitoring (1967-present) in the Sierra Nevada Network is the Merced River at Happy Isles, located in upper Yosemite Valley. Happy Isles is maintained by the US Geological Survey as part of the Hydrologic Benchmark Network. Recently, the USGS installed a chemical analyzer that records continuous nitrate plus nitrite concentrations (Peterson et al. 2005). The Happy Isles watershed area is 46,900 ha and the elevation ranges from 1,224 to 3,997 m. Like most Sierra streams, stream water at Happy Isles is dilute with a low buffering capacity; sp. conductance ranges from 3.0 to 65 uS/cm and alkalinity ranges from 20 to 360 meq/L (Mast and Clow 2000). Mast and Clow (2000) analyzed Happy Isles data set for long-term trends using water quality data from 1968-1995 (refer to Trend Analyses section, below). In addition to long-term monitoring data, there have been numerous additional research studies associated with Happy Isles (Hoffman et al. 1976, Clow et al. 1996, Brown and Short 1999).

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

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

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

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

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

## CURRENT RESEARCH PROJECTS

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

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

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

Portland State University inventoried and mapped glaciers in Sequoia and Kings Canyon, Yosemite and the surrounding national forests (Basagic 2008). Information from this study will help managers understand how climate affects hydrologic processes in the Sierra Nevada.

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

## LOCAL WATER RESOURCE ISSUES

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

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

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

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

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

# Broad-scale Spatial Surveys

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

The Western Lake Survey, conducted in 1985 by the EPA with cooperating agencies, was a one-time regional sampling of high elevation lakes in the mountainous west. The primary objectives were to determine the percentage and location of lakes that are acidic, determine the percentage and location of lakes that have low acid neutralizing capacity, determine the chemical characteristics of lake populations, and provide baseline data for future studies. Seven hundred and nineteen lakes, representing a target population of 10,393, were sampled throughout the west, including Yosemite, Sequoia and Kings Canyon and the upper Middle Fork of the San Joaquin above Devils Postpile. Clow et al. (2002) resurveyed a subset of these lakes (n=69) located in seven National Parks (Lassan, Yosemite, Sequoia, Kings Canyon, Grand Teton, Yellowstone, and Glacier). Results from both years indicate that lakes in the Sierra Nevada are some of the most dilute in the western US (Blick et al. 1987b, Eilers et al. 1989, Clow et al. 2002).

Berg et al. (2005) used the lake survey data to develop a screening procedure of Wilderness lakes to identify a subset of acid sensitive (i.e. low ANC) lakes for long-term monitoring. This model was applied to lakes in Sierra Nevada Wilderness areas by the Pacific Southwest Region, USDA Forest Service Air Resources Program to select long-term monitoring sites as part of the Sierra Nevada Forest Plan Amendment. This program has resulted in several protocols and reports specific to long-term lake monitoring in USFS lands adjacent to the Sierra Nevada Network (Berg and Grant 2004b, a, Berg 2005).

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

# Time Series Plots and Trend Analyses

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

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

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

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

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

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

explain the sulfate decline. Trends were not detected in Chamise.

A weak, but decreasing trend in raw calcium concentrations was detected for Emerald (p=.046). Calcium trends were not detected in Log or Chamise (Table D-6 and Figure D-9). Trends were not detected at any of the sites for pH, specific conductance, temperature, nitrate, magnesium, sodium, potassium, and chloride (Table D-6 and Figures D-8 to D-11). A decreasing trend in nitrate concentrations has been observed in Emerald outflow and Log Creek (Williams and Melack 1997a, Melack

**Table D-6**: Seasonal Kendall test results for Chamise Creek, Log Creek and Emerald Lake outflow. P-values are bolded where a trend was detected ($\alpha = 0.05$).

| SEASONAL KENDALL TEST RESULTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Raw Concentrations | | | Flow-adjusted Concentrations | | |
| | | n | p-value | trend | n | p-value | trend |
| pH | Chamise | 22 | 0.063 | none | 21 | 0.013 | up |
| | Log | 60 | 0.090 | none | 60 | 0.076 | none |
| | Emerald | 57 | 0.762 | none | 57 | 0.558 | none |
| Sp. Cond. | Chamise | 22 | 0.568 | none | 21 | 0.960 | none |
| | Log | 60 | 0.305 | none | 60 | 0.173 | none |
| | Emerald | 57 | 0.812 | none | 57 | 0.629 | none |
| Temp | Chamise | 19 | 0.903 | none | - | - | - |
| | Log | 56 | 0.170 | none | - | - | - |
| | Emerald | 53 | 0.121 | none | - | - | - |
| ANC | Chamise | 22 | 0.455 | none | 21 | 0.706 | none |
| | Log | 60 | 0.248 | none | 60 | 0.889 | none |
| | Emerald | 57 | 0.015 | down | 57 | 0.043 | |
| NH4 | Chamise | - | - | - | - | - | - |
| | Log | - | - | - | - | - | - |
| | Emerald | - | - | - | - | - | - |
| NO3 | Chamise | - | - | - | - | - | - |
| | Log | - | - | - | - | - | - |
| | Emerald | 57 | 0.720 | none | 57 | 0.585 | none |
| Ca | Chamise | 22 | 0.822 | none | 21 | 1.000 | none |
| | Log | 60 | 0.243 | none | 60 | 0687 | none |
| | Emerald | 57 | 0.046 | down | 57 | 0..65 | none |
| Mg | Chamise | 22 | 0.34 | none | 21 | 0.876 | none |
| | Log | 60 | 0.685 | none | 60 | 0.209 | none |
| | Emerald | 57 | 0.230 | none | 57 | 0.299 | none |
| Na | Chamise | 22 | 0.916 | none | 21 | 0.626 | none |
| | Log | 60 | 0.844 | none | 60 | 0.053 | none |
| | Emerald | 57 | 0.526 | none | 57 | 1.000 | non3 |
| K | Chamise | 22 | 0.665 | none | 21 | 0.624 | none |
| | Log | 60 | 0.119 | down | 60 | 0.214 | none |
| | Emerald | 57 | 0.068 | down | 57 | 0..92 | none |
| SO4 | Chamise | 22 | 0.230 | none | 21 | 0.236 | none |
| | Log | 60 | 0.050 | none | 60 | 0.214 | none |
| | Emerald | 57 | 0.021 | none | 57 | 0.092 | down |
| Cl | Chamise | 22 | 0.076 | none | 21 | 0.236 | none |
| | Log | 60 | 0.108 | none | 60 | 0.082 | none |
| | Emerald | 57 | 0.060 | none | 57 | 0.027 | none |

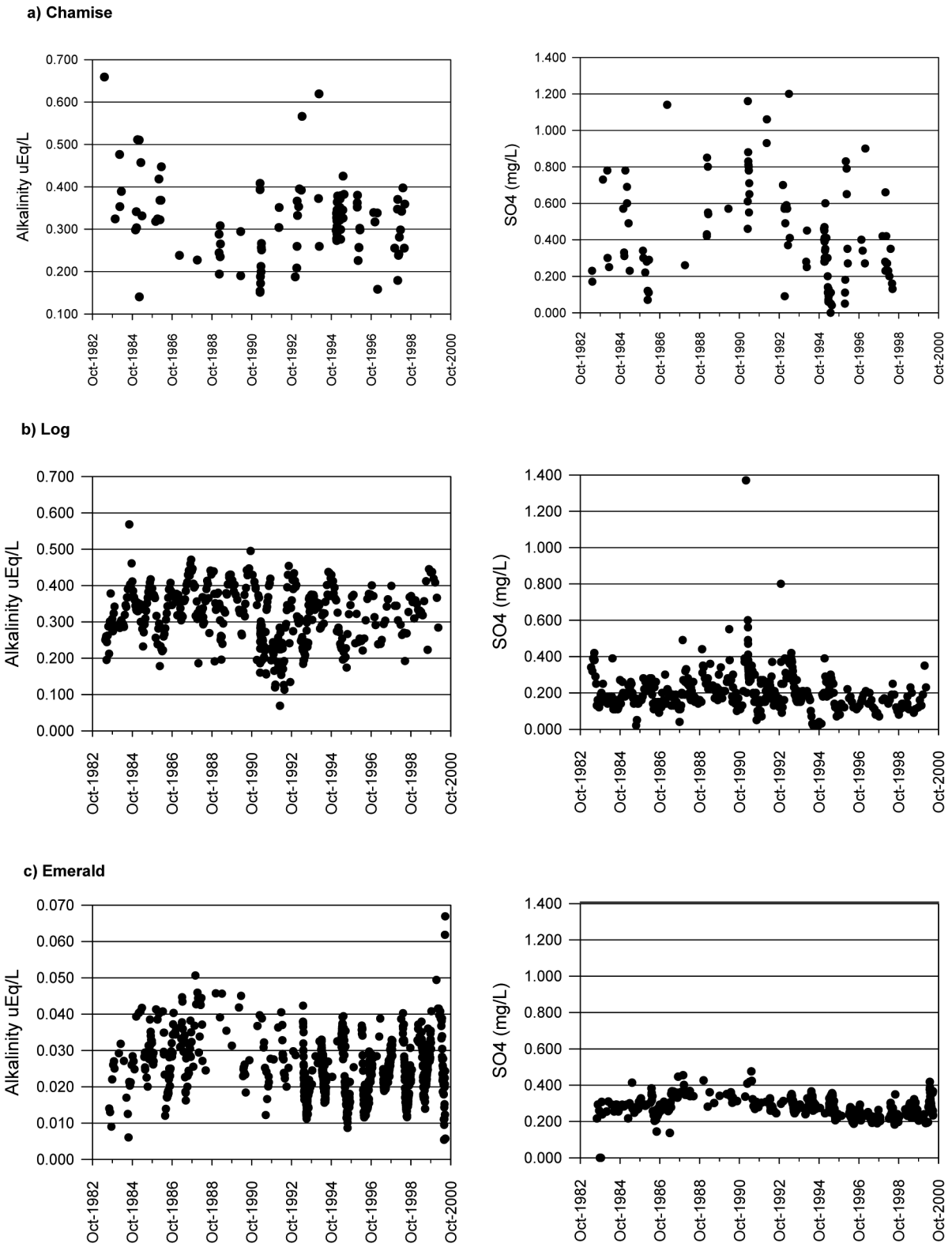



**Figure D-7**: ANC and sulfate time series plots for a) Chamise, b) Log, and, c) Emerald.

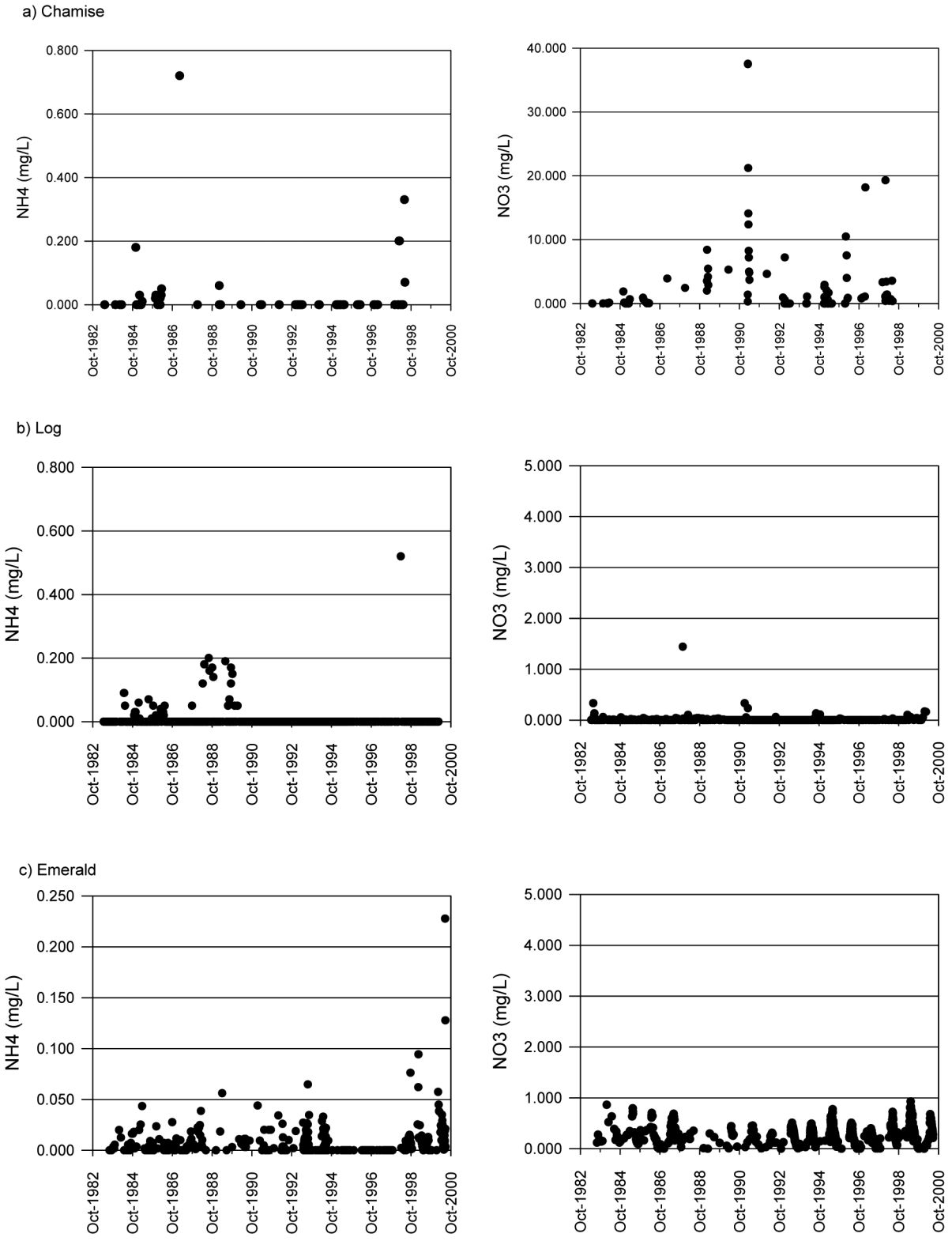



**Figure D-8**: Ammonium and nitrate time series plots for a) Chamise, b) Log, and c) Emerald.

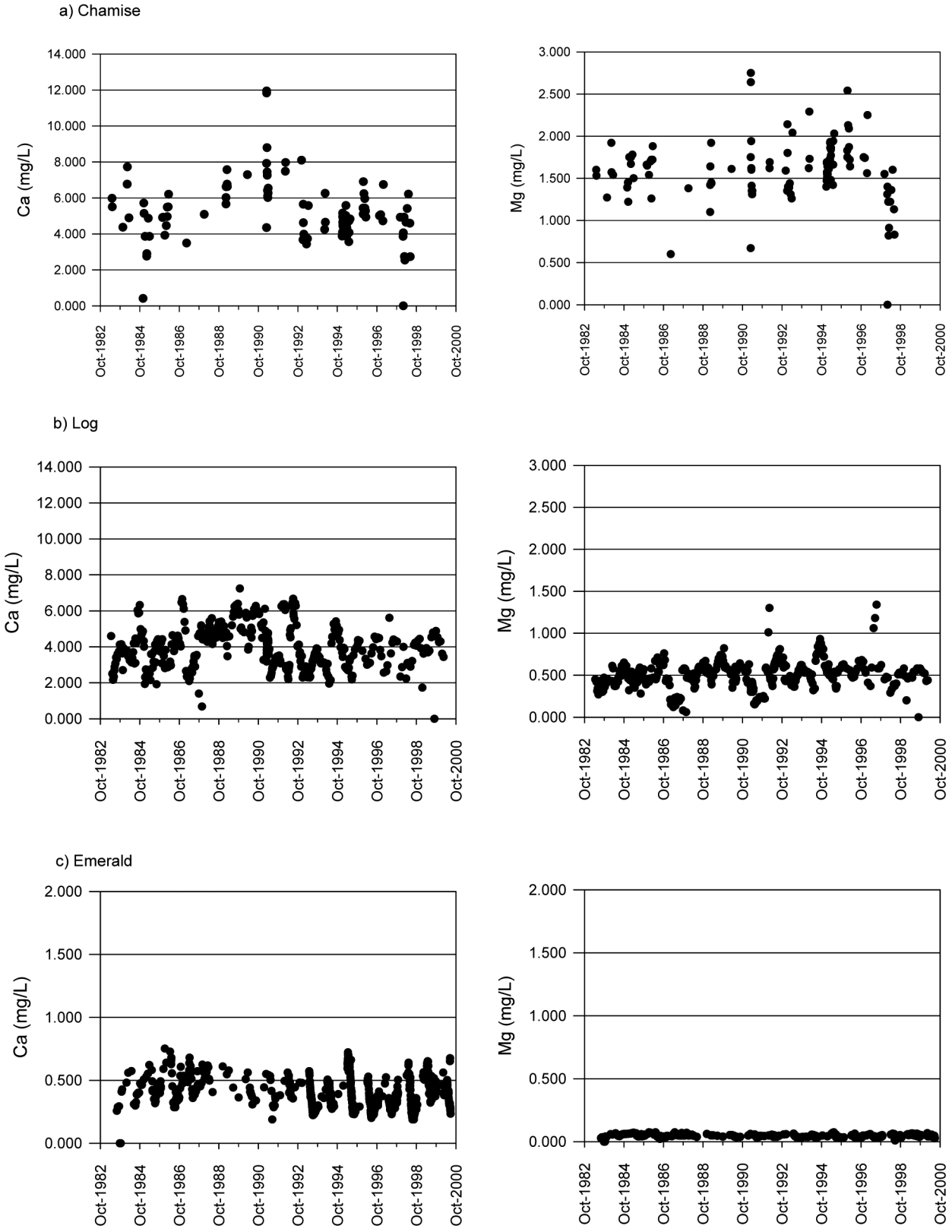



**Figure D-9**: Calcium and magnesium time series plots for a) Chamise, b) Log, and c) Emerald.

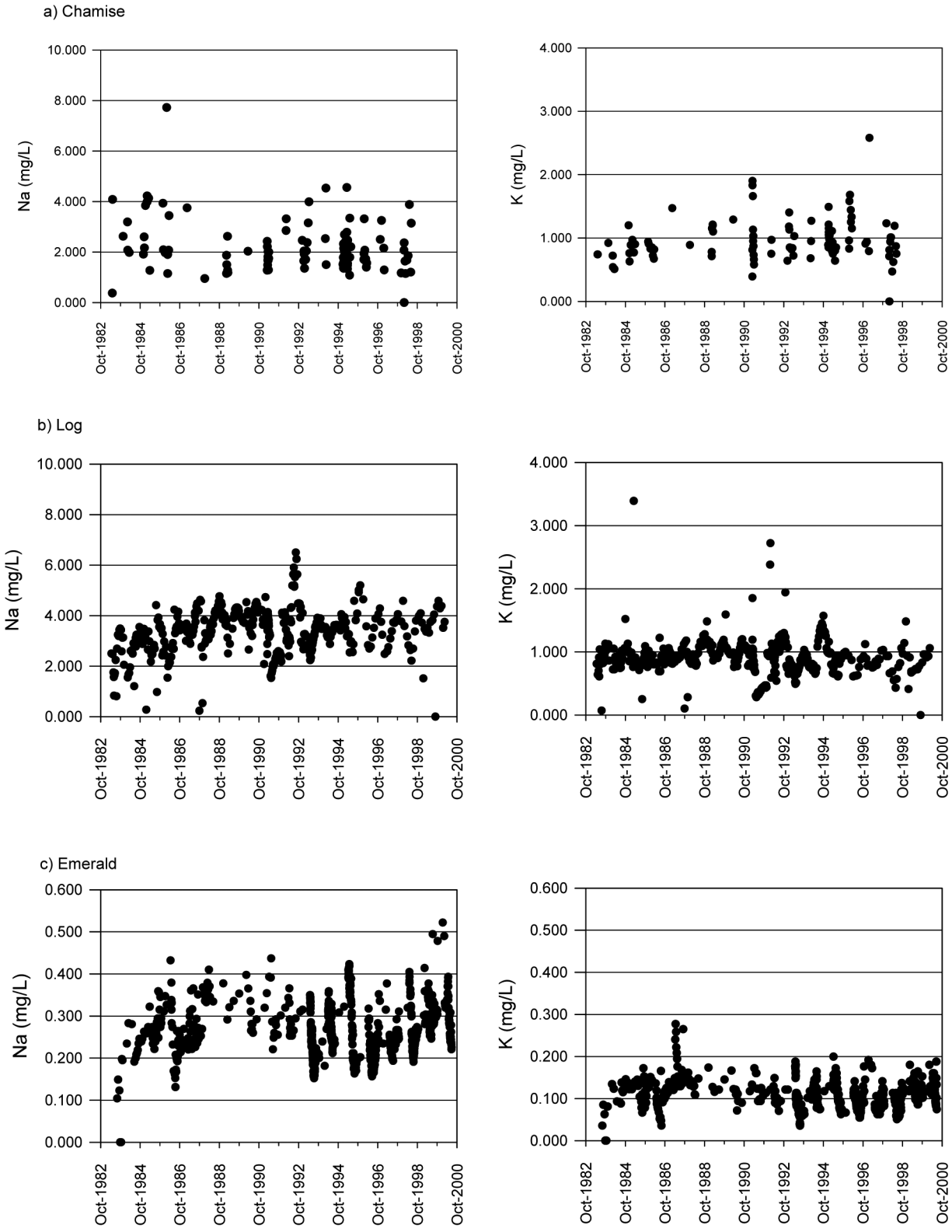



**Figure D-10**: Sodium and potassium time series plots for a) Chamise, b) Log, and c) Emerald.

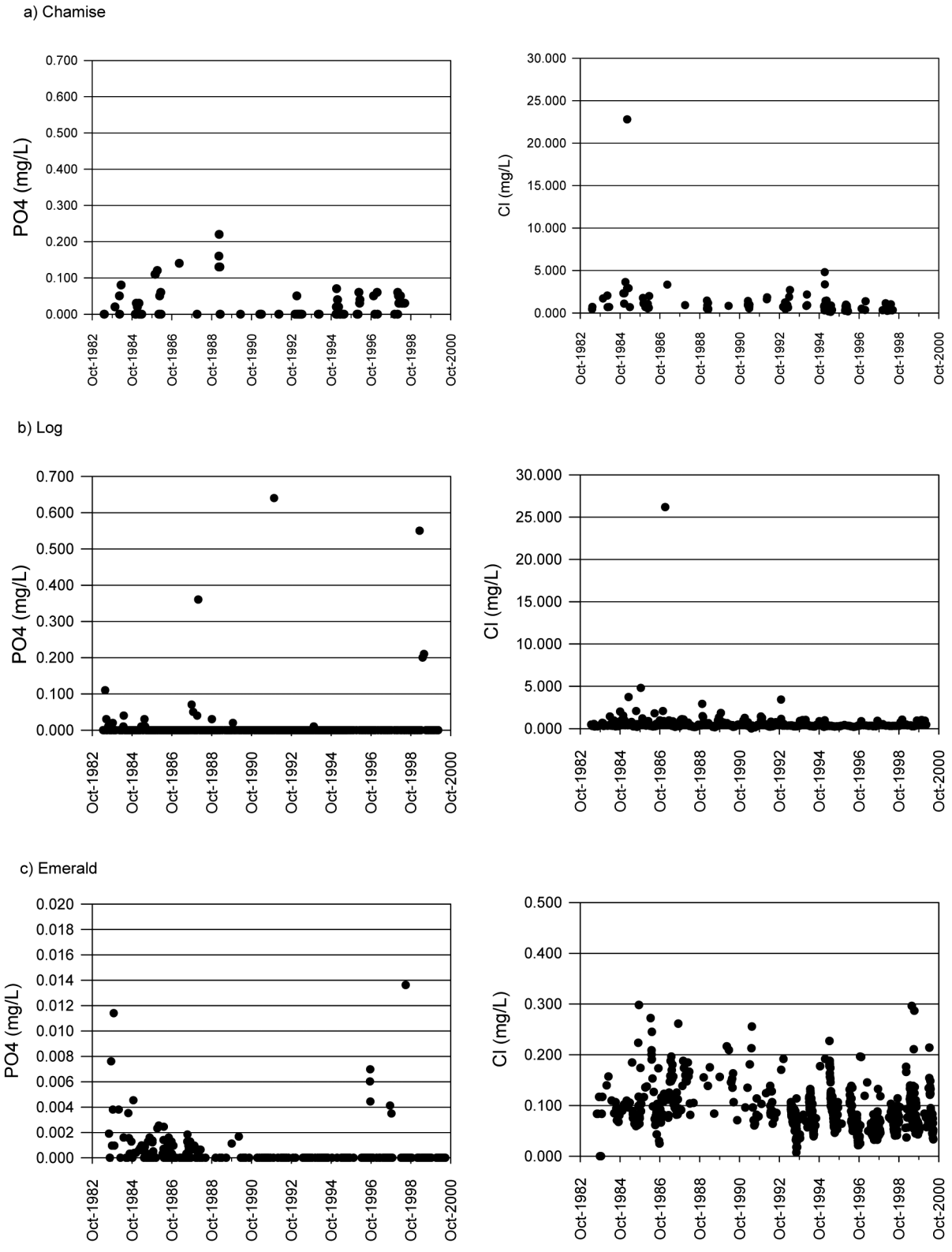



**Figure D-11**: Phosphate and chloride time series plots for a) Chamise, b) Log, and c) Emerald.

## SUMMARY

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

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

## ACKNOWLEDGMENTS

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

# LITERATURE CITED


Baas, J., F. D. Westerdahl, and R. L. Perrine. 1976. Non-point source water quality monitoring, Inyo National Forest, 1975. Progress Report Contribution No. 156, University of California, Davis, University of California, Los Angeles CA.

Basagic, H.J. 2008. Quantifying twentieth century glacier change in the Sierra Nevada, California. MS Thesis, Portland State University, Portland, OR. 103 pp.

Berg, N. H. 2005. Water quality review: Sierra Nevada 2004 lake monitoring. Draft PSW Research Station, USDA Forest Service.

Berg, N. H., A. Gallegos, T. Dell, J. Frazier, T. Procter, J. Sickman, S. Grant, T. Blett, and M. Arbaugh. 2005. A screening procedure for identifying acid-sensitive lakes from catchment characteristics. *Environmental Monitoring and Assessment* **105**:285-307.

Berg, N. H., and S. Grant. 2004a. Project Lakes: Long-term water quality monitoring and zooplankton data collection protocol. USDA Forest Service, Pacific Southwest Region.

Berg, N. H., and S. Grant. 2004b. Project Lakes: Synoptic water quality data collection protocol. Final Draft USDA Forest Service, Pacific Southwest Region.

Blick, D. J., D. F. Brakke, M. S. DeHaan, J. M. Eilers, P. Kanciruk, P. E. Kellar, D. H. Landers, R. A. McCord, W. S. Overton, and M. E. Silverstein. 1987a. Western Lake Survey, Phase I, Characteristics of lakes in the Western United States. EPA-600/3-86/054b, U. S. Environmental Protection Agency, Office of acid deposition, environmental monitoring and quality assurance, Washington, DC.

Blick, D. J., D. F. Grakke, M. S. DeHaan, J. M. Eilers, P. Kanciruk, P. E. Kellar, D. H. Landers, R. A. McCord, W. S. Overton, and M. E. Silverstein. 1987b. Western Lake Survey, Phase I, Characteristics of lakes in the Western United States. U.S. Environmental Protection Agency, Office of acid deposition, environmental monitoring and quality assurance, Washington, DC.

Bradford, D. F., S. D. Cooper, and A. D. Brown. 1994. Distribution of aquatic animals relative to naturally acidic waters in the Sierra Nevada. Final Report for Contract No. A132-173, California Air Resources Board, Sacramento, CA.

Brown, L., and T. Short. 1999. Biological, Habitat, and Water Quality Conditions in the Upper Merced River Drainage, Yosemite National Park, California, 1993-1996. USGS/WRI–99-4088, U. S. Geological Survey and National Park Service, Sacramento, 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, vol. II, Assessments and scientific basis for management options, Davis, CA.

California Regional Water Quality Control Board Central Valley Region. 1995. Water Quality Control Plan for the Tulare Lake Basin, Second Edition—1995.

California Regional Water Quality Control Board Central Valley Region. 1998. The Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin. Sacramento, CA.

Caprio, A. C. 1999. Research, inventory and monitoring: Mineral King Risk Reduction Project. Annual Report 1998, Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Caprio, A. C., and P. Lineback. 1997. Pre-twentieth century fire history of Sequoia and Kings Canyon National Park: A review and evaluation of our knowledge. Fire in California Ecosystems: Integrating Ecology, Prevention, and Management, San Diego, CA.

Chorover, J., P. M. Vitousek, D. A. Everson, A. M. Esperanza, and D. Turner. 1994. Solution chemistry profiles of mixed-conifer forests before and after fire. *Biogeochemistry* **26**:115-144.

Clow, D. W., M. A. Mast, and D. H. Campbell. 1996. Controls on surface water chemistry in the upper Merced River basin, Yosemite National Park, CA. *Hydrological Processes* **10**:727-746.

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.

Clow, D. W., R. G. Striegl, M. Nanus, M. A. Mast, D. H. Campbell, and D. P. Krabbenhoft. 2002. Chemistry of selected high-elevation lakes in seven national parks in the western United States. *Water Air and Soil Pollution* **2**:139-164.

Cooper, D., E. C. Wolf, and R. Chimner. 2005. Hydrological and ecological analysis of the effects of groundwater pumping on water levels, fen carbon budget and vegetation, in Crane Flat, Yosemite National Park, California. Progress report Colorado State University, Fort Collins, CO.

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

Derlet, R. W. 2004. Prevelance of coliform and other pathogenic bacteria in Sierra Nevada National Parks and Wilderness Area Lakes and Streams. Research Permit University of California, Davis, CA.

Despain, J.D. 2006. Hydrochemistry in an alpine karst system, Sequoia and Kings Canyon National Parks, California. MS Thesis, Western Kentucky University, Bowling Green, KY. 92 pp.

Dettinger, M. D., D. R. Cayan, M. Meyer, and A. E. Jeton. 2004. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, CA, 1900-2099. *Climatic Change* **62**:283-317.

DiLeo, J., M. Butler, D. R. Cayan, D. W. Clow, M. D. Dettinger, F. Gehrke, S. Hager, J. D. Lundquist, G. McCurdy, D. Peterson, K. Redmond, L. Riddle, R. Smith, and J. W. van Wagtendonk. 2003. Notebook of Hydroclimatology—Sites/Activities. Yosemite National Park, El Portal, CA.

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.

Eilers, J. M., D. F. Brakke, D. H. Landers, and W. S. Overton. 1989. Chemistry of wilderness lakes in the Western United States. Environmental Monitoring and Assessment 12.

Engle, D.L., J.O. Sickman, C.M. Moore, A.M. Esperanza, J.M. Melack, and J.E. Keeley. 2008. Biogeochemical legacy of prescribed fire in a giant sequoia-mixed conifer forest: A 16-year record of watershed balances. *Journal of Geophysical Research Vol. 113*, **G01014**: 1-16.

Engle, D.L., J.O. Sickman, C.M. Moore, A.M. Esperanza, J.M. Melack, and J.E. Keeley. 2008. Biogeochemical legacy of prescribed fire in a giant sequoia-mixed conifer forest: A 16-year record of watershed balances. *Journal of Geophysical Research Vol. 113*, **G01014**: 1-16.

Environmental Protection Agency. 2003. STORET Water Quality Database. http://www.epa.gov/storet/ Date Accessed: April 2005.

Fancy, S., and J. Gross. 2004. Monitoring Natural Resources in our National Parks. http://science.nature.nps.gov/im/monitor/index.htm Date Accessed: April.

Goldman, C. R., A. D. Jassby, and S. H. Hackley. 1993. Decadal, interannual and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **50**:1489-1496.

Hauer, F. R., and C. N. Spencer. 1998. Phosphorus and nitrogen dynamics in streams associated with wildfire: a study of immediate and long-term effects. *International Journal of Wildland Fire* **8**:183-198.

Heard, A. M. 2005. Effects of landscape scale prescribed fire on hydrology and stream chemistry. MS. Coloradao State University, Fort Collins, CO.

Helvey, J. D. 1980. Effects of a north central Washington fire on runoff and sediment production. *Water Resources Bulletin* **16**:627-634.

Hirsch, R. A., and J. R. Slack. 1984. A nonparametric trend test for seasonal data with serial dependence. *Water Resources Research* **20**:727-732.

Hoffman, R. J., A. E. Dong, and G. L. Keeter. 1976. Water-Quality Study of a Reach of the Merced River in Yosemite National Park and Vicinity, California—April 1973 Through September 1974. Open-file report 76-326, Geological Survey, Water Resources Div, Menlo Park, CA.

Houghton, J. T., L. G. Miera Filho, B. A. Callander, N. Harris, A. Kattenberg, and K. Maskell. 1996. Climate change 1995: the science of climate change. Cambridge University Press, Cambridge, UK.

Huber, N. K., and W. W. Eckhardt. 2002. The Story of Devils Postpile. Sequoia National History Association, Three Rivers, CA.

Information Center for the Environment. 2003. Water quality standards inventory database: beneficial uses. http://www.ice.ucdavis.edu/wqsid/bu.asp Date Accessed: November.

Kattelmann, R. 1996. Hydrology and Water Resources. In Sierra Nevada Ecosystem Project, Davis, CA.

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

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**:23-29.

Landers, D.H., S.L. Simonich, D.A. Jaffe, L.H. Geiser, D.H. Campbell, A.R. Schwindt, C.B. Schreck, M.L. Kent, W.D. Hafner, H.E. Taylor, K.J. Hageman, S. Usenko, L.K. Ackerman, J.E. Schrlau, N.L. Rose, T.F. Blett, and M.M. Erway. 2008. The Fate, Transport, and Ecological Impacts of Airborne Contaminants in Western National Parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, OR.

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.

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

Mac Donald, L. H., and J. D. Stednick. 2003. Forests and Water: A state-of-the-art review for Colorado. CWRRI Completion Report No. 196, Colorado State University, Fort Collins, CO.

Mast, M. A., and D. W. Clow. 2000. Environmental characteristics and water quality of Hydrologic Benchmark Network stations in the western United States. Circular Report U.S. Geologic Survey.

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

Melack, J. M., J. O. Sickman, and A. Leydecker. 1998b. Comparative analyses of high-altitude lakes and catchments in the Sierra Nevada: Susceptibility to acidification. Final Report, California Air Resources Board Contract A032-188, Santa Barbara, CA.

Melack, J. M., J. O. Sickman, and J. Schimel. 2002. Microbial and hydrological controls of nitrogen losses from alpine and chaparral ecosystems during seasonal transitions- research proposal. Proposal University California, Santa Barbara, Santa Barbara, CA.

Miller, A.E., J.P. Schimel, J.O. Sickman, K. Skeen, T. Meixner, and J.M. Melack. 2009. Seasonal variation in nitrogen uptake and turnover in two high-elevation soils: mineralization responses are site-dependent. *Biogeochemistry* **93**: 253-270.

Miller, A.E., J.P. Schimel, J.O. Sickman, T. Meixner, A.P. Doyle, and J.M. Melack. 2007. Mineralization responses at near-zero temperatures in three alpine soils. *Biogeochemistry* **84**: 233-245.

Miller, A.E., J.P. Schimel, T. Meixner, J.O. Sickman, and J.M. Melack. 2005. Episodic rewetting enhances carbon and nitrogen release from chaparral soils. *Soil Biology & Biochemistry* **37**: 2195-2204.

Moore, C. 2000. 1999 annual Sequoia watershed report. In 1999 annual fire report on research, monitoring and inventory. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Atmospheric Deposition Program (NRSP-3)/National Trends Network. 2004. National Atmospheric Deposition Program. http://nadp.sws.uiuc.edu/ Date Accessed: April.

National Park Service. 1994. Baseline water quality data inventory and analysis—Yosemite National Park. National Park Service, Water Resources Division, Fort Collins, CO.

National Park Service. 1998. Baseline Water Quality Data Inventory and Analysis—Devils Postpile National Monument. Technical Report NPS/NRWRD/NRTR-98/189, National Park Service, Water Resources Division, Fort Collins, CO.

National Park Service. 1999. Reference A: Reference Manual 83, Drinking Water.

National Park Service. 2000. Final Yosemite Valley Plan, Supplemental Environmental Impact Statement. National Park Service, Yosemite National Park.

National Park Service. 2002a. Devils Postpile National Monument Vital Signs Workshop Report.

National Park Service. 2002b. DRAFT: Sequoia and Kings Canyon National Parks Wild and Scenic River Plan and Study. Draft Management Plan Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2003a. 2002 Consumer Confidence Reports. National Park Service, Three Rivers, CA.

National Park Service. 2003b. Nature and Science: Devils Postpile National Monument, Water Resources. http://www.nps.gov/depo/depo_nr/water/water.htm Date Accessed: April.

National Park Service Air Resources Division. 2003. Western Airborne Contaminants Assessment Project. Fact Sheet National Park Service Air Resources Division, Denver, CO.

National Park Service—Freshwater Workgroup Subcommittee. 2002. Recommendations for core water quality monitoring parameters and other key elements of the NPS Vital Signs program, water quality monitoring component. National Park Service, Fort Collins, CO.

National Park Service, W. R. D. 1997. Baseline Water Quality Data Inventory & Analysis—Sequoia and Kings Canyon National Parks. Technical Report NPS/NRWRD/NRTR-97/121, National Park Service, Washington, D.C.

National Park Service-Water Resources Division. 2003. Draft: Surface water quality monitoring issues, overview and assessment. National Park Service-Water Resources Division, Fort Collins, CO.

Peterson, D., R. Smith, S. Hager, J. Hicke, M. Dettinger, and K. Huber. 2005. River chemistry as a monitor of Yosemite Park mountain hydroclimates. *EOS* **86**:285-292.

Riggan, P. J., R. N. Lockwood, P. M. Jacks, and C. G. Colver. 1994. Effects of fire severity on nitrate mobilization in watersheds subject to chronic atmospheric deposition. *Environ Sci Technol* **28**:369-375.

Rowan, D. E., S. C. Parmenter, and W. W. Eckhardt. 1996. Fishery and riparian resources of Devils Postpile National Monument and surrounding waters. National Park Service.

San Francisco Public Utilities Commission. 1999. 1999 annual sanitary survey update report for the Hetch Hetchy water supply. San Francisco Public Utilities Commission, Water Quality Bureau, Engineering Section, San Francisco, CA.

San Francisco Water Team, and CH2M HILL Inc. 1995. Final Sanitary Survey for the Hetch Hetchy Water Supply Project. San Francisco Water Team; CH2M HILL, Inc.

Schroeter, R. E., and J. M. Harrington. 1995. Benthic Macroinvertebrate Community Assessment of the Middle Fork San Joaquin River, Madera County, California. California Department of Fish and Game, Water Pollution Control Laboratory, Rancho Cordova, CA.

Schwarz, P. 2004. Re: Request for Water Quality Monitoring Information. A. Heard, editor., Three Rivers, CA.

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

Sequoia and Kings Canyon National Parks. 2002a. Ash Mountian Precipitation Data. 47050 Generals Highway, Three Rivers, CA 93271.

Sequoia and Kings Canyon National Parks. 2002b. lakeseki. Accessed: 2005.

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, CA. *Limnology and Oceanography* **48**:1885-1892.

Slack, J. R., D. L. Lorenz, and and others. 2003. USGS library for S-Plus for Windows—Release 2.1. Open-File Report 03-357, U.S. Geological Survey.

SNEP. 1996. Sierra Nevada Ecosystem Project: Final Report to Congress-Summary. University of California, Davis, Davis, CA.

Sparling, D. W., and D. Cowman. 2003. Amphibians and Pesitcides in Pristine Areas. In G. Linder and et al., editors. Amphibian Decline: An Integrated Analysis of Multiple Stressor Effects. Society of Environmental Toxicology and Chemistry.

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

Spencer, C. N., K. O. Gabel, and F. R. Hauer. 2003. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. *Forest Ecology and Management* **178**:141-153.

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

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

Swetnam, T. W. 1993. Fire History and Climate-Change in Giant Sequoia Groves. *Science* **262**:885-889.

Tiedemann, A. R., J. D. Helvey, and T. D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. *Journal of Environmental Quality* **7**:580-588.

U. S. Army Corps of Engineers. 2002. 1325 J Street, Sacramento CA 95814.

U. S. Geological Survey. 2000. Hydrologic Benchmark Network. http://water.usgs.gov/hbn/ Date Accessed: March.

U. S. Geological Survey. 2001. History of the National Uranium Resource Evaluation Hydrogeochemical and Stream Reconnaissance Program. http://pubs.usgs.gov/of/1997/ofr-97-0492/nurehist.htm Date Accessed: April, 2004.

U. S. Geological Survey. 2003. National Water Information System. http://nwis.waterdata.usgs.gov/ca/nwis/ Date Accessed: February 2005.

U. S. Geological Survey - Biological Resources Division. 2000. Stream and Meteorology Sampling Protocol. U. S. Geological Survey—Biological Resources Division—Sequoia and Kings Canyon Field Station, Three Rivers, CA.

Williams, M. R., and J. M. Melack. 1997a. 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. R., and J. M. Melack. 1997b. Effects of prescribed burning and drought on the solute chemistry of mixed-conifer forest streams of the Sierra Nevada, California. *Biogeochemistry* **39**:225-253.

Yosemite National Park. 2004. Visitor Experience and Resource Protection Program, 2004 annual report Merced River monitoring. National Park Service, El Portal, CA.

# Addenda

Addendum 1: Diversions, wells, and impoundments ..... 116
Addendum 2: Current and historic gaging stations ..... 117
Addendum 3: Current research projects in Sequoia and Kings Canyon National Parks ..... 122
Addendum 4: Current research projects in Yosemite National Park ..... 123
Addendum 5: Current meteorology, air quality and snow pack monitoring sites in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI) ..... 124
Addendum 6: Current meteorology stations in Yosemite National Park ..... 125
Addendum 7: Beneficial uses for the State of California ..... 126
Addendum 8: Beneficial uses for stream segments in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI) ..... 128

**Addendum 1**: Diversions, wells, and impoundments in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI) (National Park Service 1997, National Park Service 1998, 2003a, Meadows 2004, Werner 2004).

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

**Addendum 2**: Current and historic gaging stations in or near Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (SEKI), and Yosemite National Park (YOSE).

| Station Name | Period of Record | Station ID | In Park? | Data Type | Data Location | Drainage Area (ha) | Eleva. (m) | Lat | Long |
|---|---|---|---|---|---|---|---|---|---|
| **DEPO** | | | | | | | | | |
| Middle Fork San Joaquin- in DEPO | 2004-present | | Yes | Raw | Scripps | | | | |
| Middle Fork San Joaquin- at Miller Crossing | 1921-1991 | 11226500 | No | DM, PQ | NWIS Web | 47,600 | 2110 | 37.51049694 | -119.1973475 |
| **SEKI** | | | | | | | | | |
| Chamise Creek | 1985-2000, 2002-present | 1 | Yes | DM, Raw | SEKI | 4 | 750 | 36.51333565 | -118.809242 |
| Log Creek | 1983-2000, 2003-present | 4 | Yes | DM, Raw | SEKI | 49 | 2067 | 36.56108429 | -118.739121 |
| Tharps Creek | 1983-2000, 2003-present | 6 | Yes | DM, Raw | SEKI | 13 | 2067 | 36.56225693 | -118.7398502 |
| Trauger's Creek | 1996-present | 22 | Yes | DM, Raw | SEKI | 104 | 1400 | 36.44 | -118.73 |
| Deadwood Creek | 1996-present | 28 | Yes | DM, Raw | SEKI | 100 | 2000 | 36.47 | -118.66 |
| Emerald Outflow | 1983-present | 8 | Yes | DT | UCSB/SEKI | 120 | 2807 | 36.59694444 | -117.3252778 |
| Marble Fork Kaweah above falls | 1992-present | 11206800 | Yes | DT | UCSB/SEKI | 1,900 | 2621 | 36.60611111 | -117.3169444 |
| Topaz Outflow | 1986-present | 363730118381701 | Yes | DT | UCSB/SEKI | 178 | 3218 | 36.625 | -117.3636111 |
| Pear Lake | 1984-1994 | 363612118404001 | Yes | DT | UCSB/SEKI | 136 | 2904 | 36.6 | -118.67 |
| Middle Fork Kaweah - at Potwisha* | 1949-present | 11206501 | Yes | DM, PQ | NWIS Web | 26,400 | | 36.5132786 | -118.7917647 |
| Marble Fork Kaweah- at Potwisha* | 1950-present | 11208001 | Yes | DM, PQ | NWIS Web | 13,300 | | 36.51883444 | -118.8017653 |
| East Fork Kaweah - nr 3 Rivers* | 1952-present | 11208731 | No | DM, PQ | NWIS Web | 22,200 | 790 | 36.4516125 | -118.7892639 |
| Kaweah River nr Hammond* | 1993-present | 11208601 | No | DM, PQ | NWIS Web | 88,500 | 421 | 36.4860572 | -118.8367656 |
| South Fork Kaweah- nr Three Rivers | 1911-1924 | 11210000 | No | DM, PQ | NWIS Web | 17,200 | 490 | 36.3749472 | -118.8564869 |
| South Fork Kings- nr Cedar Grove | 1950-1957 | 11212500 | Yes | DM, PQ | NWIS Web | 10,500 | | 36.8068872 | -118.7495458 |

**Addendum 2**: Continued

| Station Name | Period of Record | Station ID | In Park? | Data Type | Data Location | Drainage Area (ha) | Eleva. (m) | Lat | Long |
|---|---|---|---|---|---|---|---|---|---|
| M Tuolumne River nr Mather | 1924-1933 | 11281500 | | DM, PQ | NWISWeb | 13,572 | | 37.8499241 | -119.8676789 |
| Maclure Cr bl Maclure glcr nr Toulumne Mdw | 1967-1972 | 11274710 | | DM, PQ | NWISWeb | 96 | 400.896 | 37.75242991 | -119.2820929 |
| Merced abv Lyell Fk | 2001-present | H12 | Yes | Raw | Scripps | | 2438 | 37.69700 | -119.34800 |
| Merced abv Merced Lk HSC (DC) | 2001-present | H19 | Yes | Raw | Scripps | | 2207 | 37.7383 | -119.403 |
| Merced at Ranger Cabin | | H21 | Yes | Raw | Scripps | | 2207 | 37.72949 | 119.39304 |
| Merced blw Echo | 2001-present | H15 | Yes | Raw | Scripps | | 2134 | 37.73800 | -119.44900 |
| Merced blw Lyell Fk | 2001-present | H13 | Yes | Raw | Scripps | | 2377 | 37.70200 | -119.34900 |
| Merced Lk outlet | 2002-present | H20 | Yes | Raw | Scripps | | 2207 | 37.73814 | 119.41923 |
| Merced Pk Fk Footbridge (DC) | 2001-present | H18 | Yes | Raw | Scripps | | 2486 | 37.69278 | -119.3497 |
| Merced R a Happy Isles Bridge nr Yosemite | 1915-present | 11264500 | Yes | DM, PQ | NWISWeb/cdec | 46,879 | 139.777 | 37.73159272 | -119.5587736 |
| Merced R a Pohono Bridge nr Yosemite | 1916-present | 11266500 | Yes | DM, PQ | NWISWeb/cdec | 83,139 | 134.3858 | 37.71687138 | -119.6662788 |
| Merced R a Yosemite | 1912-1917 | 11265500 | Yes | DM, PQ | NWISWeb | 61,124 | | 37.74381435 | -119.590165 |
| Merced R ab Illilouette | | 11263500 | Yes | | | 492,100 | | | |
| Merced R nr Briceburg | 1965-1974, 1999-present | 11268200 | No | DM, PQ | NWISWeb | 178,969 | | 37.63576505 | -119.9332325 |
| Middle Granite Lake | 2003-present | H36 | Yes | Raw | Scripps | | 3173 | 37.91749 | 119.27557 |
| Parker Pass Ck | 2001-present | H09 | Yes | Raw | Scripps | | 2928 | 37.87820 | -119.24695 |
| Rafferty Ck | 2001-present | H04 | Yes | Raw | Scripps | | 2665 | 37.86667 | -119.32220 |
| Reed Cr nr Long Barn | 1986-1994 | 11283350 | | DM, PQ | NWISWeb | 7,045 | 159.21 | 38.00464384 | -120.022128 |
| SF Merced R a Wawona | 1955-1975 | 11267300 | | DM, PQ | NWISWeb | 25,900 | | 37.53882469 | -119.6621022 |
| SF Merced R nr El Portal | 1950-1975 | 11268000 | | DM, PQ | NWISWeb | 62,419 | | 37.65131973 | -119.8854532 |
| SF Merced R nr Wawona | 1911-1921 | 11267500 | | DM, PQ | NWISWeb | 34,188 | | 37.54160229 | -119.6732143 |
| SF Tuolumne R at Italian F nr Sequoia | 1924-1933 | 11279500 | | DM, PQ | NWISWeb | 16,809 | | 37.82325848 | -119.9176806 |
| SF Tuolumne R nr Oakland Rec Camp | 1923-2002 | 11281000 | | DM, PQ | NWISWeb | 22,533 | 97.44 | 37.82159266 | -120.0129616 |

| Station Name | Period of Record | Station ID | In Park? | Data Type | Data Location | Drainage Area (ha) | Eleva. (m) | Lat | Long |
|---|---|---|---|---|---|---|---|---|---|
| Dana blw Gaylor | 2001-present | H28 | Yes | Raw | Scripps | | 2930 | 37.87917 | -119.30150 |
| Dana Ck | 2001-present | H02 | Yes | Raw | Scripps | | 2919 | 37.87630 | -119.33250 |
| Eleanor Cr nr Hetch Hetchy | 1909-present | 11278000 | | DM, PQ | NWISWeb/cdec | 20,306 | 156.6 | 37.96908803 | -119.8821241 |
| Falls Cr nr Hetch Hetchy | 1915-1983 | 11275000 | | DM, PQ | NWISWeb | 11,914 | 186.18 | 37.97075376 | -119.764343 |
| Fletcher Creek | 2005-present | H31 | Yes | Raw | Scripps | | | | |
| Gaylor Ck | 2001-present | H10 | Yes | Raw | Scripps | | 2930 | 37.87917 | -119.30150 |
| Hetch Hetchy Reservoir | ?-present | 11275500 | Yes | Real-time | NWISWeb | 117,850 | | 37.94769893 | -119.7879546 |
| Illillouette Ck | 2001-present | H14 | Yes | Raw | Scripps | | 1676 | 37.72300 | -119.55800 |
| Illilouette Cr ne | | 11264000 | | | | 1,566,950 | | | |
| Ireland Creek | 2002-present | H33 | Yes | Raw | Scripps | | 2704 | 37.82569 | -119.27711 |
| Jawbone Cr nr Tuolume | 1910-1911 | 11278500 | | DM | NWISWeb | 4,947 | | 37.89159079 | -119.9954609 |
| Lake Eleanor diversion tunnel | 1997-present | ECK | | DM, PQ | cdec | | 156.6 | 37.969 | -119.881 |
| Lake Eleanor nr Hetch Hetchy | ?-present | 11277500 | Yes | Real-time | NWISWeb | 20,230 | | 37.9740879 | -119.881013 |
| Lewis Creek | 2005-present | H60 | Yes | Raw | Scripps | | | | |
| Lily Cr nr Pinecrest | 1964-1974 | 11283100 | | DM, PQ | NWISWeb | 3,082 | | 38.14463936 | -119.9007361 |
| Lk Eleantor Div to Cherry Lk nr Hetch Hetchy | 1996-present | 11277100 | | DM | NWISWeb | | 162.516 | 37.97964333 | -119.8818464 |
| Lower Gaylor Lake | 2003-present | H35 | Yes | Raw | Scripps | | 3155 | 37.91333 | 119.26991 |
| Lower Granite Lake | 2003-present | H38 | Yes | Raw | Scripps | | 3066 | 37.90788 | 119.28597 |
| Lyell abv Ireland | 2002-present | H32 | Yes | Raw | Scripps | | 2704 | 37.82569 | -119.27711 |
| Lyell at Maclure Bridge | 2003-present | H34 | Yes | Raw | Scripps | | 2947 | 37.77748 | 119.26213 |
| Lyell Fk abv Merced | 2001-present | H11 | Yes | Raw | Scripps | | 2438 | 37.70200 | -119.34700 |
| Lyell Fork (Blw Twin Br) | 2001-present | H03 | Yes | Raw | Scripps | | 2671 | 37.86900 | -119.33367 |
| M Tuolumne River a Oakland Rec Camp | 1916-2002 | 11282000 | | DM, PQ | NWISWeb | 19,037 | 97.44 | 37.82825915 | -120.0115727 |

**Addendum 2**: Continued

| Station Name | Period of Record | Station ID | In Park? | Data Type | Data Location | Drainage Area (ha) | Eleva. (m) | Lat | Long |
|---|---|---|---|---|---|---|---|---|---|
| M Tuolumne River nr Mather | 1924-1933 | 11281500 | | DM, PQ | NWISWeb | 13,572 | | 37.8499241 | -119.8676789 |
| Maclure Cr bl Maclure glcr nr Toulumne Mdw | 1967-1972 | 11274710 | | DM, PQ | NWISWeb | 96 | 400.896 | 37.75242991 | -119.2820929 |
| Merced abv Lyell Fk | 2001-present | H12 | Yes | Raw | Scripps | | 2438 | 37.69700 | -119.34800 |
| Merced abv Merced Lk HSC (DC) | 2001-present | H19 | Yes | Raw | Scripps | | 2207 | 37.7383 | -119.403 |
| Merced at Ranger Cabin | | H21 | Yes | Raw | Scripps | | 2207 | 37.72949 | 119.39304 |
| Merced blw Echo | 2001-present | H15 | Yes | Raw | Scripps | | 2134 | 37.73800 | -119.44900 |
| Merced blw Lyell Fk | 2001-present | H13 | Yes | Raw | Scripps | | 2377 | 37.70200 | -119.34900 |
| Merced Lk outlet | 2002-present | H20 | Yes | Raw | Scripps | | 2207 | 37.73814 | 119.41923 |
| Merced Pk Fk Footbridge (DC) | 2001-present | H18 | Yes | Raw | Scripps | | 2486 | 37.69278 | -119.3497 |
| Merced R a Happy Isles Bridge nr Yosemite | 1915-present | 11264500 | Yes | DM, PQ | NWISWeb/cdec | 46,879 | 139.777 | 37.73159272 | -119.5587736 |
| Merced R a Pohono Bridge nr Yosemite | 1916-present | 11266500 | Yes | DM, PQ | NWISWeb/cdec | 83,139 | 134.3858 | 37.71687138 | -119.6662788 |
| Merced R a Yosemite | 1912-1917 | 11265500 | Yes | DM, PQ | NWISWeb | 61,124 | | 37.74381435 | -119.590165 |
| Merced R ab Illilouette | | 11263500 | Yes | | | 492,100 | | | |
| Merced R nr Briceburg | 1965-1974, 1999-present | 11268200 | No | DM, PQ | NWISWeb | 178,969 | | 37.63576505 | -119.9332325 |
| Middle Granite Lake | 2003-present | H36 | Yes | Raw | Scripps | | 3173 | 37.91749 | 119.27557 |
| Parker Pass Ck | 2001-present | H09 | Yes | Raw | Scripps | | 2928 | 37.87820 | -119.24695 |
| Rafferty Ck | 2001-present | H04 | Yes | Raw | Scripps | | 2665 | 37.86667 | -119.32220 |
| Reed Cr nr Long Barn | 1986-1994 | 11283350 | | DM, PQ | NWISWeb | 7,045 | 159.21 | 38.00464384 | -120.022128 |
| SF Merced R a Wawona | 1955-1975 | 11267300 | | DM, PQ | NWISWeb | 25,900 | | 37.53882469 | -119.6621022 |
| SF Merced R nr El Portal | 1950-1975 | 11268000 | | DM, PQ | NWISWeb | 62,419 | | 37.65131973 | -119.8854532 |
| SF Merced R nr Wawona | 1911-1921 | 11267500 | | DM, PQ | NWISWeb | 34,188 | | 37.54160229 | -119.6732143 |
| SF Tuolumne R at Italian F nr Sequoia | 1924-1933 | 11279500 | | DM, PQ | NWISWeb | 16,809 | | 37.82325848 | -119.9176806 |
| SF Tuolumne R nr Oakland Rec Camp | 1923-2002 | 11281000 | | DM, PQ | NWISWeb | 22,533 | 97.44 | 37.82159266 | -120.0129616 |

| Station Name | Period of Record | Station ID | In Park? | Data Type | Data Location | Drainage Area (ha) | Eleva. (m) | Lat | Long |
|---|---|---|---|---|---|---|---|---|---|
| SF Tuolumne R nr Sequoia | 1914-1917 | 11280000 | | DM, PQ | NWISWeb | 17,690 | | 37.81159223 | -119.9326811 |
| Smoky Jack Cr trib nr Yosemite Village | 1963-present | 11279300 | Yes | PQ | NWISWeb | 17,610 | | 37.81936827 | -119.7135061 |
| South Fork Tuolumne | 2002-present | H50 | Yes | Raw | Scripps | | 2759 | 37.79226 | 119.72264 |
| Strawberry Creek nr Wawona | 1963-1973 | 11267700 | Yes | PQ | NWISWeb | 27,195 | | 37.63604205 | -119.6829422 |
| Tenaya Cr nr Yosemite Village | 1912-1958 | 11265000 | Yes | DM, PQ | NWISWeb | 12,147 | 139.2 | 37.74214772 | -119.5579409 |
| Tuolumne R (Abv Glen Aulin) | 2001-present | H06 | Yes | Raw | Scripps | | 2548 | 37.89950 | -119.40983 |
| Tuolumne R (Blw Glen Aulin) | 2001-present | H08 | Yes | Raw | Scripps | | 2399 | 37.90983 | -119.42033 |
| Tuolumne R (Hwy120 Bridge) | 2001-present | H05 | Yes | Raw | Scripps | | 2651 | 37.87550 | -119.35450 |
| Tuolumne R ab Early Intake nr Mather | 1943-present | 11276600 | | DM, PQ | NWISWeb/cdec | 125,356 | | 37.87936848 | -119.9471261 |
| Tuolumne R at Hetch Hetch nr Sequoia | 1910-1916 | 11274800 | | DM, PQ | NWISWeb | 104,636 | | 37.9554763 | -119.7593427 |
| Tuolumne R bl early intake nr Mather | 1966-2004 | 11276900 | | DM, PQ | NWISWeb/cdec | 126,133 | | 37.88159083 | -119.9701824 |
| Tuolumne R nr Hetch Hetchy | 1910-2004 | 11276500 | | DM, PQ | NWISWeb/cdec | 118,363 | 119.364 | 37.93742147 | -119.7982326 |
| Upper Gaylor Lake | 2003-present | H37 | Yes | Raw | Scripps | | 3155 | 37.92122 | 119.26842 |
| Upper Granite Lake | 2003-present | H39 | Yes | Raw | Scripps | | 3181 | 37.93488 | 119.27739 |
| Vogelsang (Fletcher Lk inlet) | 2002-present | H31 | Yes | Raw | Scripps | | 3109 | 37.79657 | 119.33913 |
| Warren Creek | 2002-present | H40 | Yes | Raw | Scripps | | 2759 | 37.95251 | -119.226 |
| Yosemite Cr a Yosemite | 1912-1918 | 11266000 | | DM, PQ | NWISWeb | 11,059 | | 37.74548095 | -119.5954432 |
| Yosemite Creek | 2002-present | H60 | Yes | Raw | Scripps | | 2276 | 37.85159 | 119.57496 |
| DM= daily mean flow; DT= daily total flow; PQ= peak flow; Raw= original data as collected | | | | | | | | | |
| *Combined totals of river (below conduit diversion) and conduit flows | | | | | | | | | |

**Addendum 3**: Current research projects in Sequoia and Kings Canyon National Parks

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

**Addendum 4**: Current research projects in Yosemite National Park.

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

**Addendum 5**: Current meteorology, air quality and snow pack monitoring sites in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI).

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

**Addendum 6**: Current meteorology stations in Yosemite National Park.



**Addendum 7:** Beneficial uses for the State of California with associated codes and descriptions (Information Center for the Environment 2003).

| Code | Beneficial Use Name | Beneficial Use Description |
|---|---|---|
| AGR | Agricultural Supply | Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing. |
| ALL | All Beneficial Uses | All beneficial uses |
| AQUA | Aquaculture | Uses of water for aquaculture or mariculture operations including, but not limited to, propagation, cultivation, maintenance, or harvesting of aquatic plants and animals for human consumption or bait purposes. |
| BIOL | Preservation of Biological Habitats | Uses of water that support designated areas or habitats, such as Areas of Special Biological Significance (ASBS), established refuges, parks sanctuaries, ecological reserves, or other areas where the preservation or enhancement of natural resources required special protection. |
| COLD | Cold Freshwater Habitat | Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. |
| COMM | Commercial and Sport Fishing | Uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes. |
| EST | Estuarine Habitat | Uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish shellfish, or wildlife (e.g, estuarine mammals. waterfowl, shorebirds). |
| FLD | Flooding | Beneficial uses of riparian wetlands in flood plain areas and other wetlands that receive natural surface drainage and buffer its passage to receiving waters. |
| FRSH | Freshwater Replenishment | Uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered. |
| GWR | Ground Water Recharge | Uses of water for natural or artificial recharge of ground water for purposes of future extraction, maintenance of water quality, or halting salt water intrusion into fresh water aquifers. |
| IND | Industrial Service Supply | Uses of water for industrial activities that do not depend primarily on water quality including, but not limited to, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization. |
| MAR | Marine Habitat | Uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shore birds). |
| MIGR | Migration of Aquatic Organisms | Uses of water that support habitats necessary for migration, acclimatization between fresh and salt water, or other temporary activities by aquatic organisms, such as anadromous fish. |
| MUN | Municipal and Domestic Supply | Uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply. |
| NAV | Navigation | Uses of water for shipping, travel, or other transportation by private, military, or commercial Vessels. |
| NONE | | No designated beneficial uses |

| Code | Beneficial Use Name | Beneficial Use Description |
|---|---|---|
| POW | Hydropower Generation | Uses of water for hydropower generation. |
| PROC | Industrial Process Supply | Uses of water for industrial activities that depend primarily on water quality. |
| RARE | Rare, Threatened or Endangered Species | Preservation of Rare, Threatened, or Endangered Species. |
| REC1 | Water Contact Recreation | Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white water activities, fishing, or use of natural hot springs. |
| REC2 | Non-Contact Water Recreation | Uses of water for recreational activities involving proximity to water, but not normally involving contact with water where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing. |
| SAL | Inland Saline Water Habitat | Uses of water that support inland saline water ecosystems including, but not limited to, preservation or enhancement of aquatic saline habitats, vegetation, fish or wildlife, including invertebrates. |
| SHELL | Shellfish Harvesting | Uses of water that support habitats suitable for the collection of filter-feeding shellfish (e.g., clams, oysters, and mussels) for human consumption, commercial, or sports purposes. |
| SPWN | Spawning, Reproduction, and/or Early Development | Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish. |
| WARM | Warm Freshwater Habitat | Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. |
| WET | Wetland Habitat | Uses of water that support wetland ecosystems, including, but not limited to, preservation or enhancement of wetland habitats, vegetation, fish shellfish, or wildlife, and other unique wetland functions which enhance water quality, such as providing flood and erosion control, stream bank stabilization, and filtration and purification of naturally occurring contaminants. |
| WILD | Wildlife Habitat | Uses of water that support terrestrial ecosystems including, but not limited to, the preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources |
| WQE | Environmental Water Quality | Beneficial uses of waters that support natural enhancement or improvement of water quality in or downstream of a water body including, but not limited to, erosion control filtration and purification of naturally occurring water pollutants, streambank stabilization, maintenance of channel integrity, and siltation control. |

**Addendum 8**: Beneficial uses for stream segments in Devils Postpile National Monument (DEPO) and Sequoia and Kings Canyon National Parks (SEKI) (California Regional Water Quality Control Board Central Valley Region 1995). Beneficial use codes and descriptions are listed in Appendix 7.

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

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix E: Summary of Significant Baseline Inventories and Monitoring in Sierra Nevada Parks*

**Natural Resource Report NPS/SIEN/NRR—2008/072**

Meryl Goldin Rose, Ecologist
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Layout and design Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Goldin Rose, M. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix E. Summary of past and current monitoring in Sierra Nevada Network parks. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Contents


Introduction ..... 133
Atmospheric ..... 133
Wildlife (Terrestrial and Aquatic) ..... 134
Terrestrial Vegetation ..... 125
Fire ..... 136
Aquatic ..... 138
Geologic and Physical Resources ..... 138
Atmospheric Monitoring ..... 139
- Air Quality ..... 139
- Meteorology ..... 139

Wildlife Monitoring (Terrestrial and Aquatic ..... 139
- Multi-species Wildlife Monitoring ..... 140
- Amphibians and Reptiles ..... 140
- Birds ..... 142
- Mammals ..... 144
- Fishes ..... 147
- Invertebrates ..... 148

Terrestrial Vegetation ..... 149
- Plant Populations or Communities ..... 149
- Forest Demography ..... 151
- Alien Invasive Plants ..... 152
- Plant Phenology ..... 153
- Air Pollution Effects on Vegetation ..... 153
- White Pine Blister Rust Effects on Five-Needle Pines ..... 154
- Vegetation Change – Repeat Photography Project ..... 154

Fire-related Monitoring ..... 154
- Environmental and Fire Conditions ..... 155
- Fire Effects on Vegetation and Fuels ..... 155
- Mechanical Fuels Treatment Monitoring ..... 155
- Fire Effects on Wildlife ..... 156
- Fire Effects on Water ..... 156
- Fire Regimes ..... 157
- USGS—Western Ecological Research Center Fire Studies in Sierra Nevada Parks ..... 158

Aquatic Monitoring ..... 159
- Hydrology ..... 159
- Water Chemistry ..... 160

Geologic and Physical Resources Monitoring ..... 160
- Geomorphology ..... 160
- Cave Resources ..... 160
- Soils ..... 161

Monitoring Conducted by Other Agencies on Adjacent Lands ..... 161
Literature Cited ..... 167

## Figures

Figure E-1. Atmospheric monitoring in SIEN parks ..... 134
Figure E-2. Wildlife monitoring in SIEN parks ..... 135
Figure E-3. Vegetation monitoring in SIEN parks ..... 136
Figure E-4. Fire-related monitoring in SIEN parks ..... 137
Figure E-5. Aquatic monitoring in SIEN parks ..... 138
Figure E-6. Geologic and physical resources monitoring in SIEN parks ..... 138
Figure E-7. Summary of natural resources monitoring conducted outside SIEN park boundaries. ..... 164

Current knowledge regarding past and present monitoring, and important baseline inventory projects, are summarized below for Sierra Nevada Network parks: first organized by topic, then by park (where appropriate).

Monitoring conducted by other agencies and organizations located throughout the Sierra Nevada (e.g. U.S. Forest Service) is summarized at the end of this document, and at the end of Chapter 1 (Vital Signs Monitoring Plan).

Park-based monitoring projects likely to have the most value to the network's vital signs monitoring program are those pertaining to resources identified as potential vital signs and having formal and well-documented protocols:

- Air quality (ozone, dry and wet deposition chemistry, particulate matter)
- Meteorology (weather and climate)
- Hydrology (USGS, NPS and Southern California Edison gaging stations)
- Water quality (associated with rivers, streams and lakes—only a few long-term sites)
- Fire effects (vegetation, fuels, water chemistry, wildlife)
- Fire regimes (seasonality, severity, areal extent, frequency of fires at landscape level)
- Meadows (species composition, residual biomass, pack stock use, repeat photography)
- Forest demography (USGS forest plots in Sequoia and Yosemite)
- Ozone (e.g. effects on yellow pine)
- Avifauna (Monitoring Avian Productivity and Survivorship)
- Amphibians (e.g. Mountain yellow-legged frog—repeat inventories of high-elevation lakes, frog restoration)

Following are a listing of principal past and present inventory and monitoring projects and programs among SIEN parks. Baseline inventories with potential value to the vital signs monitoring program, are included as well (and whose summaries may be of particular interest to the park resource managers.

Project details and metadata, where available, are captured in SIEN's data documentation database (begun in 2003 and developed by SIEN staff). Additions to this database are ongoing (contact SIEN I&M staff).

## ATMOSPHERIC

In the Sierra Nevada Network there are three (YOSE, SEQU, KICA) Class I air sheds and one Class II air shed (DEPO). According to the Clean Air Act and subsequent amendments, federal land mangers have responsibility to protect visibility, flora, fauna, waterbodies, and other resources that may be potentially affected by air pollution.

SIEN Class I parks have a complex air monitoring program. Supported by national NPS Air Resources Division, these parks are included in several national networks measuring wet and dry deposition, ozone, visibility, mercury, particulate matter, and meteorology. The air resources programs strive to acquire high quality data, make information available to the public, and take the opportunity to participate in decisions being made by agencies regulating emissions.

| DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|
| **Air Quality** | | |
| | 15 sites monitor various parameters, including:<br>• ozone<br>• Precipitation chemistry<br>• visibility | 19 sites monitor various parameters, including:<br>• ozone<br>• Precipitation chemistry<br>• visibility |
| **Meteorology** | | |
| 1 site:<br>• RAWS (weather and fuel sticks) (removed from site 2004)<br>• New meteorological station installed (Summer 2005) | 14 sites—various parameters, including:<br>• RAWS (weather and fuel sticks)<br>• temperature<br>• precipitation<br>• solar radiation<br>• relative humidity<br>• windspeed/direction<br>• solar radiation<br>• snow water equivalent<br>• snow depth | 8+ sites—various parameters, including:<br>• RAWS (weather and fuel sticks)<br>• temperature<br>• precipitation<br>• solar radiation<br>• gamma radiation<br>• relative humidity<br>• windspeed/direction<br>• relative humidity<br>• snow water equivalent<br>• snow depth |

**Figure E-1.** Atmospheric monitoring in SIEN parks.

## WILDLIFE (TERRESTRIAL AND AQUATIC)

Most long-term monitoring of wildlife (terrestrial and aquatic) has been conducted on bears (interactions/ incidents with humans), birds, and a few selected groups and taxa with special status (mountain yellow-legged frog, Sierra Nevada bighorn sheep, California Spotted Owl).

Wildlife inventory projects are included in this appendix if considered important as "baseline" for future monitoring efforts (e.g. Grinnell Survey, amphibian and avian studies) (Figure 2) .

Invertebrates have generally been under-represented in inventory, monitoring, and other studies in Sierra Nevada Network parks.

| DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|
| **Multiple taxonomic groups** | | |
| | • Wildlife Observations Database | • Wildlife Observations Database<br>• Annual Wildlife Reports<br>• Grinnell Survey |
| **Amphibians & Reptiles** | | |
| | • Salamanders-baseline inventory<br>• Mountain yellow-legged frog<br>• Western pond turtle | • Lentic fauna survey (vertebrate and invertebrate)<br>• Salamanders—baseline inventory<br>• Status of Amphibians<br>• Yosemite toad<br>• Mountain yellow-legged frog |
| **Birds** | | |
| • Baseline Inventory<br>• Monitoring Avian Productivity and Survivorship (MAPS) stations | Baseline Inventory<br>• MAPS stations<br>• Breeding Bird Surveys<br>• Christmas Bird Count<br>• Peregrine Falcon<br>• California Spotted Owl<br>• Important Bird Areas<br>• Brown-headed Cowbird | • Baseline Inventory<br>• MAPS stations<br>• Christmas Bird Count<br>• Great Grey Owl<br>• Peregrine Falcon<br>• California Spotted Owl |
| **Mammals** | | |
| | • Forest carnivores<br>• Black bear<br>• Sierra Nevada bighorn sheep<br>• Bats<br>• California ground squirrel<br>• Yellow-bellied marmot<br>• Small mammals (fire studies) | • Forest carnivores<br>• Black bear<br>• Sierra Nevada bighorn sheep<br>• Bats<br>• Mountain lion<br>• Mule deer |
| **Fishes** | | |
| • Population assessments | • Species composition, density, habitat variables<br>• Little Kern golden trout | • Baseline survey<br>• Lentic fauna survey |
| **Invertebrates** | | |
| • Benthic macroinvertebrates<br>• Meadow invertebrates | • Giant Sequoia forest invertebrates-baseline inventory<br>• Bark beetles (fire studies/USGS) | • Lotic benthic invertebrates baseline survey<br>• Lentic fauna survey (macroinvertebrates)<br>• High-elevation meadow invertebrates<br>• Macroinvertebrates—Merced River |

**Figure E-2.** Wildlife monitoring in SIEN parks.

## TERRESTRIAL VEGETATION

Sequoia, Kings Canyon, and Yosemite National Parks have a rich history of vegetation-related inventories, research, and monitoring projects (Figure 3). Most long-term vegetation monitoring in these parks has been related to measuring effects of resource management programs (especially fire, exotic plant control and restoration), recreation (especially pack stock grazing), and air pollution (also described above). The USGS-Biological Resources Division also conducts long-term vegetation monitoring in Sequoia and Kings Canyon and Yosemite: forest demography across elevations is the longest term dataset.

Aside from fire-effects plots established in 1992 by the SEKI fire effects crew, Devils Postpile has not had staffing or resources to do long-term vegetation monitoring.

All parks have had vegetation inventories done that are of value as baseline data for long-term monitoring. These include vegetation maps, Natural Resource Inventories in the 1990s in Sequoia, Kings Canyon, and Yosemite (Graber et al. 1993), a vascular plant inventory in Devils Postpile (Arnett and Haultain 2004), and rare plant surveys for individual park units Moore et al. 2005, Haultain, in prep).

Restoration projects with associated monitoring (e.g. photopoints) are also included.

| DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|
| **Meadows, Wetlands, Riparian** | | |
| • Soda Springs meadow—restoration success | • Alpine meadows<br>• Meadows (pack stock use-distribution and abundance of pack stock)<br>• Meadows (pack stock effects-residual biomass, species composition, and trends in condition) | • Alpine meadows<br>• Meadows (pack stock use)<br>• Meadows (grazing effects—plant species inventory)<br>• Pavillion Square meadow<br>• Cooks meadow<br>• Happy Isles fen<br>• Eagle Creek streambank vegetation |
| **Forest Demography** | | |
| | • Forest dynamics | • Forest dynamics<br>• Ponderosa pine/mixed conifer forest |
| **Alien invasive species** | | |
| • Inventory | • Inventory (trails and developed areas)<br>• Recently burned area (McGinnis 2004) | • Inventory (trails and developed areas)<br>• Riparian (Kane et al. 2006) |
| **Phenology** | | |
| | • *Sequoiadendron giganteum*<br>• *Pinus ponderosa*<br>• *P. lambertiana*<br>• *Abies concolor*<br>• *Calocedrus decurrens*<br>• *Quercus kelloggii* | |
| **Air Pollution Effects** | | |
| *Pinus jeffreyi* | • Baseline ozone effects (*Pinus ponderosa, P. jeffreyi*)<br>• Ozone response (*Pinus ponderosa, P. jeffreyi*)<br>• Ozone reponse (multiple species)<br>• Physioecological response (*Pinus jeffreyi*) | • Ozone response (*Pinus ponderosa, P. jeffreyi*)<br>• Ozone reponse (multiple species) |
| **White Pine Blister Rust** | | |
| | • Five needle pines (*Pinus lambertiana, P. monticola, P. albicaulis, P. balfouriana, P. flexilus*) | • Five needle pines (*Pinus lambertiana, P. monticola, P. albicaulis, , P. flexilus*) |
| **Vegetation Change** | | |
| | • Repeat photography (USGS-BRD) | |

**Figure E-3.** Vegetation monitoring in SIEN parks.

## FIRE

The parks' fire monitoring programs began in 1982 for Sequoia & Kings Canyon, 1978 for Yosemite and 1992 for Devils Postpile. The programs in Sequoia & Kings Canyon and Yosemite initially focused on monitoring weather and fire behavior, vegetation, and dead and down surface fuels in giant sequoia groves and other early experimental prescribed burns in mixed-conifer forests. Over time, the monitoring programs expanded to other vegetation communities as the prescribed fire programs progressed. In recent years, Sierra Nevada fire-monitoring programs have broadened to include additional vegetation, wildlife, water, and/or fire regime components. Devils Postpile does not currently have a Fire and Fuels Management Plan (NPS in progress), however, fire effects monitoring plots were established in association with a 1992 wildfire that burned approximately two-thirds of the monument.

Monitoring environmental and fire condition provides information to guide fire management strategies for both wildland and prescribed fires; such monitoring encompasses a wide variety of fire topics, including:

- environmental and fire conditions,
- fire effects on vegetation and fuels,
- mechanical fuels-treatment monitoring,
- fire effects on animals,
- fires effects on water, and
- fire regimes, restoration, baseline fire history

In addition to fire-related monitoring

conducted by SIEN park staff, USGS-Western Ecological Research Center staff at both Sequoia and Kings Canyon and Yosemite Field Stations have contributed an inordinate amount of fire-related monitoring regarding SIEN parks and greater Sierra Nevada ecosystems. USGS projects in our parks are an integral part of NPS resource management information and decision-making.

Fire-related monitoring is summarized in Figure 4; it is described in greater detail in the Sequoia and Kings Canyon and Yosemite National Parks Fire and Fuel Management Plans (NPS 2003, 2004).

| DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|
| **Environmental and Fire Conditions** | | |
| | • weather<br>• fire conditions (for wildland and prescribed fires)<br>• burn severity<br>• fire behavior | • weather<br>• fire conditions (for wildland and prescribed fires)<br>• burn severity<br>• fire behavior |
| **Fire Effects: Vegetation and Fuels** | | |
| • Post-burn (tree and seedling mortality, char/scorch, fuel loading, burn severity)<br>• Repeat photography (1, 2, 5, 10, and 15 years post-burn) (Pre-burn conditions not measured due to wildfire.) | • Pre-burn (tree-shrub-herbaceous layer, dead-and-downed fuel)<br>• Post-burn (tree and seedling mortality, char/scorch, fuel loading, burn severity)<br>• Repeat photography (1, 2, 5, 10, and 15 years post-burn) | • Pre-burn (tree-shrub-herbaceous layer, dead-and-downed fuel)<br>• Post-burn (tree and seedling mortality, char/scorch, fuel loading, burn severity)<br>• Repeat photography (1, 2, 5, 10, and 15 years post-burn) |
| **Mechanical Fuels Treatment Monitoring** | | |
| | • Effects of mechanical thinning (overstory, seedlings, shrubs, fuels, soil, nonnative plants, potential fire hazard)<br>• Pre- and post-treatment data<br>• Repeat photography | • Effects of mechanical thinning (overstory, seedlings, shrubs, fuels, soil, nonnative plants, potential fire hazard)<br>• Pre- and post-treatment data<br>• Repeat photography |
| **Fire Effects on Wildlife** | | |
| | • Rodent populations (response to prescribed fire)<br>• Other wildlife species | |
| **Fire Effects on Water** | | |
| | • Hydrology<br>• Hydrochemistry | |
| **Fire Regime** | | |
| • Fire history/age structure | • Cumulative accomplishments<br>• Restoration goals<br>• Fire history/age structure | • Fire history/age structure<br>• Mixed-conifer forest—natural reference conditions |
| **USGS—Western Ecological Research Center Stations** | | |
| | • Fire Surrogate Study (13 sites established nationwide)<br>• Fire hazard reduction treatments<br>• Fuels, behavior<br>• Birds and small mammals<br>• Soils, forest floor<br>• Bark-beetle<br>• Pathogen infection (Heterobasidion annosum—fir)<br>• Invasive annual grasses<br>• Fire and grazing impacts on plant diversity and plant invasions | |

**Figure E-4.** Fire-related monitoring in SIEN parks; continues next page.

## AQUATIC

Hydrologic and water chemistry monitoring is summarized in Figure 5. Detailed information describing water resource activities in and around SIEN are included in Appendix D.

| DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|
| **Hydrology** | | |
| • Middle Fork of the San Joaquin | • 12 active gaging stations (all located in the Kaweah River drainage)<br>• 24 historic gaging stations | • 21 active gaging stations |
| **Water Chemistry** | | |
| • Baseline water quality (12 sites within/near boundary)<br>• Total coliform, *Escherichia coli*, minerals, inorganic chemical parameters<br>• Drinking water (one site) | • Middle Fork of the Kaweah watershed studies (stream flow and chemistry, conductivity, nutrients, cations/anions)<br>• Hydrologic Benchmark Site (long-term trends on the Marble Fork of the Kaweah)<br>• Landscape scale prescribed-fire effects on water-shed chemistry (East Fork of the Kaweah)<br>• High-elevation lake water quality and atmospheric deposition (20 lakes)<br>• Drinking water (thirteen sites, in frontcountry and wilderness) | • Hydrologic Benchmark Site (long-term trends on Merced River at Happy Isles)<br>• High-elevation lake water quality and atmospheric deposition (9 lakes)<br>• Drinking water (frontcountry and wilder-ness)<br>• Water quality (Tioga Pass, Dana Meadows, Tuolumne Meadows) |

**Figure E-5**. Aquatic monitoring in SIEN parks.

## GEOLOGIC AND PHYSICAL RESOURCES

Information on monitoring of geology, geomorphology, physical cave resources, and soils is found in Figure 6 and in a subsequent section on geological resources.

| DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|
| **Geology** | | |
| | | • Baseline geology map |
| **Geomorphology** | | |
| | | • Cross-sections (Merced River and Tenaya Creek) |
| **Caves** | | |
| | • Visitation (Crystal, Hurricane Crawl, Soldiers, Lilburn)<br>• Radon (primarily Crystal Cave)<br>• Cave and surface temp-eratures (Crystal, Kaweah, Clough, and Palmer) | |
| **Soils** | | |
| | • Pre-and post-burn soil chemistry (Tharp's)<br>• Chemistry (early versus late-season prescribed fire) | |

**Figure E-6.** A Geologic and physical resources monitoring in SIEN parks.

## ATMOSPHERIC MONITORING

*For detailed and comprehensive information on the atmospheric monitoring program in and around SIEN, please see Appendix C.*

### *Air Quality*

In the Sierra Nevada Network, there are three (YOSE, SEQU, KICA) Class I air sheds and one Class II air shed (DEPO). According to the Clean Air Act and subsequent amendments, federal land mangers have an affirmative responsibility to protect visibility, flora, fauna, bodies of water and other resources that may be potentially damaged by air pollution.

Unfortunately, SIEN parks' air quality is often degraded by pollutants originating from outside park boundaries. Adjacent to Sierra parks is the San Joaquin Valley, recognized as having some of the worst air pollution in the country (Peterson and Arbaugh 1992, Cahill et al. 1996). Pollutants which travel from the San Francisco Bay Area combine with pollutants produced in the San Joaquin Valley. Air flow patterns are such that these pollutants travel into the Sierra Nevada affecting SIEN parks. SEKI has the dubious distinction of having some of the worst air pollution found in any park, nationwide.

Class I parks in the SIEN network have a complex air monitoring program. Supported by the NPS Air Resources Division, these parks are included in several national networks measuring wet and dry deposition, ozone, visibility, mercury, particulate matter, and meteorology. The air resources programs strive to acquire high quality data, make the information available to the public, and taking the opportunity to participate in decisions being made by agencies regulating emissions.

One of the most damaging air pollutants is ozone. Research suggests chronic ozone pollution can lead to shifts in forest structure and composition (Miller 1973). If current ozone concentrations remain relatively constant or increase, they may affect the genetic composition of pine and sequoia seedling populations, and contribute to increased susceptibility to fatal insect attacks and death rates, and decreased recruitment (Miller 1973, Ferrell 1996, Miller 1996). The effects of chronic ozone pollution on other species are not yet known.

Ozone pollution in the Sierra Nevada has produced vegetation damage and is a potentially serious human health issue. YOSE and SEKI have multiple ozone monitors measuring ambient ozone levels. All parks have in, or nearby, passive ozone monitors which are in place during the ozone season (approximately April – October). SEKI uses its stations to produce a daily air advisory for park visitors and employees. Each park facilitates studies designed to better understand ozone effects on vegetation and potential changes to forested landscapes.

Visibility conditions vary by season, generally poor during the summer months and good during winter. Degraded visibility is largely due to organics, sulfates, and nitrates. Smoke from campfires, wildfires, and prescribed burns also cause reduced visibility.

The Sierra Nevada contains thousands of dilute, oligotrophic lakes that are sensitive to changes in climate and atmospheric deposition of acids, nutrients and toxic substances. Recent investigations suggest that lakes throughout the Sierra are undergoing mild eutrophication (Goldman et al. 1993, Sickman et al. 2003). Deteriorating air quality in San Joaquin Valley suggests that human activity may be to blame for these changes. Both YOSE and SEKI monitor acidic inputs and nitrogen deposition in rain and snow events to detect any reduction or increase of these pollutants.

### *Meteorology*

#### *Yosemite, Sequoia & Kings Canyon, and Devils Postpile Meteorology*

See Appendix D for summary table of meteorological monitoring. A new meteorological station was installed in Devils Postpile in 2005, using SIEN monitoring funds (a long-term USDA Forest Service RAWS station was removed in 2004).

## WILDLIFE MONITORING (TERRESTRIAL AND AQUATIC)

Most long-term monitoring of wildlife (terrestrial and aquatic) has been conducted on bears (interactions/incidents with humans), birds, amphibians, a few selected groups taxa with special status (e.g., Sierra Nevada bighorn sheep, California Spotted Owl), etc.

Wildlife inventories are briefly summarized below if considered important as "baseline" for future monitoring efforts. Invertebrates have generally been under-represented in inventory, monitoring, and other studies in Sierra Nevada Network parks.

### *Multi-species Wildlife Monitoring*

*Devils Postpile National Monument*

Wildlife Observations

Wildlife observation log maintained in visitor center. Entries made by general public and staff. Minimal-to-no quality control. Currently not in electronic format.

*Sequoia & Kings Canyon*

Wildlife Observations

A database was created to contain "notable" observations of wildlife. Data for each record includes date, species, location, description of observation, name of observer, etc. This database underwent considerable redesign by I&M, including much QA/QC (circa 2006).

*Yosemite*

Annual Wildlife Reports

Annual reports submitted to the Superintendent on wild animal life (much of which concerns mammals) in Yosemite National Park (1929-1979; 50 years) (Yosemite and NPS Archives). For the most part, the information is anecdotal and includes observations by park staff (animals and animal tracks) and experiences of "old timers of the region who have traversed the country." Noted within these reports are staff requests that "more [structured and accurate] studies" be conducted.

Wildlife Observations

A database was created to contain "notable" observations of wildlife (1939 - present; 65 years). Database structure adopted from wildlife observation database at Sequoia and Kings Canyon National Parks. Data for each record includes date, species, location, description of observation, name of observer, etc. All observations–while subjective–do undergo QA/QC (scrutinization) by park wildlife experts (Yose GIS Server: W:\rdbms\Wildlife_Database2000.mdb). This database underwent considerable redesign by I&M, including additional QA/QC (circa 2006).

Baseline Inventory: Vertebrates

The "Grinnell Survey", an inventory of the mammals, birds, reptiles, and amphibians was conducted in Yosemite National Park beginning in 1914. It encompassed 1,547 square miles (4000 km2)(excluding Mariposa Grove and Hetch Hetchy Valley). Elevation of lands surveyed ranged to over 13,000 feet (3,962 m). Field personnel traveled over most regular trails, as well as high points (from where life zones were mapped). This study is not a systematic treatise, but rather contains natural history observations relating to living animals (Grinnell and Storer 1924).

The Grinnell Survey was recently re-conducted, though employing more systematic methodology (Moritz 2007).

## Amphibians and Reptiles

### *Network-wide*

Baseline Inventory: Salamanders

A study was conducted to determine salamander status in Sierra Nevada Network Parks (Yosemite National Park, Devil's Postpile National Monument, and Sequoia and Kings Canyon National Parks). Both field and laboratory studies were combined to determine the distributions of species as well (Wake and Vredenburg 2002).

### *Sequoia & Kings Canyon*

Baseline Inventory: Terrestrial Salamanders

Collections of terrestrial salamanders were made in Sequoia, Kings Canyon, and Yosemite national parks for the purpose of identification and DNA analysis by the University of California Museum of Vertebrate Zoology as one of the Sierra Nevada Network's biological inventory projects (Wake and Vredenburg 2002). This survey was initiated to provide the distributions of known and newly-identified, described, or detected caudate amphibians (including *Batrachoseps* spp., *Ensatina* spp., *Hydromantes* spp., and *Taricha* spp.). Prior to this study, little or no data were available for terrestrial salamanders in Network parks.

Baseline Inventory: Mountain Yellow-legged Frog

The mountain yellow-legged frog (*Rana muscosa*), once abundant in high elevation waterbodies of the Sierra Nevada, has disappeared from more than 80 percent of its historic range (Bradford and Graber 1994). This decline is largely attributed to predation by introduced trout, although

airborne contaminants (pesticides) and pathogens (chytrid fungus) may also be contributing to the decline (Davidson and Shaffer 2002, Sparling and Cowman 2003). In 1997, researchers surveyed 1,059 waterbodies in Kings Canyon National Park to assess the effects of introduced fish on the native mountain yellow-legged frog (Knapp and Matthews 2000). From 2000-2002, researchers surveyed 3,640 waterbodies in the parks to inventory fish and amphibian populations and measure habitat (Knapp 2003a, Knapp 2003b). Subsets of these sites were monitored annually from 2002-2004 for the presence of mountain yellow-legged frogs and chytrid fungus.

In 2001, the National Park Service began restoring mountain yellow-legged frog habitat by removing non-native trout from six lakes and the adjacent streams in Kings Canyon National Park. As part of the restoration effort, park staff monitor mountain yellow-legged frog populations before, during, and after trout removals, and measure the abundance of frogs in the restored habitats (Boiano 2004). In 2003, the Sierra Nevada Aquatics Research Laboratory initiated a project to monitor the effects of non-native trout removal on stream invertebrates at restoration sites in Upper Bubbs Creek.

### Western Pond Turtle

The National Park Service monitors western pond turtle populations on the North Fork of the Kaweah River and Sycamore Creek to assess the population condition and long-term trends. Starting in 1991, park staff performed annual surveys using mark-recapture techniques.

### Baseline Inventory: Herpetofauna

Reptiles and amphibians have been sampled or recorded as part of other multi-species inventories, such as the Sierra Nevada Network vertebrate inventories that focused primarily on small mammals, reptiles, and amphibians (Werner 2004, Patton 2006) and within the wildlife observation database, described above and below.

## *Yosemite*

### Baseline Inventory: Lentic Fauna

The first comprehensive inventory of vertebrate and invertebrate taxa found in Yosemite's lentic habitats (i.e., lakes, ponds, marshes, wet meadows) was conducted from 2000-2002. A total of 3,107 lentic habitats were surveyed for fishes, amphibians, reptiles, fairy shrimp, and habitat conditions; zooplankton and benthic macroinvertebrates were collected at a subset of sites. Surveys indicated the presence of four native amphibian species (Yosemite toad Bufo canorus, Pacific treefrog *Hyla regilla*, mountain yellow-legged frog *Rana muscosa*, Sierra newt *Taricha torosa*), one non-native amphibian species (bullfrog *Rana catesbeiana*), four native reptile species (western pond turtle, Sierra garter snake, mountain garter snake, valley garter snake), five nonnative fish species (rainbow trout, California golden trout, Lahontan cutthroat trout, brown trout, brook trout), two fairy shrimp species (spinytail fairy shrimp, mountain fairy shrimp), 19 zooplankton taxa, and 100 benthic macroinvertebrate taxa (Knapp 2003c)(see also: Invertebrates; Fishes below).

### Baseline Inventory: Status of Amphibians

Beginning in 1992, research has been conducted on the status of amphibians within Yosemite National Park. Efforts have been focused on ponds, lakes, meadows, and selected portions of suitable streams as potential breeding sites. A total of 1,659 sites within Yosemite National Park were visited, some more than once. Target species of interest included red-legged frog (*Rana aurora*), cascades frog (*Rana cascadae*), foothill yellow-legged frog (*Rana boylii*), mountain yellow-legged frog (*Rana muscosa*), Pacific treefrog (*Hyla regilla*), western toad (*Bufo boreas*), Yosemite toad (*Bufo canorus*), California newt (*Taricha torosa*), Bullfrog (*Rana catesbeiana*) and a reptile—garter snake (*Thamnophis* spp.)(Fellers 1999).

### Baseline Inventory: Special-status Amphibians

Other work was conducted to evaluate the status of Yosemite toads (Bufo canorus), Pacific treefrogs (Hyla regilla), and mountain yellow-legged frogs (Rana muscosa) in Yosemite National Park, and to study the effects of environmental factors on these species–especially climate change. The study included extensive surveys for breeding sites for Yosemite toad Bufo canorus, Pacific

treefrog Hyla regilla, and mountain yellow-legged frog Rana muscosa. Measurements of abiotic and biotic parameters in the field were focused mainly on breeding sites of Yosemite toads and, to a lesser extent, Pacific treefrogs (Sadinski et al. 2002).

### Baseline Inventory: Special-status Amphibians

In 1997, the U. S. Geological Survey initiated a study to examine the decline of the Yosemite toad (*Bufo canorus*), Pacific treefrog (*Hyla regilla*) and mountain yellow-legged frog (*Rana muscosa*). In addition to water quality parameters discussed in the previous section, the USGS measures the numbers of breeding adults and egg masses per breeding site, hatching success, numbers of metamorphs, and other age classes. Field sites are located at Tioga Pass, Dana Meadows, and Tuolumne Meadows (Fellers 1997).

## Birds

### *Network-wide*

### Baseline Inventories: Birds

In Yosemite, point counts, coupled with detailed habitat descriptions, were the primary methods used to survey birds (1998-2000). A total of 21,072 individual birds were detected at 2,646 point locations across the park using the generalized survey protocol. A total of 149 species were documented, including 15 species not included on a predicted species list. Four guidelines – and five specific projects – are suggested for prioritizing future avian monitoring efforts in the park (DeSante et al. 2003).

Inventories for Devils Postpile and Sequoia & Kings Canyon are in-progress (Siegel and Wilkerson 2004, 2005) and had the following objectives: 1) describe and map the distribution and abundance of birds across habitat type; 2) collect and summarize data on vegetation structure and composition; 3) describe specific habitat associations of bird species; 4) estimate species richness; 5) provide summary information necessary to develop a general monitoring strategy and design that can be implemented by park staff; and 6) provide information that can be used to educate the public. The purpose of this project is to improve baseline data on bird populations and habitat associations of bird species and to develop strategies for long-term monitoring (Siegel and Wilkerson 2004, 2005)).

### *Devils Postpile*

### Monitoring Avian Productivity and Survivorship

In 2002-2004, Point Reyes Bird Observatory (PRBO) implemented a standardized bird monitoring program (10 mist net stations in Soda Springs Meadow using MAPS protocols). PRBO established 15 independent point count stations along the San Joaquin River and Red's Meadow Creek within monument boundaries (Gates and Heath 2003b).

### *Sequoia & Kings Canyon*

### Monitoring Avian Productivity and Survivorship (MAPS)

MAPS protocol was established by the Institute for Bird Populations (Ralph et al. 1993). The objective is to determine the productivity and survivorship of various species to detect whether population changes on the birds' wintering or breeding grounds. In Kings Canyon, there are currently two MAPS stations, one in Cedar Grove at Zumwalt Meadow, and one in Grant Grove at Lion Meadow. These stations are run in collaboration with The Institute for Bird Populations and Central American biologists, through the Partners in Flight program. The stations were operated from 1991-1993 (Burton et al. 1992, Burton and DeSante 1993) and 2000-2004 (Rachel Mazur, pers. comm.).

### Breeding Bird Surveys

Breeding Bird Surveys (BBS) are conducted at thousands of sites across North America in order to assess regional population trends of migratory species. Two BBS are conducted at Sequoia and Kings Canyon (once each June)—one at Mineral King (SEQU), and one at Cedar Grove (KICA). A total of 50 point counts are conducted following BBS protocols (2001-present).

### Christmas Bird Counts

The Christmas Bird Count is a monitoring program that targets resident birds, and conducted at thousands of sites throughout North America. The count is done for one day, along

established routes, with multiple observers, within an established count circle (circa 1960-present).

### Peregrine Falcon

Peregrine Falcon (*Falco peregrinus*): The Santa Cruz Predatory Bird Research Group restored peregrine falcons to Sequoia, Kings Canyon, Yosemite, and the surrounding national forests. The Peregrine Falcon was federally de-listed (federal endangered species list) by US Fish and Wildlife Service in 1999 (still listed as endangered in California). There are now at least five active, or potentially active, eyries in Sequoia & Kings Canyon. The sites are monitored on an annual basis for occupancy, nesting activity, eggs, young, and successful fledglings. Monitoring also provides data needed for NPS and USFS staff to temporarily close rock-climbing routes that are near eyries.

### California Spotted Owl

California Spotted Owl (*Strix occidentalis occidentalis*): The California Spotted Owl is designated federally endangered (listed by California as a species of special concern). There are four ongoing California spotted owl demography studies within the Sierra Nevada bioregion: (1) Sequoia and Kings Canyon National Parks (1990-present); (2) Lassen National forest(1990-present); (3) Eldorado National Forest (1986-present); and (4) Sierra National Forest (1990 and 1994-present).

Study objectives vary, but generally include all or most of the following: occupancy and density of territory; survival and reproductive success, site fidelity; habitat relations; and diet). Data from the five demographic studies were analyzed in a meta-analysis conducted by Spotted Owl biologists in conjunction with scientists with expertise in population biology, statistics, and data analysis (Franklin et al. 2003). Data from the demographic studies comprise the only empirical information on California spotted owl population trends, survival, and reproduction over the past 7-12 years.

### Important Bird Areas

An Important Bird Area study was conducted in Sequoia & Kings Canyon National Parks and Sequoia and Sierra National Forests in 1999 and 2000 by the Institute for Bird Populations as part of a national effort to classify land areas that are of particular importance to birds. Meadows in both national parks and surrounding national forests were assessed by point counts and mist netting.

### Brown-headed Cowbirds

Brown-headed cowbirds are an obligate nest parasite, native to the United States but not the Sierra Nevada. Several species of warblers in particular have fallen precipitously in numbers due to the arrival of cowbirds. A two-year nest study (1995-1996) was done to assess the impact of the cowbirds on native warblers in Cedar Grove area of Kings Canyon National Park (Halterman and Laymon 2000).

## *Yosemite*

### Monitoring Avian Productivity and Survivorship (MAPS)

Yosemite has the longest term dataset in our network for monitoring of avian productivity and survivorship. Beginning in 1990, a MAPS station has been run in Hodgdon Meadow through a partnership with the Institute for Bird Populations. In 1993, four more sites were added: Big Meadow, Crane Flat, Tamarack Meadow, and White Wolf Meadow. All five sites have been run annually since then. All of these sites are meadows, although the mist netting includes forest edge. MAPS sites have been run in the park for 13 years. About 80 species have been captured at these sites, with about 70 of those being species captured in a majority of years (Pyle et al. 2006).

### Christmas Bird Count

The Christmas Bird Count is a monitoring program that targets resident birds, and conducted at thousands of sites throughout North America. The count is done for one day, along established routes, with multiple observers, within an established geographic area (i.e., “count circle”)(circa 1960-present).

### Peregrine Falcon

Nest location(s) for Peregrine Falcons (Falco peregrinus), primarily within the greater Yosemite Valley surroundings,

is determined annually (1978–present; 26 years). Reproductive success data are generally only available for a single nest location that is easily observed. One site within Yosemite Valley is monitored by USFWS, as part of their monitoring program for de-listed species (Steve Thompson, pers. comm.).

### Baseline Inventory: Great Grey Owl

The status and distribution of the Great Grey Owl (*Strix nebulosa*) in California is examined based on field surveys conducted in 1979 and 1984, and the analysis of 222 sight and specimen records; the main concentration of this species is in the region of Yosemite National Park. The purpose of this study was to (1) determine the status and distribution of Grey Gray Owls in California, particularly the region of Yosemite National Park, and (2) determine the habitat and nesting requirements, prey preference and abundance, space-use ecology, and behavior of three pairs of Great Gray Owls (1980-1985)(Winter 1985).

During the winters of 1986-88, and 1989-90, a total of nine Great Grey Owls were monitored in Yosemite National park to determine their winter migration patterns (Skiff 1995).

A sample of the montane meadow systems of Yosemite National Park were surveyed for the presence of Great Grey Owls (1992 and 1994) as part of a long-term population trend study which began in 1992 (Unpublished Natural Resources Report NPS-YOSE-NRW-93-02).

A study was conducted to investigate habitat requirements (based on landscape patterns) of Great Grey Owls in the central Sierra Nevada (Yosemite and adjacent Stanislaus national forest), particularly nest site availability and prey preference and abundance (Greene 1995).

### Baseline Inventory: Spotted Owl

Surveys and inventories to determine the distribution and abundance of Spotted Owls (*Strix occidentalis*) were conducted in Yosemite National Park (April through August of 1988 and 1989), covering 577.4 square km of forest habitat at elevations between 1,220 m and 2,465 m (Gould and Norton 1993).

As of the writing of this report (field season 2004), surveys for California Spotted Owls are being conducted to develop a predictive model of their occurrence in Yosemite National Park. The objectives of this project are to: (1) develop models for the relationship between fire, distribution and reproductive success of spotted owls, and certain structural components of their habitat; and (2) examine linkages between fire history and spotted owl abundance with current forest structure and the dynamics of Spotted Owl prey species (Task Agreement Number F8800-03-2400 between Yosemite and USGS).

## Mammals

### *Multi-Park*

See "Multiple Vertebrate Groups", and "Fire-related Monitoring" sections (below) for more information on small mammals monitoring.

### *Sequoia & Kings Canyon*

### Focal Resource: Black Bear

Monitoring of human/bear incidents and other bear activities (see also, description under Yosemite, above): The Bear Information Management System (BIMS) is used to record bear incidents and observations in SIEN parks. The purpose of BIMS is to track temporal and spatial trends of bear activities, to track activity of specific bears, and to track effectiveness of outreach and educational efforts and actions taken by management in response to incidents. This system has been in place for more than 20 years, but is highly subject to observer bias and has been used inconsistently.

Bear research: Bear population and behavioral studies were conducted in Yosemite and in Sequoia and Kings Canyon beginning in the 1970s until presently, and more is planned in Sequoia. Some of this work provided robust estimates of population size and structure in local areas (e.g. Yosemite Valley, Giant Forest), but these are not amenable to extrapolation to larger landscapes, and were not conducted for sufficient duration to detect change.

### Focal Resource: California Ground Squirrel

California ground squirrels (*Spermophilus beecheyi*) were inventoried in campgrounds in Sequoia National Park (1984-1998) to monitor the relative abundance due to concerns that the

number of squirrels in the campgrounds was too high and needed to be controlled (Harold Werner, pers.comm.).

### Focal Resource: Yellow-bellied Marmots

Yellow-bellied marmots (*Marmota flaviventris*) were studied in the Mineral King area of Sequoia National Park from 1987 to 1993 to try to determine why marmots were chewing on car parts (and often causing damage) during early to mid summer of each year. Data were collected on blood chemistry, movements and population structure of the marmots. Please see below for additional information about monitoring of small mammals associated with fire effects studies and the Multiple Vertebrate Group Studies section below for baseline inventories of small mammals.

### Focal Resource: Bats

Exit Counts—The Sequoia and Kings Canyon Cave Specialist and staff conduct exit counts for bats at Clough Cave in Sequoia National Park (1996 to present).

Baseline Data—(Koshear and Lawton 1993) conducted a 10-day survey through the Kaweah, Kern and Kings River drainages in Sequoia National Park to study bats. Mist nets were used to sample bats during their active period and their sounds were recorded to aid in species identification. The objective of this study was to develop a baseline database regarding bat species composition, abundance, distribution and ecology.

Structure Use—(Pierson and Heady 1996) conducted a survey to determine the bat use of buildings in Giant Forest, prior to building removal as part of a restoration project in Sequoia National Park. Recommendations included additional monitoring and some mitigation to protect bat habitat in the area.

Sierra Nevada Network Bat Inventory Project—The purpose of this project was to document at least 90% of bat species expected to occur in Devils Postpile National Monument and Sequoia and Kings Canyon National Parks. Literature and museum searches and extensive field sampling (mist-netting and acoustic survey) was conducted. Sampling was initiated in Devils Postpile in August 2001, and 10 bat species were newly documented for the monument (Pierson and Rainey 2002). Sequoia and Kings Canyon field sampling began during the summer of 2002. Of the 17 species expected to occur, 15 of these were identified in Kings Canyon; 14 in Sequoia. Three species were newly documented for both parks (Pierson and Rainey 2003).

Other products for Sequoia and Kings Canyon and Devils Postpile from Pierson and Rainey's work for SIEN will include: (a) summaries of information on Sierra Nevada bat species from literature reviews; and a literature review that includes identification of species sensitive to disturbance; and ( b) identification of bat species detected or mist-netted, characterization of breeding status, discussion of locations/ habitats where species were detected and foraging areas/roosting features in those habitats. At least two additional years of field work will be conducted.

### Forest Carnivores

Four species of Sierra Nevada carnivores are special status species: California wolverine (*Gulo gulo*), Pacific fisher (*Martes pennanti pacifica*), American marten (*Martes pennanti pacifica*), and Sierra Nevada red fox (*Vulpes vulpes necator*). The American (pine) marten and Pacific fisher are declining throughout their range. California wolverines are elusive and there has been no definitive documentation of their occurrence in California in over twenty years.

Two recent inventories in Sierra Nevada parks have provided additional information about some of these species and other carnivores: (1) assess the presence and distribution of American marten, Pacific fisher and California wolverine and measure their associated habitats (2002-2004). Non-target species surveyed include: spotted skunk (*Spilogale putorius*), gray fox (*Urocyon cinereoargenteus*), ringtail (*Bassariscus astutus*), weasel species (*Mustela* spp.), coyote (*Canis latrans*), mountain lion (*Puma concolor*), black bear and Virginia opossum (*Didelphis virginiana*).

### Sierra Nevada Bighorn Sheep

See project description, below, under Yosemite.

*Yosemite*

Focal Resource: Rare Mammals

A study is being conducted (1992 – present) to determine the status and distribution of Pacific fisher (*Martes pennanti pacifica*), Sierra Nevada red fox (*Vulpes vulpes necator*), and California wolverine (*Gulo gulo luteus*) in Yosemite National Park; species designated as Category II (being considered for protection under the Endangered Species Act) (Federal Register, 21 November 1991, 56:58804-58836). A species is designated Category II when the USFWS receives a petition for listing but lacks the information necessary to determine whether Endangered Species status is warranted.

Focal Resource: Black Bear

Monitoring of human/bear incidents and other bear activities: Monitoring of black bears (*Ursus americanus*) is limited to individual bears, not the population. The Bear Information Management System (BIMS) is used to record bear incidents and observations in SIEN parks. The purpose of BIMS is to track temporal and spatial trends of bear activities, to track activity of specific bears, and to track effectiveness of outreach and educational efforts and actions taken by management in response to incidents. This system has been in place for more than 20 years, but is highly subject to observer bias and has been used inconsistently. The ultimate goal is to develop management strategies to mitigate conflicts (Thompson and McCurdy 1995, Yosemite Bear Council 2002).

At Yosemite, data collected annually (1960 – present; 44 years) are related to human-black bear interactions (injuries and property damage). Some behavioral data is collected for individual animals where possible (range, reproductive success)(Thompson, S., pers. comm.).

Bear research: Bear population and behavioral studies were conducted in Yosemite and in Sequoia and Kings Canyon beginning in the 1970s until presently, and more is planned in Sequoia. Some of this work provided robust estimates of population size and structure in local areas (e.g. Yosemite Valley, Giant Forest), but these are not amenable to extrapolation to larger landscapes, and were not conducted for sufficient duration to detect change.

Focal Resource: Sierra Nevada Bighorn Sheep

Sierra Nevada bighorn sheep (Ovis canadensis sierrae) are federally and state listed as Endangered. The entire subspecies was first censused during the 1970s (Wehausen 1980) when it consisted of only two surviving populations which spent winters on the eastern slopes of the Sierra in the Inyo National Forest, and their summers near the crest. The larger of the two populations spent a portion of the year in Kings Canyon National Park; the second herd occasionally wandered into Sequoia National Park from the Inyo N.F. During the period 1979-1988, bighorn sheep were translocated from the larger herd to sites in the Inyo National Forest where sheep had once been reported, to establish three additional herds in the Sierra Nevada. One of these introduced herds includes a portion of Sequoia Natonal Park within its range, and a second sporadically visits Yosemite National Park. In 2002 a band of sheep was discovered near Bubbs Creek which appears to spend the entire year west of the Sierra crest in Kings Canyon National Park; it likely established recently from the nearest established herd.

*Monitoring of Sierra bighorn herds*

The California Department of Fish and Game (CDFG) has been the agency with principal responsibility for monitoring Sierra Nevada bighorn sheep. Attempts have been made to census all extant herds annually since the early 1980s, using various combinations of agency personnel from CDFG, the National Park Service, the U.S. Forest Service, and the Bureau of Land Management, as well as volunteers. These efforts have been coordinated by Dr. John D. Wehausen, generally under contract to CDFG. Population models have then been employed to convert fragmentary raw census data into estimates of population size and structure.

Estimated population size for the entire subspecies has varied from 310 in 1986 to 100 in 1998. The principal controlling factor appears to be mountain lion predation. The species is soon to be recognized as a new, distinct subspecies,

*Ovis canadensis sierrae*.

Focal Resource: Bats

Eight species of bats in the Sierra Nevada are federal and/or state species of concern: Pallid bat (*Antrozous pallidus*), Townsend's/pale big-eared bat (*Corynorhinus townsendii*), spotted bat (*Euderma maculatum*), greater western mastiff bat (*Eumops perotis Californicus*), long-eared myotis (*Myotis evotis*), fringed myotis (*Myotis thysanodes*), long-legged myotis (*Myotis volans*) and Yuma myotis (*Myotis yumanensis*).

Bat surveys have been ongoing in Yosemite since 1993 (10 years). Three survey methods are used: bridge roost, acoustic, and mist-netting. Results include species diversity, seasonal and elevational distribution, relative abundance, and reproductive status (Pierson et al. 2001).

Another bat project (FY 2002) was initiated to investigate the seasonal and elevational distribution of bats in Yosemite in response to aquatic insect abundance and distribution (sites were sampled at monthly intervals from May through October). Stable nitrogen isotopes will be examined to determine the role that aquatic ecosystems play in the structure and function of terrestrial communities. Investigators will resample insects and bats at the 2002 sample sites (Pierson and Rainey—SIEN unpublished data).

In 2003, newly designed bat detectors were installed at several locations in Yosemite to monitor bats on a year-round basis (USGS-WERC unpublished data).

Focal Resource: Mountain Lion

In 1994, a dramatic rise in the number of reported mountain lion (*Puma concolor*) sightings and apparent changes in mountain lion behavior raised concerns about the potential for conflict between lions and humans in developed areas in Yosemite National Park. To assess the level of threat these individuals posed to human safety, a study was conducted to determine why mountain lions had increased their use of Yosemite Valley and other developed areas in the park. Seven mountain lions were captured and equipped with radio-telemetry collars; nine additional lions, that occurred in the study area, were never captured (USGS—WERC unpublished data).

Focal Resource: Mule Deer

Yosemite-region mule deer (*Odocoileus hemionus*) herds are monitored annually (population size and health) in Yosemite and surrounding national forests (Stanislaus and Sierra or Tuolumne). Composition counts are obtained (i.e., number of bucks, does, and fawns). In addition, hunting statistics are used as an indicator for estimating mule deer numbers (e.g. car counts—carcasses on tops of cars or in bed of trucks). Other data gleaned from examining such carcasses (e.g. antler growth) includes indication of overall deer health.

## Fishes

### *Devils Postpile*

The California Department of Fish and Game conduct annual fish population assessments on the Middle Fork of the San Joaquin River. Monitoring began sometime around 1997; some monitoring continues (funding dependent).

### *Sequoia & Kings Canyon*

Sequoia and Kings Canyon staff monitors fish density, species composition and habitat variables at twelve sites to evaluate the effects of human access, elevation and fishing regulations on fish populations. Monitoring was initiated in 1980 and is repeated approximately every five years.

Focal Resource: Little Kern golden trout

Found in headwater streams of Sequoia National Park, are listed as threatened under the federal Endangered Species Act. The National Park Service and California Department of Fish and Game monitor fish populations and pool habitat on Soda Springs Creek to assess annual and long-term changes in restored and source populations of Little Kern golden trout.

### *Yosemite*

Baseline Survey: Fishes

A single-season survey of the status of fish populations in 102 "planted" lakes. This report: (1) summarizes the findings for each lake, including stocking history; and (2) a broader discussion

and qualitative description of each lake, including shoreline and nearby terrain, inlet/outlet stream(s), bottom sediment, aquatic plant(s), and food availability for fishes (invertebrate type and abundance). In addition, the report notes that "[m]ost of these lakes were [previously] surveyed close to or in 1953" (Botti 1977). Editor's note: amphibian larvae are not listed as present as a food source, but the researchers do not note whether they were a target species of the survey.

Baseline Inventory: Lentic Habitat

The first comprehensive inventory of vertebrate and invertebrate taxa found in Yosemite's lentic habitats (i.e., lakes, ponds, marshes, wet meadows) was conducted from 2000-2002. A total of 3,107 lentic habitats were surveyed for fishes, amphibians, reptiles, fairy shrimp, and habitat conditions; zooplankton and benthic macroinvertebrates were collected at a subset of sites. Surveys indicated the presence of four native amphibian species (Yosemite toad, Pacific treefrog, mountain yellow-legged frog, Sierra newt), one non-native amphibian species (bullfrog), four native reptile species (western pond turtle, Sierra garter snake, mountain garter snake, valley garter snake), five nonnative fish species (rainbow trout, California golden trout, Lahontan cutthroat trout, brown trout, brook trout), two fairy shrimp species (spinytail fairy shrimp, mountain fairy shrimp), 19 zooplankton taxa, and 100 benthic macroinvertebrate taxa (Knapp 2003c)(see also: Invertebrates, below; Amphibians and Reptiles, above).

## Invertebrates

### *Devils Postpile*

Benthic Macroinvertebrates

The National Park Service and California Department of Fish and Game sampled benthic macroinvertebrate communities using the California Stream Bioassessment Procedure, a biological monitoring tool used to detect change in aquatic systems (Schroeter and Harrington 1995). They sampled in 1994 and 1999, concurrently with the water quality monitoring discussed in the previous section.

Meadow invertebrates

Stream and terrestrial invertebrate sampling the San Joaquin River and adjacent meadows of Devils Postpile National Monument is being conducted across two seasons (2003-2004). The objectives of this project were to: (1) describe the spatial and temporal distribution of invertebrates; (2) document the presence of sensitive taxa; (3) establish a baseline against which impacts can be assessed; and (4) identify the invertebrate groups most likely to prove informative as monitoring elements (Holmquist and Schmidt-Gengenbach 2005).

### *Sequoia & Kings Canyon*

Giant Sequoia Forest Invertebrates

Staff from the UC Davis Bohart Museum collected insect data from giant sequoia forest areas and adjacent vegetation types in the Kaweah River drainage of Sequoia National Park (2001-2002) to provide additional baseline information on park insects in and around sequoia forests as well as develop baseline information on Chironomids as water quality indicators. Data were collected primarily by drift net (primarily for Chironomids), malaise traps, and sweep nets (Kimsey and Cranston 2002). These data were collected as a SIEN biological inventory project-NPS 2001.

### *Yosemite*

Baseline Inventory: Lotic Benthic Invertebrates

Lotic benthic invertebrates were collected from riffles, glides (runs), pools, wood, and margin habitats from eight sites on the Merced River in Yosemite Valley, Yosemite National Park. Collections were made near the beginning of October during four contiguous years, 1992-1995. A total of 338 taxa were collected over the four years. In general, total taxon richness was similar in 1992, 1993, and 1995. Total taxon richness was somewhat higher in 1994. Riffle and margin habitats had near equal mean taxon richness and were higher than glide, pool, or wood habitats (Carter 1997).

Baseline Inventory: Lentic Macroinvertebrates

This is the first comprehensive inventory of vertebrate and invertebrate taxa found in Yosemite's lentic habitats (i.e., lakes, ponds, marshes, wet meadows). A total of 3,107 lentic habitats were surveyed for

fishes, amphibians, reptiles, fairy shrimp, and habitat conditions; zooplankton and benthic macroinvertebrates were collected at a subset of sites. Surveys indicated the presence of four native amphibian species (Yosemite toad, Pacific treefrog, mountain yellow-legged frog, Sierra newt), one non-native amphibian species (bullfrog), four native reptile species (western pond turtle, Sierra garter snake, mountain garter snake, valley garter snake), five nonnative fish species (rainbow trout, California golden trout, Lahontan cutthroat trout, brown trout, brook trout), two fairy shrimp species (spinytail fairy shrimp, mountain fairy shrimp), 19 zooplankton taxa, and 100 benthic macroinvertebrate taxa (Knapp 2003c)(see also: Fishes, Amphibians and Reptiles, above).

### *Pilot Monitoring: Meadow Invertebrates*

A cooperative agreement was initiated with Jeff Holmquist (identified above) to conduct a pilot study to assess the efficacy of invertebrates as indicators of meadow change. A literature review to inform the network's conceptual modeling was completed in 2003 (Holmquist 2004), and the pilot study field work was completed in 2005 in Tuolumne Meadows of Yosemite National Park (Holmquist and Schmidt-Gengenbach 2006). The objectives were to: (1) produce an initial inventory of invertebrates within diverse habitats of one Sierra Nevada Network meadow; (2) quantitatively document the spatial and temporal distribution of invertebrates within the meadow; (3) document the presence of sensitive invertebrate taxa (listed species and species of concern); (4) provide a first approximation of a baseline against which the impacts of management and recreational activities on meadow systems can be assessed; and (5) identify those groups, species and/or other elements most likely to prove informative as indicators for long-term monitoring.

### Focal Resource: River Macroinvertebrates

The Yosemite Institute, in conjunction with the Sierra Nevada Aquatics Research Laboratory, conducts an aquatic bio-monitoring program along a short section of the Merced River. This is an environmental education program where students collect stream invertebrates and divide them into categories that reflect "tolerances for polluted water" to evaluate stream health. Sampling is conducted annually (Yosemite Institute, pers. comm.).

## TERRESTRIAL VEGETATION

Sequoia, Kings Canyon and Yosemite National Parks have a rich history of vegetation-related inventories, research and monitoring projects. Most of the long-term vegetation monitoring in these parks has been related to measuring the effects of management programs (especially fire, exotic plant control and restoration), recreation (especially pack stock grazing) and air pollution. Aside from fire effects plots established in 1992, Devils Postpile has not had the staffing or resources to do long-term vegetation monitoring.

All parks have had vegetation inventories done that are of value as baseline data for long-term monitoring. These include vegetation maps, vascular plant surveys in the 1990s in Sequoia, Kings Canyon and Yosemite (P. Moore and S. Haultain, pers. comm.), a vascular plant inventory in Devils Postpile (Arnett and Haultain 2004), and rare plant surveys for all parks (Moore et al. 2005, S. Haultain, in progress).

### *Plant Populations or Communities*

#### *Meadows, Wetlands, and Riparian Areas*

Sierra Nevada montane and non-meadow riparian areas are recognized as Globally Important Bird Areas (American Bird Conservancy, National Audubon Society) and as Priority Habitats for bird conservation in the Sierra Nevada Bioregion (Siegel and DeSante 1999). Participants in Sierra Nevada Network vital signs workshops identified meadows as a priority for long-term monitoring due to their ecological importance, their potential sensitivity to climatic change and their use as recreational and pack stock grazing sites by backcountry travelers.

Devils Postpile National Monument

While there is not currently a comprehensive monitoring program in place for meadows in the monument, a meadow restoration project is underway in Soda Springs Meadow and some baseline inventory data are being collected on aquatic and terrestrial invertebrates to determine if there will be changes in invertebrate communities in response to reduction in social trailing and restoration of more natural water flow patterns in the meadow (discussed in more detail under Invertebrate Section)(Holmquist and Schmidt-Gengenbach 2005). Other monitoring associated with Soda Springs Meadow is a songbird demographic monitoring project (Gates and Heath 2003a), discussed in more detail under Terrestrial Animals section.

### *Sequoia and Kings Canyon National Parks*

Most of the meadow monitoring in Sequoia and Kings Canyon National Parks has focused on measuring effects of grazing by pack stock on wilderness meadows (S. Haultain, pers. comm.). The Plant Ecologist in Division of Natural Resources, with support from backcountry patrol rangers, monitors:

- The annual distribution and abundance of overnight pack stock use in Sequoia and Kings Canyon National Parks.
- Species composition in five pairs of meadows—each pair consisting of one grazed meadow and one ungrazed reference meadow.
- Residual biomass, or the amount of above ground plant material remaining in a meadow at the end of the growing season. This provides park managers with information on the status of selected wilderness meadows that are being grazed. In the long term, these data will enable park managers to set appropriate use levels for popular meadows by establishing site specific minimal residual biomass standards. In the short term, residual biomass serves as an indicator of meadow conditions that can be referred to when timely decisions are needed to prevent or mitigate the effects of overgrazing.
- Coarse trends in meadow condition and species composition (e.g. invasion by woody species) through use of repeat photography. Collection currently consists of repeat photographs of approximately 250 scenes throughout meadows in Sequoia and Kings Canyon National Parks, which are retaken as time and resources allow. Collections of photos specific to each backcountry patrol area are compiled into photo binders that are sent out to each station in the spring of each year.

These complementary datasets are combined to illuminate the relationship between pack stock use and meadow condition, and to inform management decisions regarding pack stock use and grazing within the two national parks.

### *Yosemite National Park*

Monitoring associated with vegetation restoration: In Yosemite, Science and Resources Management staff members have undertaken numerous wetlands and meadow restoration projects. Some of these projects have multi-year monitoring projects associated with them.

- Pavillion Square, Sentinel Meadow Restoration: In spring 1993 this formerly developed area was restored through removal of fill and re-contouring. Five transects were established to monitor: 1) vegetation change following site treatment, 2) proportion of native and nonnative plant species, and 3) assess relationships between establishment of nonnative plant species and water table. Untreated control transects were established for comparison to treated areas.
- Cooks Meadow Restoration: 7 year project (1998 - present). Monitoring is being conducted to document changes in hydrology and vegetation following restoration of a lower montane wet meadow in Yosemite Valley. Restoration involved removal of fill, filling ditches, installation of culverts under roads, installation of boardwalks in place of paved trails, and removal of nonnative plants.
- Happy Isles Fen Restoration: 8 year project (2001-2009). Monitoring is being conducted to document

changes in species composition. The Happy Isles fen is a four acre wetland representative of a rare plant community. Site restoration involved removal of fill, re-contouring, and revegetation.

- Eagle Creek Restoration: 2 year project (2002-2004). The site restoration intended to retard erosion and encourage re-establishment of native stream bank vegetation at the confluence of Eagle Creek and the Merced River in Yosemite Valley.
- Packstock: The Yosemite USGS Field Station conducted a study on the effects of stock use on meadows (Moore et al. 2000)

### *Forest Demography*

#### *Sequoia and Yosemite National Parks*

Permanent forest reference plots were established in Sequoia and Yosemite National Parks to develop a quantitative description of Sierra Nevada forest dynamics across an elevational and latitudinal gradient. From 1982 to 1995 three separate programs orchestrated the establishment of permanent forest plots in Sequoia and/or Yosemite: Sierran Pulse (Dr. Jerry Franklin, University of Washington), Watershed Program (Dr. David Parsons, formerly of Sequoia NP Research Office—(Parsons et al. 1992), and USGS Global Change Research Program (Stephenson and Parsons 1993, Stephenson et al. 2004). Forest demography is now monitored in all plots under the USGS Global Change Research Program.

There are nineteen plots in Sequoia and five in Yosemite. They range from about 1,500 m to 3,300 m in elevation; plot size ranges from 0.9 to 2.5 hectares. Forest types represented include: ponderosa pine-mixed conifer, white fir-mixed conifer, xeric conifer, red fir, and subalpine. All trees above 1.37 m in height are tagged and monitored annually for mortality, disease, and insect and weather damage. When trees die, factors associated with death are identified and recorded. New establishment is monitored by tagging trees annually that reach 1.37 m in height. Every five years diameters of trees are re-measured to monitor tree growth. Two of these plots were burned in 1990; mortality rates and factors associated with death of trees have been compared between burned and unburned stands. Forest seedling dynamics and forest seed rain research and monitoring projects were initiated in these plots in 1999 and 2000, respectively. Long-term demographic data associated with these plots have yielded a variety of publications (Parsons et al. 1992, Mutch and Parsons 1998, van Mantgem et al. 2003, Stephenson and van Mantgem 2005), and contributed to additional research with academic scientists (e.g.,(Kern 1996, Miller 1996, Miller and Urban 1999).

To aid in development of forest restoration targets, Yosemite is undertaking follow-up data collection on 61 forest plots that first were inventoried in 1911. Plots are in ponderosa pine and mixed conifer forests. Transects used for data collection are large (4 acres each), systematically located, spread over a large area, and were sampled before the major impacts of fire suppression had become apparent.

Stand and landscape-scale structure and composition of these forests will be summarized, thereby providing concrete targets for use in planned forest restoration activities (as specified in the Yosemite Fire Management Plan (National Park Service 2004a). This step will quantify the demographic structure of these transects, their spatial patterns, and their relationship to environmental and topographic variables. It will be statistically oriented and dependent on Geographic Information System (GIS) analysis. Second, the original transects will be re-sampled to quantify changes that have occurred in the past 90+ years, when forests were subject to substantial human impact. Analysis of results of re-sampling will be based on stratification of transects according to their original structural characteristics, topographic and elevation positions, and severity of fire damage from the 1996 Ackerson fire (which burned part of the study area). Forest change will be quantified with respect to these explanatory variables.

Yosemite resource staffs are seeking funds to conduct the same work on adjacent Stanislaus National Forest.

Combined data, covering a 150 mi2 area, will allow comparison of temporal changes between these two land management agencies, which have had very different histories of vegetation management.

Contact: Dr. Jim Bouldin, PhD, Research Ecologist, USDA Forest Service Pacific Southwest Research Station, Davis, CA

### *Alien Invasive Plants*

In Spring 2005, SIEN I&M staff hosted a network-wide alien invasive plant workshop, attended by park resources management staff, as well as regional, WASO, and other national invasive plant experts across the country. The purpose of this workshop was to identify and refine network invasive plant objectives and priorities, with special emphasis on early-detection monitoring. The results of this workshop are available (Moritsch and Goldin-Rose 2006).

#### *Devils Postpile*

The most problematic alien invasive plant in the monument is bull thistle (*Cirsium vulgare*). Monument staff began eradicating bull thistle, as time was available, after the 2001 vascular plant inventory identified it as the most invasive of the eight alien invasives identified in the monument (Arnett and Haultain 2003). The California Exotic Plant Management Team has visited the monument to remove bull thistle and other alien invasives.

#### *Sequoia, Kings Canyon and Yosemite*

The purpose of nonnative plant inventory and monitoring in these parks is to (1) document location and abundance of exotic plant infestations, (2) document management actions, (3) document exotic plant taxa and their priorities for management, (4) summarize yearly accomplishments, and (5) monitor effectiveness of control actions over time. Areas to be searched on a regular basis are documented, including roadsides, campgrounds, housing areas, developments, trail-sides, dumps, corrals and pack stations, pastures, burned areas, and park boundaries throughout the parks. Methods include mapping (with GPS) infestations of nonnative plants as points or polygons. Associated data includes ocular cover estimates, number and density of plants, elevation, aspect, overstory cover, plant community, land use, and control method.

A nonnative plant inventory done by USGS in the late 1990s for Sequoia, Kings Canyon and Yosemite targeted developed areas and trails and provided a threat assessment and management prioritization for nonnative plants in these parks (Moore and Gerlach 2001, Gerlach et al. 2003). Additional alien invasive plant surveys are currently underway (fieldwork 2005, 2006) for riparian areas in Yosemite and a recently burned area in Sequoia National Park, through the network's Inventory & Monitoring program.

#### *Yosemite*

##### Invasive Plant Management Plan / EIS

Yosemite has prepared an Invasive Plan Management Plan/EIS which in part may inform future early detection or trends monitoring.

##### Alien Invasive Surveys

Yosemite National Park conducted alien invasive plant surveys in 1998 and 1999, primarily focused on anthropogenically disturbed areas, including campgrounds, picnic areas, developments, corrals, roads, and trails. Survey results indicated 130 nonnative species occurred in these anthropogenically disturbed sites. The majority occurred at lower elevations, but non-natives were recorded at some of the highest elevations surveyed. At that time, there was little information on the presence of nonnative plants in areas of natural disturbance (riparian areas) in Yosemite.

##### Alien Invasive Survey: Riparian Habitat

In 2005, SIEN funded a plot-based survey of alien invasive plants within the Merced River watershed. The purpose of this project was to refine knowledge of vegetation conditions—specifically non-native plant species presence—in areas subject to natural disturbance, specifically riparian habitat. Results will provide a baseline against which changes in distribution and abundance of selected species can be measured, and will assist with prioritization of

individual sites and species suitable for monitoring. The project focused on riparian habitat within the entire Merced River drainage.

Alien Invasive Plants as a Function of Burn Severity

In 2006, we supported pilot monitoring efforts already underway in SEKI and YOSE related to early detection of invasive plants in burned areas. In YOSE, Kristin Kaczynski and Dr. Susan Beatty of University of Colorado at Boulder and in SEKI, Nate Bensen and Jeff Morisette of NASA Goddard Space Flight Center are working on projects to narrow the search frame within burned areas to successfully and efficiently detect target non-native plants after fire. The objectives of the Kaczynski and Beatty project in YOSE are the following: (1) to determine if there is a relationship between fire severity and the density, frequency, and percent cover of invasive species in wilderness areas of Yosemite National Park. The result will be a predictive evaluation/model of the probability of encountering an invasive plant population based on fire severity and habitat characteristics, and a evaluation of the feasibility of using remote sensing for early detection in Sierra burned areas (Kaczynski 2007).

### *Plant Phenology*

#### *Sequoia National Park*

From 1988 to 1990, the Research Office in Sequoia and Kings Canyon National Parks monitored seasonal timing of growth of giant sequoias (*Sequoiadendron giganteum*) using band dendrometers and increment corers (Mutch 1990). From 2000 through 2004, Sequoia and Kings Canyon National Parks' Fire Ecologist has monitored growth of 3-12 trees (*Pinus ponderosa, Pinus lambertiana, Abies concolor, Calocedrus decurrens*, and *Quercus kelloggii*) in the Giant Forest area. The purpose of these projects is to determine timing of onset of earlywood and latewood growth and cessation of growth for Sierra Nevada tree species. This information is needed to better estimate the seasonal timing of fire scars in the tree-ring record (Swetnam et al. 1992, Caprio and Swetnam 1995). Data, collected on a long-term basis in conjunction with meteorological data, could also be of interest in examining effects of climate change on tree phenology.

### *Air Pollution Effects on Vegetation*

Numerous inventory and research studies, and a few long-term monitoring projects, have documented ozone effects on yellow pines (*Pinus ponderosa* and *P. jeffreyi*) and a few other species, e.g. black oak (*Quercus kelloggi*) and giant sequoia (*Sequoiadendron giganteum*). It is primarily the pine studies that collected long-term data, and these are summarized below by topic or project, rather than by park:

Baseline ozone effects survey, Sequoia and Kings Canyon: Fifty-four, 10-tree permanent plots were established in Sequoia and Kings Canyon National Parks between 1980 and 1982 to determine the distribution and intensity of ozone injury to two indicator species (ponderosa pine *Pinus ponderosa* and jeffrey pine *Pinus jeffreyi*) and provide baseline data. Plot ratings ranged from "no symptoms" to "severe symptoms." Moderate-to-severe damage appeared to occur in open drainages and on aspects that directly face San Joaquin Valley (Duriscoe 1987, Duriscoe and Stolte 1992).

The Sierra Forest Ozone Response Study (Project FOREST): This joint NPS/USFS effort, begun in 1989, established a network of plots throughout the Sierra Nevada and San Bernardino Mountains to evaluate effects of ozone on *Pinus ponderosa* and *Pinus jeffreyi*. The network includes six plots at Sequoia and Kings Canyon National Parks and six plots in Yosemite National Park, along with a total of 50 additional plots in Tahoe, Eldorado, Stanislaus, Sierra and Sequoia National Forests. These plots were re-visited in 1993, 1996 and 2001 and evaluated for foliar injury (chlorotic mottling), needle retention, and other variables. Dendroecological studies also evaluated effects of ozone on radial growth of trees in these stands (Peterson et al. 1989, Peterson 1991).

An additional plot, not part of the original study network, was established at Devils Postpile in 1993 and re-read in 1996 and 2001. This single 50-tree

plot, encompassing about 2 ha, was established to monitor effects of ozone air pollution on Jeffrey pine. Jeffrey pine was found to be rare in Devils Postpile after significant mortality caused by the 1992 Rainbow wildfire.

Forest Inventory and Analysis (FIA) plots: One plot was established in Sequoia National Park specifically to examine ozone effects on multiple species. Two plots were established outside the boundary of Yosemite National Park for the same purpose. These plots are read annually by USDA Forest Service staff.

Physioecological studies: (Beyers et al. 1992) evaluated the effects of long-term ozone exposure and drought on photosynthetic capacity of ponderosa pine during summer and fall, 1988-1990. (Patterson and Rundel 1989) examined physiological responses (photosynthetic rates and stomatal conductance) between seasons and among ozone-sensitive and ozone-resistant Jeffrey pine for two years, 1987-1988.

### *White Pine Blister Rust Effects on Five-Needle Pines*

An extensive ground survey of white pine species in Sequoia and Kings Canyon National Parks was conducted from 1995-1999 (Duriscoe and Duriscoe 2002). The objectives of the project were to: (1) Assess geographic extent and severity of white pine blister rust on the following species: *Pinus lambertiana, Pinus monticola, Pinus albicaulis, Pinus balfouriana, Pinus flexilus*; (2) delineate the geographic distribution of the above pine species based on a synthesis of all currently available information; and (3) establish permanent monitoring plots to provide a baseline for long-term monitoring of rust incidence and severity–151 permanent plots were established.

### *Vegetation Change – Repeat Photography Project*

The USGS Sequoia and Kings Canyon Field Station used repeat photography to document vegetation changes in ponderosa pine forests and oak-chaparral communities of Kings Canyon in Kings Canyon National Park, and compared these changes with those documented in Yosemite Valley. Yosemite Valley and Kings Canyon share similar geologic and human histories, and a comparison of vegetation change in the two areas could provide new information for management. Unlike other repeat photography projects, they quantitatively analyzed some photo pairs (as well as qualitatively described all pairs) using a simple, dot-grid overlay counting method. They concluded that, although there are apparent density and cover increases in plant communities of Kings Canyon, they are not as dramatic as those documented for Yosemite Valley. Changes in vegetation conditions in Kings Canyon followed a change in fire regime of the area after Euroamerican settlement. In contrast, changes observed in Yosemite Valley may be a result of a change in fire regime as well as human induced changes in hydrology.

## FIRE-RELATED MONITORING

The purpose of fire monitoring programs in Sierra Nevada parks is to provide effective evaluation of the parks' fire management programs. Fire monitoring programs are designed to determine whether fire and resource management objectives are met, as well as to document any unexpected consequences of fire management activities (National Park Service 2004b).

The parks' fire monitoring programs began circa 1982 for Sequoia & Kings Canyon, 1978 for Yosemite, and 1992 for Devils Postpile. The programs in both Sequoia & Kings Canyon and Yosemite initially focused on monitoring weather and fire behavior, vegetation, and dead-and-down surface fuels in giant sequoia groves and other early experimental prescribed burns in mixed-conifer forests. As prescribed-fire programs evolved, the monitoring programs expanded to other vegetation communities. Some fire monitoring in Sierra Nevada parks is guided by the Fire Monitoring Handbook (FMH; (National Park Service 2001) which establishes goals, objectives, and protocols for fire-related monitoring Servicewide—this program became a Servicewide standard in 1988. In recent years, Sierra Nevada fire-monitoring programs have broadened to include additional vegetation, wildlife, water, and/or fire regime components. Devils Postpile does not currently have a completed Fire

and Fuels Management Plan (NPS in progress); however, fire effects monitoring plots were established in association with a 1992 wildfire that burned approximately two-thirds of the monument.

More information on fire can be found in SEKI and YOSE Fire and Fuel Management Plans ((National Park Service 2003, 2004a).

### *Environmental and Fire Conditions*

Monitoring of environmental and fire conditions are the first two levels of monitoring described in the Fire Monitoring Handbook. NPS resources management and/or fire management staff collect information on environmental conditions (weather [current and forecasted], fuel model) and fire conditions (name, location, slope, aspect, spread, intensity, smoke transport, and dispersal) for all wildland and prescribed fires. Monitoring these environmental and fire conditions provides information to guide fire-management strategies for both wildland and prescribed fires.

Recently, Sequoia & Kings Canyon and Yosemite National Parks have been implementing monitoring of burn severity (2002–present). Using Composite Burn Index rankings and Landsat images, fire monitoring crews are ground-truthing data from large wildland fires to assess accuracy of satellite-imagery interpretation of burn severity.

USGS-BRD staff in Sequoia and Kings Canyon have monitored weather, fuel moisture and fire behavior in association with a national Fire/Fire Surrogate project (U.S. Geological Survey 2004). See section on USGS fire-related studies below.

### *Fire Effects on Vegetation and Fuels*

Monitoring levels 3 and 4 of the Fire Monitoring Handbook (National Park Service 2001), describe short- and long-term monitoring of the effects of fire on fuels and vegetation to guide prescribed fire management strategies. Pre-burn plot data include information on tree, shrub and herbaceous layer vegetation, dead and downed fuels (woody debris, litter and duff), and fuel load, and plot photographs. After burning, data are collected on tree mortality, char and scorch, seedling mortality, fuel loading, and burn severity, and plots are re-photographed. Data are collected 1, 2, 5, 10, and 15 years post-burn.

Data from the standard vegetation and fuels monitoring program, along with other projects that supplement the standard program for Sequoia, Kings Canyon and/or Yosemite, provide the following information:

- dead and down fuel reduction and accumulation
- changes in overstory tree density and species composition by diameter class and condition
- changes in seedling tree density and species composition by height class
- changes in snag density and snag formation/breakdown rates
- changes in shrub density (or cover) and species composition
- changes in cover and species composition of herbaceous vegetation
- changes in ground cover
- changes in species richness
- detection of alien invasive species
- burn severity
- immediate-postburn effects on trees (maximum bark char and crown scorch heights, percent crown scorch)
- mortality of large pines (with and without basal fuel removal mortality) and survival of postfire-regenerated giant sequoia

USGS-BRD staff in Sequoia and Kings Canyon monitor vegetation and fuels in association with a national Fire/Fire Surrogate project (U.S. Geological Survey 2004); see also USGS fire-related studies, below.

### *Mechanical Fuels Treatment Monitoring*

Mechanical fuels treatments are being implemented in areas associated with development as part of Fire and Fuels Management Plans in Sequoia & Kings Canyon and Yosemite National Parks (National Park Service 2003, 2004b). Plots are being established to

monitor effects of mechanical thinning on overstory trees, seedlings, shrubs (brush), fuels, soils, nonnative plants, and potential fire hazard.

Nested frequency plots are being established in Yosemite Valley and Foresta, in sites subject to mechanical treatment and pile burning, to monitor invasion by nonnative plants after treatment. Pre- and post-treatment data are collected; photographs are taken of each plot.

### *Fire Effects on Wildlife*

Many wildlife species are affected by fire, with significant changes to both structure and vegetative composition of habitat. Because rodents are sensitive to habitat change, they make good indicators of wildlife response to fire. Changes in rodent populations lead to changes in food availability for raptors and forest carnivores—many of which are either sensitive or of public interest (e.g. fisher, martin, goshawk, etc.). In Sequoia National Park, some limited monitoring of wildlife has focused on areas where prescribed fire is the primary management activity.

In association with the Mineral King Risk Reduction Project in Sequoia (Werner 1995-1998), long-term monitoring plots were established in a variety of vegetation types where prescribed burning was planned; serendipity surveys were done for common and unique habitats. Long-term monitoring documents long-term changes in rodent populations and habitat following fire under known conditions. Serendipity surveys inventory rodent species and relative abundance within both common and unique environments to facilitate large-scale assessment of potential fire effects.

USGS-BRD staff in Sequoia and Kings Canyon have monitored wildlife species in association with a national Fire/Fire Surrogate project (U.S. Geological Survey 2004); also see USGS fire-related studies below.

### *Fire Effects on Water*

The effects of fire on water quantity and quality and sediment transport are second order fire effects that have important ecosystem consequences (Keifer et al. 2003). In Sequoia National Park, stream flow and water chemistry monitoring has focused on specific watersheds where prescribed fire is the primary management activity. The objectives of this monitoring were to:

1. Evaluate changes in hydrology following prescribed fire by measuring pre-fire and post-fire continuous stream discharge.
2. Document changes in hydrochemistry by quantifying solute inputs using wet deposition data from the National Acid Deposition Program (NADP) and California Air Resources Board (CARB) collection sites and solute exports using stream discharge and periodic chemical samples.

A pilot study in the paired mixed-conifer Log Meadow and Tharp's watersheds examined the effects of a single fire on a small (<50 ha), low gradient watershed. This study took advantage of a watershed monitoring program initiated in 1982 (supra) to study forest demography, atmospheric deposition and watershed processes. Tharp's Creek watershed was prescribed burned in 1990, and provided an opportunity to study stream chemistry and hydrology pre- and post-burn and to compare these data with the unburned Log Creek watershed.

In contrast, ongoing landscape-scale burning in the East Fork Kaweah watershed provides a unique opportunity to evaluate fire effects on watersheds at two very different scales: large (ca. 20,000 ha) and small (ca. 100 ha). Additional sites were established in 1995 to meet the needs of fire management when a large project in the East Fork of the Kaweah River (originally called the Mineral King Risk Reduction Project) was funded. This project was initiated to determine whether accelerating the application of prescribed fire across an entire watershed was feasible and to document the costs and effects of such a landscape-scale program. Monitoring of hydrology and hydrochemistry of this entire watershed is intended to provide information that may be applicable to other large watersheds.

Hydrology results will be used to

determine the influence of landscape scale and geomorphology on watershed response to fire. Hydrochemistry results will determine how fire effects the nitrogen and sulfur cycles in small watersheds, and at what spatial and temporal scale are these effects most pronounced (Heard and Stednick 2001, Heard and Stednick 2004, Heard 2005).

### *Fire Regimes*

One of the primary goals of the Sierra Nevada parks' fire management programs is to restore fire as an ecosystem process across the landscape. As a result, park managers need to both understand underlying baseline processes and be able to measure success of the program's efforts at restoring and maintaining this process.

Fire regime can be defined as the interactions–from simple to complex–of a suite of attributes that constitute how fire operates as a process in a particular vegetation type or specific location. Attributes that describe characteristics of a fire regime include: fire return interval (distribution, mean, minimum, maximum), season of occurrence, fire size and pattern, fire type (surface, crown, etc.), fire intensity (quantity of heat produced), and fire severity (level of damage to what is affected by fire).

Important modifiers of these attributes include topographic features such as aspect and elevation, climate, and lag effects of historic biotic events. Taken together, these attributes define fire as a process in a particular location and setting. Ideally, design of a program to monitor restoration and maintenance of fire regimes would include evaluation of all these attributes; however, available information is currently limited by our ability to acquire this knowledge and by associated costs. Due to its landscape-level scope, fire regime monitoring encompasses all fire management activities occurring throughout all areas of the parks, including wildland fires (both fire-use and suppression fires) and prescribed fire.

> Monitoring Goal: Fire regime monitoring provides information to evaluate cumulative accomplishments of a fire management program in restoring and maintaining natural fire regime over time, and across the entire landscape.
>
> Monitoring Objectives: (1) track and evaluate the continued implementation of the restoration of fire into park ecosystems; and (2) determine whether the continued occurrence (maintenance) of fire over the long term, either from natural or human ignition sources, falls within a target range as determined from specific resource objectives.

The Sequoia & Kings Canyon and Yosemite National Parks Fire Ecologists, GIS Specialists, and USGS BRD staffs have worked collaboratively in developing spatial models that allow inventory and monitoring of fire regimes through dendrochronological fire histories, human fire records, vegetation classifications, and other spatial data.

#### Baseline Fire History and Age-Structure Data

The data described below are utilized in the parks' GIS systems to define historic fire regimes for different forest types and landscape areas, and to prioritize areas for future burning.

#### *Devils Postpile*

The SEKI Fire Ecologist is currently conducting a fire history and age structure study in Devils Postpile National Monument using dendro-ecological analysis of tree-ring samples (Caprio in progress,). The information from this study will be used to help formulate a Fire and Fuels Management Plan for the monument.

#### *Sequoia, Kings Canyon and Yosemite*

The Laboratory of Tree-Ring Research at the University of Arizona (Swetnam et al. 1992) conducted fire history studies in giant sequoia groves and later, across elevation transects in mixed-confer forests in Sequoia, Kings Canyon, and Yosemite National Parks (Caprio and Swetnam 1995). This work has provided valuable information about variation in fire frequency over time, seasonality of fires, relationships between fire frequency, severity and climate, and differences in fire frequency across

elevations.

The SEKI Fire Ecologist has built upon Swetnam et al. (Swetnam et al. 1992) baseline fire history data by expanding fire history and age structure research to additional watersheds and sites in the parks. Sampling is designed to answer questions about fire regime attributes such as area burned annually and frequency patterns relating to aspect, vegetation type and elevation.

### *Yosemite*

Yosemite is conducting a project under the Joint Fire Science Program to identify natural reference conditions for mixed conifer forests. From this information, prescribed fire managers can develop goals for both process and structure for the park's program to reintroduce fire to altered forests. The project objectives are to: 1) quantitatively describe pre-settlement, settlement, and fire suppression period regimes; 2) identify how fire regimes vary along major environmental and forest compositional gradients; and 3) identify pre-fire suppression forest characteristics (basal area, density, size structure) at plot and landscape scales.

### *USGS—Western Ecological Research Center Fire Studies in Sierra Nevada Parks*

#### Fire and Fire Surrogate

(Jon Keeley, Eric Knapp and Dylan Schwilke, Sequoia and Kings Canyon Field Station)

The Fire and Fire Surrogate study is a network of 13 long-term sites established nationwide to evaluate the ecosystem impacts of different fire hazard reduction treatment in forests that historically experienced short-interval, low- to moderate-severity fire regimes. Fuel reduction treatments being investigated by USGS researchers at Sequoia National Park are early-season and late-season prescribed fire. USGS is cooperating with National Park Service in this effort (USGS 2004). The experimental design consists of nine plots, with three replications of early-season burn, late-season burn, and control treatments in a completely randomized design. Early season burns were conducted 20 and 27 June 2002; late season burns were conducted 28 September and 17 and 28 October 2001.

Detailed data were collected as follows:

- Vegetation: (1) trees and saplings; (2) shrubs, tree seedlings, and understory species; (3) light environment and gap/patch distribution; (4) seedling demography.
- Fuels and fire: (1) down and dead fuel, duff/litter depth; and (2) fuel moisture and fire behavior.
- Birds and small mammals: (1) diversity, abundance, reproductive success—birds; (2) diversity, abundance, microhabitat—small mammals.
- Soils and forest floor: (1) litter, duff; (2) soil layer macronutrient content; (3) soil biodiversity.
- Invertebrates: (1) bark beetle presence; (2) ground macroarthropod diversity and abundance.
- Pathogens

#### Fire and Invasive Annual Grasses in Western Ecosystems

(Jon Keeley and Tom McGinnis for Kings Canyon National Park; Matt Brooks, Jayne Belnap, and Robert Sanford).

Information from: http://www.werc.usgs.gov/fire/lv/fireandinvasives/index.htm

Annual grasses have invaded a number of shrub and forest ecosystems in western North America and are linked to changes in both ecosystem structure and function. In addition to well documented impacts on native plant diversity, these invasives have the potential for altering fuel structure and fire behavior. Research on ways to prevent invasive annual grass invasions and restore invaded habitats has independently and repeatedly been identified by all land management agencies as a top national research priority.

Study ecosystems include: Great Basin Sagebrush Steppe, Sierra Nevada Yellow Pine Forest and Mojave Desert Scrub.

Objectives:

- Examine interactions between fire, soil, nutrients, and invasive grass productivity over a range of low-nutrient ecosystems currently dominated or threatened by invasive

annual grasses in Western North America

- Find common factors driving the fire/annual grass cycle in these ecosystems with the goal of producing generalizations widely applicable beyond the ecosystems under study
- Investigate and document the process by which invasive plant species are inhibited, stimulated, and/or proliferated by fire
- Determine which ecosystems or vegetation types are most susceptible to invasion following fire
- Observe the effects of treatments by which invasive plants can be controlled

A combination of intensive field experiments, extensive field surveys, laboratory experiments, and seedbank analyses are being used to evaluate the interrelationships between fire, soil, nutrient availability and invasive grass dominance. These three components complement each other and will be used to develop a comprehensive model that relates mechanisms of annual grass invasion after fire to field conditions and potential postfire mitigation techniques.

The Sierra Nevada (Kings Canyon) portion of this study (2001-2003) included the following: Pre-fire sampling of soils and plants, nutrient applications, burns in fall and summer, and post-fire soil and plant sampling and monitoring.

Fire and grazing impacts on plant diversity and alien plant invasions in the southern Sierra Nevada

(Jon Keeley and Daniel Lubin)

Patterns of native and alien plant diversity in response to disturbance were examined along an elevational gradient in blue oak savanna, chaparral, and coniferous forests in the southern Sierra Nevada. Total species richness, alien invasive species richness, and alien invasive cover declined with elevation (scale ranging from 1 to 1000 m2). Community diversity did not inhibit alien invasive invasion in this study.

## AQUATIC MONITORING

For detailed information on monitoring of aquatic resources in and around SIEN, please see Appendix D.

### *Hydrology*

#### *Devils Postpile*

Throughout 1994, the National Park Service and California Department of Fish and Game monitored stream flow along the Middle Fork of the San Joaquin River as part of a fishery and riparian resources assessment project (Rowan et al. 1996). Monitoring (opportunistic) continued for several more years.

#### *Sequoia and Kings Canyon*

There are twelve active gaging stations located in or near the parks' boundary; period of record range from eight to 54 years. The U. S. Geological Survey in conjunction with Southern California Edison, monitors streamflow on the lower Marble, Middle, East and Main Forks of the Kaweah River. The National Park Service and UC Santa Barbara monitor streamflow at eight small, research watersheds located throughout the Kaweah watershed. In addition, water quantity data exist for 24 historic gaging stations; stream flow records range from three to 71 years.

#### *Yosemite*

There are 21 active gaging stations located in or near the parks' boundary.

The site with the longest period of water quality monitoring (1967-present) in the Sierra Nevada Network is the Merced River at Happy Isles, located in upper Yosemite Valley. Happy Isles is maintained by the US Geological Survey as part of the Hydrologic Benchmark Network. Recently, the USGS installed a chemical analyzer that records continuous nitrate plus nitrite concentrations. The Happy Isles watershed area is 46,900 ha and the elevation ranges from 1,224 to 3,997 m. Like most Sierra streams, stream water at Happy Isles is dilute with a low buffering capacity; sp. conductance ranges from 3.0 to 65 uS/cm and alkalinity ranges from 20 to 360 meq/L (Mast and Clow 2000). Mast and Clow (2000) analyzed Happy Isles data set for long-term trends using water quality data from 1968-1995. Using the seasonal Kendall test, they detected statistically significant trends ($\alpha$

= .01) for pH and sulfate concentrations. They attributed the increasing trend in pH to inconsistencies between instruments or personnel through time as opposed to environmental factors. The decrease in sulfate was partially explained by variations in streamflow; however, interpretation was complicated by coinciding changes in analytical methods during the study period. In addition to long-term monitoring data, there have been numerous additional research studies associated with Happy Isles (Hoffman et al. 1976, Clow et al. 1996, Brown and Short 1999).

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

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

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

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

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

See also, vegetation monitoring projects, supra, that include hydrology monitoring.

#### *Water Chemistry*

See Appendix D.

## GEOLOGIC AND PHYSICAL RESOURCES MONITORING

### *Geomorphology*

#### *Yosemite National Park*

In 1989, Mary Ann Madej, Research Geologist, USGS Redwood Field Station, initiated long-term monitoring of the geomorphology of the Merced River and Tenaya Creek in Yosemite Valley. Nineteen cross-sections were established where elevational profiles are measured once every three to five years. Since that time, Yosemite National Park has continued to survey these sites and has increased monitoring to 61 cross-sections (Madej et al. 1994).

### *Cave Resources*

#### *Sequoia and Kings Canyon National Parks*

Sequoia and Kings Canyon National

Parks monitor the number of visitors to Crystal, Hurricane Crawl, Soldiers and Lilburn Caves. Managers monitor visitation using permits, trip reports, and cave registers in order to track and manage underground visits. The Cave Visitation History data set begins in 1962 and continues through present day.

Sequoia and Kings Canyon National Parks and the Sequoia Natural History Association have been monitoring radon concentrations in park caves since 1977. Although radon monitoring data exist for numerous park caves, the majority of the data are from Crystal Cave, which is monitored annually. The Sequoia Natural History Association offers guided tours of the Crystal Cave throughout the summer months. The radon monitoring is conducted to protect their employees' health.

UC Santa Cruz monitored surface and cave temperature and relative humidity from 2000 to 2004. The purpose was to evaluate cave temperatures with a high degree of accuracy over time. Monitoring was conducted in Crystal, Kaweah, Clough, and Palmer caves.

### *Soils*

#### *Sequoia and Kings Canyon National Parks*

The U. S. Geological Survey is monitoring soil nutrient dynamics as a component of the Fire and Fire Surrogate Study. This is a nationwide study evaluating ecosystem impacts of different fuel reduction treatments. USGS researchers at Sequoia National Park are comparing the effects between early season and late season prescribed fire. From 2001 to 2004, USGS researchers in conjunction with Colorado State University are analyzing soil and forest floor samples for carbon and nitrogen content, available nitrogen, soil pH, cation exchange capacity, soil organic matter, calcium, magnesium and potassium content, and soil enzyme activity.

See also, Tharp's and Log soils'research pre- and post-Tharp's burn (Chorover et al. 1994).

## MONITORING CONDUCTED BY OTHER AGENCIES ON ADJACENT LANDS

USFS Sierra Nevada Framework monitoring projects: As of 2005, USFS was in its third year of implementing peer-reviewed monitoring protocols (USFS 2004) on national forest lands Sierra Nevada-wide. The protocols of potential interest to SIEN parks include: amphibians (Yosemite toad and mountain yellow-legged frog), meadows (status and change), forest carnivores, vegetation communities and landscape-level fire mapping and monitoring. Unfortunately, many of the USDA Sierra Nevada Forest Service monitoring projects have lost funding and are no longer being monitored (though some protocols may be useful if they have similar objectives).

From an initial monitoring plan for California Spotted Owl (circa 1995-1996), the Sierra Nevada USDA Forest Service monitoring program began a broader, more strategic approach (circa 1997). In 1997, a Sierran Province Assessment and Monitoring (SPAM) team was formed and began a 5-year planning phase (funding level of $1 million per year). This planning team consisted of 20 biologists. However, as of 2005, many of the individual monitoring programs that were developed (discussed below) have lost funding.

Similar to SIEN's monitoring–planning efforts, SPAM's review and assessment of land management plans on Sierra Nevada forests revealed that not much systematic monitoring was occurring. In addition, no other regional-level ecosystem monitoring programs were in place in other USFS regions.

Over a span of 5 years (through 2001), SPAM worked to create a cost-effective, science-based strategy for monitoring, and developed an Ecosystem Process Model (Manley et al. 2000). Two subsequent initiatives affected this planning endeavor: Sierra Nevada Ecosystem Project (SNEP) completed in 1996 and the Sierra Nevada Framework for Conservation and Collaboration. The SPAM team was commissioned to work on the Framework EIS in 1999.

The Framework identified 5 key "problem" areas that then became the focus of the monitoring team and their planning efforts.

1) Old forest ecosystems
2) Lower westside hardwood forests
3) Fire and fuels
4) Noxious weeds
5) Aquatic, riparian and meadow systems

In 2001, the Sierra Nevada Forest Plan Amendment was completed; a description of monitoring issues, questions and needs is contained therein (www.fs.fed.us/r5/snfpa).In addition, the monitoring team received $3 million. A lead team of 10 biologists, with 60 temporary biologists, prepared 40 "study plans" and used a ranking process to prioritize monitoring topics. Such monitoring "topics" could be considered similar to SIEN's vital signs. However, the monitoring objectives, questions, and metrics–and therefore study design and sampling protocols–could be very different from SIEN parks' needs and objectives.

From these 40 topics, the following seven were implemented (pilot testing) in 2001. Some were never funded, and, as of 2005, several others lost funding (noted in parentheses):

1) Carnivore (main focus on fisher and marten)
2) Amphibians (Yosemite toad, mountain yellow-legged frog)
3) Multi-species
4) Meadows (last year of funding was 2004)
5) Fire and fuels (last year of funding was 2004; some work continuing)
6) Noxious weeds (never funded)
7) Old forest and lower westside hardwoods (last year of funding was 2004)

Two air quality–and one lake chemistry–topics were identified in an additional air quality study plan, but no funding was available until circa 2003:

8) Ozone injury to pines (last year of funding was 2004)
9) Smoke from prescribed burns
10) Lake acidification (from air pollution) (last year of funding was 2004)

Sierra Nevada USFS short-term monitoring goals were to have some (1) "condition" information in 5 years, and (2) "trend" information in 10 years.

SIEN will evaluate USDA Forest Service's monitoring objectives and protocols, for the topics noted above, to see where collaboration is feasible and prudent for those projects still being funded (e.g. amphibians), or to see where protocols can be used or adapted (e.g. meadows) as we embark on protocol development and implementation. In addition, SIEN will investigate the newly-available "Multiple Species Inventory and Monitoring" (MSIM) protocol which has been designed to collect statistically valid information on a wide range of plant and animal species over a broad area and at a minimal cost. The MSIM is apparently a robust monitoring protocol, with repeated sampling, that obtains basic presence and distribution data for a large number of plant and animal species and condition data for their habitats.

USFS Forest Inventory & Assessment and Forest Health Monitoring Plots: These plots, installed throughout the Sierra Nevada (including several in Sequoia, Kings Canyon and Yosemite National Parks), could be of value for a number of potential indicators of interest (forest community species composition and structure, lichens, and ozone effects on vegetation).

USGS Western Ecological Research Center: While most of the research and monitoring done by the USGS Sequoia & Kings Canyon and Yosemite Field Stations is accounted for in the in-park monitoring list above, we want to emphasize that the USGS projects in our parks are an integral part of NPS resource management information and decision-making. The USGS Global Change Research program (including forest demography and other projects), the numerous fire-related research and monitoring projects and the invasive species research projects done by the Sierra Nevada USGS field stations provide valuable information to inform development of additional long-term monitoring.

Focal Species Monitoring (USFS and CDFG): Some of the monitoring efforts of USFS and/or CDFG on focal species or species of concern, such as Sierra bighorn sheep, Peregrine Falcon, neotropical migrants and sensitive plants may be of interest to the Sierra Nevada Network, if adequate protocols are in place and the network chooses to monitor any of these groups of organisms.

Monitoring conducted by outside agencies and organizations (Figure 7)

that currently have the most potential value to the SIEN vital signs monitoring plan are summarized below.

| MONITORING OR STUDY | NOTES |
|---|---|
| **United States Department of Agriculture, U.S. Forest Service—Sierra Nevada Framework** | |
| California Spotted Owl | Response to fuels treatment and habitat modification; demographic studies |
| Pacific fisher and other forest carnivores | Status and change; effects of fire and fuels treatments; habitat relationships; reproduction and mortality |
| Yosemite toad | Direct and indirect effects of various livestock grazing practices; habitat requirements |
| Willow flycatcher | Conservation strategy; management planning |
| meadows | Status and change; distribution of animal species that use meadow ecosystems |
| Kings River project | • small mammals, forest birds, spotted owls;<br>• evaluate response of forests to uneven-aged silviculture and prescribed fire |
| soil productivity | status and change |
| air quality | smoke monitoring; ozone |
| vegetation communities | status of the quantity and quality of conifer and hardwood forest ecosystems and how they are changing over time |
| landscape-level fire mapping | fire size, fire severity |
| amphibians | Yosemite toad and mountain yellow-legged frog |
| **United States Department of Agriculture, U.S. Forest Service Inyo National Forest** | |
| air quality | visibility |
| soil productivity | porosity, cover, organic matter, etc. monitored in a random sample of prescribed burn areas, fuelwood sale areas, site prep areas; compaction is monitored in specified grazing areas |
| Northern goshawk | annual surveys of all known nest sites within areas managed for timber; occupancy and reproductive success |
| Peregrine falcon | implementing USFWS recovery plan; nesting and reproductive success |
| Sierra Nevada and Nelson mountain sheep (with California Department of Fish and Game) | annual counts; habitat evaluations |
| wintering Bald Eagle | implementing USFWS recovery plan |
| pine marten | camera detection techniques to determine species presence |
| mule deer (with California Department of Fish and Game) | annual herd census and demographic assessments |
| songbirds | PRBO Conservation Science (Point Reyes, California) monitors abundance, richness, diversity, breeding status survival, productivity, and parasitism rates in riparian habitats |
| Threatened & Endangered fish (with California Department of Fish and Game) | Owens tui chub, Paiute cutthroat, Lahontan cutthroat trout |
| resident trout | habitat condition |
| riparian vegetation | |
| sensitive plants | population trends |
| floristic analysis of San Joaquin Roadless Area | inventory |
| snags and downed logs | quantity and distribution |
| ecological surveys of Research Natural Areas (Connie Millar, USFS, PSW Research Station) | vegetation mapping, community descriptions, plant and animal species lists, cursory geology and soils, impacts, etc |

**Figure E-7**: Summary of natural resources monitoring conducted outside SIEN park boundaries.

| MONITORING OR STUDY | NOTES |
|---|---|
| Meadow and forest conditions (Connie Millar, USFS, PSW Research Station) | tree invasion in meadows and in shrinking permanent snowfields; periodicity of krummholz whitebark pine vertical leader release; branch length extension in krummholz whitebark pine; quantitative vegetation plots; climate reconstruction and dating of Glass Ck vent; genetic and dendrochronological work on krummholz whitebark pine; dendrochronological work on limber pine |
| **United States Geological Survey** | |
| volcanic parameters for Long Valley Caldera and Mono Craters Region | seismicity, deformation, water-well levels, CO2 gas concentrations and flux rates; geochemistry; hydrology |
| **Sierra Nevada Aquatic Research Laboratory, University of California, Santa Barbara** | |
| ecology of Mono Lake | physical-limnology modeling and monitoring of brine shrimp and alkali fly populations |
| Sierran snowpack | snowpack properties and snowmelt runoff |
| aquatic biology | effects of impacts of livestock grazing on stream ecology and effects of nonnative trout on Sierra Nevada lake ecosystems |
| **White Mountain Research Station, University of California** | |
| | wide range of projects—see Appendix for details |
| **The Nature Conservancy** | |
| | early stages of developing studies and monitoring for an area west of Sequoia |
| **California Department of Fish and Game (The Resources Agency)** | |
| montane meadows | monitoring and predictive modeling for all Sierran meadows |
| mountain lakes and amphibians | |
| Sierra Nevada bighorn sheep/mountain lion | |

**Figure E-7**: Summary of natural resources monitoring conducted outside SIEN park boundaries.

# LITERATURE CITED


Arnett, M., and S. Haultain. 2003. An inventory of the vascular plants of Devils Postpile National Monument. Final report to Sierra Nevada Network Inventory & Monitoring program.

Arnett, M., and S. Haultain. 2004. Vascular plants of Devils Postpile National Monument, Final report to Sierra Nevada Inventory & Monitoring program. National Park Service, Three Rivers, CA.

Beyers, J. L., G. H. Riechers, and P. Temple. 1992. Effects of long-term ozone exposure and drought on the photosynthetic capacity of ponderosa pine (*Pinus ponderosa* Laws.). *New Phytol*. **122**:81-90.

Boiano, D. 2004. Mountain yellow-legged frog restoration project, 2003 field season summary, Sequoia and Kings Canyon National Parks. National Park Service, Three Rivers, CA.

Botti, S. 1977. Status of fish populations in 102 planted lakes. Unpublished report to the National Park Service.

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

Brown, L., and T. Short. 1999. Biological, Habitat, and Water Quality Conditions in the Upper Merced River Drainage, Yosemite National Park, California, 1993-1996. USGS/WRI- 99-4088, U. S. Geological Survey and National Park Service, Sacramento, CA.

Burton, K. M., and D. F. DeSante. 1993. The Monitoring Avian Productivity and Survivorship (MAPS) program third (1993) annual report. Progress report to National Park Service, Sequoia and Kings Canyon National Parks.

Burton, K. M., D. F. DeSante, and O. E. Williams. 1992. The Monitoring Avian Productivity and Survivorship (MAPS) program second (1992) annual report. Progress report to National Park Service, Sequoia and Kings Canyon National Park.

Cahill, T. A., J. J. Carroll, D. Campbbell, and T. E. Gill. 1996. Air Quality. Sierra Nevada Ecosystem Project: final report to Congress UC Davis, Davis, CA.

Caprio, A. C. in progress. Fire history and forest age structure of Devils Postpile National Monument.

Caprio, A. C., and T. W. Swetnam. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. Pages 173-179 *In* J. K. Brown, R. W. Mutch, C. W. Spoon, and R. H. Wakimoto, editors. Proceedings of a Symposium on Fire in Wilderness and Park Management. USDA Forest Service Gen. Tech. Rep. INT-GRT-320.

Carter, J. L. 1997. The interannual distribution and abundance of lotic invertebrates from five habitats of the Merced River in Yosemite Valley, Yosemite National Park, 1992-1995, Menlo Park, CA.

Chorover, J., P. M. Vitousek, D. A. Everson, A. M. Esperanza, and D. Turner. 1994. Solution chemistry profiles of mixed-conifer forests before and after fire. *Biogeochemistry* **26**:115-144.

Clow, D. W., M. A. Mast, and D. H. Campbell. 1996. Controls on surface water chemistry in the upper Merced River basin, Yosemite National Park, California. *Hydrological Processes* **10**:727-746.

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

DeSante, D. F., P. Pyle, and D. R. Kaschube. 2003. The 2002 (ten-year) annual report of the monitoring avian productivity and survivorship (MAPS) program in Yosemite National Park. Institute for Bird Populations, Point Reyes Station, CA.

DiLeo, J., M. Butler, D. R. Cayan, D. W. Clow, M. D. Dettinger, F. Gehrke, S. Hager, J. D. Lundquist, G. McCurdy, D. Peterson, K. Redmond, L. Riddle, R. Smith, and J. W. van Wagtendonk. 2003. Notebook of Hydroclimatology —Sites/Activities. Yosemite National Park, El Portal, CA.

Duriscoe, D. M. 1987. Evaluation of ozone injury to selected tree species in Sequoia and Kings Canyon National Parks, 1985 survey results. Air Quality Division, National Park Service, Denver, CO.

Duriscoe, D. M., and C. S. Duriscoe. 2002. Survey and monitoring of white pine blister rust in Sequoia and Kings Canyon National Parks. Final report on 1995-1999 survey and monitoring plot network. Three Rivers, CA.

Duriscoe, D. M., and K. W. Stolte. 1992. Decreased foliage production and longevity observed in ozone-injured Jeffrey and ponderosa pine in Sequoia National Park, California. Pages 663-680 *In* Tropospheric Ozone and the Environment II: Effects, Modeling and Control. Air and Waste Management Association, Pittsburgh, PA.

Fellers, G. M. 1997. 1997 Aquatic Amphibian Surveys Yosemite National Park. US Geological Survey, Biological Resources Division, Point Reyes National Seashore, Point Reyes, CA.

Fellers, G. M. 1999. Declining amphibians: Yosemite National Park. Final Report, 1999. USGS, Point Reyes National Seashore, CA.

Ferrell, G. M. 1996. The influence of insect pests and pathogens on Sierra forests. Pages 1177-1192 *In* Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University California, Centers for Water and Wildlands Resources, Davis, CA.

Gates, H. R., and S. K. Heath. 2003a. Bird Monitoring, Habitat Assessment and Visitor Education in Montane Meadow and Riparian Habitats of Devils Postpile National Monument. Point Reyes Bird Observatory, Conservation Science, Contribution #1064.

Gates, H. R., and S. K. Heath. 2003b. Bird Monitoring, Habitat Assessment and Visitor Education in Montane Meadow and Riparian Habitats of Devils Postpile National Monument. Point Reyes Bird Observatory. Point Reyes Bird Observatory.

Gerlach, J. D. J., P. E. Moore, B. Johnson, D. G. Roy, D. M. Whitmarsh, D. M. Lubin, D. M. Graber, S. Haultain, A. Pfaff, and J. Keeley. 2003. Alien Plant Species Threat Assessment and Management Prioritization for Sequoia-Kings Canyon and Yosemite National Parks. Open File Report 02-170, U.S. Geological Survey, Carson City, NV.

Goldman, C. R., A. D. Jassby, and S. H. Hackley. 1993. Decadal, interannual and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **50**:1489-1496.

Gould, G. I., and K. M. Norton. 1993. Spotted Owl distribution and abundance in Yosemite National Park, 1988-1989. 1993-3, Nongame Bird and Mammal Section, Department of Fish and Game, CA.

Graber, D. M., S. A. Haultain, J. E. Fessenden, S. D. Veirs, T. J. Stohlgren, and C. M. Schonewald-Cox. 1993. Conducting a biological survey: A case study from Sequoia and Kings Canyon National Parks. Fourth Conference on Research in California's National Parks: National Park Service.

Greene, C. 1995. Habitat requirements of great grey owls in the central Sierra Nevada. University of Michigan.

Grinnell, J., and T. I. Storer. 1924. Animal Life in the Yosemite. An account of the mammals, birds, reptiles, and amphibians in a cross-section of the Sierra Nevada. University of California Press, Berkeley, CA.

Halterman, M. D., and S. A. Laymon. 2000. The effects of Brown-headed Cowbird parasitism on neotropical migrants in Sequoia and Kings Canyon National Parks. Final report National Park Service—Kern River Research Center.

Heard, A., and J. D. Stednick. 2001. The effects of prescribed burning on stream water chemistry at different spatial and temporal scales. *In* A. C. Caprio, editor. Annual fire report 2000: research, inventory and monitoring. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Heard, A., and J. D. Stednick. 2004. Summary of Existing Water Resources Information in Sierra Nevada Network for the Vital Signs Water Quality Monitoring Plan. Colorado State University, Fort Collins, CO.

Heard, A. M. 2005. Effects of landscape scale prescribed fire on hydrology and stream chemistry. MS. Coloradao State University, Fort Collins, CO.

Hoffman, R. J., A. E. Dong, and G. L. Keeter. 1976. Water-Quality Study of a Reach of the Merced River in Yosemite National Park and Vicinity, California–April 1973 Through September 1974. Open-file report 76-326, Geological Survey, Water Resources Div, Menlo Park, CA.

Holmquist, J.G. and J.M. Schmidt-Gengenbach. 2006. Final Report: A pilot study and assessment of the efficacy of invertebrates as indicators of meadow change in Sierra Nevada Network Parks. Report submitted to Inventory and Monitoring in partial fulfillment of: Cooperative Agreement H8R07010001 and Task Agreement J8R07030011. 158pp.

Holmquist, J. G., and J. Schmidt-Gengenbach. 2005. Inventory of Invertebrate Fauna of Devils Postpile National Monument. Unpublished report submitted to National Park Service (Contract R8590030067). White Mountain Research Station, Bishop, CA; Three Rivers, CA.

Holmquist, J.G. 2004. Terrestrial invertebrates: functional roles in ecosystems and utility as vital signs in the Sierra Nevada. Report submitted to Sierra Nevada Network Inventory and Monitoring Program in partial fulfillment of: Cooperative Agreement H8R07010001 and Task Agreement J8R07030011, White Mountain Research Station, University of California, Bishop, CA. 50 pp.

Kaczynski, K. M. 2007. Invasive Species in Wilderness as a Function of Burn Severity: A Case Study in Yosemite National Park, California. Master of Arts. University of Colorado, Boulder, CO.

Kane, J. M., S. K. Heath, and B. Kuhn. 2006. Non-native Vascular Plant Inventory of Riparian Areas in Yosemite National Park, California. PRBO Contribution #1335. PRBO Conservation Science, Petaluma, CA.

Kane, J. M., S.K. Heath, and B. Kuhn. 2006. Non-native vascular plant inventory of riparian areas in Yosemite National Park, California. Final report to Yosemite National Park and Sierra Nevada Network. Point Reyes Bird Observatory Contribution #1335., Petaluma, CA. 51 pp.

Kern, R. A. 1996. A comparative field study of growth and survival of Sierran conifer seedlings. Ph.D. dissertation. Duke University, Durham NC.

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

Knapp, E.E., D.W. Schwilk, J.M. Kane, and J.E. Keeley. 2007. Role of burning season on initial understory vegetation response to prescribed fire in a mixed conifer forest. *Canadian Journal of Forest Research* **37**:11-22.

Knapp, R. A. 2003a. Database: inventory of high-elevation waterbodies in Sequoia and Kings Canyon National Parks.

Knapp, R. A. 2003b. Inventory of high-elevation waterbodies in Sequoia and Kings Canyon National Parks.

Knapp, R. A. 2003c. Yosemite Lakes Survey: 2000-2002. Sierra Nevada Aquatic Research Laboratory.

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

Koshear, J., and B. Lawton. 1993. Fieldwork report and summary of results: bat netting, Sequoia and Kings Canyon National Parks. Report to Sierra Nevada Global Change Research Program, NPS.

Madej, M. A., W. E. Weaver, and D. K. Hagans. 1994. Analysis of Bank Erosion on the Merced River, Yosemite Valley, Yosemite National Park, California, USA. *Environmental Management* **18**:235-250.

Manley, P. N., W. J. Zielinski, C. M. Stuart, J. J. Keane, A. J. Lind, C. Brown, B. L. Plymale, and C. O. Napper. 2000. Monitoring ecosystems in the Sierra Nevada: The conceptual model foundation. *Environmental Monitoring and Assessment* **64**:139-152.

Mast, M. A., and D. W. Clow. 2000. Environmental characteristics and water quality of Hydrologic Benchmark Network stations in the western United States. Circular Report U.S. Geologic Survey.

McGinnis, T.M. 2004. Kern watershed week inventory of 2004. Final report to Sequoia and Kings Canyon National Parks and Sierra Nevada Network. USGS Western Ecological Research Center, Sequoia-Kings Canyon Field Station.

Miller, C., and D. L. Urban. 1999. Forest pattern, fire, and climatic change in the Sierra Nevada. *Ecosystems* **2**:76-87.

Miller, P. R. 1973. Oxidant-induced community change in a mixed-conifer forest. Pages 101-117 *In* J. A. Naegele, editor. Air pollution damage to vegetation, Washington, D.C.

Miller, P. R. 1996. Biological effects of air pollution in the Sierra Nevada. Sierra Nevada Ecosystem Project: final report to Congress, vol.III, Assessments, commissioned reports, and background information. Centers for Water and Wildlands Resources, University of California, Davis, CA.

Moore, P., A. E. L. Colwell, and C. L. Coulter. 2005. Special Status Vascular Plant Surveys and Habitat Modeling in Yosemite National Park. Unpublished report submitted to National Park Service, Intra-agency Agreement number F88000-02-001. U.S. Geological Survey, Western Ecological Research Center, Yosemite Field Station, Sacramento, CA.

Moore, P. E., D. N. Cole, J. W. Van Wagtendonk, M. P. McClaren, and N. K. McDougald. 2000. Meadow response to pack stock grazing in Yosemite wilderness: integrating research and management. USDA Forest Service Proceedings RMRS-P-15, Vol.5, pps 160-163, Fort Collins, CO.

Moore, P. E., and J. D. Gerlach. 2001. Exotic species threat assessment in Sequoia, Kings Canyon, and Yosemite national parks. D. Harmon. Crossing Boundaries in Park Management: 11th Conference on Reseach and Resource Management in Parks and on Public Land.

Moritsch, B., and M. Goldin-Rose. 2006. Prioritization Workshop: Invasive Alien Plant Monitoring. Inventory & Monitoring Program, Sierra Nevada Network, Three Rivers, CA.

Moritz, C. J.L. Patton, A. Leach, and A. Rush. 2009. A re-survey of the historic Grinnell-Storer vertebrate transect through Yosemite National Park, California. Final Report to Yosemite National Park and Sierra Nevada Network. Museum of Vertebrate Zoology, University of California, Berkeley, CA.

Moritz, C. 2007. A Re-survey of the Historic Grinnell-Storer Vertebrate Transect in Yosemite National Park, California. Unpublished Report submitted to Sierra Nevada Network Inventory & Monitoring Program, Three Rivers, CA. Museum of Vertebrate Zoology, Berkeley, CA.

Mutch, L. S. 1990. Giant sequoia cambial phenology. Progress report to Sequoia and Kings Canyon National Parks Research Office.

Mutch, L. S., and D. J. Parsons. 1998. Mixed conifer forest mortality and establishment before and after prescribed fire in Sequoia National Park, California. *Forest Science*, **44**:341-355.

National Park Service. 1999. Reference A: Reference Manual 83, Drinking Water.

National Park Service. 2003. Fire and fuels management plan. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2004a. Fire and Fuels Management Plan. Yosemite National Park.

National Park Service. 2004b. Yosemite Fire Management Plan and Environmental Impact Statement. Yosemite National Park.

National Park Service, U. S. D. o. I. 2001. Fire Monitoring Handbook. http://www.nps.gov/fire/fmh/FEMHandbook.pdf. Date Accessed: July, 2004.

Parsons, D. J., A. C. Workinger, and A. M. Esperanza. 1992. Composition, structure and physical and pathological characteristics of nine forest stands in Sequoia National Park. Tech. Rep. NPS/WRUC/NRTR-92/50, USDI National Park Service, Western National Park Studies Unit, University of California, Davis, CA.

Patterson, M. T., and P. W. Rundel. 1989. Seasonal physiological responses of ozone stressed Jeffrey pine in Sequoia National Park. Pages 419-428 *In* R. K. Olson and A. S. Lefohn, editors. Transactions: Effects of Air Pollution on Western Forests, Anaheim, CA. Air & Waste Management Association, Pittsburgh, PA.

Patton, J. L. 2006. Draft report: The Grinnel resurvey project, Yosemite National Park. Museum of Vertebrate Zoology and Dept. of Integrative Biology, University of California, Berkeley, CA.

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. Springer-Verlag, NY.

Peterson, D. L., A. M.J., and R. L.J. 1989. Ozone injury and growth trends of ponderosa pine in the Sierra Nevada. *In* R. K. Olson and A. S. Lefohn, editors. Transactions: Effects of Air Pollution on Western Forests, Anaheim, CA. Air & Waste Management Association, Pittsburgh, PA.

Peterson, D. L., M.J. Arbaugh, L.J. Robinson. 1991. Regional growth changes in ozone-stressed ponderosa pine (*Pinus ponderosa*) in the Sierra Nevada, California, USA. *The Holocene* 1:50-61.

Pierson, E. D., and P. A. Heady. 1996. Bat surveys: Giant Forest Village and vicinity, Sequoia National Park. Final report to National Park Service.

Pierson, E. D., and W. E. Rainey. 2002. Preliminary surveys for bat species at Devils Postpile National Monument. Progress report to Sierra Nevada Network Inventory & Monitoring Program National Park Service.

Pierson, E. D., and W. E. Rainey. 2003. Inventory of bat species in Kings Canyon and Sequoia National Parks. Report on 2002 surveys to Sierra Nevada Network Inventory and Monitoring Program, Berkely, CA.

Pierson, E. D., W. E. Rainey, and C. J. Corben. 2001. Seasonal patterns of bat distribution along an altitudinal gradient in the Sierra Nevada. Report to California State University at Sacramento Foundation, Yosemite Association and Yosemite Fund.

Pyle, P., D. R. Kaschube, R. B. Siegel, and D. F. DeSante. 2006. The 2005 Annual Report of the Monitoring Avian Productivity and Survivorship (MAPS) Program in Yosemite National Park The Institute for Bird Populations, Point Reyes Station, CA.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Field Methods for Monitoring Landbirds. USDA Forest Service Publication, Albany, CA.

Rowan, D. E., S. C. Parmenter, and W. W. Eckhardt. 1996. Fishery and riparian resources of Devils Postpile National Monument and surrounding waters. National Park Service.

Sadinski, W., M. Wilson, and J. Cleaver. 2002. Environmental factors impacting Yosemite toads in Yosemite National Park. Ecological Society of America, Tucson, AZ.

San Francisco Public Utilities Commission. 1999. 1999 annual sanitary survey update report for the Hetch Hetchy water supply. San Francisco Public Utilities Commission, Water Quality Bureau, Engineering Section, San Francisco, CA.

San Francisco Water Team, and CH2M HILL Inc. 1995. Final Sanitary Survey for the Hetch Hetchy Water Supply Project. San Francisco Water Team; CH2M HILL, Inc.

Schroeter, R. E., and J. M. Harrington. 1995. Benthic Macroinvertebrate Community Assessment of the Middle Fork San Joaquin River, Madera County, California. California Department of Fish and Game, Water Pollution Control Laboratory, Rancho Cordova, CA.

Schwilk, D.W., E.E. Knapp, S.M. Ferrenberg, J.E. Keeley, and A.C. Caprio. 2006. Tree mortality from fire and bark beetles following early and late season prescribed fires in a Sierra Nevada mixed-conifer forest. *Forest Ecology and Mangement* **232**:36-75.

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* **48**:1885-1892.

Siegel, R.B. and R.L. Wilkerson. 2005. Landbird inventory for Sequoia and Kings Canyon National Parks (2003-2004). 237 pp. Final report to Sequoia and Kings Canyon National Parks. Cooperative Agreement H9471011196. The Institute for Bird Populations, Point Reyes Station, CA.

Siegel, R. B. and R. L. Wilkerson. 2004a. Landbird inventory for Devils Postpile National Monument. The Institute for Bird Populations, Pt. Reyes Station, CA.

Siegel, R. B., and D. F. DeSante. 1999. The Draft Avian Conservation Plan for the Sierra Nevada Bioregion: conservation priorities and strategies for safeguarding Sierra bird populations. Institute for Bird Populations Report to California Partners in Flight. Version 1.0.

Siegel, R. B., and R. L. Wilkerson. 2004a. Landbird inventory for Devils Postpile National Monument. The Institute for Bird Populations, Pt. Reyes Station, CA.

Siegel, R. B., and R. L. Wilkerson. 2004b. Landbird inventory for Sequoia and Kings Canyon National Parks: First Annual Report., The Institute for Bird Populations, Pt. Reyes Station, CA.

Skiff, S. L. 1995. Winter ecology of great grey owls (*Strix nebulosa*) in Yosemite National Park, California. M.S. Thesis. UC Davis. University of California, Davis, CA.

Sparling, D. W., and D. Cowman. 2003. Amphibians and Pesitcides in Pristine Areas. In G. Linder and et al., editors. Amphibian Decline: An Integrated Analysis of Multiple Stressor Effects. Society of Environmental Toxicology and Chemistry.

Stephenson, N. L., and D. J. Parsons. 1993. A research program to predict the effects of climatic change on the Sierra Nevada. S. D. Veirs, T. J. Stohlgren, and C. Schonewald-Cox. Proceedings 4th conference on research in California's National Parks, Washington, D.C.

Stephenson, N. L., D. L. Peterson, C. D. Allen, D. McKenzie, J. S. Baron, D. B. Fagre, and J. Keeley. 2004. Response of western mountain ecosystems to climatic variability and change: The Western Mountain Initiative. Competitive grant. USGS-BRD Global Change Research Program.

Stephenson, N. L., and P. J. van Mantgem. 2005. Forest turnover rates follow global and regional patterns of productivity. *Ecology Letters* **8**:524-531.

Swetnam, T. W., C. H. Baisan, A. C. Caprio, R. Touchan, and P. M. Brown. 1992. Tree-ring reconstruction of giant sequoia fire regimes. Final report to Sequoia, Kings Canyon and Yosemite National Parks Coop. Agreement No. DOI 8018-1-0002, University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ.

Thompson, S. C., and K. E. McCurdy. 1995. Black bear management in Yosemite National Park: More a people management problem. J. E. Auger and H. L. Black. Proceedings to the Fifth Western Black Bear Workshop, Provo, UT.

U.S. Geological Survey. 2004. Fire and Fire Surrogate Study:Sequoia National Park Site. http://www.werc.usgs.gov/fire/seki/ffs/

van Mantgem, P.J. and N.L. Stephenson. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. *Ecology Letters* **10**: 909-916.

van Mantgem, P. J., N. L. Stephenson, L. S. Mutch, V. G. Johnson, A. M. Esperanza, and D. J. Parsons. 2003. Growth rate predicts mortality of Abies concolor in both burned and unburned stands. *Canadian Journal of Forest Research* **33**:1029-1038.

Wake, D., and V. Vredenburg. 2002. Findings from causdate amphibian surveys in Kings Canyon, Sequoia and Yosemite National Parks. Final report to Sierra Nevada Network Inventory and Monitoring Program.

Wehausen, J. D. 1980. Sierra Nevada bighorn sheep: History and population ecology. Ph. D. thesis. University of Michigan, Ann Arbor, MI.

Werner, H. 1995-1998. Small mammal monitoring in East Fork prescribed burns. Annual reports.

Werner, H. W. 2004. Vertebrate survey for Sequoia and Kings Canyon National Parks and Devils Postpile National Monument. Final report to Sierra Nevada Inventory and Monitoring Program.

Winter, J. 1985. Great gray owl survey. Unpublished progress report Project W-65-R-2(554), State of California, The Resources Agency, Department of Fish and Game.

Yosemite Bear Council. 2002. Human-bear management plan. Unpublished report submitted to superintendent, Yosemite National Park, CA Yosemite National Park.

Yosemite National Park. 2004. Visitor Experience and Resource Protection Program, 2004 annual report Merced River monitoring. National Park Service, El Portal, CA.

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix F: Ecosystem Conceptual Models*

**Natural Resource Report NPS/SIEN/NRR—2008/072**

Linda Mutch[1], Meryl Goldin Rose[1], Andi Heard[1], Don Schweizer[1], Scott Martens[2], Harold Werner[3], Sarah Stock[4], Kristen Kaczynski[5], Tony Caprio[3], Sylvia Haultain[3], Jan van Wagtendonk[6], Peter Rowlands[3], Steve Thompson[4], and Lara Rachowicz[4]

[1] Sierra Nevada Network Inventory & Monitoring Program
Devils Postpile National Monument,
Sequoia & Kings Canyon and Yosemite National Parks

[2] Sierra Science Consulting, Three Rivers, CA

[3] Division of Natural Resources,
Sequoia and Kings Canyon National Parks, Three Rivers, CA

[4] Resources Management & Science Division, Yosemite National Park, El Portal, CA

[5] University of Colorado, Boulder, CO

[6] US Geological Survey, Western Ecological Research Center,
Yosemite Field Station, El Portal, CA

Layout and design Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Mutch, L., Goldin Rose, M., A. Heard, D. Schweizer, S. Martens, H. Werner, S. Stock, K. Kaczynski, T. Caprio, S. Haultain, J. van Wagtendonk, P. Rowlands, S. Thompson, and L. Rachowicz. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix F. Ecosystem conceptual models. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Contents


Table of Contents ..... 177
List of Figures ..... 179
List of Tables ..... 180
Introduction: Ecosystem Conceptual Models ..... 181
Purpose and Objectives ..... 181
Approach to Conceptual Model Development ..... 181
Future Development and Applications of Models ..... 182
I. Overview Models ..... 183
Overview Model: Sierra Nevada Ecosystems ..... 187
Overview Model: Sierra Nevada Stressors ..... 184
Climate Change ..... 185
Altered Fire Regimes ..... 187
Non-native Invasive Species ..... 188
Air Pollution: Air Contaminants and Atmospheric Deposition ..... 189
Habitat Fragmentation and Human Use ..... 191
Additional Resources Management Issues in SIEN Parks ..... 192
Overview Model: Landscape Exchange ..... 192
Overview Model: Landscape Dynamics ..... 194
Introduction ..... 194
Drivers, System Components, Functions ..... 195
Stressors ..... 198
Vital Signs ..... 200
II. Models: Systems, Processes, and Populations ..... 202
Introduction ..... 202
Model: Atmospheric System ..... 203
Introduction ..... 203
Drivers, System Components, Functions ..... 203
Stressors ..... 207
Vital Signs ..... 209
*Sub-Model*: Nitrogen Deposition ..... 209
Introduction ..... 209
Drivers, System Components, Functions ..... 209
Nitrogen: A Stressor ..... 210
Vital Sign ..... 211
Model: Hydrologic System ..... 211
Introduction ..... 211
Drivers, System Components, Functions ..... 211
Stressors ..... 213
Vital Signs ..... 213
Model: Aquatic Systems ..... 213
Introduction ..... 213
Model: Lake System ..... 213
Drivers, System Components, Functions—Lake Model ..... 214

*Sub-Model:* Anuran Populations ..... 216
Introduction ..... 216
Status of Anuran Populations ..... 216
Stressors ..... 217
Model: River & Stream System ..... 218
Drivers, System Components, Functions—River & Stream Model ..... 219
Aquatic System Stressors: Lakes, Rivers & Streams ..... 221
Vital Signs—Lakes ..... 224
Vital Signs: Rivers & Streams ..... 224
Model: Wetlands ..... 225
Introduction ..... 225
Drivers, System Components, Functions ..... 226
Stressors ..... 228
Vital Signs ..... 229
*Sub-Model:* Invertebrates ..... 229
Introduction ..... 229
Drivers, Functions ..... 230
Stressors ..... 230
Model: Forest System ..... 230
Introduction ..... 230
Drivers, System Components, Function ..... 230
Stressors ..... 232
Vital Sign ..... 234
Model: Fire Regimes ..... 235
Introduction ..... 235
Climate—A Driver & Stressor ..... 235
Stressors ..... 236
Fire Regime Attributes ..... 238
Vital Sign ..... 240
Model: Non-native Invasive Plant Populations ..... 241
Introduction ..... 241
Status of Non-native Plants in Network Parks ..... 242
Stressors ..... 243
Vital Sign ..... 244
*Sub-Model:* Non-native Plant Populations—Invasion Susceptibility ..... 244
Introduction ..... 244
Invasibility of a Community ..... 245
Model: Bird Populations ..... 248
Introduction ..... 248
Status of Bird Populations ..... 248
Stressors ..... 248
Vital Sign ..... 249
Literature Cited ..... 251

## List of Figures

Figure F–1. Generalization model for Sierra Nevada ecosystems ..... 183
Figure F–2. Sierra Nevada stressors and associative, or synergistic, effects ..... 185
Figure F–3. Air flow patterns in the San Joaquin Valley. ..... 189
Figure F–4. Major inputs and exchange of energy ..... 194
Figure F–5. Landscape dynamics model for the Sierra Nevada ..... 196
Figure F–6. The structure of a landscape ..... 197
Figure F–7. Repeat photos of Middle Fork of the Kaweah River, Sequoia National Park ..... 201
Figure F–8. Repeat photos of Dana Glacier, Yosemite National Park ..... 202
Figure F–9. Atmospheric system conceptual diagram for Sierra Nevada. ..... 205
Figure F–10. The approximate distribution of forest types in southern Sierra Nevada ..... 207
Figure F–11. Relationship of nitrogen deposition to other ecosystem processes ..... 210
Figure F–12. Hydrologic system model for the Sierra Nevada. ..... 211
Figure F–13. Sierra Nevada Lake Conceptual Diagram. ..... 214
Figure F–14. Main interactions of anuran (frog and toad) populations and stressors ..... 217
Figure F–15. Yosemite Valley campground during flooding event. ..... 218
Figure F–16. Representative mean annual hydrograph from the Merced River ..... 219
Figure F–17. Sierra Nevada river and stream conceptual diagram. ..... 220
Figure F–18. Wetland system conceptual diagram ..... 225
Figure F–19. Main interactions of invertebrate populations and stressors. ..... 228
Figure F–20. The approximate distribution of forest types in southern Sierra Nevada ..... 231
Figure F–21. White Fir–Mixed Conifer Forest Model. ..... 233
Figure F–22. The distribution of general vegetation types ..... 235
Figure F–23. Fire regime attributes and selected ecosystem properties influenced by fire ..... 236
Figure F–24. Fire regime effects on white fir-mixed conifer forest ..... 238
Figure F–25. Relationship between fire frequency and elevation ..... 239
Figure F–26. Non-native Invasive Plant population conceptual diagram ..... 241
Figure F–27. Community invasibility ..... 245
Figure F–28. Resource availability and windows of invasibility ..... 247
Figure F–29. Conceptual diagram of invasibility. ..... 247
Figure F–30. Bird populations conceptual diagram ..... 250

## List of Tables

Table F–1. Conceptual models included within this Appendix ..... 182
Table F–2. Definition of SIEN ecosystem model "interactive controls" ..... 184
Table F–3. Listing of stressors and documented resources management issues ..... 192
Table F–4. Conceptual models (narratives and conceptual diagrams..... 204
Table F–5. Factors that result in changes in resource availability ..... 246

# Introduction: Ecosystem Conceptual Models

This appendix presents the following information for the Sierra Nevada Network (SIEN) conceptual ecosystem models:

1. Purpose and goals of conceptual models
2. SIEN approach to model development
3. SIEN overview, system, process, and population models—encompassing Network vital signs

Conceptual models are working hypotheses about system form and function: they depict essential attributes of a system, express ideas about important components and processes, document assumptions, identify gaps in knowledge, and evolve to capture an increasing understanding of the system (Manley et al. 2000). Conceptual model development has been identified as a key component of a scientifically based monitoring plan (National Research Council 1995, Noon et al. 1999, National Park Service 2006). Conceptual models help in the design and interpretation of long-term monitoring by identifying important biotic and environmental features and processes, providing insight into potential cause-and-effect relationships, and establishing standard formats and concepts for communication of complex ideas (Roman and Barrett 1999). Conceptual models serve as communication tools among scientists from different disciplines, between scientists and managers, and between managers and the public.

Conceptual models can take the form of any combination of narratives, tables, matrices of factors, box-and-arrow diagrams, or conceptual diagrams. Jorgensen (1988) discusses 10 kinds of models and evaluates their advantages and disadvantages. We use a combination of these forms as a means to summarize and illustrate large quantities of information.

## Purpose and Objectives

Conceptual models have served the following objectives in development of our monitoring program:

- Formalized current understanding of ecosystem structure and function as well as relationships among ecosystem components at various levels of organization (landscape, community, watershed, population)
- Highlighted effects of important drivers and stressors on park resources and ecosystem processes
- Identified and articulated relationships among ecosystem attributes of interest and vital signs (indicators)
- Allowed for a shared vision to be created: facilitate communication among participants in the iterative process of vital signs identification, prioritization, selection, and protocol development
- Useful for integration and application––identify gaps, establish priorities, and solicit an agreed syntheses

As the Network progresses toward implementation of vital signs monitoring, the models will inform our thinking about sample design, facilitate integration and synthesis of data, and serve as communication tools about the program (Gross 2005). We hope that future models will assist us in communicating connections between management decisions and information gained from monitoring, such as identification of threshold conditions that could trigger a management action.

## Approach to Conceptual Model Development

Development of models for the Sierra Nevada Network (SIEN) began with the Science Committee, during planning of Phases I and II of vital signs monitoring. Park, USGS and Network staff worked with a contractor to develop draft models that illustrated current understanding of key interactions among proposed vital signs and other ecosystem components and processes. These models helped inform vital signs prioritization processes, and, subsequently, the Science Committee's selection of a subset of vital signs for protocol development.

As we have progressed through Phases I, II and III of vital signs' monitoring planning, we have worked to organize–

what were initially disparate models–into a hierarchical framework, to standardize the format of systems models, and to learn from the approaches of other networks with similar ecosystems, ecosystem stressors, or monitoring interests (especially Rocky Mountain Network, Northern and Southern Colorado Plateau Networks, Mojave Network, and North Coast/Cascades Network).

We follow hierarchy theory, which provides a context for conceptualizing a complex system as a set of less complex sub-models spanning a range of scales and ecological levels (Allen and Hoekstra 1992). Our model framework (Table F- 1) is organized into:

1. Overview models: Our overview models provide context at broad spatial or temporal scales for Sierra Nevada ecosystem drivers, stressors, processes, and components.
2. System models: Our system models describe focal systems of interest for vital signs monitoring, and illustrate the core drivers, system components and functions, and major stressors influencing these systems.
3. Detailed (process, population) models: Our detailed models explain key processes (e.g., fire regimes, nitrogen deposition) or organisms (e.g., invertebrates, anurans, non-native invasive plants, birds), illustrating relationships among system components and functions, drivers, and stressors.

**Table F–1.** Conceptual models included within this Appendix. Models are dynamic; as new relationships are elucidated, our models will evolve. Further, new models may be developed and included as part of our monitoring protocol development process.

| | MODEL | LOCATION |
|---|---|---|
| Overview | Sierra Nevada Ecosystems | Chapter 2 and *Within* |
| | Sierra Nevada Stressors | Chapter 1 and *Within* |
| | Landscape Exchange | Chapter 2 and *Within* |
| | Landscape Dynamics | *Within* |
| System, Process, Population | Atmospheric System<br>Nitrogen Deposition | *Within* |
| | Hydrologic System | *Within* |
| | Aquatic System<br>Lakes<br>Amphibians<br>Rivers and Streams | *Within* |
| | Wetland System<br>Invertebrates | *Within* |
| | Forest System<br>Fire Regimens | *Within* |
| | Non-native Invasive Plant Populations<br>Invasion Susceptibility | *Within* |
| | Bird Populations | *Within* |

## Future Development and Applications of Models

As protocols are developed and implemented, the models can correspondingly evolve to capture an increasing understanding of the system. Monitoring results will be analyzed and interpreted, and resultant information will be shared with a variety of audiences. The Sierra Nevada Network may further develop conceptual models: for the following purposes:

- Outreach & Communication: Attractive, simple pictorial models that explain focal systems and relationships of components and drivers for interpretive applications, general audiences, web pages, etc.
- Information Interpretion & Gap Identification: complete models that elaborate more detailed relationships among components and drivers, capture and incorporate improved understanding from on-going research and monitoring projects, and identify specific gaps in understanding in various systems.
- Prediction: Predictive models that use actual data to identify areas most sensitive to climatic change, most vulnerable to non-native plant invasions, or most affected by nitrogen deposition and ozone pollution.
- Simulation and analysis: Mathematical, statistical, or null models that predict patterns of species diversity, niche overlap, and species co-occurrence. Some networks in the NPS are beginning to use modeling simulation programs such as EcoSim (Gotelli and Entsminger 2006).

The Network will need to consider modeling capability in its development of university partnerships and long-term network staffing, as conceptual and predictive modeling will be an integral

part of monitoring program development, data analysis and interpretation, and communication and outreach.

## I. Overview Models

Below, we present four overview models to: (1) highlight ecosystem factors that interact with processes to structure the physical environment and its biotic communities, (2) depict stressors and synergistic effects, (3) illustrate inputs and outputs (i.e., exchanges of materials and organisms) that affect Sierra Nevada landscapes, and (4) highlight interactions of core drivers, stressors, and system components, as they apply to Sierran landscapes.

### Overview Model: Sierra Nevada Ecosystems

SIEN has modified a general ecosystem model from Jenny (Jenny 1941) and Chapin et al. (Chapin et al. 1996) to serve as a foundation for our other models. This model (Figure F–1) presents ecosystem processes as a function of hierarchical state factors and interactive controls.

State factors operate at the largest (broadest) scales and include global climate, continental- and regional-scale topography, parent material (e.g., geologic substrate), time (e.g., age of the system), and the types and distributions of organisms within a landscape. Interactive controls–such as local climate patterns, soil function and development, and the type and distribution of organisms–both control and respond to ecosystem characteristics, and are constrained by state factors (Chapin et al. 1996, Dale et al. 2000). However, we modify the Jenny-Chapin model components in several ways to better represent Sierra Nevada park systems by:

- Adding "anthropogenic change" as another state factor that affects (a) most other state factors at a regional to global scale, and (b) affects the local interactive controls (please refer to Chapter 1 for a discussion of the major stressors associated with anthropogenic change in the Sierra Nevada).
- Adding "ecosystem processes" as an interactive control.

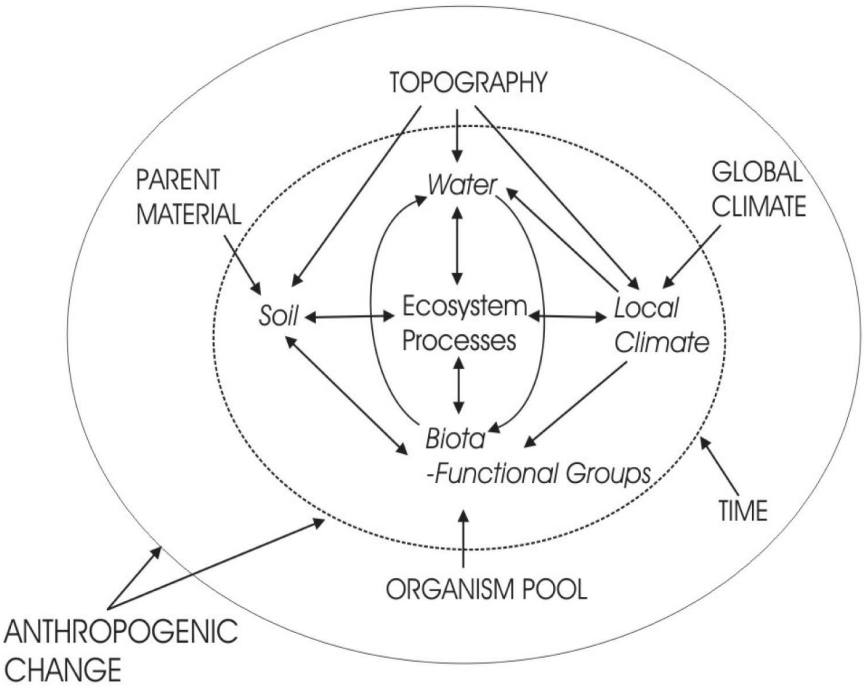



**Figure F–1**. Generalization model for Sierra Nevada ecosystems depicting the relationship among state factors, interactive controls, and ecosystem processes. See text for explanation. State factors are capitalized, interactive controls are italicized, the region (here=Network) is represented by the inner dotted-circle, and the Earth is represented by the solid circle.

- Omitting "disturbance regime" as an interactive control; instead, we place fire and flood disturbance regimes under "ecosystem processes" (we see these primarily as climate-driven processes of change that should not be considered separately from other ecosystem processes).
- Making "water" explicit as an interactive control to emphasize its critical role as a limited–and limiting–resource in our Mediterranean climate regime.

Table F–2 provides an overview of the functions and characteristics of interactive controls and ecosystem processes.

**Table F–2.** Definition of SIEN ecosystem model "interactive controls" and their characteristics and function. Definitions primarily from (Chapin et al. 1996).

| SIEN INTERACTIVE CONTROLS | CHARACTERISTICS AND FUNCTIONS OF INTERACTIVE CONTROLS |
|---|---|
| **Climate** strongly governs structure, productivity, and biogeochemistry of ecosystems | • Mediterranean: dry summers/wet winters<br>• Affects dynamics of ecosystem processes, distribution of organisms, water availability |
| **Soil** resource supply determines maximum productivity and structural diversity of vegetation | • Characterized by physical structure and chemistry<br>• Functions include nutrient cycling and availability, water availability and loss, microorganism habitat<br>• Soil type and depth affect vegetation distribution |
| Water is a limiting resource in Mediterranean climate regimes; driver of productivity, abundance, and growth form | • Surface water, snowpack, soil & ground water<br>• Characterized by temporal flow cycles, water quality; provides habitat for aquatic organisms and is driver for distribution of terrestrial organisms |
| **Biota (i.e., functional groups)** are groups of species that have similar effects on ecosystem processes | • Ecosystem productivity, nutrient cycling, carbon fixation, evapotranspiration, herbivory, predation, decomposition, pollination, biodiversity |
| **Ecosystem Processes** are flows of energy and materials in an ecosystem; climate-driven processes of change | • Climate-driven processes: fire, flood, avalanche<br>• Biogeochemical cycling, plant productivity, erosion, weathering, population dynamics |

## Overview Model: Sierra Nevada Stressors

Network park managers and researchers, using well-considered professional judgment, a substantial supporting body of research, and findings from the Sierra Nevada Ecosystem Project (SNEP 1996, Sequoia And Kings Canyon National Parks 1999b), have identified five important systemic stressors posing the greatest threat to Sierra Nevada Network parks. To reiterate and elaborate here, five systemic stressors currently pose the greatest threat to Sierra Nevada Network parks:

1. Rapid anthropogenic climate change
2. Altered fire regimes
3. Non-native invasive species
4. Air pollution
5. Habitat fragmentation and human use

Of these, rapid anthropogenic climatic change may have the greatest potential to affect ecosystems, in part because of its pervasiveness and extent across ecosystems, as well as synergistic effects with other stressors (Figure F- 2).

Conversely, localized stressors (e.g., vegetation trampling by livestock or park visitors, small dams and diversions, and mines) generally affect small areas of Sierra Nevada Network parks, although they might threaten special-status species or alter rare habitats. These localized stressors and resource issues are discussed below.

The effects of the above systemic stressors on ecosystem biota and processes strongly influenced our selection of Network vital signs, indicators, and measures (see Chapter 3).

We characterize drivers as major external driving forces having large-scale influences on natural systems; drivers can be natural or anthropogenic Network drivers include: atmospheric system, fire regime, and geology and topography (conceptual models, below). We characterize *anthropogenic* drivers as stressors.

> Stressors are defined as physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems.

Non-native invasive species (plants and animals, including pathogens) can severely alter plant community composition and structure, competition and predation, native plant and animal diversity, fire regime, and soil water dynamics.

Air pollution affects water and soil chemistry, forest population dynamics (e.g., reduced vigor), plant community composition, and may affect wildlife (e.g., endocrine disruption of amphibians). In addition, it may favor non-native plants through nitrogen deposition, and affects fuel availability for fire by affecting plant productivity.

Finally, human use and park fragmentation typically results in: habitat loss, altered fire regime, diversion of water, disruption to wildlife, increases in non-native species invasions and may degrade wilderness values (e.g., dark night sky, natural soundscape).

### *Climate Change*

Climate change may have the greatest potential to affect ecosystems in part because it helps generate associative or synergistic effects which couple with other stressors, particularly—altered fire regime, air pollution, and non-native invasive plants. Climate change can affect critical ecosystem components and processes, including: entire forests and other plant communities; phenology of plants and animals; ranges of disease vectors; precipitation amounts, type and timing of natural events; snowpack; surface water dynamics; and hydrologic processes. Anthropogenic climate change might soon influence all other stressors and become the predominant stressor.

Average global temperatures have been rising, and the earth's atmosphere is warmer than at any point during the last several centuries (Mann et al. 1998). The present $CO_2$ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years; the current rate of increase is unprecedented during at least the last 20,000 years. About three-quarters of anthropogenic emission of $CO_2$ to the atmosphere is due to fossil fuel burning; the rest is predominantly due to land-use change, especially deforestation (IPPC 2001, IPCC 2007).

There is broad international consensus among climatologists and atmospheric

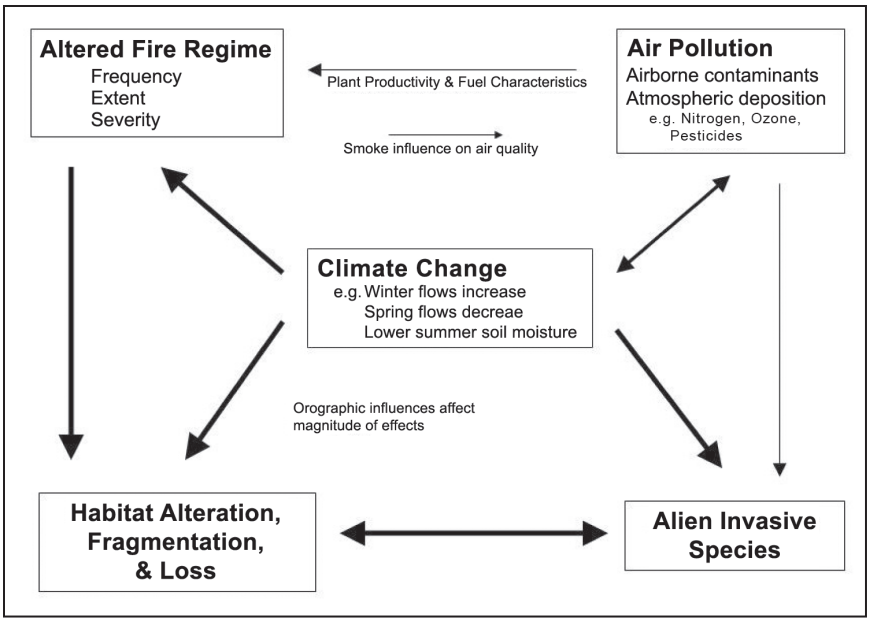



**Figure F–2.** Sierra Nevada stressors and associative, or synergistic, effects.

scientists that "most of the observed warming over the last 50 years is likely [attributable to a human-induced] increase in greenhouse gas [e.g., CO2, from the burning of fossil fuel] concentrations" (Houghton et al. 2001). Global temperatures (and globally-averaged surface temperatures) are projected to increase another 1.4 to 5.8° C (2.5 to 10.4° F) over the next century—a rate probably unprecedented over the last 10,000 years (Houghton et al. 2001). This is expected to have profound effects on weather and climate.

The last several decades in the Sierra Nevada were among the warmest of the last millennium (Graumlich 1993). Recent simulations of climate change models suggest that by the years 2050 to 2100, average annual temperature in the Sierra Nevada could increase by as much as 3.8° C (6.8° F) (Snyder et al. 2002)—the equivalent of about an 800 m upward displacement in climatic zones. Average temperatures in May could increase by 9° C (16.2° F).

Paleoecological records show the early and middle Holocene (ca. 10,000 to 4,500 years ago) was a period of generally higher global summer temperatures, perhaps as much as 2° C (3.6° F) and prolonged summer drought in California. During this period, fire regimes and plant community composition of

Sierra Nevada forests differed from those of today (including some species combinations that no longer exist) (Anderson 1990, Anderson and Smith 1991, Anderson 1994, Anderson and Smith 1994, 1997). Although the past is an imperfect analog of the future, these and other paleo-ecological records indicate climatic change smaller than, or comparable to, those projected for the next century could profoundly alter Sierra Nevada ecosystems.

Phenological studies indicated that in much of the West, lilacs and honeysuckles are responding to the warming trend by blooming and leafing out earlier (Cayan et al. 2001).

Human-influenced temperature patterns are significantly associated with discernible changes in plant and animal (invertebrate, bird, amphibian, tree, shrub) phenological traits (Root et al. 2005).

Researchers predict that even a relatively modest 2.5° C (4.5° F) mean temperature increase would significantly alter precipitation, snow pack, surface water dynamics (e.g., flow), and hydrologic processes in the Sierra Nevada. The most pronounced changes would probably be earlier snowmelt runoff and reduced summer base flows and soil moisture (Dettinger et al. 2004, Dettinger 2005), a lower snowpack volume at midelevations (Knowles and Cayan 2001), and increased winter and spring flooding (Dettinger et al. 2004). Two climate models predict significant reductions in Sierra Nevada snowpack by the year 2100: one model predicts 30–70% reduction, the other a 73–90% reduction (Hayhoe et al. 2004).

Flows in many western streams begin a week to almost three weeks earlier than they did in the mid 20th century (Cayan et al. 2001, Dettinger 2005). There is also a trend towards slightly later precipitation (Dettinger 2005). Observed stream flow timing and winter-spring warming trends are consistent with current projections of how greenhouse effects may influence western climates and hydrology. Changes in precipitation type and timing may result in longer and drier summers, i.e., less water available during the months when it is most needed (Dettinger 2005). Glacial extent in the Sierra Nevada has declined markedly in the past several decades.

Changes in Sierra Nevada climate related to precipitation quantity (e.g., snowpack) are less certain (Howat and Tulaczyk 2005). If current trends continue, researchers predict that natural reservoirs provided by snowpack will become progressively less useful for water resources management. A trend in the Sierra Nevada, towards smaller ratios of 'winter-total snowfall water equivalent' to 'winter-total precipitation', during the period 1949–2004, has already been documented (Knowles et al. 2006). If warming trends in our region continue, as projected in response to increasing greenhouse gas concentrations (IPCC 2007), the snowfall fraction of precipitation is likely to continue to decline (Knowles et al. 2006).In addition, flood risk may change in unpredictable ways and Sierra Nevada ecosystems may experience increasingly severe summer-drought conditions (Dettinger 2005, Dettinger et al. 2005, Mote et al. 2005). Prolonged summer drought alters natural fire regime and would increase the potential for high-severity wildfires and further threaten water quality.

The atmospheric concentration of carbon dioxide ($CO_2$) has increased by 31% since 1750. The present $CO_2$ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years; the current rate of increase is unprecedented during at least the last 20,000 years. About three-quarters of anthropogenic emission of $CO_2$ to the atmosphere is due to fossil fuel burning; the rest is predominantly due to land-use change, especially deforestation (IPPC 2001).

It has been argued that the earth's biosphere (primarily, terrestrial biosphere) may have the capacity to sequester much of the increased carbon dioxide ($CO_2$) in the atmosphere associated with fossil fuel burning. This effect is termed "$CO_2$ fertilization" because, in the envisioned scenario, higher ambient $CO_2$ levels in the atmosphere literally fertilize plant growth. Further, because photosynthesis by plants

converts $CO_2$ into oxygen, it has been argued that "$CO_2$ fertilization" could potentially provide a strong negative feedback on changing $CO_2$ levels.

However, climatologists contend that as $CO_2$ concentration of the atmosphere increases, ocean and land will take up a decreasing fraction of anthropogenic $CO_2$ emissions. The net effect of land and ocean climate feedbacks as indicated by models will further increase projected atmospheric $CO_2$ concentrations, by reducing both the ocean and land uptake of $CO_2$ (IPCC 2001).

Some habitats (e.g., high alpine) may shrink dramatically or disappear entirely, leading to irreversible loss of some species (e.g., Clark's Nutcracker, pika) Two climate models predict significant reductions in Sierra Nevada alpine-subalpine forest by the year 2100: one model predicts 50–75% reduction, the other a 75–90% reduction (Hayhoe et al. 2004).

Global climate change is also likely to exacerbate three other systemic stressors of the Sierra Nevada: altered fire regime, air pollution, and non-native invasive species. Some models predict future climate change will be accompanied by increased lightning strikes at latitudes spanned by the Sierra Nevada (Price and Rind 1991). Compounding the increase in wildfire ignitions, extreme weather conditions such as drought are likely to result in fires burning larger areas, being more severe, and escaping containment more frequently (Torn and Fried 1992, Miller and Urban 1999c). Warm temperatures create the perfect conditions for the production of smog and ground-level ozone. Global warming is therefore likely to make air pollution problems worse. A warmer climate would create conditions that would allow the expansion of species better adapted to such conditions.

### *Altered Fire Regimes*

Altered fire regime significantly affects forests and other plant community composition and structure (e.g., increases in forest and shrub density). It can result in shifts in plant and animal species composition, including possible loss of fire-dependent species, and will almost certainly increase the probability of unnaturally severe fire. It influences presence of non-native invasive species, hydrology, water and soil chemistry, biogeochemical cycling and air quality.

From the late 1890s through 1960s, Sierra Nevada park and national forest personnel attempted to suppress all fires, and these efforts were mostly successful. Consequently, numerous ecosystems that had evolved with frequent fires have since experienced prolonged periods without fire (Swetnam et al. 1992, Swetnam 1993, Caprio and Graber 2000, Caprio et al. 2002, Caprio and Lineback 2002).

Change in fire regime has modified ecosystems. In foothill grasslands for example, lack of fire encourages dominance by non-native invasive grasses (Parsons and Stohlgren 1989). Reproduction of shade-intolerant species (e.g., giant sequoia) has been reduced (Harvey et al. 1980, Stephenson 1994). More land is dominated by dense, intermediateaged forest patches, and less by young patches (Bonnicksen and Stone 1978, Vankat and Major 1978, Bonnicksen and Stone 1982, Stephenson 1987). Forests are denser, dominated by shade-tolerant species, and shrubs and herbaceous plants may be less abundant (Kilgore and Biswell 1971, Harvey et al. 1980). A buildup of surface fuels has accumulated (Agee et al. 1978, van Wagtendonk 1985) and increasing numbers of small trees have created "ladder fuels", which carry fire into mature tree crowns (Kilgore and Sando 1975, Parsons and DeBenedetti 1979). These changes have led to a higher risk of high-severity wildfires than was present before European settlement and fire suppression activities (Kilgore and Sando 1975, Vankat 1977, Stephens 1995, Stephens 1998).

Lack of fire can affect water resources by reducing stream flows, altering biogeochemical cycling, and decreasing nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires can also impair water resources, resulting in loss of vegetation cover, litter, and organic matter. The formation of these water repellant soil layers can affect evapotranspiration, infiltration, and snowmelt patterns (Helvey 1980, Inbar and Wittenberg 1998, DeBano 2000, Huffman et al. 2001). Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003, Heard 2005).

Lack of fire has reduced habitat (and food) critical for some wildlife species. Number and extent of forest openings have been reduced, which in turn has reduced key herbaceous and shrub species (e.g., nitrogen fixers such as Ceanothus) (Bonnicksen and Stone 1982). Wildlife that require these plants, such as deer, now have less habitat available.

In 1968 (Sequoia & Kings Canyon) and 1970 (Yosemite), NPS staff began prescribed burning. After more than 30 years of prescribed fires, significant progress has been made, although park efforts are far from restoring natural fire regimes at the landscape level (e.g., (Caprio and Graber 2000, National Park Service 2004).

### *Non-native Invasive Species*

Non-native invasive species (plants and animals, including pathogens) can severely alter plant community composition and structure, competition and predation, native plant and animal diversity, fire regime, and soil water dynamics.

#### *Plants*

Some of the most widespread invasive grasses first arrived in California during the 16th century as propagules hitchhiking on explorers; their spread was subsequently exacerbated by grazing, drought, and burning by Native Americans (Hendry 1934, Heady et al. 1992).

Numerous invasive vascular plant species are present in Sierra Nevada parks. Despite management efforts, many are spreading and new invasions continue: at least 180 species now occur in Yosemite, 200 in Sequoia and Kings Canyon, and eight in Devils Postpile.

Herbaceous biomass of foothill grasslands in Sequoia is 99% invasive species (Parsons and Stohlgren 1989), and altered fire regime (i.e., a particular fire frequency, intensity, or seasonal distribution) may be one of the reasons (Parsons and Stohlgren 1989). Fire suppression has likely inhibited plant invasion into montane landscapes because closedcanopy forests are not generally favorable sites for invasive plants. However, reintroduction of fire onto the landscape may promote establishment of invasive species, particularly in resultant light gaps or areas of high fire severity (Keeley 2001). Because plant species evolve–not in association with fire per se– but within a particular fire regime, some highly fire-adapted plant communities (e.g., chapparal) may be vulnerable to invasive competition (Keeley 2001). Also, the invasion process is affected by (1) the extent to which fires and fire management practices encourage establishment and spread, and (2) the degree to which such practices inhibit or reverse the invasion process (Keeley 2001). Concomitantly, the presence of invasive plant can lead to altered fire regimes, including increased fire frequency (Keeley 2001).

Invasive plants can severely alter ecosystems. They can alter soil water dynamics, thereby stressing native species and perhaps increasing the potential for invasion by noxious species such as yellow star-thistle (Gerlach 2004). Parts of Sequoia National Park that have been severely grazed by cattle (trespassing) now harbor numerous invasive species.

#### *Animals*

At least 30 invasive vertebrate species have been reported in Sequoia and Kings Canyon, and 21 have been reported in Yosemite. Many of these species (e.g., trout, bullfrog) are of concern to management because they may have deleterious effects on native wildlife populations.

The widespread introduction of brown, rainbow, and brook trout into high elevation lakes and streams has altered ecosystems, which were naturally without fish. Introduced fish and chytrid fungus are suspected of being leading factors in declines of native amphibian species in the Sierra Nevada, including the precipitous decline of the yellow-legged frogs (Bradford 1989, Bradford et al. 1993, Knapp and Matthews 2000, Rachowicz and Vredenburg 2004, Rachowicz et al. 2005, Rachowicz et al. 2006, Rachowicz et al. In press). Bullfrogs are voracious predators, and carriers of chytrid fungus. The full impact of bullfrogs on native species in the parks is unknown, but extirpation of California redlegged frog (federally threatened) from Yosemite is attributed to bullfrog presence (S. Thompson, Wildlife Biologist, Yosemite, pers. comm.). Domestic animal species (e.g., free-ranging house and feral cats) consume native species and compete with native wildlife for resources.

### *Air Pollution: Air Contaminants and Atmospheric Deposition*

Air pollution affects water and soil chemistry, forest population dynamics (e.g., reduced vigor), plant community composition, and may affect wildlife (e.g., endocrine disruption of amphibians). In addition, it may favor nonnative plants through nitrogen deposition, and affects fuel availability for fire by affecting plant productivity.

The southern and central Sierra Nevada are subject to some of the worst air quality in the United States (Peterson and Arbaugh 1992, Cahill et al. 1996), particularly during the summer months. The San Joaquin Valley, west of the Sierra Nevada parks, is a trap for air pollutants originating in the valley as well as pollutants from cities along the central California coast that are carried in on prevailing winds. Southward-flowing air currents enter California at the San Francisco Bay and move through the valley until they reach the mountains at the southern end of the basin, causing an eddy to form in the vicinity of Visalia and Fresno, just west of the southern Sierra Nevada (Lin and Jao 1995) (Figure F–3). Thermal inversions frequently trap air over the valley at night during the summertime. Airborne pollutants are then transported into the mountains when this air rises during the day. As a result, Sequoia and Kings Canyon have some of the worst air quality found in any NPS unit in the country (Bradford and Gordon 1992, Cahill et al. 1996). Yosemite and Devils Postpile are also impacted, but to a lesser degree.




**Figure F–3.** Air flow patterns in the San Joaquin Valley.

One of the most damaging air pollutants is ozone. Research suggests chronic ozone pollution can lead to shifts in forest structure and composition (Miller 1973). If current ozone concentrations remain relatively constant, or increase, they may affect the genetic composition of pine and sequoia seedling populations and contribute to increased susceptibility to fatal insect attacks, death rates, and decreased recruitment (Miller 1973, Ferrell 1996, Miller 1996). The effects of

chronic ozone pollution on other species are not yet known.

There are resultant biological effects of nutrient deposition on aquatic and terrestrial ecosystems, and this enrichment can have considerable effects on sensitive organisms or communities (e.g., lichens and phytoplankton)—even at very low levels of atmospheric deposition (Fenn et al. 2003).

High-elevation aquatic ecosystems in the Sierra Nevada are particularly sensitive to change from atmospheric deposition because the waters are oligotrophic and have a low buffering capacity. In Yosemite, correlations between higher nitrate concentrations in sensitive surface waters and areas of higher nitrogen deposition have been observed (D. Clow, Hydrologist, USGS, pers. comm.). In contrast, decreased exports in dissolved nitrogen were observed in Emerald Lake in Sequoia.National Park. The decrease was attributed to increased phosphorus inputs that caused a switch from a lake dominated by phosphorus limitation to one dominated by nitrogen limitation. Sickman et al. (2003) described two trends in nitrate concentrations in Emerald Lake. During snowmelt, nitrate pulses (i.e., peak values during April) were related to snowpack depth–the deeper the snowpack the greater the nitrate pulse. There is little variation in precipitation concentration, therefore, the quantity of precipitation (i.e. snowpack depth) is the determining factor.

The second pattern, and the one most relevant to phytoplankton, is a decline in summer/autumn lake nitrate concentrations to zero between the 1980s and 1990s. This late season decline occurred despite the fact that N deposition did not decrease. Instead, increased phosphorus loading allowed the phytoplankton to fully utilize nitrate during the summer/autumn seasons, driving them into a N-limited trophic state. The cause of increased phosphorus loading is unknown, but inputs from atmospheric deposition, soils, and, sediments are likely reasons and the subject of ongoing research.

Mid-elevation, mixed-conifer watersheds in Sequoia's Giant Forest have shown net retention of nitrogen, with stream concentrations often below detection limits (Williams and Melack 1997a). Giant sequoia forests are particularly effective at immobilizing nitrogen and reducing leaching losses; they may be adapted to even more nutrient poor environments than other coniferous ecosystems (Stohlgren 1988).

The consequences of increased nitrogen deposition and retention on terrestrial plant communities in the Sierra Nevada are unknown, but greater foliar biomass production, resulting in enhanced litter accumulation on the forest floor (fuel) and in aboveground biomass (stand densification), may increase the risk of severe fire damage (Fenn et al. 2003). Nitrogen pollutants are likely to be important in causing changes in lichen communities—e.g., shifts to nitrophilous species or changes in abundance (Nash and Sigal 1999). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition can increase the dominance of non-native invasive plants and decrease diversity of native plant communities (Vitousek and Howarth 1991, Vitousek et al. 1997). Enhanced growth of invasive species from increased nitrogen has been observed in coastal sage scrub of Southern California, and is implicated in exacerbating invasion of Mediterranean nonnative grasses (Allen et al. 1988). Changes in the alpine plant community of the Rocky Mountains from nitrogen deposition have been observed (Bowman 2000).

With continued urbanization of California's Central Valley, with increasing livestock operations, and with the possibility of transpacific N transport from Asia, it is probable that N deposition and its ecosystem effects in the High Sierra will increase in the next several decades (Fenn et al. 2003).

High elevation lakes and streams in the parks are very dilute and sensitive to change from atmospheric deposition of nutrients, toxic substances, and acids. While chronic acidification is currently not a problem, episodic depression of acid-neutralizing capacity occurs during snowmelt (Melack and Sickman 1995b, Melack et al. 1998b) and episodic acidification occurs during

what are known as "dirty rainstorms", i.e., rainstorms of summer and early fall (Stohlgren and Parsons 1987). If acid deposition increases–which is likely due to rapid population growth in the San Joaquin Valley–episodic acidification will become more frequent and may alter aquatic communities. Recent research suggests Sierra Nevada waters may be fairly resilient and able to buffer current and potentially increased inputs (Leydecker et al. 1999). The actual threat to water quality posed by episodic acidification, however, is unknown.

Sequoia, Kings Canyon, and Yosemite are downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, millions of pounds of pesticides (net weight of active ingredient) are applied to crops—9,872,707 pounds in 2003 alone (Pesticide Use Database, managed by California Department of Pesticide Regulation, http://www.cdpr.ca.gov/). Pesticides volatilize, i.e., become suspended in the atmosphere as particulate matter (atmospheric contaminants), then drift into the parks on prevailing winds. Organophosphates have been found in precipitation up to an elevation of 1,920 meters in Sequoia (Zabik and Seiber 1993). Some synthetic chemicals are endocrine disruptors (hormonal mimics) in concentrations of parts per trillion, potentially leading to altered wildlife reproductive capacity, longevity, behavior, and cancer and mutations (Colburn et al. 1996). Synthetic chemical drift also may play a role in decline of mountain yellow-legged frogs and other amphibians in the Sierra Nevada (Sparling et al. 2001, Davidson and Shaffer 2002). While there is correlation between ecosystem effects and synthetic chemical presence, the mechanism for specific pesticide effects has not been established.

### *Habitat Fragmentation and Human Use*

Human use and park fragmentation typically results in: habitat loss, altered fire regime, diversion of water, disruption to wildlife, increases in non-native species invasions and may degrade wilderness values (e.g., dark night sky, natural soundscape).

Sierra Nevada parks have the potential to become functional biological islands due to future human population growth and increases in amounts and types of development on adjacent lands. Population growth for the Sierra bioregion is forecasted to increase by over 50 percent in the next 20 years, from 717,400 in 1990 to 1,110,200 by 2020 (Fire and Resource Assessment Program 1997). This will pose increasing challenges for preserving park ecosystems and biodiversity. Several species already have disappeared from the parks (e.g., grizzly bear, California Condor, California red-legged frog), and others survive in greatly reduced numbers (e.g., mountain yellow-legged frog, Yosemite Toad, Western pond turtle, Willow Flycatcher) (NPSpecies Database https://science1.nature.nps.gov/npspecies/). These losses are partly due to habitat loss on adjacent lands, with park habitat being insufficient to support local populations over the long term (Graber 1996). This problem is particularly serious for foothill species, including seasonally resident species, because most land adjacent to undisturbed foothill habitat is primarily privately owned and subject to development, grazing, agriculture, water diversions, altered fire regime, and non-native invasive species (including freeranging pets and feral animals).

Coniferous forests on lands adjacent to park boundaries are mostly within national forests, where forest ecosystems have been altered by timber harvest, grazing, water diversions, non-native invasive species, and altered fire regimes. Declines of forest mesocarnivores (e.g., wolverine, fisher, red fox), bats, and owl species are attributed to forest structure changes in the region (DeSante 1995, Graber 1996).

Livestock grazing on other non-park public land east of the Sierra Nevada crest has prevented re-establishment of healthy metapopulations of Sierra Nevada bighorn sheep (*Ovis canadensis* ssp. *nova*) within the parks, leading to their endangerment (Wehausen 2003).

Animals that routinely travel outside park boundaries (e.g., mule deer, black

**Table F–3.** Listing of stressors and documented resources management issues, by park.

| STRESSORS AND RESOURCE ISSUES | DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|---|
| **Air and Climate** | | | |
| Climate change | • | • | • |
| Precipitation change & spring runoff pattern | • | • | • |
| Elevated ozone | | • | • |
| Particulate matter | | • | • |
| Smoke management | | • | • |
| Visibility Impairment | | • | • |
| Nitrogen deposition | | • | • |
| Persistent organic pollutants | | • | • |
| **Water** | | | |
| Recreational use (litter, human waste, stock) | • | • | • |
| Reduction in snowpack, icefields, glaciers | • | • | • |
| Change in snowmelt timing | • | • | • |
| Road runoff | • | • | • |
| Riverbank compaction & erosion | • | • | • |
| Atmospheric contaminants | | • | • |
| Elevated nutrients | | • | • |
| Diversions and dams | | • | • |
| Altered fire regimes and resultant effects on flow and chemistry | | • | • |
| Groundwater withdrawal | | • | • |
| Water diversion | | • | • |
| Arsenic from volcanic sources--potential threat to drinking water | • | | |
| Better hydrology baseline data needed | • | | |
| Old mines | | • | |
| **Biologic** | | | |
| Effects of climbing on large granite faces (hardware litter, rock face damage) | | | • |
| Sedimentation and erosion after severe fire | • | • | • |
| Development in rockfall zones | | | • |
| Erosion of riverbank soils due to visitor use | • | | • |
| Soil compaction due to visitor use | | • | • |
| Effects of rockclimbing | • | • | • |
| Roads across braided stream channels | | | • |
| Effects of contaminants originating from waste accumulation sites (e.g., old dumps) | | | • |
| Loss of glacial polish on postpile columns (trailing, erosion) | • | | |

bear, and band-tailed pigeon) thereby become part of hunted populations. Such management activities outside parks are likely to affect age structure and abundance of species within park boundaries. Non-hunted park populations are a likely reservoir for hunted and less dense populations outside the parks.

Concomitant with population growth are changes in wilderness values such as dark night sky and the natural soundscape. Dark night sky benefits many living things, and light pollution is rapidly eroding the unspoiled view of stars. Natural sounds (e.g., morning bird chorus) are integral to the park experience for visitors and essential to the health of ecosystems. Increases in anthropogenic sound such as from airline over-flights can disrupt wildlife behavior.

### *Additional Resources Management Issues in SIEN Parks*

Network park managers and researchers, using best professional judgment, have identified a suite of resources management issues and concerns, in addition to the five systemic stressors. We identify both broad scale and localized stressors and resource issues for individual Sierra Nevada Network parks, in Table F–3.

## Overview Model: Landscape Exchange

A landscape can be thought of as an "open" system that exchanges energy, materials, and organisms with its surroundings. In this context, broad-scale processes constrain these exchanges among landscapes. For example, our regional climate is considered a constraint on the Sierra Nevada landscape. The various ecosystems in a given landscape are linked by the movement of plants and animals, air, water, energy, and biogeochemical cycles (Turner 1989). Park "boundaries" are mostly arbitrary demarcations with respect to atmospheric, hydrologic, and other ecosystem processes.

The major interactions between park landscapes, with the larger surrounding Sierra Nevada ecoregion, are illustrated

in Figure F- 4. Many of the portrayed exchanges are common to all Sierra Nevada landscapes, regardless of shape, size, or locality. Some external inputs into parks are little-influenced by the parks themselves—these include meteorological inputs (e.g., precipitation, solar radiation) and airborne pollutants (e.g., nitrogen, persistent organic pollutants). As depicted, park landscapes exchange energy, materials, organisms, and processes with the adjacent landscapes and larger eco-region (within which it is embedded).

For example, birds and other animals freely cross the boundary between park and nonpark habitats. Fire can propagate into or out of a park unit. Non-native invasive species present outside park boundaries can be transported into a park area by wind, animals, or human activities. River flows can originate within a park watershed, passing through its boundary on its way to lower elevations, or may only flow through a park and therefore not encompass the uppermost reach of the watershed (e.g., San Joaquin River through Devils Postpile). Park areas of smaller extent, such as Devils Postpile, may be more profoundly influenced by their surroundings than those of larger extent; larger parks may be better able to buffer disturbances and other outside influences.

Implications of these exchanges (of materials, organisms, etc.) on park resources need to be explored and related to management concerns. Although we often cannot control what enters a park, we can monitor its effects, communicate that information widely, and mitigate, to some extent, through thoughtful management.

**Table F–3.** Cont'd.

| STRESSORS AND RESOURCE ISSUES | DEVILS POSTPILE | SEQUOIA & KINGS CANYON | YOSEMITE |
|---|---|---|---|
| **Biologic (cont'd)** | | | |
| Erosion of fragile volcanic soils from social trailing | • | | |
| Volcanic and earthquake activity (regional) | • | | |
| Erosion and undercutting along riverbanks—visitor use | • | | • |
| Roads in rockfall zones | | • | • |
| Damage to caves (e.g., visitation, vandalism) | • | | • |
| **Ecosystem Processes** | | | |
| Altered fire regimes | • | • | • |
| Altered biogeochemical cycles (elevated $PO_4$, NOx, $NH_4$) | • | • | • |
| **Wilderness** | | | |
| Preserving natural soundscape (e.g., overflight issues) | • | • | • |
| Preservation of dark night sky (from light intrusion) | • | • | • |
| Snowmobile trespass | • | | • |
| Day use | • | • | • |
| **Habitat Fragmentaion, Loss, and Land-use Change (e.g. development)** | | | |
| Development, logging, grazing outside boundaries | • | • | • |
| Roads and developed areas inside boundaries | | • | • |
| Logging, grazing, ski resort, and other development outside boundaries | • | | |
| Potential groundwater pumping by Mammoth Lakes at San Joaquin Ridge-reduced flows | • | | |
| Dams–impediment to fish migration | | | • |

Sources: Park vital signs workshop reports ((Mutch and Lineback 2001, Mutch 2002, Mutch and Thompson 2003); Evaluation of Existing Water Resources Information in Sierra Nevada Network for the Vital Signs Water Quality Monitoring Plan (Appendix D); water resources scoping meeting summary (Heard and Mutch 2003); Sequoia and Kings Canyon Resources Management Plan (Sequoia And Kings Canyon National Parks 1999b); Yosemite National Park Resources Management Briefing Package (National Park Service 2003b); Sierra Nevada Ecosystem Project Report (SNEP 1996); and park staff.

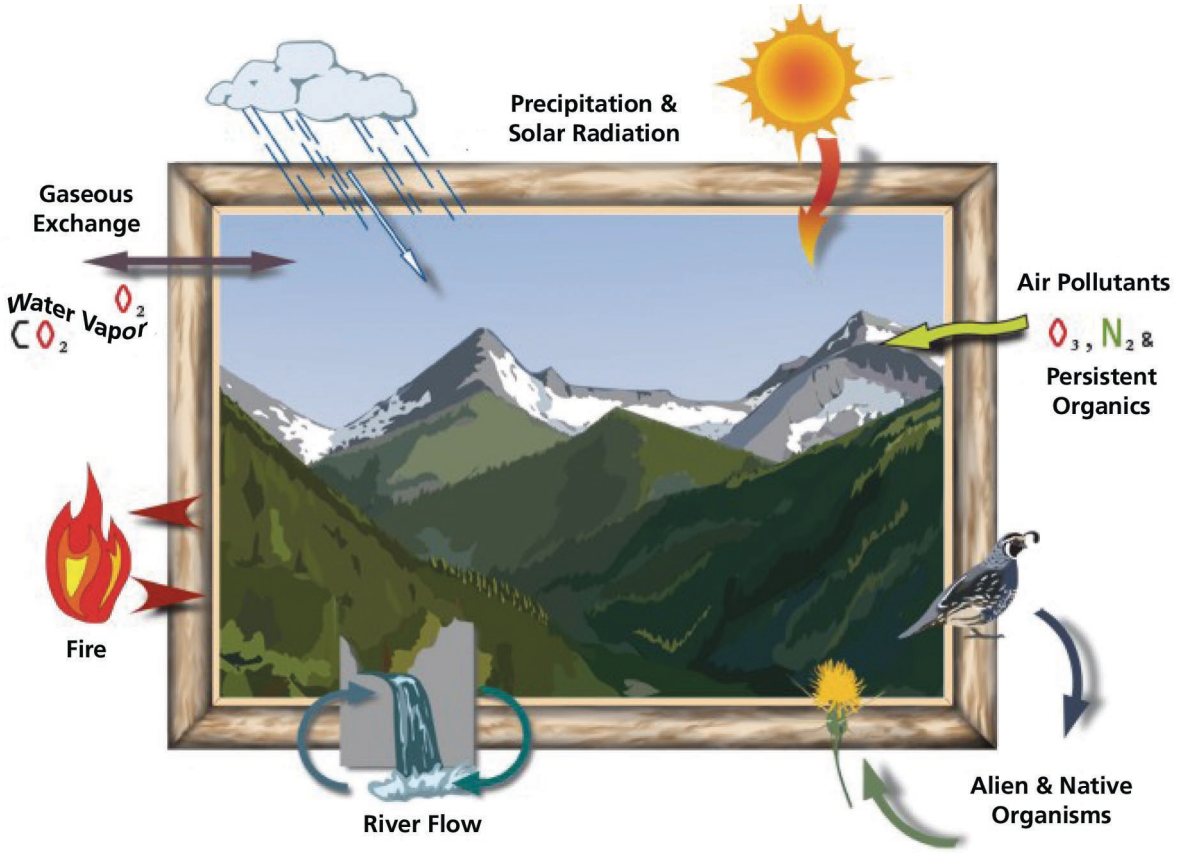



**Figure F–4.** Major inputs and exchange of energy, materials, organisms, and processes for a given Sierra Nevada parkland (landscape) and its physical surroundings. Illustration by Justin Hofman (NPS intern).

## Overview Model: Landscape Dynamics

### *Introduction*

There are a variety of major factors threatening the integrity of Sierra Nevada ecosystems. As mentioned, science has identified rapid anthropogenic driven climate change (rapid anthropogenic), altered fire regimes, invasive species, pollution, and habitat fragmentation as the five primary threats to Sierran systems (SNEP 1996). With a rapidly expanding human population, and a steeply rising projection in the state's population size, these threats are likely to increase in scope and severity. In particular, the Sierra Nevada foothills are projected to be heavily impacted by future development.

Climate change is predicted to play an increasingly important and serious role in California, posing a significant threat to the existence and persistence of native ecosystems and species (California Energy Commission 2003, Hayhoe et al. 2004). Decades of fire suppression and predicted climate shifts are likely to bring dramatically altered fire dynamics to the Sierra Nevada.

We have selected landscape dynamics as a high-priority monitoring protocol for development because many landscape elements and processes are sensitive to the stressors identified above (see Figure F- 5) and associated discussion for additional detail on these threats and stressors). Another reason we are interested in monitoring landscape dynamics is because remote-sensing technology provides a cost-effective means of detecting and assessing change in our large Wilderness parks, where spatially-extensive on-the-ground monitoring will not be feasible for all vital signs. Remote-sensing data when used with other ground-based monitoring data and modeling can help establish relationships among major drivers, stressors, and landscape patterns and provide early warning of changes that may at times be mitigated

by management actions.

The landscape model (Figure F-5) highlights core drivers, system components and functions, and stressors that interact to influence landscape dynamics and patterns. We include definitions of important landscape terms below.

**Landscape Definitions**

**Ecosystem**: a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity 2005)

**Landscape**: a mosaic where a cluster of local ecosystems is repeated in similar form over a kilometers-wide area (Forman 1997)

**Landscape element**: each of the relatively homogeneous units, or spatial elements recognized at the scale of a landscape mosaic. This refers to each patch, corridor, and area of matrix in the landscape (Forman 1997)

**Landscape mosaic**: a geographic group of site-level ecosystems (Bailey 1998)

**Patch**: a relatively homogeneous nonlinear area that differs from its surroundings (Forman 1997)

**Mosaic**: a pattern of patches, corridors, and matrices, each composed of small similar aggregated objects (Forman 1997)

## *Drivers, System Components, Functions*

Climate and atmosphere, geology and topography, and various processes of change are core drivers that influence the Sierra Nevada landscape, and interact with each other to influence patterns of vegetation, animal distributions, water dynamics, and soil characteristics.

### *Climate*

Climatic forces are a major driver of Sierra Nevada ecosystems. Strong climatic gradients occur with changing elevation from west to east. Low to mid-elevations have a Mediterranean climate, characterized by hot, dry summers and cool, wet winters. Higher elevations are dominated by a micro-thermal (or Boreal) climate. As a result, a steep temperature gradient parallels the elevation gradient as one climbs from the hot lowlands to the alpine crest (Stephenson 1988). The west slope of the Sierra receives between 50 and 200 cm of rainfall each year, depending on elevation. Above 2,100 m on the western slope, about 50% of precipitation falls as snow (Stephenson 1988), creating a significant snowpack in the montane and subalpine elevations. East of the crest, the mountains create a rain shadow with significantly less moisture falling throughout the season. Long-term changes in past climate regimes have resulted in shifts in fire regimes and vegetation distribution.

### *Geology & Topography*

The Sierra Nevada range has been formed and shaped by a variety of geologic events:

- Uplift and tilting to the west from a magma intrusion approximately 215–70 million years ago, giving the range its asymmetric geometry (gentle west slope, steep east espcarpment)
- Erosion and incision from streams, resulting in deep canyons
- Volcanic activity at approximately 100 thousand years ago on the eastern flank of the Sierra Nevada that sent a lava flow into a valley, now designated Devils Postpile National Monument, which cooled uniformly, contracted, and fractured into hexagonal columns for which the monument is named
- Several glacial periods in the Sierra Nevada, beginning at approximately 1 million years ago and continuing until approximately 10 thousand years ago, which scoured and eroded the landscape and resulted in landforms that include U-shaped canyons, jagged peaks, rounded domes, waterfalls, moraines, and lakes & ponds

Many of these processes continue to gradually change the terrain of the Sierra Nevada today.

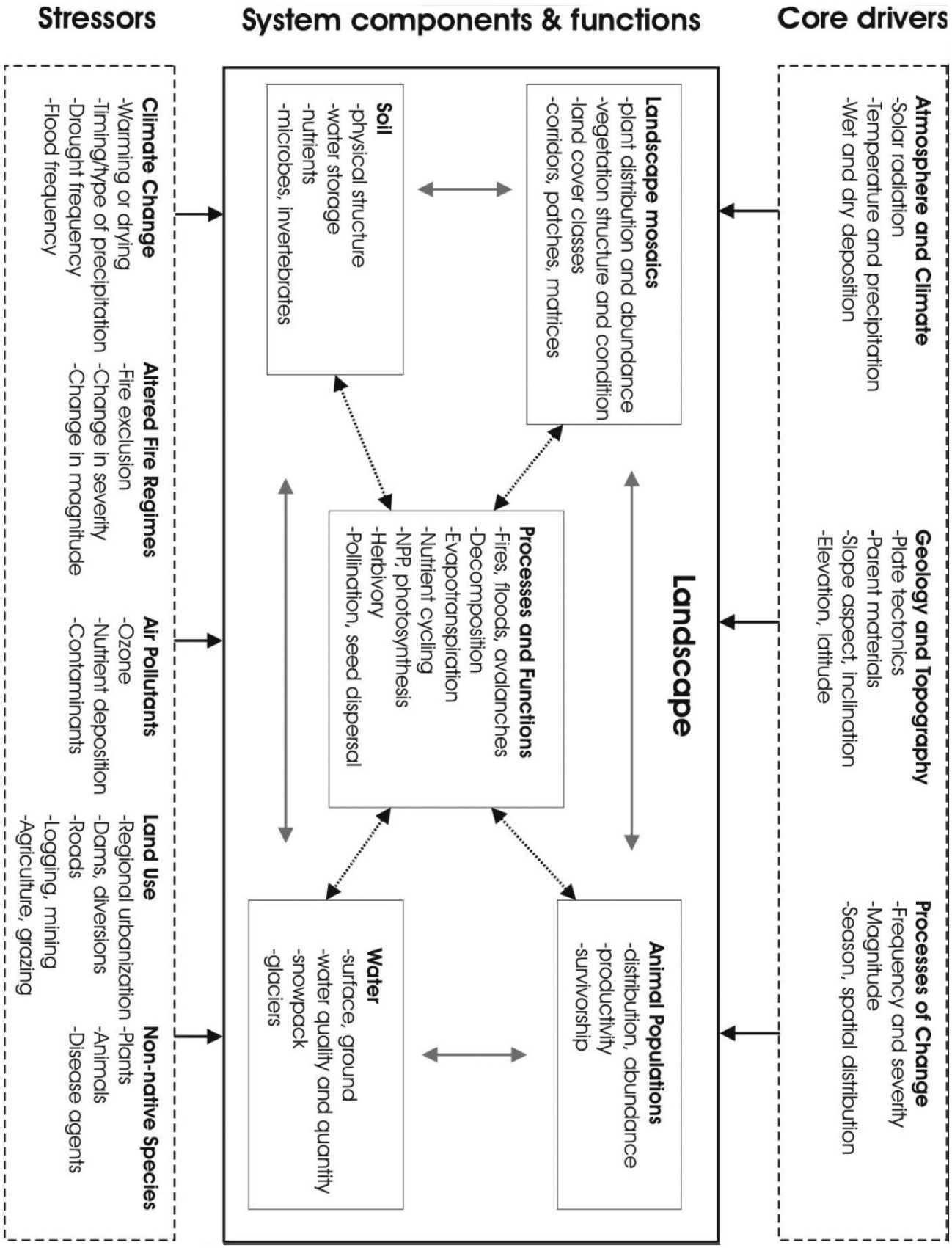



**Figure F–5**. Landscape dynamics model for the Sierra Nevada.

Massive granite outcrops dominate the range. The granite formed deep within the Earth when molten rock solidified, and later was exposed following erosion of overlying rocks. Layered metamorphic rocks in the western foothills and along the eastern margin near the Sierra crest are remnants of ancient sedimentary and volcanic rocks. Most of these rocks were long ago eroded away to expose the granitic core of the range, and only small isolated remnants remain.

Topography of the Sierra Nevada interacts with climate to strongly influence the distribution of plants and animals. Temperature, precipitation, and moisture available to plants vary with changes in elevation, latitude, and slope inclination. The length and elevation range of the Sierra Nevada, combined with its topographic diversity result in large gradients in temperature and precipitation and high diversity of plants and animals.

### *Fire*

While many processes of change have formed and shaped the Sierra Nevada landscape, the current process that has the most pronounced effect on plant community structure and composition is fire. Characteristics and influences of fire regimes are discussed in a later section, associated with both the "fire regimes" and "forest system" descriptive models. Other processes of change that periodically are important in limited portions of Sierra Nevada landscapes include floods, avalanches, rock slides, and hillslope erosion.

Some of these processes are linked to particular weather events (such as large amounts of rain on snowpack), topographic or geologic characteristics (steep rock walls or slopes, tectonic activity), or severe fire events. Processes of change have varying effects on landscape mosaics, and these effects are related to their frequency and severity, magnitude, and seasonal and spatial distribution.

### *Water & Soil*

Additional landscape components or elements that we emphasize in our model include water, soil, landscape mosaics, and animal populations. These components interact directly through exchange of materials or provision of habitat as represented by the solid grey arrows linking landscape element boxes. Much of the interaction and exchange among landscape elements occurs via processes and functions shown in the middle box of the model. For example, key processes such as decomposition, fire, and herbivory result in exchanges of nutrients from one "box" to another. As a result of fire, organic matter tied up in fuel and vegetation can be deposited as nutrients in soil.

Water in a landscape context is characterized by drainage networks across an elevation gradient. Drainage networks provide surface pathways for water flow across the landscape, and the distribution of species is strongly influenced by the spatial and temporal patterns of water availability. Water quantity in the Sierra Nevada and the region at large is strongly influenced by the winter snowpack, which serves as a reservoir that gradually releases water through snowmelt and runoff. Atmospheric deposition, surface runoff, sedimentation, and processes such as fire, erosion, and flooding all influence water quality. Soil is a source of nutrients that are transported into streams, rivers, and lakes, and it is also provides storage for water making it available for plant uptake.

Soil provides physical structure and habitat for plants as well as other organisms (microbes, fungi, invertebrates, vertebrates). Soil is the medium through which nutrients and water are made available to most plants, and provides varying levels of water storage capacity. Soil formation depends upon parent materials, slope, exposure, hydrology, organic matter content, and surface vegetation, among other factors. The soils of the large parks are primarily granitic in origin. Depths vary from several feet in limited low elevation areas on the western slope, to a very thin or nonexistent soil mantle at higher elevations which resulted from glacial scouring in the alpine and subalpine areas. Soil depth is an important factor in determining water availability to plants, and thus plays a role in the distribution

of vegetation (see "Forest System Model").

Devils Postpile National Monument is predominantly covered with pumice, indicating postglacial volcanic activity in the Mono Lake—Mono Basin area. This pumice plays an important role in the area's phytogeography and vegetation development.

On slopes underlain by basalt and andesite, where the water table is low and percolation is high, a sparse conifer forest normally exists. Here, pines and firs contribute little organic matter towards extensive soil formation. The soils remain barren with a paucity of litter and insufficient moisture to enhance soil-formation. It is common, on steeper slopes, to see bare rock and few plants. The plants often creep downhill with the soil, further inhibiting soil development (National Park Service 1982). These dry, unstable soils result in slow recovery of vegetation after human disturbance and more prolonged re-vegetation periods in areas that have burned.

### *Landscape Mosaics*

Landscape mosaics are primarily influenced by abiotic constraints (elevation, soil, microclimate, topography), biotic processes (demography, competition, dispersal) and disturbance regimes (Urban et al. 2000). Landscape mosaics consist of contiguous patches of different types (Figure F- 6), which are areas that are relatively homogeneous in character (e.g., wetlands, high-elevation lakes). Vegetation forms a primary and dynamic component of landscape mosaics, and its relationship to climate and fire in the Sierra Nevada as well as its importance to wildlife habitat make it an important landscape component to monitor.

Other important elements of landscape mosaics include corridors (connectors or barriers). These are primarily linear features in the landscape. Barriers prevent flow across the landscape. The flows could be physical, such as water, or biological, such as animal migration. In contrast, connectors provide paths that promote flow through the landscape. Some landscape features, such as a river or a road, may be both a barrier and a connector depending on the process or organism of interest. These corridors are important to animal populations as they either link patches of habitat (as streams link lakes for amphibians), or they fragment habitat (as trails fragment invertebrate habitat in wetlands).

### *Animals*

The distribution and abundance of animal populations are tied closely to the pattern of landscape mosaics and the varieties of wildlife habitat that they provide. The mobility of many animal populations makes them sensitive to changes that occur in landscapes both within and outside of park boundaries. Animals can form links among different landscape mosaics (lakes, wetlands, forests) by spending parts of their life cycles in different environments, or by moving among various environments for foraging and hunting. Animal productivity and survivorship are sensitive to weather patterns, fire regimes, and other factors that influence habitat availability and quality. Animals affect vegetation dynamics through herbivory, pollination, and seed dispersal. They influence nutrient cycling in both aquatic and terrestrial systems. Animals contribute substantially to the biodiversity of the Sierra Nevada landscape, and they are major components of complex food webs.

## *Stressors*

*Ecosystem stressors are detailed within our stressor model (supra), and in Chapter 1 of our Vital Signs Monitoring Plan. We review their effects, related to landscape, briefly below.*

As detailed supra, five systemic stressors pose the greatest threat to Sierra Nevada Network parks and landscapes:

- Climate change (rapid, anthropogenic)
- Altered fire regimes
- Non-native invasive species
- Air pollution
- Habitat fragmentation and human use

Climatic change may have the greatest potential to affect ecosystems at the

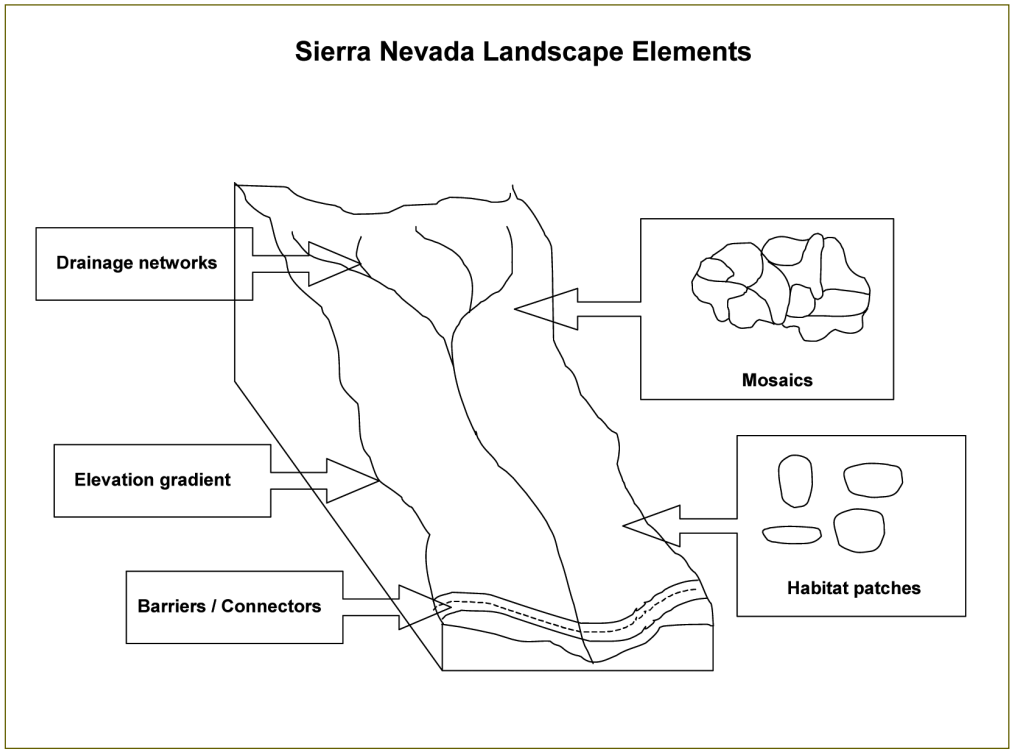



**Figure F–6**. The structure of a landscape is defined by the spatial arrangement of the components within that landscape. These spatial components include such elements as drainage networks, patches, mosaics, elevation gradients, barriers, and connectors.

landscape scale in part because of its pervasiveness and extent across ecosystems as well as synergistic effects with other stressors.

Recent simulations of climate change models suggest that by the years 2050 to 2100, average annual temperature in the Sierra Nevada could increase by as much as 3.8° C (6.8° F) (Snyder et al. 2002). Even more modest temperature increases (2.5° C, 4.5° F) would significantly alter precipitation, snow pack, surface water dynamics (e.g., flow), and hydrologic processes in the Sierra Nevada. The most pronounced changes would probably be earlier snowmelt runoff and reduced summer base flows and soil moisture (IPCC 2007), a lower snowpack volume at mid-elevations (Knowles and Cayan 2001), and increased winter and spring flooding (Dettinger et al. 2004).

Other anticipated effects from warming temperatures include potential shifts in distributions of plants and animals (especially those with narrow niches or at the edges of their ranges), changes in phenological events (nesting, timing of bloom), and exacerbation of other systemic stressors—altered fire regimes, air pollution, and nonnative plant invasions.

Climate change and associated predicted changes in fire extent, severity, and occurrence are expected to be the primary drivers of landscape change in the Sierra Nevada in the foreseeable future. The altered fire regimes that have resulted from fire exclusion are currently considered one of the most important stressors on our natural systems.

Therefore, it is imperative that we document and understand how climate change will affect fire regimes which will in turn to help interpret changes in plant community composition, structure and function; water chemistry and dynamics; and animal populations' abundance and distribution.

We know from historic photos and other research on vegetation change and fire history that, over the past 150 years, there have been significant changes in landscape mosaics (patterns of vegetation) in the Sierra Nevada. Changes in these landscape mosaics

can be readily observed in repeat photographs (Figure F-7). Sierra Nevada research on vegetation change (Vankat 1970, Vankat and Major 1978, Parsons and DeBenedetti 1979, Roy and Vankat 1999) and fire history (Kilgore and Taylor 1979, Swetnam et al. 1992, Swetnam 1993, Caprio and Swetnam 1995) has demonstrated strong links between vegetation structure and composition, fire, and climate.

Air pollution (ozone, deposition of nutrients, pesticides from agricultural areas) threatens Sierra Nevada ecosystems. Research suggests chronic ozone pollution can lead to shifts in forest structure and composition (Miller 1973). Since then, injury has been welldocumented in remote pine forests of southern California (Arbaugh et al. 1998; Bytnerowicz 1996; Grulke 1998; Miller et al. 1996), throughout the Sierra Nevada (Arbaugh et al. 1998; Duriscoe 1987b; Duriscoe 1990; Pronos and Vogler 1981) and in other remote forested areas throughout the US downwind of sources. While ozone pollution in California's urban areas has declined in general over the last 20 years, ozone pollution in remote natural areas has increased (CARB 1999). In 1999 the National Park Service ranked Sequoia National Park among the "worst ozone polluted national parks" in the country (National Park Service 1999). If current ozone concentrations remain relatively constant or increase, they may affect the genetic composition of pine and sequoia seedling populations, and contribute to increased susceptibility to fatal insect attacks, death rates, and decreased recruitment (Miller 1973, Ferrell 1996, Miller 1996). Vegetation condition deterioration may occur in the form of foliage damage and dieback from ozone pollution, and shifts in aquatic and terrestrial community composition and function may result from nutrient and pesticide deposition.

Large portions of the three large Sierra Nevada parks (Kings Canyon, Sequoia, and Yosemite) are buffered to some extent from the effects of habitat fragmentation and land-use change that occur in the Central Valley of California to the west of the parks, in the Sierra Nevada foothills, and on Sierra Nevada national forest lands. Nonetheless, edges of parks bordering these lands, as well as areas/corridors extending into parks, are affected by non-native species invasions, effects of urbanization, agriculture, and deforestation (such as reduced wildlife habitat outside parks and loss of connections among habitats), deterioration of air quality, and deterioration of natural soundscapes and dark night skies. Other forms of land use change include dams and diversions, and within SIEN parks, Hetch-Hetchy Dam on the Tuolumne River is the largest scale example of water impoundment and fragmentation of aquatic habitat.

We selected vital signs to monitor at the landscape scale that we believe will be sensitive indicators of change due to ecosystem stressors.

### *Vital Signs*

There are two primary justifications for wanting to monitor predicted change in landscape dynamics over time:

1. To document the change where and when it occurs. This information can then be applied to direct managers to areas of heightened concern. Remote sensing provides techniques and data to allow for the preparation of scientific responses to environmental change across large landscapes.
2. To use data to build models of predicted future landscape mosaic patterns. This will allow managers to prepare for and then manage for ecosystem changes that are likely to affect processes, systems, and species.

Justification and details (e.g., vital signs, monitoring questions, objectives) for all monitoring protocols are found in Appendix H "Protocol Development Summaries."

Our landscape workgroup has initially selected four vital signs to be monitored as part of our Landscape Dynamics Monitoring Protocol (under development).

#### *Landscape mosaics*

Land cover and land-use change




**Figure F–7.** Repeat photos of Middle Fork of the Kaweah River, Sequoia National Park. Evident in these photos is the change from shrub land to conifer forest over large areas—likely related to a decrease in fire frequency (1900 photo–George Smith, 1993 photo–Nate Stephenson).

are key components of a long-term monitoring program.

Quantifying the occurrence of land cover/use classes within a particular area, over multiple time periods, allows for detection of change in relative occurrence of natural, agricultural, and urban cover types, and provides an index for potential direct (e.g., decreased functional ecosystem size through loss of habitat area, elimination of unique habitats) and indirect (e.g. edge effects, altered ecological flows across landscape, increased human disturbance) ecological impacts of urbanization on park resources (Hansen and Gryskiewicz 2003). Land cover/use characterization captures changes related to urbanization and logging—equally relevant to all park landscapes and ecosystems, but particularly relevant to areas along park edges bordering private and other land management agency lands (e.g., USDA Forest Service, BLM).

### *Fire regimes*

Attributes of pre-Euro-american fire regimes can provide vital reference information for understanding changes in ecosystems over the last 150 years and in developing goals for the restoration of fire. The concept of a fire regime allows us to view fire as a multifaceted variable rather than a single event within an ecosystem (Whelan 1995). Thus, areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability, and having both spatial and temporal attributes. Fire regime characteristics vary through time and across the landscape in response to climatic variation, number of lightning ignitions, topography, vegetation, specific historic events and human cultural practices (SNEP 1996).

*For more information on fire regimes, see "Stressor Model," and "Fire Regime Model."*

### *Snowpack*

Snow is the dominant environmental factor in mountainous regions for more than half of the year (Mote et al. 2005). Sierra Nevada snowpack acts as a temporary reservoir, storing water until the spring snowmelt. Recent modeling work predicts that the average temperature in California will increase 2.1°C (3.8 °F) by 2090, resulting in a 43% reduction to the April snowpack in the southern Sierra Nevada (measured as snow water equivalent) (Knowles and Cayan 2001, 2002, Mote et al. 2005). A trend in the Sierra Nevada, towards smaller ratios of 'winter-total snowfall water equivalent' to 'winter-total precipitation', during the period 1949–2004, has already been documented (Knowles et al. 2006). If warming trends in our region continue, as projected in response to increasing greenhouse gas concentrations (IPCC 2007), the snowfall fraction of precipitation is likely to continue to decline (Knowles et al. 2006). Monitoring of snowpack at the landscape scale provides information directly related to changing climate and relevant to the water supply of the region—both have high ecological and

economic value.

*For detailed information on snowpack, see Stressor Model, and Appendix B, "Parks."*

### *Phenology*

Human-influenced temperature patterns are significantly associated with discernible changes in plant and animal (invertebrate, bird, amphibian, tree, shrub) phenological traits (Root et al. 2005). Our objective is to determine how vegetation types are responding to changes in climate and other disturbances. A national phenological monitoring network has been initiated, and recommendations on different approaches to monitoring phenological change in parks and other areas are being developed, see (http://www.uwm.edu/Dept/ Geography/npn/).

### *Other*

*Additional vital signs may be pursued within our landscape dynamics monitoring protocol if resources and adequate methods permit.*

### *Glaciers—spatial extent and distribution*

The Sierra Nevada contains approximately 497 alpine glaciers and perennial ice features (Raub et al. 1980). These features provide an opportunity to determine regional responses to warming global temperatures over the past century, i.e., changes in spatial extent and distribution. During the summer of 2003 and 2004, over 52 repeat images of historic photos were collected from ten glaciers located throughout the Sierra Nevada, providing evidence of glacial shrinking in the past 100+ years (Figure F–8). When a glacier disappears, the water source for that watershed during dry times of the year is reduced, with cascading effects to watershed habitats.

### *Extent and spatial arrangement of wetlands*

Please see wetlands model (below), and Appendix H, "Protocol Development Summaries," for information describing why wetlands are a focal system for vital signs monitoring. Our ability to monitor wetland extent and spatial arrangement will be limited by the resolution of remotely-sensed imagery that we can acquire with available resources.

### *Fire Regime Attributes*

Please see "Fire Regime Model."

## II. Models: Systems, Processes, and Populations

### *Introduction*

The following sections present models of the drivers and main focal systems selected for vital signs monitoring in the Sierra Nevada Network. Associated with these focal systems models are details and sub-models that further describe ecosystem processes (e.g., fire regimes, nitrogen deposition, and invasion of non-native plants), effects of drivers on plant and animal community dynamics, population dynamics of focal species,




**Figure F–8**. Repeat photos of Dana Glacier, Yosemite National Park.

and interactions among biotic and physical components in specific systems (e.g., lakes).

We present models that include vital signs selected for monitoring protocol development, or those already monitored by parks within our Network. Linkages among vital signs and models are listed in Table F–4. Where necessary and appropriate, we will develop new—and modify existing—models as part of our monitoring protocols. Our models are at different scales, namely system, process, and population.

## Model: Atmospheric System

Our model and text for this section are adapted from Draft Conceptual Ecological Models for the Mojave Network Inventory and Monitoring Program (2006).

### *Introduction*

The atmospheric system drives weather, and the long-term characteristics of weather are described as climate. Stine (1996) generalizes that climate exerts a predominant influence on the following components of the Sierra Nevada landscape:

- Vegetation (type, biomass, distribution)
- Hydrology (size, distribution, fluctuations, and water quality of lakes and streams)
- Soils (stability, nutrient capacity)
- Landforms (rates of formation and loss)
- Fire (location, frequency, seasonal timing, intensity and/or severity)

### *Drivers, System Components, Functions*

#### *Climate & Weather*

Climate strongly influences the landscape by determining the flux of both energy (solar radiation) and mass in the form of moisture (rain, snow, water vapor). The atmospheric system conducts most mass and energy, including pollution, to and from the Sierra Nevada. The atmosphere receives solar radiation, which is mediated by reflective aerosols and absorbent trace gases before reaching Earth's surface (Figure F- 9). It also receives water vapor from evaporation at the Earth's surface, and transpiration from plants.

In the zone near the Earth's surface, heat exchange mediates vertical temperature gradient in the atmosphere (Bradley 1985). Although the atmosphere has low heat capacity, it couples with water bodies of much higher heat capacity with the result that energy in the atmosphere is primarily driven by ocean circulation patterns. Interactions between atmosphere and land include evaporation and transpiration, reflected radiation, precipitation, wind, and heat exchange.

**Table F–4.** Conceptual models (narratives and conceptual diagrams) and the high priority Sierra Nevada Network vital signs that the models include.. Vital signs (bolded) are those currently incorporated into monitoring protocol development (see Appendix H, "Protocol Development Summaries"); other vital signs listed are monitored by Network parks.

| CONCEPTUAL MODEL | VITAL SIGN |
|---|---|
| Sierra Nevada Stressors<br>Landscape Exchange<br>Landscape Dynamics<br>Atmospheric System | Air quality–ozone |
| Sierra Nevada Stressors<br>Landscape Exchange<br>Landscape Dynamics<br>Atmospheric System<br>Nitrogen Deposition | Air quality–atmospheric deposition |
| Atmospheric System | Air quality–particulate matter |
| Atmospheric System<br>Lake System<br>Anuran Populations<br>Rivers & Streams | Air quality–contaminants |
| Atmospheric System | Air quality–visibility |
| Sierra Nevada Stressors<br>Atmospheric System | **Weather and climate** |
| Sierra Nevada Stressors<br>Landscape Dynamics<br>Atmospheric System | **Snowpack** |
| Sierra Nevada Stressors<br>Hydrologic System<br>Aquatic System<br>Lake System<br>River & Stream System | **Surface water dynamics (hydrology)** |
| Sierra Nevada Stressors<br>Hydrologic System<br>Aquatic System<br>Wetland System | **Wetland water dynamics** (hydrology) |
| Sierra Nevada Stressors<br>Hydrologic System<br>Aquatic System<br>Lake System<br>Anuran Population<br>Rivers & Streams<br>Atmospheric Nitrogen | **Water quality–water chemistry** |
| Sierra Nevada Stressors<br>Atmospheric Nitrogen<br>Forest System<br>Non-native Invasive Plants<br>Community Invasibility Models | **Non-native invasive plants** |
| Landscape Dynamics<br>Atmospheric Nitrogen<br>Wetland System | **Wetland plant communities** (wet meadows and fens) |
| Wetland System<br>Invertebrates | **Macroinvertebrates** (wet meadows and fens) |
| Landscape Dynamics<br>Forest System | **Forest population dynamics** |

**Table F–4.** Continued

| CONCEPTUAL MODEL | VITAL SIGN |
|---|---|
| Aquatic System<br>Lake System<br>Anuran Populations | **Amphibians** |
| Bird Populations | **Birds** |
| Sierra Nevada Stressors<br>Landscape Exchange<br>Landscape Dynamics<br>Atmospheric Nitrogen<br>Forest System<br>Fire Regimes | **Fire regimes** |
| Landscape Dynamics<br>Fire Regimes | Fire effects on plant communities |
| Landscape Dynamics | **Landscape mosaics** |
| Landscape Dynamics | **Phenology** |

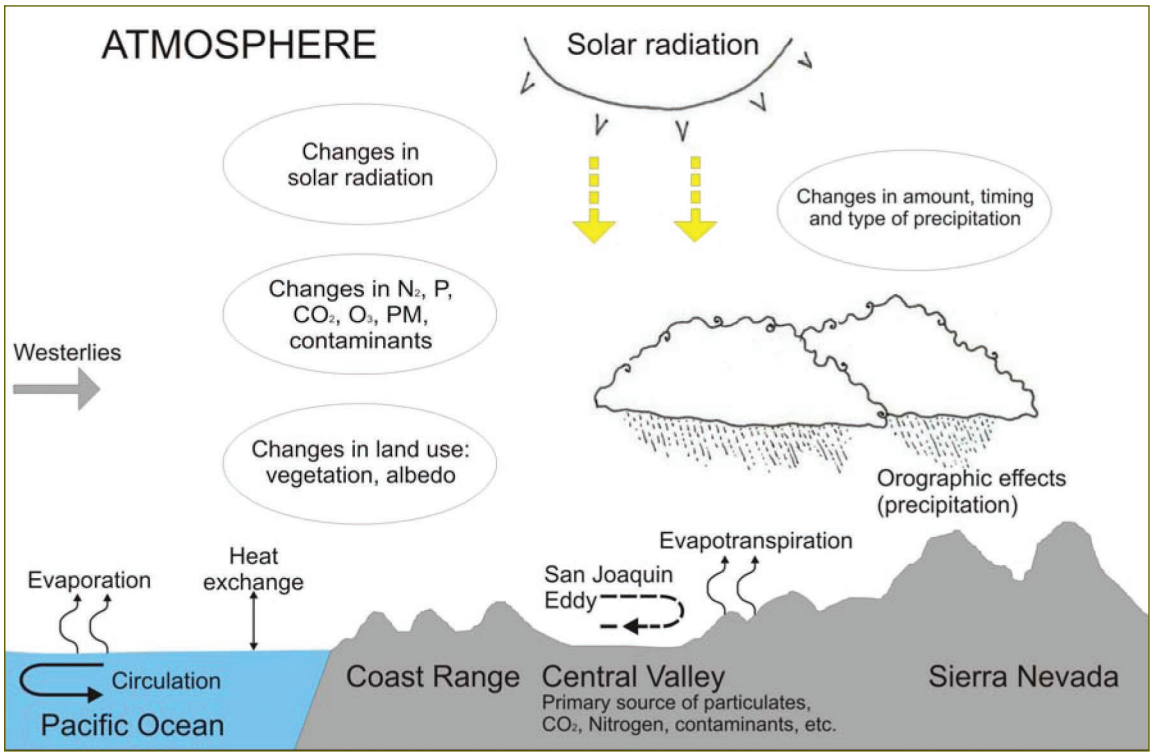



**Figure F–9.** Atmospheric system conceptual diagram for Sierra Nevada. Principal components, key landscape features, and prominent drivers (in ovals) are depicted.

Strong climatic gradients develop with changing elevation in the Sierra Nevada (low to high elevations, from west to east). Low to mid-elevations have a Mediterranean climate, characterized by hot, dry summers and cool, wet winters. Higher elevations are dominated by a microthermal (or Boreal) climate, characterized by having average temperatures of the coldest month below -3° C (26.6° F). As a result, a steep temperature gradient parallels the elevation and climatic gradient; on average, each 100 m gain in elevation results in a 0.6° C (1.1° F) drop in air temperature. This lapse rate varies locally according to air speed, relative humidity, slope aspect, insolation, and vegetation cover (Stephenson 1988), but the general pattern holds true as one climbs from the hot lowlands to the alpine crest.

As temperature decreases with increasing elevation, so does the moisture-holding capacity of air. The west slope of the Sierra receives between 50 and 200 cm of rainfall each year, depending on elevation. Above 2100 m on the western slope, about 50% of precipitation falls as snow (Stephenson 1988), creating a significant snowpack in the montane and subalpine elevations. By the time winter storms reach the alpine, much of the moisture has been lost from the clouds and the amount of snow accumulating on the ground begins to decline with increasing elevation. East of the crest, the mountains create a rain shadow with significantly less moisture falling throughout the season. Precipitation also increases with latitude, due to the pacific jet stream position and subtropical high pressure cells. Across elevations and latitudes, nearly 70% of precipitation falls from December through March and only about 4% from June through September (Stephenson 1988). Precipitation increases with latitude, due to pacific jet stream position and subtropical high pressure cells. Across Sierra Nevada elevations and latitudes, nearly 70% of precipitation falls during December through March, in contrast to only about 4% during June through September (Stephenson 1988).

Climate varies spatially and at annual, decadal, centennial, and millennial time scales.

### *Topography and Geology*

Topography also directly influences the amount and timing of precipitation, and variability in temperature across large and localized spatial scales. As is evident in Figure F–10, elevation, aspect, and soil depth (e.g., as a result of underlying geology and processes) interact with climate to influence evaporative demand and distribution of Sierra Nevada forest types.

### *Plants and Animals*

Climatic forces are a major driver of Sierra Nevada ecosystems, and thereby strongly influence the distribution of plants and animals.

Numerous paleo-ecological studies have documented vegetation changes over the past many thousands of years in response to changes in climate. Woolfenden (1996) summarizes that during the Quaternary period of the past 2.4 million years, at least six successive major glacial cycles covered the Sierra Nevada with ice caps and mountain glaciers, filled lake basins in the adjacent deserts, and lowered the elevation limits of plant species. These ice ages were interspersed with shorter warm intervals when habitats expanded into northerly latitudes and tree lines gained elevation. Species responded individualistically to these changes, sometimes assembling into communities with no modern analog (Woolfenden 1996).

Climate affects the distribution of forest types and other plant communities of the Sierra Nevada through its influence on the soil water balance Stephenson (1988, 1998). With increasing elevation, temperature decreases (causing decreasing evaporative demand) while precipitation increases. The mixed-conifer zone of the Sierra Nevada is sandwiched between low-elevation sites that are chronically droughty, and high-elevation sites that are too cold to be very productive (Urban et al. 2000). Thus, these systems are quite sensitive to climate variability (Graumlich 1993, Swetnam 1993a). The soil moisture regime interacts strongly with forest

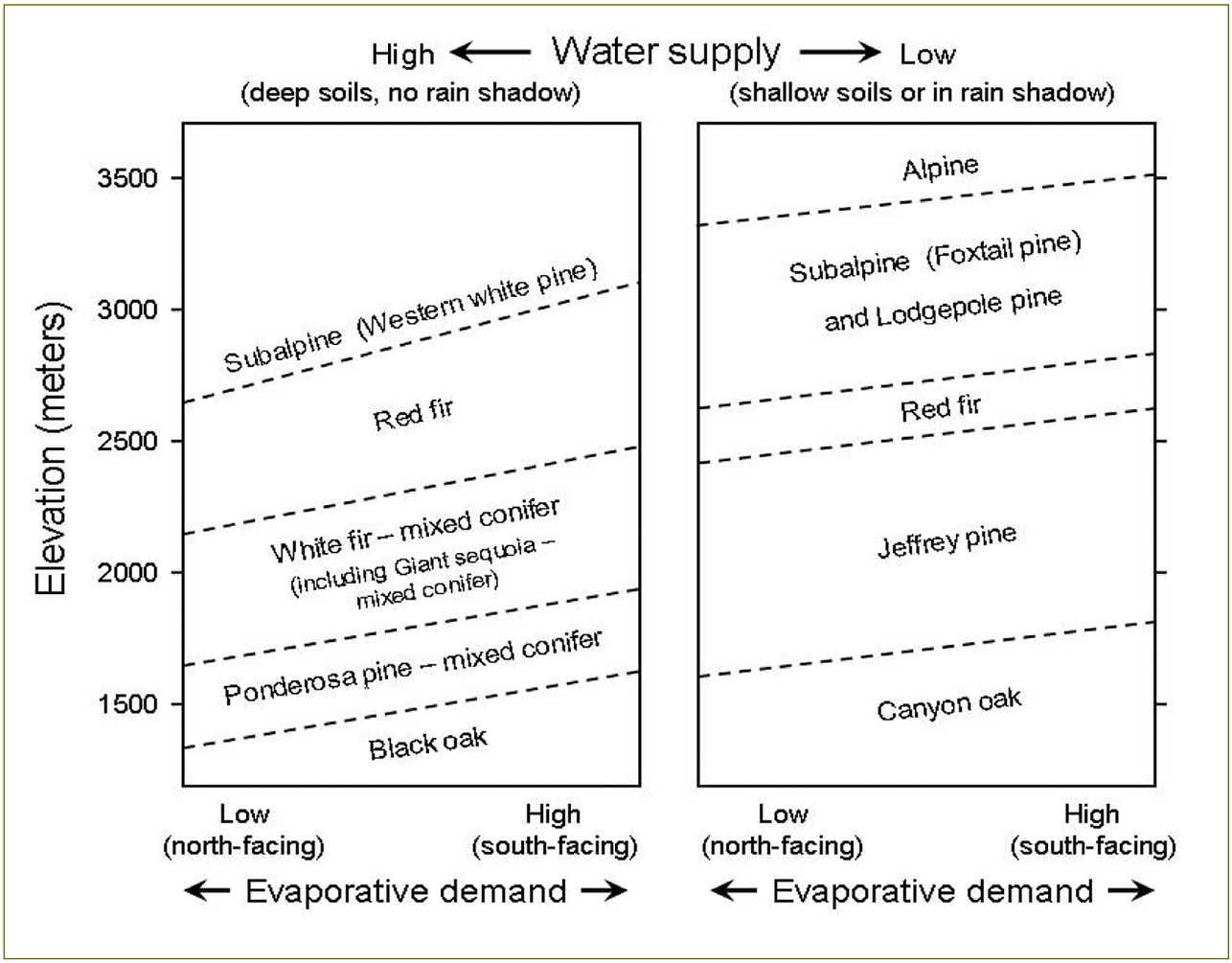



**Figure F–10.** The approximate distribution of forest types in southern Sierra Nevada relative to elevation, evaporative demand, and water supply.

productivity (via fuel loads) and climate (via fuel moisture), and these systems are especially responsive to fire regime as it interacts with forest dynamics and climate (Miller and Urban 1999c, Miller and Urban 1999a, b).

### *Stressors*

Predicted potential effects of anthropogenic climate change on the Sierra Nevada were discussed in Chapter 1 (Section 1.9.2). These effects will likely be highly synergistic, affecting a host of physical and biological systems in unpredictable ways (CIRMOUNT Committee 2006) Current patterns of vegetation, water dynamics, and animal distribution in the Sierra are determined largely by cumulative effects of past and present climates. Anthropogenic climate change is the stressor predicted to have the most pronounced effects on Sierra Nevada ecosystems. Some of the expected–or already occurring–changes include:

- Altered fire regimes – larger, more severe fires (Torn and Fried 1992, Miller and Urban 1999c)
- Lower snowpack volume at mid-elevations (Adam 1981, Knowles and Cayan 2001, Knowles et al. 2006); a trend towards smaller ratios of 'winter-total snowfall water equivalent' to 'winter-total precipitation' (Knowles et al. 2006)
- Increased winter and spring flooding (Dettinger et al. 2004)
- Earlier snowmelt runoff, reduced summer base flows and soil moisture (Dettinger et al. 2004, Dettinger 2005)
- Increased turnover rates in forests (Stephenson and van Mantgem 2005,

Knowles et al. 2006)

- Upward shifts in species or habitats, and losses of species that cannot adjust; potential shrinkage of some habitats (alpine, wetlands) (Patton 2006).

In addition to influencing weather and climate patterns, atmosphere dynamics interact with topography to influence air patterns, affecting the distribution and deposition of pollutants. Ozone, agricultural pesticides, particulate matter, and nitrogen compounds are a few examples of pollutants deposited through dry and wet deposition in Network parks (see Chapter 1, Stressor Model (Figure F–2), and Appendix C, "Air Quality Synthesis" for more detail on pollutants, sources, air flow patterns, and ecosystem effects).

Atmospheric dynamics combine with emissions of air pollutants to influence air quality. The San Joaquin Valley, west of Sierra Nevada parks, is a trap for air pollutants. Pollutants originating in the valley and pollutants from cities along the central California coast are carried in on prevailing winds. Southward-flowing air currents enter California at San Francisco Bay and move southeast, through the valley, until reaching the east-west mountain block at the southern end of the basin. An eddy thereby forms in the vicinity of Visalia and Fresno, just west of the southern Sierra Nevada (see Figure F- 3) (Lin and Jao 1995). Thermal inversions frequently trap air over the valley at night during the summertime. Airborne pollutants are then transported into the mountains when this air rises during the day. As a result, Sequoia and Kings Canyon have some of the worst air quality found in any NPS unit in the country (Cahill et al. 1996). Yosemite and Devils Postpile are also impacted, but to a lesser degree.

Sierra Nevada parks are subjected to the following sulfur-based and nitrogen-based pollutants, elevated levels of ozone, and pesticides:

Sulfur-based pollutants: Fossil fuel combustion, vehicle exhaust, paper manufacturing, and other industry produces $SO_2$ . Although levels of $SO_2$ toxic to lichens are found in Los Angeles and other urban areas, SO2 occurs in relatively low concentrations in more remote areas in California (Jovan and McCune 2005).

Acid Deposition: Acid deposition is the generic term to include wet and dry deposition of acidic forms of primarily nitrogen and sulfur compounds. Acidic derivatives of sulfur dioxide (SO2) and nitrogen oxides (NOx) are the principle acidifying agents. In the Sierra Nevada, air monitoring suggests that sulfuric acid is likely to be less of a problem than nitric acid. Sierra lakes have shown sensitivity to low levels of acid deposition due to thin topsoils, granitic subsurface layers, sparse vegetation, steep slopes, and dry climate. Precipitation in the Sierra Nevada comes during late summer rains and spring snowmelts, delivering acidic pulses of water to lakes and creeks (Stohlgren and Parsons 1987, Melack and Sickman 1995, Melack et al. 1998).

Ozone: Ozone is a photochemical pollutant formed when nitrogen oxides (NOx) and hydrocarbons react with oxygen and sunlight. Tropospheric ozone (O3) pollution is widespread in California, occurring in both urban and rural areas, causing injury to both wild and crop plants (Miller 1973, Duriscoe and Stolte 1992, Peterson and Arbaugh 1992, Stolte et al. 1992, Miller 1996), and causing human health problems because it damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants.

Pesticides: Sequoia, Kings Canyon and Yosemite are downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, millions of pounds of pesticides (net weight of active ingredient) are applied to crops—9,872,707 pounds in 2003 alone (California Department of Pesticide Regulation, http://www.cdpr.ca.gov/); 2 billion pounds of active ingredients were applied in California between 1991 and 2000 (see Appendix C, "Air Quality Synthesis"). Pesticides volatilize or become suspended in the atmosphere as particulates, then drift into the parks on prevailing winds.

Nitrogen: Inputs of fixed nitrogen into ecosystems of the United States

have doubled since 1961 due mainly to agricultural application of nitrogen fertilizers, combustion of fossil fuels, and industry (Howarth et al. 2002). In the Sierra Nevada, too, nitrogen deposition has become a major concern (Fenn et al. 2003). Ammonium nitrate ($NH_4NO_3$) is a major component of fine particulate matter deposited in Sequoia and Kings Canyon National Parks (see Appendix C, "Air Quality Synthesis"), and is likely active in altering the plant communities (e.g., lichen) in Sierra parks (McCune et al. 2006). In Sequoia National Park, ammonia and ammonium are the dominant N pollutants in summer, indicating strong influence of agricultural emissions (Bytnerowicz et al. 2002).

*Because nitrogen deposition is a major concern in Sierra Nevada ecosystems, we include a separate nitrogen conceptual model).*

The severity of air pollution may worsen with warmer climate conditions because temperatures create perfect conditions for the production of "smog," or ground-level ozone. Monitoring of climate, along with various indicators associated with poor air quality in the Sierra Nevada (such as those currently monitored by parks), will be important in understanding current changes in physical processes in aquatic and terrestrial systems, nutrient dynamics, and plant and animal communities. It is an important part of modeling future changes in these systems.

### Vital Signs

The Sierra Nevada Network will monitor selected components of weather and climate because: (1) changes in regional climate patterns will cause change in ecosystems, and (2) climate data will be used to explain patterns observed in other vital sign measures.

We will assess current climate monitoring, including identifying data gaps and determining 'high priority' sites for both park and individual vital signs monitoring. Assessment will also include: (1) the need for, and feasibility of, adding new stations in the parks, (2) determining the need for added instrumentation for existing sites, (3) making data more available or real-time, and (4) assisting with maintenance of meteorological stations and sites.

We will also coordinate micro-scale weather monitoring across vital signs, depending on the needs of other work groups—if any of our vital sign protocols include the collection of weather/climate parameters (e.g., air temperature, relative humidity, etc.), then the type of equipment and protocols should be consistent.

Vital signs and (measures) include: weather and climate (precipitation, temperature, wind speed, wind direction, solar radiation, relative humidity, soil moisture, soil temperature), and snowpack (snow depth, snow cover, snow water equivalent, timing of snowmelt).

### Sub-Model: Nitrogen Deposition

#### *Introduction*

Nitrogen (N) is a limiting nutrient for many terrestrial and aquatic organisms (Vitousek and Howarth 1991). Resulting biological effects of nitrogen deposition on aquatic and terrestrial ecosystems, and this enrichment can have considerable effects on sensitive organisms or communities (e.g., lichens and phytoplankton)—even at very low levels of atmospheric deposition (Fenn et al. 2003).

#### *Drivers, System Components, Functions*

The biogeochemistry of nitrogen is complex, with significant control of its cycling relegated to biotic processes (Delwiche 1970). We include a model illustrating possible linkages among nitrogen deposition, N cycling, carbon allocation, invasive plant species, fire regime, and community composition because of documented increased deposition of nitrogen to Sierra Nevada ecosystems (Figure F–11) (Fenn et al. 2003).



Meteorological station, Sequoia National Park, monitors precipitation and numerous other components of weather and climate. NPS photo.

### *Nitrogen: A Stressor*

Presumably a result of prevailing wind patterns, 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. 1998b). These changes parallel an observed shift in the phytoplankton community of Emerald Lake in Sequoia—from a lake dominated by phosphorus limitation, to one dominated by nitrogen limitation. Mixed-conifer watersheds in Sequoia's Giant Forest have also shown net retention of nitrogen, with stream concentrations often below detection limits (Williams and Melack 1997a).

Elevated nitrate concentrations have been observed in lake and stream water samples from the upper Merced River watershed of Yosemite (D. Clow, pers. comm.). With continued urbanization of California's Central Valley, increasing livestock operations, and the possibility of transpacific N transport (and deposition) from Asia, it is probable that N deposition and its ecosystem effects in the high Sierra will increase over the next

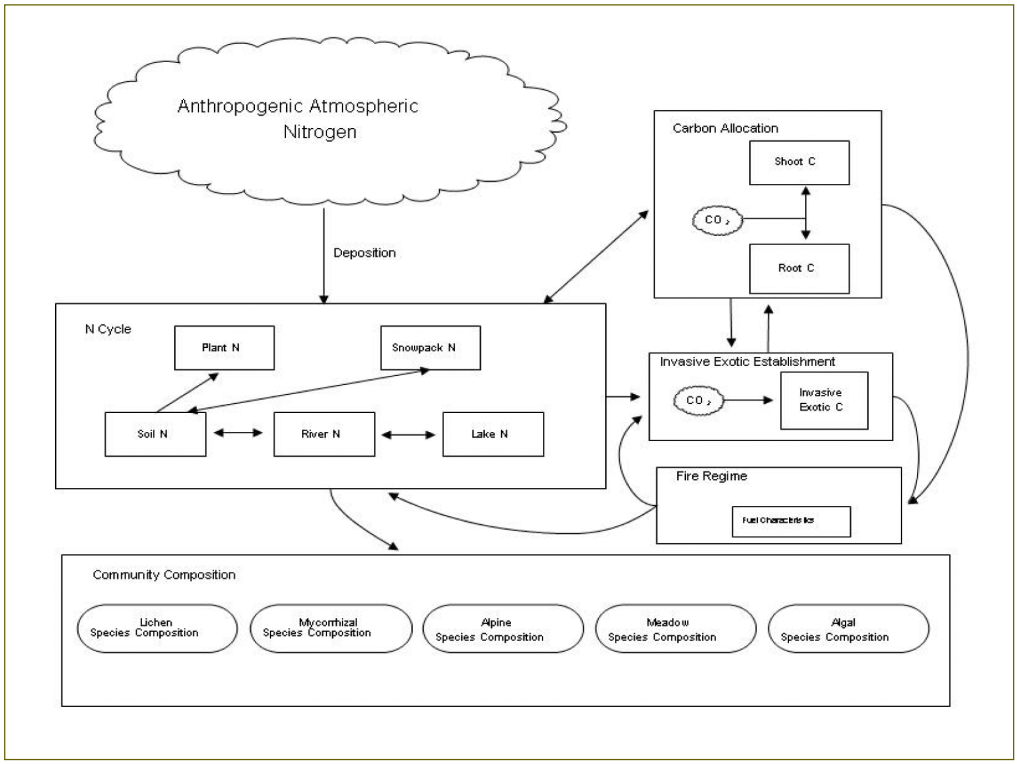



**Figure F–11.** Relationship of nitrogen deposition to other ecosystem processes and components.

several decades (Fenn et al. 2003).

The consequences of increased nitrogen deposition and retention on terrestrial plant communities in the Sierra Nevada are unknown, but greater foliar biomass production, resulting in enhanced litter accumulation on the forest floor (fuel) and in aboveground biomass (stand densification), may increase the risk of severe fire damage (Fenn et al. 2003). Nitrogen pollutants are likely to cause changes in lichen communities (e.g. shifts to nitrophilous species, changes in abundance) (Nash and Sigal 1999). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition can increase the dominance of invasive alien plants and decrease diversity of native plant communities (Vitousek and Howarth 1991, Vitousek et al. 1997). Enhanced growth of invasive species, from increased nitrogen, has been observed in coastal sage scrub of Southern California, and is implicated in exacerbating invasion of Mediterranean non-native grasses (Allen et al. 1988). Changes in the alpine plant community of the Rocky Mountains from nitrogen deposition have been observed (Bowman 2000).

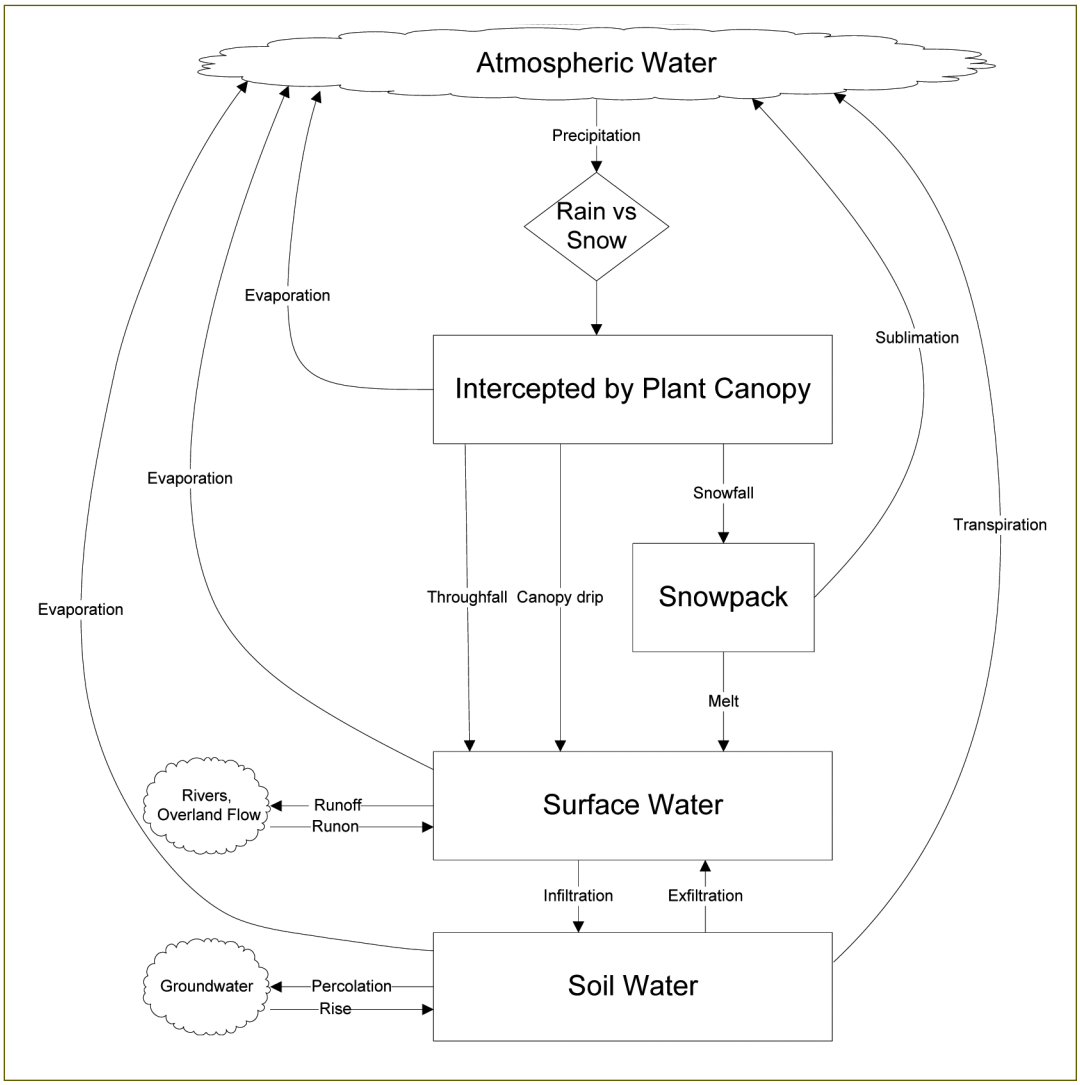



**Figure F–12.** Hydrologic system model for the Sierra Nevada.

### *Vital Sign*

Nitrogen deposition has the potential for deleterious effects to water chemistry (e.g., high-elevation lakes), selected plant communities (e.g., wet meadows and fens, lichens), and fire regime.

Through our vital signs monitoring program, we will include nitrate, dissolved organic nitrogen, total dissolved nitrogen, and particulate nitrogen as a measure of water chemistry (vital sign) monitoring in Sierra Nevada lakes.

To date, SIEN parks have conducted limited monitoring of nitrogen, through wet and dry deposition monitoring at a few air quality sites (see Appendix C, "Air Quality Synthesis").

## Model: Hydrologic System

### *Introduction*

Components of the hydrologic cycle , such as evapotranspiration, are of great importance to plant growth and the main link between the hydrologic cycle and ecosystems.

### *Drivers, System Components, Functions*

The hydrologic system is driven by atmosphere, climate, weather, geology, and topography. Our

hydrologic system model includes major pathways and stores for water in Sierra Nevada ecosystems (Figure F–12). This model depicts four major water storage compartments: water or snow intercepted on the plant canopy, snowpack, surface water, and soil water.

Most atmospheric water in the Sierra Nevada originates as water vapor from the Pacific Ocean. Precipitation may be intercepted by a plant canopy or pass through to the ground (throughfall for rain, or snowfall). Intercepted precipitation may be evaporated from the canopy or drip through to the ground. Plant canopies have a finite storage capacity that may not be exceeded by very small precipitation events, thus most rainwater from those events may be evaporated. Conversely, precipitation events exceed the storage capacity of the plant canopy, and most precipitation falls to the ground. Changes in vegetation composition and structure will alter the canopy storage capacity, thereby affecting evaporation, throughfall, etc.

Sierra Nevada snowpack is an important component of the hydrologic cycle because it is a natural reservoir that collects and stores water in the winter. The water is later released and available to ecosystems during the warmer and drier months. Loss of water from snowpacks is primarily by melting; however, sublimation (solid to vapor transport) also occurs under dry atmospheric conditions. Shortwave (solar) and long-wave (terrestrial) radiation are the main energy processes that contribute to snowmelt. However, rain-onsnow events can cause extensive and rapid melting, which can lead to flooding. The primary melting processes during these events are heat advection to the snowpack by rain, coupled with turbulent heat exchange between the atmosphere and snowpack (Dingman 2002).

Surface water describes any water on the surface that is free to flow, including overland sheet flow, streams, rivers, ponds, and lakes. Surface water is lost to the following: evaporation, infiltration into the ground, and overland flow (e.g., runoff). It may be gained through precipitation events, by overland flow (e.g., runon) from surrounding landscape elements, or by exfiltration of water from an underlying saturated substrate (e.g., a seep). Where surface water does not exist, it is relevant to think of that "model compartment" as storing zero water; thus, throughfall or snowmelt can directly infiltrate the soil. Infiltration of water into soil can be limited under two conditions. The first is that water arrives at the soil surface faster than the soil can absorb it. This results in standing water on the surface and the potential runoff of that water. The second condition limiting infiltration is when the underlying soil is at or near saturation. The lack of space for water storage hinders infiltration. In the higher Sierra where soils are sparse and thin, both mechanisms may operate to result in a high proportion of rainfall becoming runoff.

Soil water is gained by infiltration of surface water or by the rise of groundwater from below. Soil water is lost by evaporation, transpiration to the atmosphere, and by percolation to saturated soil below (groundwater). Evaporation of soil water is decreased by a cover of plant litter on the soil surface. Transpiration is the loss of water through the stomatal openings in plant leaves. Transpired water is replaced by soil water taken up through plant roots.

Losses from transpiration are generally much larger than evaporative losses in Sierra Nevada ecosystems. This can give rise to the seemingly paradoxical increase in soil moisture when trees are removed from an area and bare soil is exposed to the elements. When calculating water balances, these two processes can be difficult to separate and are often considered together as evapotranspiration. Evapotranspiration is responsible for a significant 'loss' of water from the landscape. In the U.S., more than two thirds of precipitation is returned to the atmosphere by evaporation from plants and water surfaces (Dunne and Leopold 1978). Evapotranspiration is of high importance to plant growth and the main link between hydrologic cycle and ecosystems.

Soil water can flow laterally. The lateral

flow of water in unsaturated soils is very slow compared to saturated flow, which in turn is very slow compared to overland flow of surface water. Numerous seeps and springs are fed by slow unsaturated as well as saturated soil water flow. Where unsaturated flow feeds into shallower soils those soils may become saturated and exfiltrate water to the surface.

*Lakes, river, and stream ecosystems are discussed below, see "Aquatic System" models.*

### *Stressors*

The hydrologic system is intimately linked to the atmospheric system.

Changes in climate, and thus vegetation composition and structure, will alter the canopy storage capacity, thereby affecting evaporation and throughfall.

Snowpack has been decreasing over most of the West in recent decades (Mote et al. 2005), and spring stream flow has been occurring earlier (Stewart et al. 2004). Further, researchers in the Sierra Nevada have documented earlier snowmelt runoff, reduced summer base flows, and soil moisture (Dettinger et al. 2004, Dettinger 2005), and increased winter and spring flooding (Dettinger et al. 2004). There has been a trend towards lower snowpack volume at mid-elevations (Adam 1981, Knowles and Cayan 2001, Knowles et al. 2006), and smaller ratios of 'winter-total snowfall water equivalent' to 'winter-total precipitation' (Knowles et al. 2006).

### *Vital Signs*

We selected several vital signs that capture various aspects of the hydrologic system. These include surface water dynamics (e.g., streamflow, lake volume), wetland water dynamics (e.g., wet meadow and fen groundwater level, soil moisture, surface flows), meteorological parameters (e.g., precipitation, solar radiation, air temperature), snowpack (i.e. depth and water content), and landscape mosaics (i.e. glacial extent, snow cover).

## Model: Aquatic Systems

### *Introduction*

The Sierra Nevada parks protect a diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs and karst springs. Some of these aquatic systems have high biodiversity relative to the area they occupy in the parks (especially wetlands and meadows), some host endemic invertebrates (karst systems), and some provide habitat to sensitive and declining species (such as mountain yellow-legged frog in high-elevation lakes). Water dynamics in the Sierra Nevada are a critical component of both the parks' ecosystems and the larger California water infrastructure. The snow pack acts as a temporary reservoir, storing water that will be released during the warmer and drier months.

Hydrology of the Sierra Nevada is dominated by the winter wet, summer dry Mediterranean climate. Persistent winter snowpacks at higher elevations result in peak runoff in late May to early June. Runoff usually continues through the summer to supply flow to streams, but is typically very low by summer's end. Sierra Nevada ecosystems are adapted to drastic differences in water availability between seasons. As a result, temporal and spatial components of the hydrologic cycle are critical to these systems. Thus, hydrologic disturbances (drought, severe flooding) can have profound effects throughout the greater ecosystem.

In this section, aquatic system components, processes, and drivers (including the anthropogenic stressors) are described to provide a general framework for the aquatic vital signs. Three conceptual models are presented to describe major physical, chemical, and biological relationships of lotic and lentic systems in the SIEN:

1. Lake System
2. River & Stream System
3. Anuran Populations

### *Model: Lake System*

High-elevation lakes are critical components of the parks' ecosystems, popular visitor destinations, and habitat for aquatic and terrestrial organisms

including declining amphibian species. Lake ecosystems were selected for monitoring because they are valued for their ecological importance, recreational opportunities, and importance to regional water supplies, are threatened by multiple stressors and are sensitive to change. We will be monitoring three vital signs at high-elevation lake ecosystems: water chemistry, surface water dynamics, and amphibians.

The majority of Sierra Nevada Network lakes are located in the higher elevations (i.e., above 2500 m). Though a few lakes exceed 28 ha, most are only a few hectares in size and vary in depth from about 0.3 m to over 30 m. Sierra Nevada lakes are very dilute and characterized as oligotrophic, especially in the sub-alpine and alpine basins where there is sparse vegetative cover, shallow soils, and small contributing area. Sierra Nevada lakes have some of the lowest acid neutralizing capacity (ANC) concentrations in the western U.S. (Eilers et al. 1989).

With low nutrient concentrations, these lakes still support a variety of aquatic fauna including zooplankton assemblages, micro-crustaceans, macro-invertebrates, fish (primarily non-native), and amphibians (Boiano et al. 2005). Three amphibian species (discussed below), Sierra Nevada and Sierra Madre yellow-legged frog (*Rana sierrae* and *R. muscosa*), and Yosemite toad (*Bufo canorus*), are candidates for listing as 'endangered'. Current level of funding does not allow for a specific amphibian monitoring protocol; instead, we are working to integrate amphibian monitoring–at some level–into our Lake Monitoring Protocol).

### *Drivers, System Components, Functions—Lake Model*

Lakes are a dynamic heterogeneous ecological system with characteristics that change over short and long

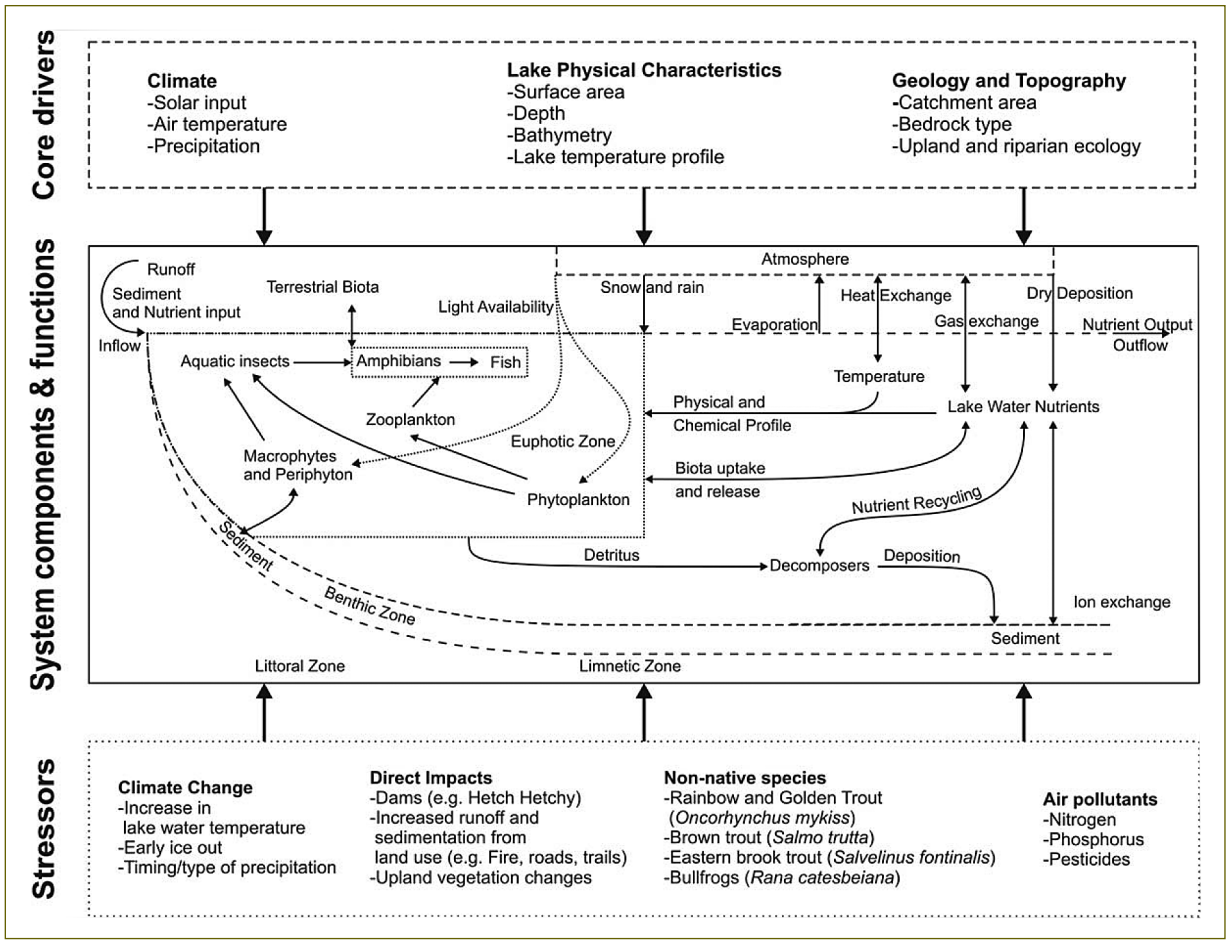



**Figure F–13.** Sierra Nevada Lake Conceptual Diagram.

time periods (Figure F–13). A lake is a function of its parent material, formation, and past climate evolving with present climatic conditions. Most lakes in the SIEN network are formed from glacial action. They were formed as glaciers scoured basins leaving a depression that was later filled with water. The watershed or drainage basin typically encompasses a small geographic area with shallow soil. Snowmelt is the primary water source. Geologic parent material, through weathering, provides ions to the lake system from overland and groundwater flow. The reduced soil contact and leaching of minerals produces the oligotrophic lakes in SIEN.

Climate is a core driver to the lake system. Precipitation provides the water source and timing of runoff inputs. Light drives the biotic lake processes. Light availability defines distinct lake zones where lake biota are linked to the unique topography of individual lake bathymetry. The euphotic zone is the depth in the lake where enough light penetrates to allow photosynthesis. This can be relatively deep in SIEN lakes because of water clarity. The littoral zone is where light penetrates to the lake bottom and rooted submergent, emergent, and floating aquatic plants or macrophytes and periphyton can grow. The limnetic zone is in the deeper waters of the lake where the sunlight needed for photosynthesis does not penetrate to the lake bottom. In the both the littoral and limnetic zones, phytoplankton are suspended in the water column and photosynthesize throughout the euphotic zone.

Water temperature is an important component of the lake ecosystem. The high specific heat of water allows for water to store large quantities of heat from the sun gained during the day and summer moderating lake temperature relative to air temperature. Water is less dense as a solid than a liquid, allowing for ice to form on the top of the lake. This insulates the lake allowing deep enough lakes to not entirely freeze. Water is most dense at 4° C (39° F). Following ice out, lake water temperatures are normally equal throughout the water column. Typically the bottom waters are 4° C, and the temperature decreases toward freezing (0° C) at the lake surface. With the ice out, more solar energy can penetrate the top layer of water increasing the water density as the temperature approaches 4° C. As the water in the lake nears the same density it becomes easier for the lake water to mix. With the addition of wind mixing the water, and near equal densities, the entire lake can turnover and mix completely. Turnover can also occur by this same process when the lake cools. The process of turnover can happen multiple times in a year.

As the surface temperature continues to rise during the summer, the upper layer becomes warmer than 4° C and more buoyant, eventually becoming too buoyant to mix with the deeper water, forming distinct thermal layers. The lake is stratified by density into three distinct layers. The upper layer or epilimnion is warmest and well mixed. The mixed layer is primarily dependent on lake size and wind. The bigger the lake, the deeper the wind driven mixing occurs. The thermocline is the layer below the epilimnion where the water temperature declines quickly. The hypolimnion is the bottom layer consisting of the most dense water.

The basic physical and chemical properties of the lake are further influenced by the aquatic biotic system supported by the lake. SIEN aquatic biota consist primarily of fish, adult and larval anurans, several snakes and birds, a few mammals, a number of aquatic vascular plants, benthic algae, zooplankton and phytoplankton (lakes), bacteria, fungi, protists, and a large and diverse invertebrate fauna. In addition, foothill rivers include one species of salamander and turtle. Some of the largest aquatic invertebrate taxa include larvae of mayflies, stoneflies, caddis flies, and various dipterans; adult and larval beetles; amphipods; several mollusks; mites; nematodes; flatworms, and annelids. The numerous invertebrate insect taxa metamorphose into adult terrestrial organisms that disperse beyond the wetlands to provide food to upland species as well as serve other terrestrial functions. Recent work

here in SIEN supports the hypothesis that wetlands are extremely productive and have a large net export of food to upland areas (Holmquist and Schmidt-Gengenbach 2006).

While the above taxa occur in most SIEN waters, individual species' distributions vary with elevation. For example, large bivalves found in foothill streams (*Margaritifera* sp.) are represented by smaller bivalves in subalpine lakes (*Pisidium* sp.). The aquatic garter snake (*Thamnophis couchii*), which is common in the foothills, is replaced by the terrestrial garter snake (*Thamnophis elegans*) at high elevations.

Food webs within Sierra parks are complex. Aquatic invertebrates provide food for many of the vertebrate and invertebrate food chains (see Invertebrate Model, infra). This includes both predation directly within the aquatic environment (e.g., dytiscids eating odonate nymphs) and predation on metamorphosed adults in the upland world (e.g. flycatchers eating mosquitoes). Fish are one of the major predators of both aquatic and terrestrial insects. They collect insects drifting in the water column (e.g., Chironomidae) as well as terrestrial insects that can be taken near the water's surface (e.g., adult mayflies). At high elevations, mountain yellow-legged frogs play a significant role in the aquatic community. Besides being a major predator of metamorphosed insects and occasionally treefrogs, they are a source of food for other vertebrate predators like garter snakes (*Thamnophis elegans* ), Clark's Nutcrackers (*Nucifraga columbiana*), and Brewer's Blackbirds (*Euphagus cyanocephalus*). Matthews et al. (2002) found a direct relationship between the abundance of garter snakes and mountain yellow-legged frogs.

Macrophytes (aquatic vascular plants), both submergent and emergent, providemultiple functions. In addition to providing basic photosynthesis and food for herbivorous fauna (e.g., meadow voles, Chironomids), macrophytes provide structure to aquatic habitat, cover for fauna, and substrate for periphyton (along with soil and rocks); they buffer erosion, absorb nuturients, and contribute organic detritus when they perish. This detritus provides food and habitat for aquatic insects (e.g., Baetidae).

### *Sub-Model: Anuran Populations*

#### Introduction

Amphibians are sensitive to changes in ecosystem conditions, including: introduction of nonnative species and pathogens (i.e., trout, chytrid fungus), habitat fragmentation and degradation (e.g., from packstock grazing), water quality (e.g., from toxics such as airborne pesticides), and climate (e.g., global warming, changes in hydrology) (Figure F–14) .

A recent Global Amphibian Assessment conducted by over 500 biologists (2000 to 2004) found that nearly one-third of all known amphibian species are globally threatened The Assessment concluded that amphibians are currently more threatened than other vertebrate groups such as birds or mammals (Stuart et al. 2004) . For North American fauna, amphibians have the second highest extinction rate (freshwater mussels being the first) (Ricciardi and Rasmussen 1999).

The loss of yellow-legged frogs is likely to have measureable impact on the natural functioning of lakes and streams within their historic range. Yellow-legged frogs are a sub-alpine and alpine predator (of primarily both aquatic and terrestrial invertebrates). They are also a major source of food for larger alpine predators such as western terrestrial garter snake (*Thamnophis elegans*).

Current funding does not allow for a separate amphibian monitoring protocol, but, because of their status and sensitivity as an indicator, we will integrate limited monitoring within our Lake Monitoring Protocol (see below; also, Appendix H, "Protocol Development Summaries").

#### Status of Anuran Populations

Two very rare, declining (State endangered; federal candidates for endangered status) yellowlegged frog species (*Rana sierrae* and *R. muscosa*) occupy upper elevations of SEKI and YOSE. Yellow-legged frogs were once

the most common vertebrate in the high elevation Sierra Nevada.(Grinnell and Storer 1924). Foothill yellow-legged frog (*Rana boylii*) formerly occurred in the foothills, but is now extirpated. Pacific treefrog (*Hyla regilla*) occurs at all elevations, in all parks. Yosemite toad (*Bufo canorus*) (State endangered; federal candidate for endangered status) breeds in ponds, wet meadows, along slow-flowing streams and empheral wetlands. Within SIEN, the species is found primarily in YOSE. It has also been documented in the northern portion of SEKI (Kings Canyon unit); however, distribution and abundance data are lacking. While not targeted within our Lake Monitoring Protocol, the Yosemite Toad (*Bufo canorus*) is endemic to the high Sierra Nevada. The Yosemite toad has disappeared from more than 50% of the sites where it was known to occur historically, and formerly large populations have been reduced in numbers (Jennings 1996).

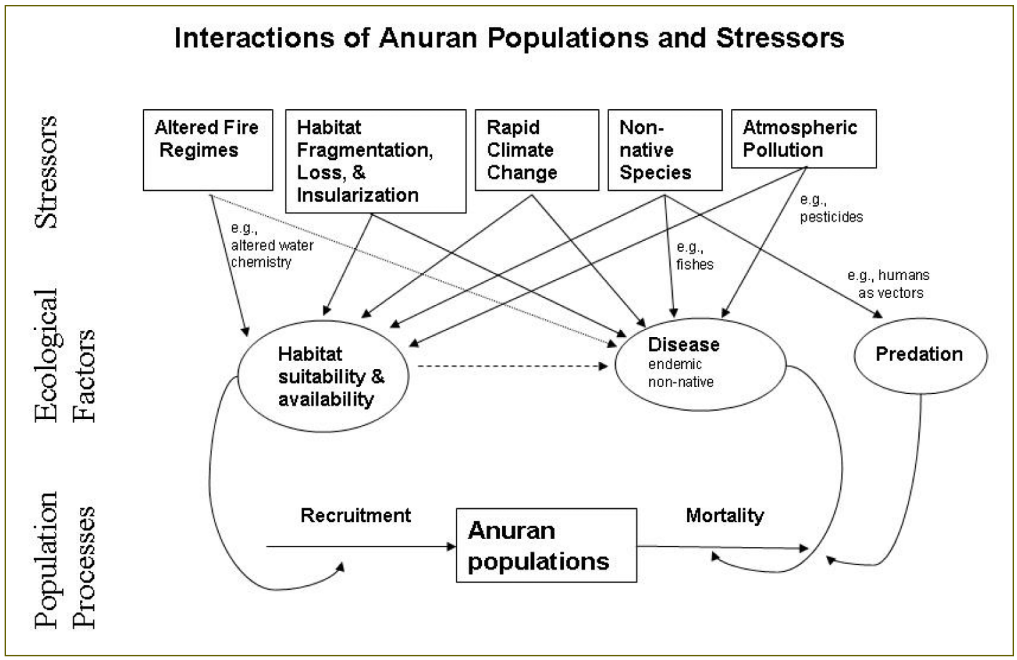



**Figure F–14.** Main interactions of anuran (frog and toad) populations and stressors.

## Stressors

### *Disease*

Amphibians are of particular concern because of an emerging infectious disease (chytridiomycosis, *Batrachochytrium dendrobatidis*) Chytrid fungus has now been determined as a proximate cause of mass mortality in both yellow-legged species (Rachowicz et al. 2006). Chytrid fungus has been found in Yosemite toads, including as early as 1970s (Speare and Berger, Green and Katarise-Sherman 2001, Vredenberg and Summers 2001); the impact of chytridiomycosis on population levels of this species has not been quantified.

Chytrid fungus had now been determined as a proximate factor in Sierra Nevada amphibian declines, causing death in post-metamorphic frogs (Rachowicz et al. 2005, Rachowicz et al. 2006) and infecting the keratinized mouthparts of tadpoles.



Rainbow Falls, Devils Postpile National Monument. NPS photo.

### *Competition*

Initially (i.e., before chytrid research), introduced fish were documented as a primary factor in declines of native lake-breeding amphibian species in the Sierra Nevada, including the precipitous decline of the yellow-legged frog (Bradford 1989, Bradford et al. 1993, Drost and Fellers 1996, Knapp and Matthews 2000, Knapp 2003a, Knapp 2003b, Knapp 2005).

### *Non-native Species—Predation and*

While trout are the most prevalent of

the introduced aquatic biota, they are not the only alien species of concern. Bullfrogs (*Rana catesbeiana*), introduced from eastern and central states, exist in several network parks (typically at lower elevations). Bullfrogs threaten native amphibians by eating tadpoles and could impact future opportunities for restoration of foothill yellow-legged frogs (*Rana boylii*).

### *Toxics*

Pesticides are also being examined in association with Sierra Nevada amphibian declines (Datta et al. 1998a, Sparling et al. 2001, Davidson 2004, Fellers et al. 2004). Of 11 western national parks studied as part of Western Airborne Contaminant Assessment Project, scientists detected the highest concentrations of pesticides in snow from Sequoia National Park (Hagerman et al., unpublished data, www2.nature.nps.gov/air/Studies/ air_ toxics/wacap.cfm).

## *Model: River & Stream System*

SIEN parks span seven major watersheds: Tuolumne, Merced, San Joaquin, Kings, Kaweah, Kern and Tule. Runoff from these watersheds drains into the San Francisco Bay/Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south.

Yosemite, Sequoia, and Kings Canyon parks contain most headwater streams for these watersheds. Devils Postpile National Monument is located within the upper Middle Fork of the San Joaquin watershed. The headwaters of the Middle Fork of the San Joaquin begin 14.1 km upstream of the monument at Thousand Island Lake. The watershed area above the monument is managed by Inyo National Forest.

Flow in Sierra Nevada rivers and streams is highly variable in time, both within and between years. Peak flows can be up to five orders of magnitude greater than minimum flows. Annual volumes can be twenty times greater in very wet years than in very dry years (Kattelmann 1996). Some smaller streams cease flowing during prolonged dry periods.

High water levels are an integral feature of Sierra Nevada Rivers and have a variety of effects on aquatic biota as well as channel morphology (Erman et al. 1988, Kattelmann 1996). Peak flows in the Sierra Nevada result from snowmelt, warm winter storms, summer and early-autumn convective storms, and outbursts from storage (Kattelmann 1990). In rivers with headwaters in the snowpack zone (true of all SIEN rivers), snowmelt floods occur each spring as periods of sustained high flow, long duration, and large volume. Midwinter rainfall on snow cover has produced all the highest flows in major Sierra Nevada rivers in the past century (Kattleman et al. 1991). The last such flood of this type with high impacts to SIEN parks' infrastructure and aquatic systems occurred in January 1997 (Figure F–15).

At the other extreme, stream flow into Sierra Nevada rivers can become quite low during intense or extended droughts. The past two decades have included record droughts for one year (1977), two years (1976-1977), three years (1990-1993), and six years (1987-1992). Total stream flow averaged across many Sierra Nevada rivers was about half of average in each case (Kattelmann 1996). Changes in precipitation type and timing that are expected with climate




**Figure F–15.** Yosemite Valley campground during flooding event in the Merced River, January 1997 (100-year flood). Such floods are predicted to increase due to climate change in the Sierra Nevada (Knowles et al. 2006). Photo by Steve Thompson.

change will result in longer and drier summers with less water available for ecosystems and regional economic uses.

The Sierra Nevada is generally regarded as producing surface water of excellent quality, meaning the water is suitable for almost any use and contains lower amounts of contaminants than specified in state and federal standards. Most runoff would be suitable for human consumption except for risk of pathogens (Kattelmann 1996). Very little of the water of the Sierra Nevada can be considered highly polluted (i.e., contaminated with materials having potential adverse effects at concentrations above background level).

Areas of lower water quality correspond to those areas with greater human activities and access. While SIEN park waters are of high quality compared to waters in agricultural and urban areas in the state, there are still a number of threats to park water quality that will be discussed in the Drivers section below.

### *Drivers, System Components, Functions—River & Stream Model*

SIEN streams encompass the headwaters of seven major watersheds. These watersheds, from north to south, are the Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule and Kern. Runoff from these watersheds drains into the San Francisco Bay/ Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south. Our stream system model includes core drivers, system components and functions, and stressors (Figure F-17).

Stream processes in SIEN parks are driven by the Mediterranean climate and snow melt. Peak runoff is typically May-June (Figure F–16) and punctuated by large flood events (e.g., January 2007). See the Hydrologic System Model, supra, a for more detailed discussion. Water chemistry has a spring pulse of ions flushed from the snowpack during the early stages of spring melt. The low ionic strength of the stream waters are susceptible to changes in atmospheric inputs, and increases from fire in the catchment.

Streams move water, sediment, and

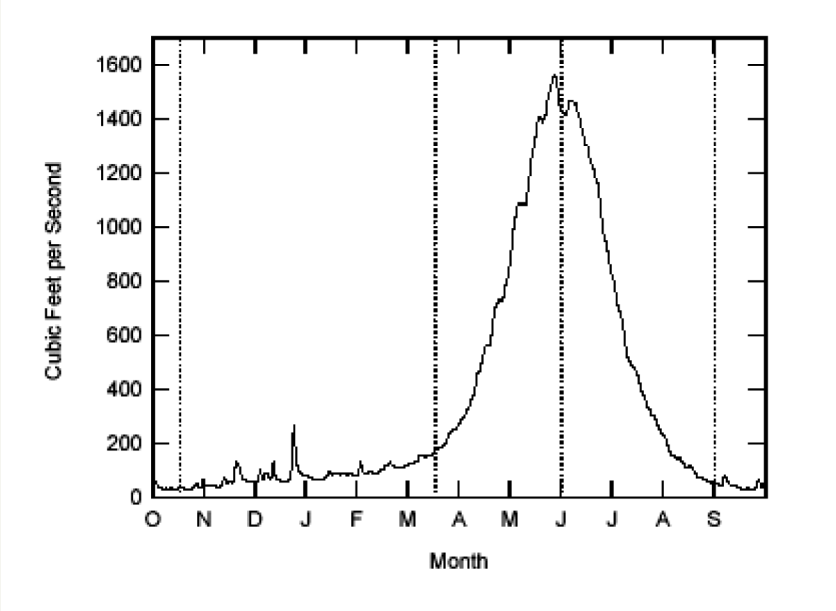



**Figure F–16**. Representative mean annual hydrograph from the Merced River at Happy Isles in Yosemite National Park. National Park Service—Water Resources Division plotted the hydrograph using a 72 year record (National Park Service 1998). Vertical lines divide the hydrograph into four seasons.

nutrients altering landforms with erosion and deposition. The stream system receives inputs from precipitation into the watershed basin, and moves water and sediments downstream shaping the landscape through fluvial processes. Stream processes alter existing landforms, reducing topographic relief.

Stream water is a function of direct precipitation to the stream channel, runoff from the basin, evapotranspiration, and groundwater flow. Over time, geology and topography define the drainage pattern. Streams develop onto areas that are less resistant to erosion.

Erosion drives the stream load which is comprised of the dissolved load, suspended load, and bed load. Most organisms are near or on the substrate, and are largely dependent on flowing water.

Slope and sediment availability define the channel type. A stream with little slope, fine sediments, and strong bank cohesion will usually have a meandering stream channel. A stream with coarse sediment tends to have a braided channel. The stream's "long" profile generally is concave up with headwater slopes typically steeper than those near the stream mouth.

In-channel stream processes are dynamic, adjusting the stream-wetted perimeter in a response to stream competency, sediment size, grade, and water velocity. Headwaters typically have a high stream velocity, moving larger sediments both along the bed, and in suspension with turbulent flow through a V shaped valley. As the stream flows into lower gradient areas stream competence is lowered. The stream velocity decreases, turbulent flow is not enough to support the larger suspended particles, which are deposited creating a braided channel. The aggradation spreads the stream flow across a greater wetted perimeter allowing more of the heavier sediments to be moved as bed flow.

As the stream flows farther into lower-slope areas, finer sediments dominate the stream capacity. The finer sediments are suspended and transported with lower flow creating a more sinuous stream channel. A meandering stream is U shaped, and has a high sinuosity ratio—it travels a much farther distance through the channel when compared to linear travel distance. A straight channel has a low sinuosity ratio. The spiral flow of the stream creates a preferential outside bank cut and depositional point bar on the inside bank.

Meandering rivers create fluvial landscape features such as back swamps, wetlands, and oxbow lakes. SIEN streams show meandering stream characteristics in wetland (i.e., wet meadow) areas such as Yosemite Valley, and Tuolumne Meadows supporting a large diverse riparian area.

Riparian systems form a dynamic and intricate buffer strip along stream banks between base-flow and high water levels. The riparian zone helps slow runoff and is an important nutrient source and sink. Riparian vegetation provides bank stabilization, organic matter input such as

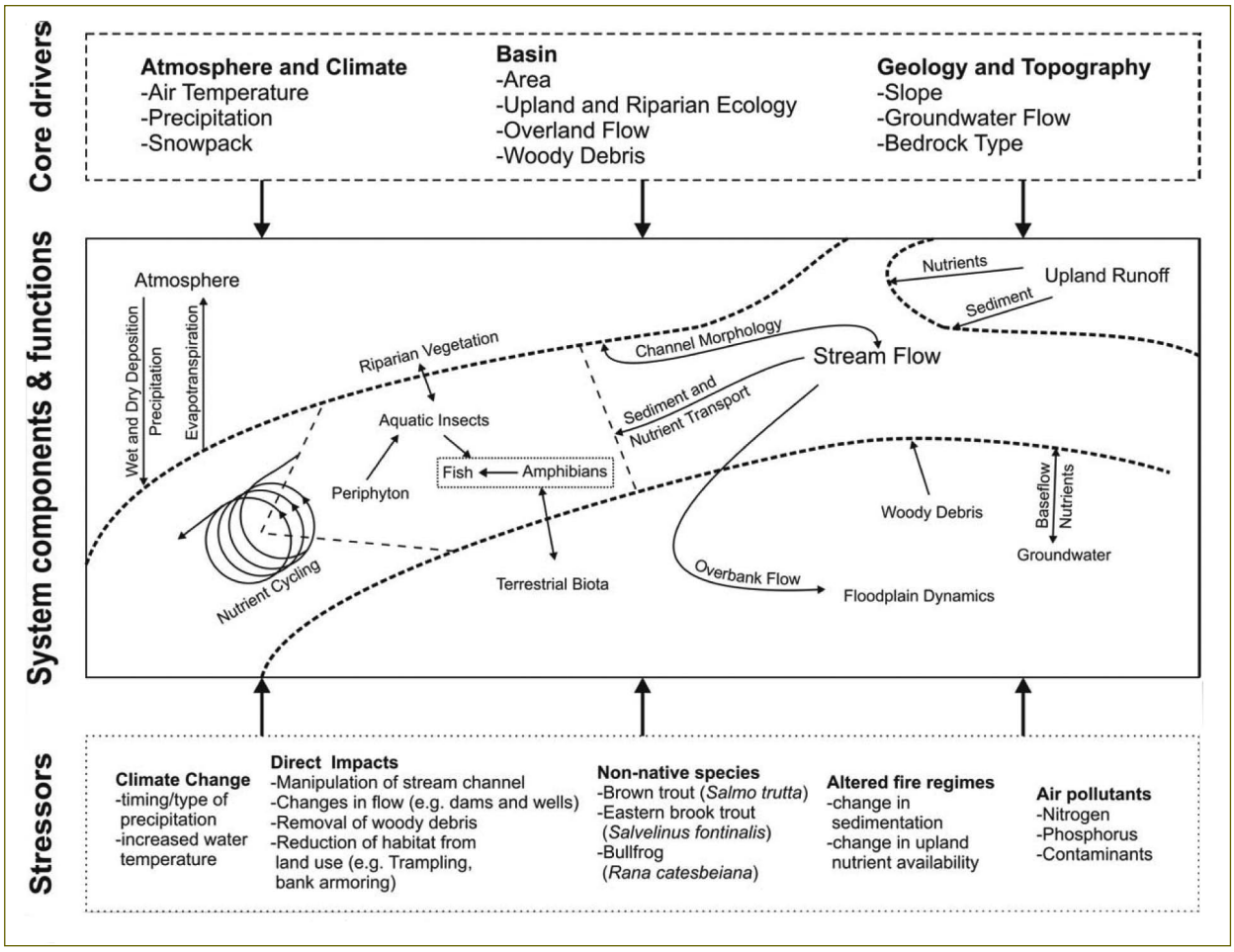



**Figure F–17.** Sierra Nevada river and stream conceptual diagram.

woody debris, and habitat. Large terrestrial woody debris alters channel hydraulics and provides unique aquatic habitat.

Periphyton and riparian vegetation cycle nutrients delivered by the stream system.

Aquatic organisms, including microorganisms and mayfly nymphs, break down organic matter, and are a food source for fish and amphibians creating a spiraling effect on stream nutrients of storage in stream biota and transport in stream flow. Nutrients are accumulated by aquatic organisms and cycle between organic and inorganic forms while slowly being moved downstream with spiral length being an indicator of metabolic activity.

### *Aquatic System Stressors: Lakes, Rivers & Streams*

Aquatic systems are among the most altered ecosystems in the Sierra Nevada (SNEP 1996). Introduced alien invasive species caused much of this alteration. For over a hundred and thirty-five years, trout were planted in park waters, both in areas that contained native fish populations and in waters that were naturally barren of fish (Christensen 1977). The effects of these introductions on lentic environments have been to eliminate large zooplankton (e.g. *Hesperodiaptomus* sp.), (Stoddard 1987, Bradford et al. 1998) and open-water insects (e.g., Corixidae).

When comparing streams with and without introduced trout, Herbst et al. (2003) found streams with introduced trout to have more and denser algae cover, more midges, and reduced density of *Doroneuria baumanni*, a stonefly that was probably the dominant predator prior to trout introductions. Native fish were impacted directly by competition with introduced brown trout (*Salmo trutta*) and eastern brook trout (*Salvelinus fontinalis*), and by genetic introgression from introduced genotypes of rainbow and golden trout (*Oncorhynchus mykiss*). Little Kern golden trout (*Oncorhynchus mykiss whitei*) became federally listed as threatened after being nearly extirpated by introduced trout. Knapp (2005b) found an inverse relationship between the presence of introduced fish and garter snakes. This is likely due to introduced trout eliminating a major source of the garter snake's diet, i.e., mountain yellow-legged frogs. Introduced fish impacted the distribution and abundance of the mountain yellow-legged frogs (Knapp and Matthews 2000) by eating their larvae and some adults, by displacing frogs from deep lakes critical to their winter survival, and by fragmenting populations which destroyed functionality of their metapopulations.

In addition, mountain yellow-legged frogs have experienced dramatic population losses from a newly discovered fungus, *Batrachochytrium dendrobatidis*, which causes chytridiomycosis, a condition that destroys keratin in frog skin and results in death. This fungus was only discovered in the early 1990s, and the current available information suggests that it too has been introduced (Weldon et al. 2004, Rachowicz et al. 2005). The parks' waters receive considerable input from agricultural pesticides (Cory et al. 1970, Zabik and Seiber 1993, Aston and Sieber 1997, Datta et al. 1998a, Datta et al. 1998b, McConnell et al. 1998, LeNoir et al. 1999, Angerman et al. 2002). It is not know if these chemicals weaken a frogs' susceptibility to chytridiomycosis, but recent studies have showed endocrine disruption (Sparling et al. 2001, Fellers et al. 2004). Further, there exists an inverse relationship between pesticide use and downwind occurrence of frog populations (Davidson 2004).

While trout are the most prevalent of the introduced aquatic biota, they are not the only alien species of concern. Bullfrogs (*Rana catesbeiana*), introduced from eastern and central states, exist in several network parks. Bullfrogs threaten native turtles by eating their young (Jennings and Hayes 1994), and could impact future opportunities to restore foothill yellow-legged frogs (*Rana boylii*). An non-native amphipod (Hyalella azteca) was introduced into the Rae Lakes, and now they have become the most abundant species in plankton tows (Silverman and Erman 1979). On the North Fork Kaweah, *Potamogeton*

*crispus*, a plant from Eurasia, has become common and may be competing with native Potamogeton sp..

As mentioned, SIEN parks have some of the worst air quality in the country (Peterson and Arbaugh 1992, Cahill et al. 1996). Among air contaminants, are ionic forms of nitrogen that contribute to episodic pH depression and to nutrient deposition in both upland and aquatic systems. Effects of acidification on aquatic systems were examined on aquatic systems in the Emerald Lake basin in the 1980s. In lentic environments, Sickman and Melack (1989) found no inhibition of phytoplankton growth above a pH of 4.0. Certain species of zooplankton (e.g., *Daphinia rosea* and *Diaptomas signicauda*) virtually disappeared when pH was reduced below 5.0, but density of certain other species increased with certain levels of acidification (e.g. *Kerotella taurocephala* and *Bosmina longirostris*), probably due to a lack of competition from *Daphinia rosea* (Melack et al. 1989). Melack et al. (1989) did not find a relationship between benthic invertebrates and acidification. In lotic environments, acidification down to pH levels between 4.6 and 5.2, for time periods of 6-8 hours, increased insect drift and the proportion of dead organisms within the drift (Hopkins et al. 1989, Kratz et al. 1994), though different taxa showed different levels of susceptibility and some groups showed no response to acidification (Kratz et al. 1994).

*Climate*

Most atmospheric water in the Sierra Nevada originates as water vapor from the Pacific Ocean. This moisture is transported across California and precipitated as rain or snow.

Rain is the dominant precipitation type at the lower elevations (less than 1,500 m) and snow is the dominant type at higher elevations (above 1,500 m). Warming climatic conditions have the most potential to alter snowpack storage; current models predict lower snowpack volume at mid-elevations (Knowles and Cayan 2001) and earlier melting at all elevations (Dettinger 2005). Glaciers, which store water year-round, have been shrinking throughout the west for the past several decades (Basagic).

*Air Pollutants*

Contaminants and nutrients, produced from agricultural, urban, and industrial sources in the San Francisco Bay Area and the Central Valley, are transported by air currents into the Sierra Nevada where they are deposited as wet or dry deposition. Increased nitrogen deposition in the Transverse Ranges of southern California, low elevations in the southern Sierra Nevada, and high-elevations in the Colorado Rocky Mountains has already led to excessive leaching of nitrate into receiving waters (Fenn et al. 2003).

Elevated nitrate concentrations in streams are a primary symptom of N-saturated ecosystems (Fenn et al. 1998). High elevation lakes and streams in the Sierra Nevada are especially sensitive to change from atmospheric deposition because the waters are oligotrophic and have a low buffering capacity. In addition, alpine watersheds have a low capacity to retain nitrogen primarily due to steep talus slopes, shallow soils, and sparse vegetation. Changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes have been detected and attributed to increased nitrogen and phosphorous inputs (Goldman et al. 1993, Sickman et al. 2003). Rates of nitrogen loss and their controlling mechanisms vary along the elevational gradient. Mid-elevation mixed-conifer forests, especially giant sequoia, are more effective at retaining nitrogen than ecosystems near the elevational extremes (e.g. chaparral and alpine) (Stohlgren 1988, Melack et al. 2002, Fenn et al. 2003).

Pesticides from the adjacent Central Valley (LeNoir et al. 1999) and global sources (National Park Service Air Resources Division 2003) have been detected in Sierra Nevada streams and lakes at all elevations. The extent of the effects on aquatic ecosystems is largely unknown; however, current research suggests that pesticides may be a threat to aquatic species, including declining amphibian populations (Sparling et al. 2001, Davidson and Shaffer 2002).

*Altered Fire Regime*

Over 100 years of fire suppression polices have altered fire regimes in the Sierra Nevada Network parks. In general, fire frequencies have decreased and the potential for higher severity wildfires has increased (Swetnam 1993, Caprio and Lineback 1997, Caprio 2004). Potential effects on water resources from a lack of fire are reduced stream flows, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998, Moore 2000). Less frequent but higher severity wildfires have the potential to impair water resources. Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003). Deposition of ash particles in the surrounding landscape may contribute to increasing nutrient inputs to oligotrophic waters (Spencer et al. 2003).

Since 1968 and 1970, Sequoia and Kings Canyon, and Yosemite National Parks have used fire extensively as a tool to reduce fuel loads and restore the natural processes of fire to park ecosystems (Caprio 1999). Although the parks' fire management programs made significant progress in the last 35 years, altered fire regimes are still considered one of the largest threats to the parks' ecosystems (Sequoia and Kings Canyon National Parks 1999). Changes in fire frequency and intensity affect sediment transport, water chemistry including nutrient dispersal, water quantity by altering evapotranspiration, and stream canopy cover which in turn affects light penetration and water temperature.

Chan (1998) found that increased fine sediment input caused by prescribed burns reduced macro-invertebrate diversity the following year. Water quality research in the parks has focused on the effects of prescribed burning on hydrology, stream chemistry and nutrient cycles. Increases in stream flows and solute concentrations were detected following prescribed fires in headwater streams of Sequoia National Park (Williams and Melack 1997b, Heard 2005). However, solute concentrations were still well below levels that would threaten aquatic ecosystems. Long-term monitoring with repeated prescribed burning are needed to determine if these increases were within the natural range of variability. Effects of prescribed burning on stream flows or water quality have not been detected at the landscape scale (Heard 2005). The effects of a large, high-severity wildfire are likely to be more pronounced and detectable at larger scales.

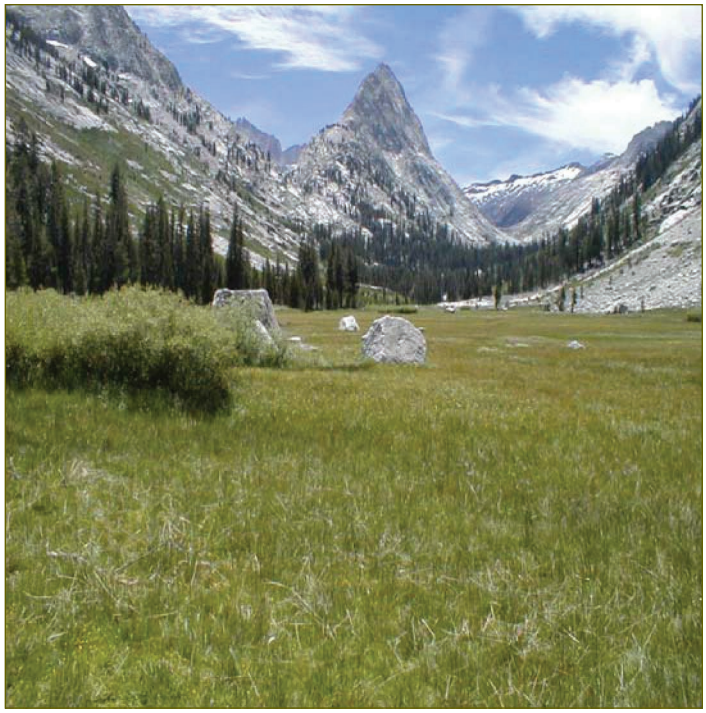
*Direct Impacts: Impoundments and Dams*

Six major water impoundments occur in SIEN parks. There are four large impoundments within Sequoia National Park. All four were built on existing lakes in the upper East Fork of the Kaweah River in the early 1900s and are currently operated by Southern California Edison. Numerous small impoundments also exist in small creeks primarily used for water supplies. There are at least 18 water diversions and seven wells within the park boundary.

Yosemite National Park contains two major impoundments: Hetch Hetchy (4.45 x 108 m3) and Lake Eleanor (3.34 x 107 m3). Hetch Hetchy, which impounds the Tuolumne River, was created in 1938 with the completion of O'Shaughnessy Dam. Hetch Hetchy Reservoir is part of the larger Hetch Hetchy Regional Water System that supplies drinking water to the City of San Francisco and irrigation water to the Central Valley.

Lake Eleanor was created in 1918 and the water is used primarily for hydroelectric power. Cascades Dam, located on the Merced River downstream of Yosemite Valley since 1918, was recently removed and the river corridor restored. Numerous small dams and diversion are located throughout the park; most of these are associated with the High Sierra Camps.

SIEN parks have numerous wells for drinking water sources. Most of the larger wells are located in various developed areas in the parks. Groundwater pumping from wells located in Yosemite's Doghouse Meadow and potentially other park fens



Big Wet Meadow, Kings Canyon National Park. NPS Photo.

are changing the soil and vegetation type in sections of these wetlands (see Heard and Stednick, and also, Appendix C, "Air Quality Synthesis").

Areas of general park operations or high visitor use are sources for nutrient and contaminant inputs to aquatic systems. Sources include sewage treatment plants, pack stations, campgrounds, roads, and popular swimming holes. Elevated concentrations of nutrients have been detected downstream of park spray fields (Sequoia And Kings Canyon National Parks 1999b), and fecal coliform counts have been observed in popular Yosemite swimming holes (Williamson et al. 1996). However, at a larger scale, research in Sierra Nevada wilderness lakes, rivers, and streams shows concentrations of coliform and other human pathogens are very low (Derlet and Carlson 2002, 2003).

Recreational and administrative packstock grazing in wetlands/meadows within SIEN parks can affect aquatic systems through effects of trampling, erosion, and additional nutrients on wetland systems and adjacent lakes and streams. Human use has also had measurable impacts to aquatic biota. Taylor and Erman (1979, 1980) found that growth of aquatic macrophytes and benthic invertebrates increased with increasing human use of lakes, and hypothesized that growth stimulation was from plant nutrients acquired from human presence.

Potential acid rock drainage from abandoned mines in the upper San Joaquin River watershed above Devils Postpile and in the Mineral King area of Sequoia National Park could degrade water quality in portions of these watersheds. Impacts on water quality have been observed from one mine in Sequoia. Impacts from other mines and cumulative impacts at a larger scale have not been quantified.

### *Vital Signs—Lakes*

The SIEN plans to monitor water chemistry and surface water dynamics (or flow) in selected lakes, rivers, and streams. Flow (or discharge) is the most fundamental aspect of watershed hydrology (Figures F-13 and F-17).

Water chemistry components measured will include: pH, dissolved oxygen, specific conductance, temperature, major ions, acid neutralizing capacity, nitrate, dissolved organic nitrogen, total dissolved nitrogen, total dissolved phosphorus, particulate nitrogen, particulate carbon, particulate phosphorus.

Surface-water dynamics' measures include: lake outlet discharge lake elevation, lake volume. Phenological measures, including timing and duration of ice-out and ice-up, may be included as part of our Landscape Dynamics protocol, if possible.

Relative anuran abundance (adults, tadpoles, egg masses) and species distribution are measures for three targeted amphibian species: Sierra Nevada and Sierra Madre yellowlegged frogs, and Pacific treefrog.

### *Vital Signs: Rivers & Streams*

River and stream indicators have not yet been determined, but will occur during protocol development (see Appendix H, "Protocol Development Summaries").

Water chemistry components have not yet been selected, but surface water dynamics measures will include stream

discharge (peak flow/low flow/water yield) and qualitative estimate of flow relative to bank full.

## Model: Wetlands

### *Introduction*

Wetlands are the boundary between aquatic and terrestrial ecosystems. They are a transition zone with an important role in biogeochemical cycles (especially carbon, nitrogen, sulfur). This interface creates an area of high biodiversity, which is sensitive to local, regional, and global stressors, making wetlands a unique ecosystem focal point to monitor.

Wetlands are diverse and complex ecosystems varying widely in character and composition although they occupy only a small fraction (<1%) of the land surface of the Sierra Nevada (Benedict and Major 1982, Ratliff 1982). Sierra Nevada wetlands range in size from small patches to large expanses, such as Tuolumne Meadow in Yosemite.

Despite this variability, the processes that govern the creation and maintenance of wetlands can be generalized in a simplified model. Our conceptual model illustrates the main functions, components and processes operating in Sierran wetlands (Figure F–18), and the key drivers and stressors affecting these systems (discussed below).

Wetlands are a hydro-geologic concept: (1) they are ecosystems with seasonally or periodically saturated and anoxic soils, and (2) their hydrologic regime is driven by surface and/or ground water. In addition to hydrology and hydric soils, wetlands are characterized by vegetation.

There are several major types of wetlands in the Sierra Nevada (and mountain regions throughout the world). In SIEN, we classify wetlands according to Cooper et al. (Cooper et al. 2005):

> **Dry Meadows**: too dry to support trees due to a steep gradient or south facing aspect, summer aridity; fine grained or gravel soils, and competition for water that allows grasses to

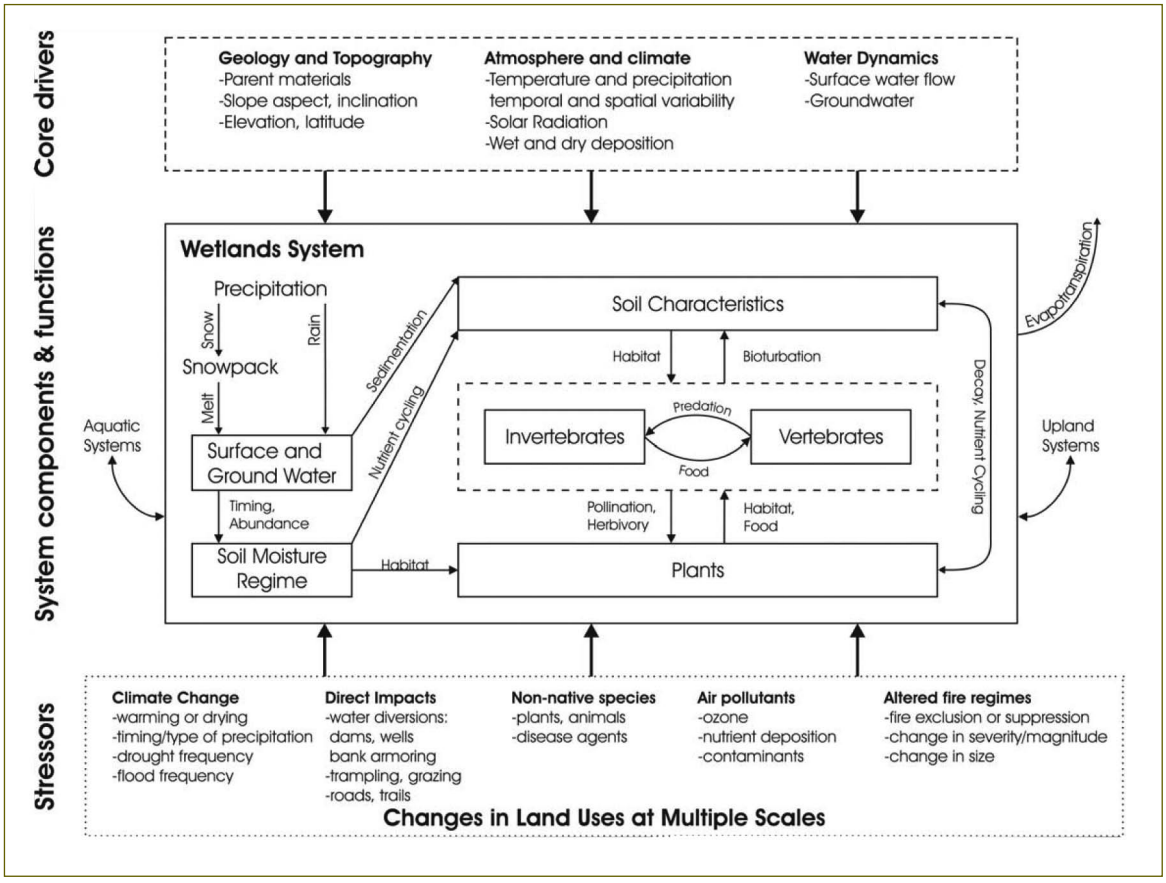



**Figure F–18.** Wetland system conceptual diagram.

dominate.

**Wet Meadows**: typified by seasonal saturation or flooding, high water tables, mineral soils, and too wet to support most tree species.

**Riparian Meadows**: driven by hydrologic and geomorphic processes of streams or rivers.

**Fens**: perennially saturated and anoxic soils (limits organic matter decomposition), organic matter production>decomposition, organic matter accumulates (average ~20 cm/1000 yrs) , peat accumulation creates landforms, numerous fen types.

### *Drivers, System Components, Functions*

Wetlands are a vital sign for long-term monitoring in the Sierra Nevada because of their high biodiversity relative to area occupied, and the important ecosystem, cultural, and social functions they provide. Sierra Nevada wetlands have the following functions (Williams 1990, Mitsch and Gosselink 1993):

- Influence regional water-flow regimes including flood mitigation by intercepting and slowing the release of water to streams
- Improve water quality by removing nutrients and toxins
- Trap sediments
- Are highly productive
- Provide important habitat for wildlife
- Have aesthetic value to the people who visit them

Core drivers of Sierran wetlands include geology and topography, atmosphere and climate, and water dynamics.

Geology and topography create the physical structure necessary to produce a wetland. Glaciation, sedimentation, and fluvial processes establish the basic landscape needed to develop a wetland. Geologic parent material defines some of the physical parameters of a wetland such as hydraulic conductivity and nutrient availability from weathering. Local topography such as slope, aspect, and inclination affect runoff rates, precipitation distribution, snow load, and solar input.

Elevation and latitude affect precipitation amounts, snow pack, and snow melt timing. Atmosphere and climate determine the amount and type of precipitation. Timing and amount of precipitation primarily drives the inundation of wetlands. Nutrient, water, and sunlight availability combine to provide the unique wetland habitat niche where wetland plants can dominate.

Wetlands form in level to near-level catchments, where soils are saturated or inundated at least part of the year, as in basins formerly occupied by glacial lakes or along perennial stream courses. Prolonged saturation of the soil creates an anaerobic environment. When saturation is combined with microbial activity, oxygen is depleted creating a reducing environment. The anaerobic environment produces wetland soil characteristics such as a thick layer of organic matter from slowed decomposition in the upper soil profile, and oxidized root channels, gleying, and mottling from the reduction and translocation of elements such as iron and manganese. The resultant hydric soil supports hydrophytic vegetation that is an attribute of a functioning wetland.

Sierran wetlands occur in basins, on slopes, along streams, and adjacent to lakes and ponds. Wetlands generally occur above snowline, where snow (namely snowmelt) provides moisture during the summer growing season. In addition to surface flow, moisture enters wetlands from rivers, streams, and sub-surface flows forced to the surface by local geomorphology. Meadows are characterized as wet, moist or dry, reflecting the relative availability of moisture during the summer growing season.

Solar radiation provides the energy to physically and biologically drive the system. Amount, duration, and intensity of solar radiation determine temperature, growing season, and rate of evapotranspiration. Ambient temperature dictates whether precipitation is rain or snow, and the timing and speed of snowpack melt. Sierra Nevada wetlands generally occur above snowline, where snow pack

determines the length of the growing season, and snowmelt provides moisture during the summer growing season.

Wetlands provide important ecological and cultural functions. Some of the functions described by Mitsch and Gosselink (1993) and Williams (1990) that apply to Sierra Network wetlands include: (1) influencing regional water-flow regimes, including flood mitigation, by intercepting and slowing the release of water to streams, (2) improving water quality by removing nutrients and toxic materials, (3) sediment trapping, (4) sources of some of the highest productivity in the world, (5) important habitat for wildlife, and (6) aesthetic values to people. Peat-accumulating wetlands, in their natural condition, remove and store carbon. If altered, such as by drainage, the process would reverse contributing to atmospheric carbon dioxide through oxidation (Gorham 1991). Wetlands also play an important role in nitrogen and sulfur cycles.

Wetland areas typically slow surface water flow allowing for increased sedimentation and infiltration during peak flows. They serve as a reservoir for water that is slowly expended through drier seasons. In addition to surface flow, moisture enters wetlands from sub-surface flow forced to the surface by local geomorphology. Geologic parent material helps to determine permeability, infiltration, and pore space that control water flow through the hydric soil.

Nutrients weathered from upland landscapes are transported in surface and sub-surface water and delivered to wetlands along with nutrients scavenged from the atmosphere as wet and dry deposition. These nutrients are cycled by biota, and leached in surface and subsurface flows. Additional nutrients are moved into and out of wetlands as fauna move between upland and wetland areas. In organic soils, the anaerobic conditions usually allow for accumulation to exceed decay resulting in a thick muck or peat layer. In mineral soils, elements can be reduced and leached or reduced and reoxidized depending on the length of time the soil is saturated.

Sierra Nevada wetland vegetation is dominated by perennial graminoids, which reflect the relatively short growing season of the middle and high elevations. Key genera include *Carex, Deschampsia, Calamagrostis, Juncus, Danthonia*, and *Eleocharis*, with species composition of individual wetlands determined by local moisture regime and soil characteristics. Annual productivity of wetland graminoids is closely tied to the amount and timing of winter snows as well as changes in length of growing season associated with such fluctuation; when late lying snows shorten the growing season, productivity declines accordingly. Upland woody plants are generally excluded from wetlands because of seasonally saturated soils. However, willows (*Salix* spp.) are frequently found along stream channels and often form patches within wetlands. Lodgepole pine, *Pinus contorta*, with a high tolerance for saturated soils, is commonly encountered in and adjacent to wetlands—taking hold during dry years and giving way to wetland vegetation under setter conditions, in a cycle of invasion and retreat.

Wetlands provide critical breeding and foraging habitat for a suite of animal species. Mule deer take advantage of the cover provided by montane wetland vegetation by hiding their fawns under the dense herbaceous canopy. Small mammals, such as Belding ground squirrels, pocket gophers, deer mice, and voles, feed on wetland vegetation, and ground squirrels and pocket gophers play a significant role in soil perturbation. Frogs and toads may breed in wetlands, and shrews frequent the moist vegetation preying on insects and other invertebrates.

A number of bird species, such as the federally endangered Willow Flycatcher (*Empidomax trailii*) and state-endangered Great Grey Owl (*Strix nebulosa*), use Sierra Nevada wetlands for foraging, nesting, or both. Mule deer take advantage of the cover provided by montane wetland vegetation by hiding their fawns under its dense herbaceous canopy. Small mammals (e.g., ground squirrels, mountain beaver, pocket gophers, and voles), feed on both above- and below-ground wetland



Sampling invertebrates in Tuolumne Meadow, Yosemite National Park. Photo by Jutta Schmidt-Gengenbach.

vegetation, playing a significant role in decomposition through soil perturbation.

Recent work by Holmquist and Schmidt-Gengenbach (Holmquist and Schmidt-Gengenbach 2006) in Sierra Nevada Network parks demonstrates the importance of wetlands as breeding grounds for invertebrates, which form the energetic basis of many food chains. Many insects breed in wetlands, and disperse into adjacent forests and woodlands as the season progresses.

Invertebrates also serve as pollinators for montane and high elevation plants.

*We present an individual invertebrate conceptual model below (narrative and diagram, Figure F-19).*

### *Stressors*

Wetlands are susceptible to the same stressors that affect the Sierran parks as a whole. Climate change has the potential to shift the species composition of mountain wetlands through changes in the timing and amount of snowmelt and subsequent alteration of the underlying hydrology of local systems. Experimental manipulations in the Rocky Mountains demonstrate that increased temperatures can lead to a general drying down of mountain wetlands with subsequent invasion by woody species such as sagebrush, influence carbon fluxes (Saleska et al. 1999), and cause shifts in timing of flowering of wetland species (Dunne et al. 2003).

Although Sierran high elevation wetlands have so far proven to be relatively resistant to invasion by non-native plants (Gerlach et al. 2003b), wetlands in the lower montane are demonstrably susceptible to invasion by the non-native Kentucky blue grass (*Poa pratensis*), which now dominates some heavily grazed wetlands (e.g., wet meadows) in Sequoia and Kings Canyon National Parks (Neuman 1990, Gerlach et al. 2003). Dandelion (*Taraxacum officinale*), a common invader of mountain wetlands worldwide, is also frequently encountered in disturbed wetlands and riparian areas of the Sierra, especially in those that are heavily grazed. Velvet grass (*Holcus lanatus*), Himalayan blackberry (*Rubus discolor*), and Bull thistle (*Cirsium vulgare*) are found in wet meadows in Yosemite Valley, Wawona, and elsewhere in the Park.

Nitrogen pollution from atmospheric deposition has the potential to affect productivity and species

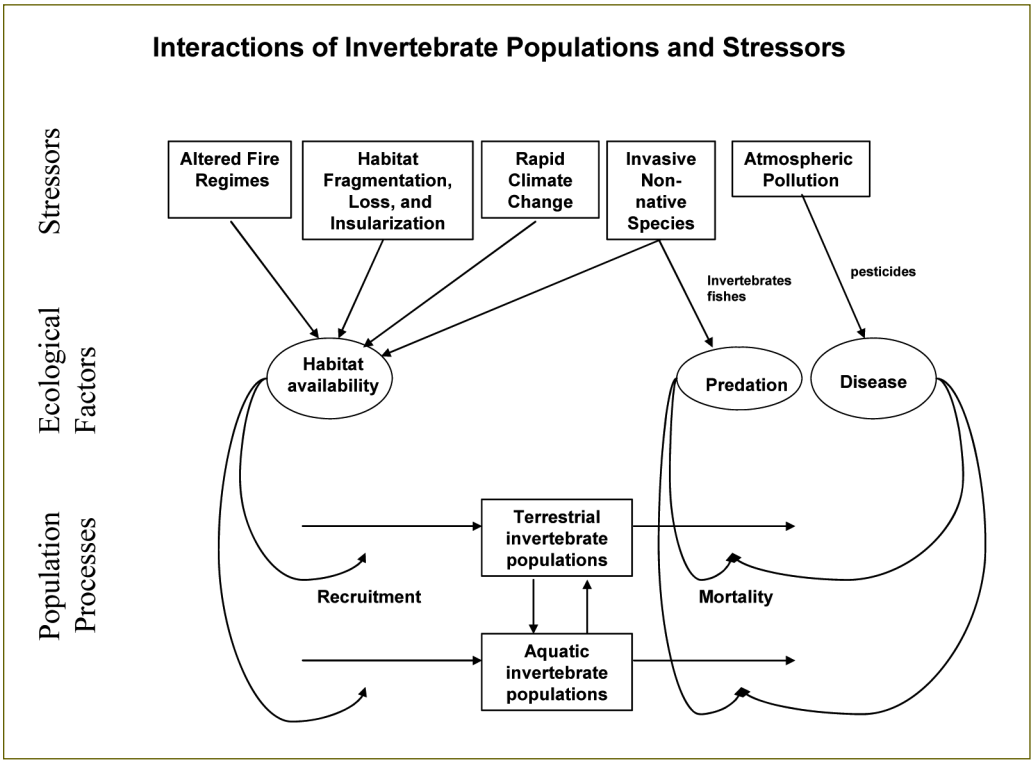



**Figure F–19.** Main interactions of invertebrate populations and stressors.

composition of wetland vegetation, and depending on seasonal timing, may affect aquatic organisms such as algae and microbes (see "Nitrogen Model," infra). Affects to the primary producers of the aquatic food chain has the potential to significantly alter all wetland biota. Atmospheric deposition of pesticide contaminants has the potential to adversely impact aquatic biota through estrogenic effects from low concentrations, and also bioaccumulation.

Although fire can impact wetlands directly when vegetation is dry enough to burn, such events do not appear to lead to long-term changes (DeBenedetti and Parsons 1984). More long-lasting impacts are seen when in adjacent forests–specifically stand-removing fires, as a result of altered fire regime–are followed by increased flooding and surface erosion. This can lead to the deposition of sands and gravels during storm events and thus return the wetland vegetation to an earlier successional stage.

During the mid-1800s and into the early 1900s, most Sierran wetlands were grazed, in some cases severely, by cattle and sheep. Many park wetlands continue to be grazed by recreational pack stock, and this activity has a suite of known impacts to wetlands such as soil compaction, erosion, trampling of vegetation, and changes in plant species composition (McClaren and Cole 1993). Recent research in Yosemite National Park suggests that even moderate levels of such grazing can have a measurable effect on wetland productivity (Cole et al. 2004).

Wetlands have historically been manipulated in high use areas of Sierra Nevada network parks. Multiple direct anthropogenic impacts are a stressor of Sierra Nevada wetlands. Wetlands have been drained to provide parking, had flow modified to allow roads and trails to bisect them, had inundation levels altered by extraction of water from wells, and have been degraded by trampling from heavy use.

### *Vital Signs*

Wetlands concentrate resources, provide critical habitat for both resident and transient animals, are extremely productive, and have therefore been identified as key ecosystem elements in Sierra Nevada Network parks.

Our Wetland Ecological Integrity monitoring protocol targets the Network population of wet meadows and fens (see Appendix H, "Protocol Development Summaries"). This protocol will integrate monitoring of three indicators (i.e., vital signs): wetland plant communities (including vascular and non-vascular plants), and wetland water dynamics (groundwater and surface water), and wetland invertebrates.

### *Sub-Model: Invertebrates*

#### *Introduction*

(Coleman and Hendrix 2000)) argue persuasively that invertebrates are "webmasters" that govern ecosystem function to a degree far out of proportion to their biomass. They form the energetic basis of many food chains (Figure F–19).

#### *Drivers, Functions*

Invertebrates are critical in decomposition, nutrient cycling, physical processes, and disturbance regimes (Meffe and Carroll 1997). As an example, soil invertebrates modulate the following, to varying degrees: soil temperature, moisture, nutrients, plant species composition, soil compaction, mixing, trace gas production, aggregate formation and stability, soil crusting, aeration, runoff, carbon storage, organic matter stabilization, macropores, water transport, and microbial community structure (Anderson 2000, Whitford 2000).

For example, ants can be considered keystone species in seasonally dry ecosystems because of their role in macropore formation alone (Whitford 2000). Insects are also important ecosystem regulators via the action of many species as powerful herbivores. The strength of this regulation is a function of small size, easily amplified biomass via short time to first reproduction, sensitivity to ecosystem condition communicated via airborne chemicals, diversity of niches occupied, and direct and indirect effects on primary production (Schowalter 2000).



Giant sequoia–mixed conifer forest. NPS photo.

Alpine wetlands are a particularly active arena for mobile, trophic-link organisms. Wetland invertebrates are tightly bound to neighboring streams, lakes, ponds, and upland habitats. Many aquatic larvae emerge from streams and ponds to spend their adult lives in wetlands before returning to the water to deposit eggs; examples include beetles, Diptera, mayflies, stoneflies, and caddisflies (Arnett 2000). Many organisms that are aquatic as larvae, are important pollinators in wetlands; these species are also important prey for vertebrates (e.g., amphibians, birds) in these habitats.

Recent work by Holmquist and Schmidt-Gengenbach in Sierra Nevada Network parks (Holmquist and Schmidt-Gengenbach 2006) demonstrated the importance of wetlands as breeding grounds for invertebrates, which form the energetic basis of many food chains Many insects breed in wetlands, their offspring dispersing into adjacent upland forests and woodlands as the season progresses. Invertebrates also serve as pollinators for montane and high elevation plants. Wetland invertebrates are especially sensitive to fragmentation by trail corridors, with declines in species abundance and diversity observed as much as 2 meters away from trail beds in seemingly undisturbed vegetation (Holmquist and Schmidt-Gengenbach 2004).

### *Stressors*

Invertebrates are particularly sensitive to disturbance—and some are exquisitely sensitive—because most of these organisms can emigrate as well as suffer mortality in situ. Because of generally limited dispersal capabilities and/or behavior, even comparatively mobile fauna may be influenced by climate change. Species with narrow temperature tolerances, such as alpine wetland grasshoppers ((Coxwell and Bock 1995), are likely to be affected strongly by climate change.In addition, effects are often amplified by rapid reproduction or lack thereof. However, disturbance will often increase diversity in invertebrate assemblages if disturbance levels are similar to, or lower than, natural rates of disturbance (Brown 1997).

## Model: Forest System

### *Introduction*

Sierra Nevada montane and subalpine coniferous forests comprise one of the largest and most economically, ecologically important vegetation regions in California (Rundel et al. 1988). This expanse includes most of the area of both slopes of the Sierra Nevada, from 600-1500 m at its lower margin, to 3000-3500 m at its upper limit (Rundel et al. 1988).

At the lower elevation range, montane conifer forests are characterized by ponderosa pine, incense-cedar, white fir, sugar pine, and black oak. More xeric sites are characterized by ponderosa pine-mixed conifer forests, while white fir-mixed conifer forests–with scattered giant sequoia groves–are found on more mesic sites. Above this zone–forming a transition to higher subalpine forests–occur upper montane red fir, Jeffrey pine, and lodgepole pine forests. The subalpine zone includes several geographically restricted forest types––this zone is dominated by mountain hemlock, western white pine, whitebark pine, foxtail pine, limber pine, and western juniper (Rundel et al. 1988).

### *Drivers, System Components, Function*

Forest dynamics–primarily birth, growth, and death rates of trees–are sensitive to

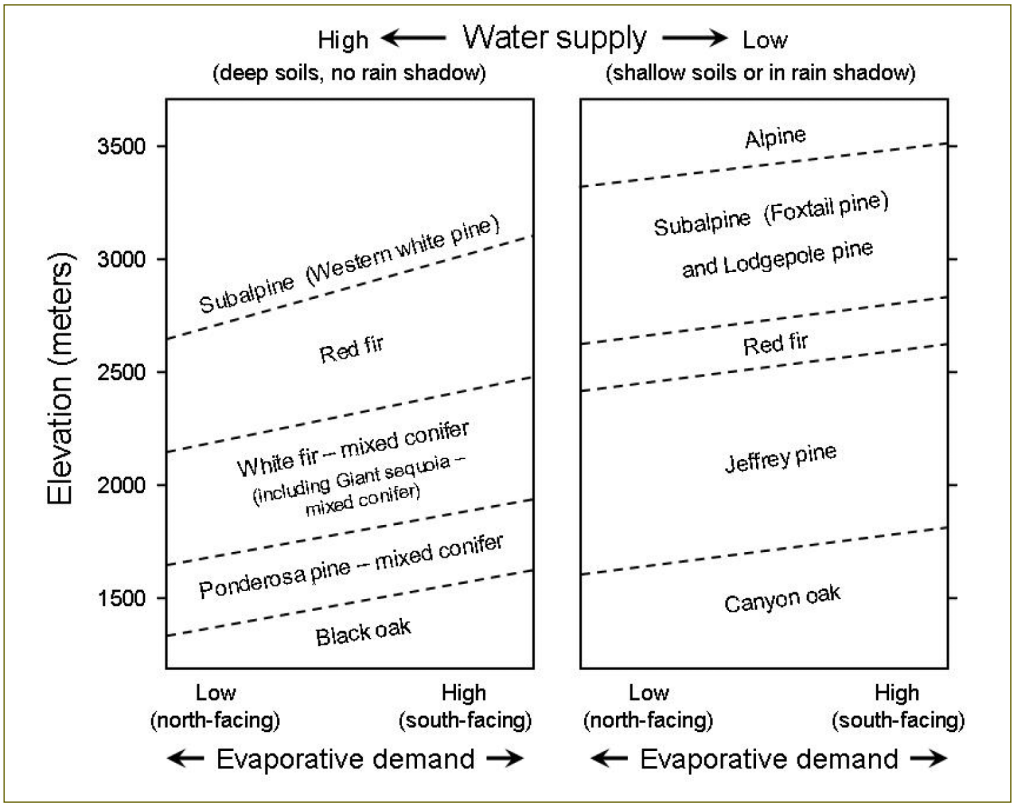



**Figure F–20.** The approximate distribution of forest types in southern Sierra Nevada relative to elevation, evaporative demand, and water supply. Only upland forest types (away from open water and wetland edges) are shown. Forest types intergrade extensively; boundaries between types are not sharply defined. In particular, intergradations between foxtail pines and lodgepole pines is so extensive that no boundary between the two types is shown. Because deep soils able to retain abundant water generally disappear at high elevations, no upper treeline is indicated in the high water supply diagram (on left). Modified from Stephenson (1988).

climate and fire regimes. Subsequently, human alteration of these regimes can stress forest ecosystems.

Sierra Nevada forest ecosystems are very complex in composition, structure, and function (Franklin and Fites-Kaufmann 1996). Forest distributions are linked to moisture availability, as determined by geology and topography, soil depth, and evaporative demand (Figure F- 20). Moisture availability affects growth, recruitment and death rates of trees, as well as frequency and intensity of fire.

The steep elevation gradient in the Sierra Nevada has a strong influence on vegetation, climate, and fire patterns. In the conifer zone of the central and southern Sierra Nevada, most (approximately 95%) precipitation falls from October through May. Thus, the amount of snowpack is much more important than rain in determining soil water availability through the growing season. In our white fir-mixed conifer forests, moisture is more limiting to tree growth than temperature, because soil moisture usually declines throughout summer and into fall (while temperatures are still optimal for growth). High soil moisture availability in well-drained soils is believed to be the primary factor allowing giant sequoia to grow within present grove boundaries, but not in adjacent mixed-conifer forest (Rundel 1969, 1972). Thus, undisturbed grove hydrology is critical to giant sequoia ecosystem sustainability (Stephenson 1996). In addition to elevation, slope, aspect, and soil depth are also important to forest distribution, as explained by differences in water balance on north versus south slopes, and in deep versus shallow soils (Stephenson 1998).

Elevation is inversely related to fire

frequency (Caprio and Swetnam 1995, Caprio and Lineback 1997), and aspect differences result in different fire frequencies within the same elevations in a watershed (Caprio 2000). More mesic conditions on north slopes result in higher fuel moisture, and thus fires on these slopes tend to occur and spread mostly in drier years, compared to south slopes at similar elevations.

Vertebrates that live in white fir-mixed conifer forests do not, at larger scales, have substantial influence on population dynamics of trees. Animal (deer, small mammal) browsing of foliage may have small, localized effects on tree reproduction and vigor. Squirrels and chipmunks feed on conifer seeds, with large pine seeds (sugar pine, ponderosa pine, Jeffrey pine) being the preferred type of food, and white fir and red fir seeds preferred over the very small incense-cedar and giant sequoia seeds (Harvey et al. 1980). Douglas squirrels (Tamiasciurus douglasi) harvest green giant sequoia cones as well as seeds from other conifer cones for food (Harvey et al. 1980). At local scales, and in low seed production years, rodents may have some influence on seed availability and regeneration success. These species, including birds, do influence forest regeneration through the dispersal of seeds. Clark's Nutcrackers form a tight alliance with the subalpine white pine, although they are also known to descend into the upper montane to harvest fir seeds during the fall.

Our Network has tentatively identified several forest types for potential long-term monitoring (see Appendix H, "Protocol Development Summaries"). As an example of a forest system, we present a model of white fir-mixed conifer forest to highlight important ecosystem features, processes, and stressors that influence vegetation structure and composition in this forest type (Figure F-21). Population dynamics (seed fall, germination, recruitment, growth, and mortality) are highlighted.

Models for lower, and higher, elevation forest types will be similar, yet with different influences from fire, climate, insects/disease, invasive non-native species, management action, and land use as agents of change affecting forest population dynamics, structure, and composition.

### *Stressors*

#### *Climate Change, Air Pollution*

Stressors on forest dynamics that can be categorized under physical environment include anthropogenic climate change and air pollution. Climatic change may alter forest dynamics directly by affecting growth, mortality and recruitment rates of trees. Reduced water availability may increase frequency of drought events. The effects of drought on various life cycle stages of trees are likely to be more acute when accompanied by other stressors such as air pollution and fire exclusion (Savage 1994). Research and observation suggest that summer-time desiccation is the main cause of death of giant sequoia seedlings (Harvey et al. 1980, Stephenson 1994), thus warmer, drier summers could reduce recruitment of giant sequoias and other conifer species. A long time period of warming and/or drying could result in actual shifts in tree species distributions upward in elevation.

Recent research results suggest that forest dynamics may already be showing effects of climatic changes. Forest turnover rates (defined as the average of tree mortality and recruitment rates) have been increasing in tropical Amazonia (Phillips et al. 2004) and in the Sierra Nevada (Stephenson and van Mantgem 2005). In the Sierra Nevada, a possible cause for this rapid forest turnover rate is that summers have been getting warmer and drier. Snowpack has been decreasing over most of the West in recent decades (Mote et al. 2005), and spring stream flow has been occurring earlier (Stewart et al. 2004); see Stressor Model, and Atmospheric and Hydrologic System Models.

High levels of ozone in the southern Sierra Nevada are known to produce foliar injury and premature needle abscission (Duriscoe and Stolte 1989, Miller et al. 1991) and growth reduction (Peterson et al. 1987) in ponderosa and Jeffrey pines. Ozone also affects photosynthetic rates and stomatal

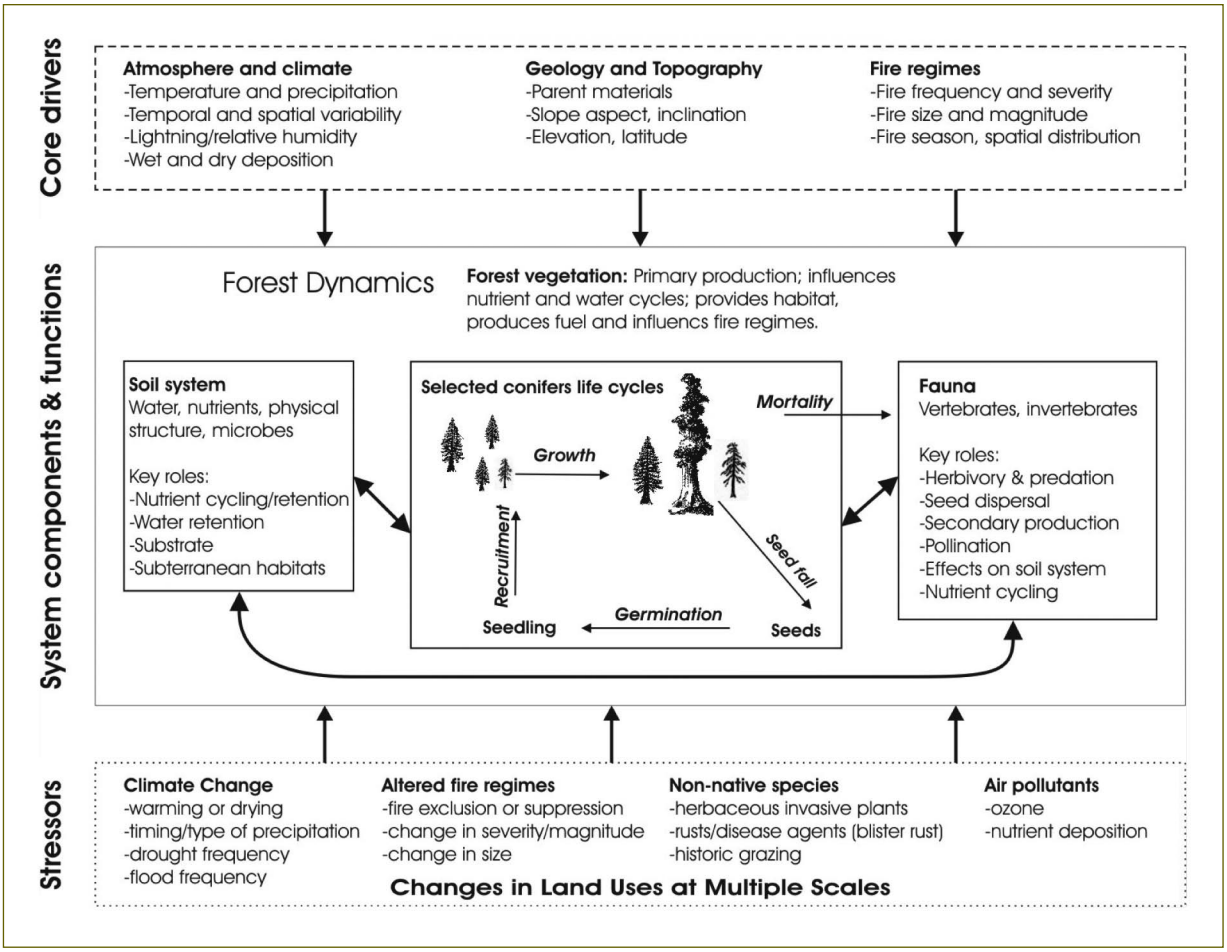



**Figure F–21.** White Fir–Mixed Conifer Forest Model, adapted from Vankat (Vankat 2004), to emphasize forest population dynamics). Rectangles=biotic components.

conductance in Jeffrey pine (Patterson and Rundel 1989). Giant sequoia seedlings were also demonstrated to have sensitivity (chlorotic mottle and leaf necrosis) to present ambient ozone levels and to 1.5X ambient ozone levels in fumigation experiments (Miller et al. 1992) . Ozone injury can lead to reduced root development in sequoia seedlings, and this could prevent seedlings from being able to reach adequate subsoil moisture, critical to their survival in the first season of growth (Miller et al. 1992). In many cases, pollution weakens trees without being a direct cause of death (Savage 1994). Ozone damage may weaken trees' resistance to disease and insect attack.

### *Disease*

A variety of native insects, rusts, fungi, cankers, and parasitic plants are associated with tree disease and death. Sierra Nevada forest demography research has identified dwarf mistletoe (*Arceuthobium* spp.), fir canker (*Cytospera abietis*), and fir engraver (*Scolytus ventralis*) as commonly associated with mortality in fir species, and pine beetles (*Dendroctonus* spp.) as commonly associated with pine mortality (Parsons et al. 1992, Mutch and Parsons 1998). Occasional outbreaks of Douglas-Fir tussock moth (*Orgyia pseudotsugata*) occur, causing defoliation and mortality primarily in white fir. The nonnative white pine blister rust (*Cronartium ribicola*) is an important factor associated with 5-needle pine mortality in the Sierra Nevada (Duriscoe and Duriscoe 2002) and elsewhere. Over the past 15 years, sugar pine deaths in Sequoia National Park associated with blister rust and stress (i.e., resource competition) were common, suggesting significant roles for both blister rust and fire exclusion in population trajectories (van Mantgem et al. 2004)

### *Non-native Plants*

Non-native plants do not currently represent a major problem in Sierra Nevada parks' white fir-mixed conifer forests. The return of fire through prescribed burning, and allowing lightning-caused fires to burn, has increased species richness in this montane forest type (Keeley et al. 2003). However, increased gap formation from fire also increases potential for invasions of alien plants (Hobbs and Huenneke 1992, Keeley et al. 2003). In Sequoia and Kings Canyon National Parks, Keeley et al. (2003) found that aliens comprised only 0.3% of understory flora in unburned forests (unburned for at least 75 years) and 3.4% in burned forests. Disturbances created by timber harvest may result in many times greater alien composition (Battles et al. 2001). The invasive problem in central and southern Sierra Nevada forests centers primarily around cheatgrass (Bromus tectorum). Bromus tectorum has had drastic effects on fire regimes throughout the Great Basin (Mack 1981, Whisenant 1989), and there is concern that it could alter fire regimes in the Sierra Nevada as well (Keeley 2001). It is through altering fire regimes that invasive species are likely to have the most impact on montane forests. Other alien invasive species most commonly associated with burned areas in network white fir-mixed conifer forests include: bull thistle (*Cirsium vulgare*) and wooly mullein (*Verbascum thapsus*) (Demetry, pers. comm.).



Prescribed fire in giant sequoia–mixed conifer forest. NPS photo.

Alien plants do not currently represent a major problem in Sierra Nevada parks' white firmixed conifer forests. The return of fire through prescribed burning, and allowing lightning-caused fires to burn, has increased species richness in this montane forest type (Keeley et al. 2003). However, increased gap formation from fire also increases potential for invasions of alien plants (Hobbs and Huenneke 1992, Keeley et al. 2003). In Sequoia and Kings Canyon National Parks, Keeley et al. (2003) found that aliens comprised only 0.3% of understory flora in unburned forests (unburned for at least 75 years) and 3.4% in burned forests. Disturbances created by timber harvest may result in many times greater alien composition (Battles et al. 2001). The invasive problem in central and southern Sierra Nevada forests primarily concerns cheatgrass (*Bromus tectorum*). Cheatgrass has had drastic effects on fire regimes throughout the Great Basin (Mack 1981, Whisenant 1989), and there is concern that it could alter fire regimes in the Sierra Nevada as well (Keeley 2001). It is through altering fire regimes that invasive species are likely to have the most impact on montane forests. Other alien invasive species most commonly associated with burned areas in network white fir-mixed conifer forests include: bull thistle (*Cirsium vulgare*) and wooly mullein (*Verbascum thapsus*) (Demetry, pers. comm.).

### *Fire Regime*

*Please refer to detailed "Fire Regime Model" (below).*

### *Vital Sign*

The Sierra Nevada Network has identified several forest types for potential long-term monitoring; final selection will occur during Forest Monitoring Protocol development (see Appendix H, "Protocol Development Summaries").

We are interested in monitoring forest dynamics, and primarily—birth, growth and death rates of trees, because they are sensitive to changes in two major drivers in the Sierra Nevada: climate and fire regimes. These two drivers are subject to substantial alteration by human impacts, and in these altered states can act as stressors on forest systems.

Monitoring recruitment, growth, and mortality rates, along with causes of tree death, provides simple and well-understood metrics for quantifying and interpreting changes in forest tree populations in response to climate, fire, and other agents of change (e.g. insects, pathogens).

Monitoring of forest dynamics will need to be linked to monitoring of fire regime, fire effects, and climate to enable effective interpretation of trends in tree population dynamics and large-scale forest landscape changes in pattern and structure.

## Model: Fire Regimes

*Text Adapted from Caprio (Caprio 2003)*

### *Introduction*

Fire is a process that helps link terrestrial, atmospheric, and aquatic systems through its role in moving nutrients across these systems. Fire regimes–in combination with climate and topography–shape vegetation structure and pattern on the landscape, affect water quality and quantity, and indirectly affect wildlife habitat.

The importance of fire as a key driver and process in Sierra Nevada ecosystems was discussed in "Forest System" and "Stressor" model, supra, and Chapter 1. Here, we elaborate and emphasize linkages between fire and climate and their roles in influencing vegetation pattern and various ecosystem processes.

### *Climate—A Driver & Stressor*

Climate primarily affects fire regime through its direct effect on fuel moisture. A short period of dry, hot weather can severely dry fuels, often overwhelming any effects that might be due to fuel loads or fuel bed structure. Climate also affects the geographic distribution of vegetation types and site productivity, and, thus, indirectly influences the intensity, frequency, and size of fires (Miller and Urban 1999c). Fire frequency tends to decrease with increasing elevation and soil moisture (Figure F- 22), interacting with topographic moisture gradients and fuel availability to help shape vegetation distribution and landscape pattern. Over longer time scales, climatic fluctuations are responsible for driving variations in fire regimes (Clark 1988, Swetnam 1993a).

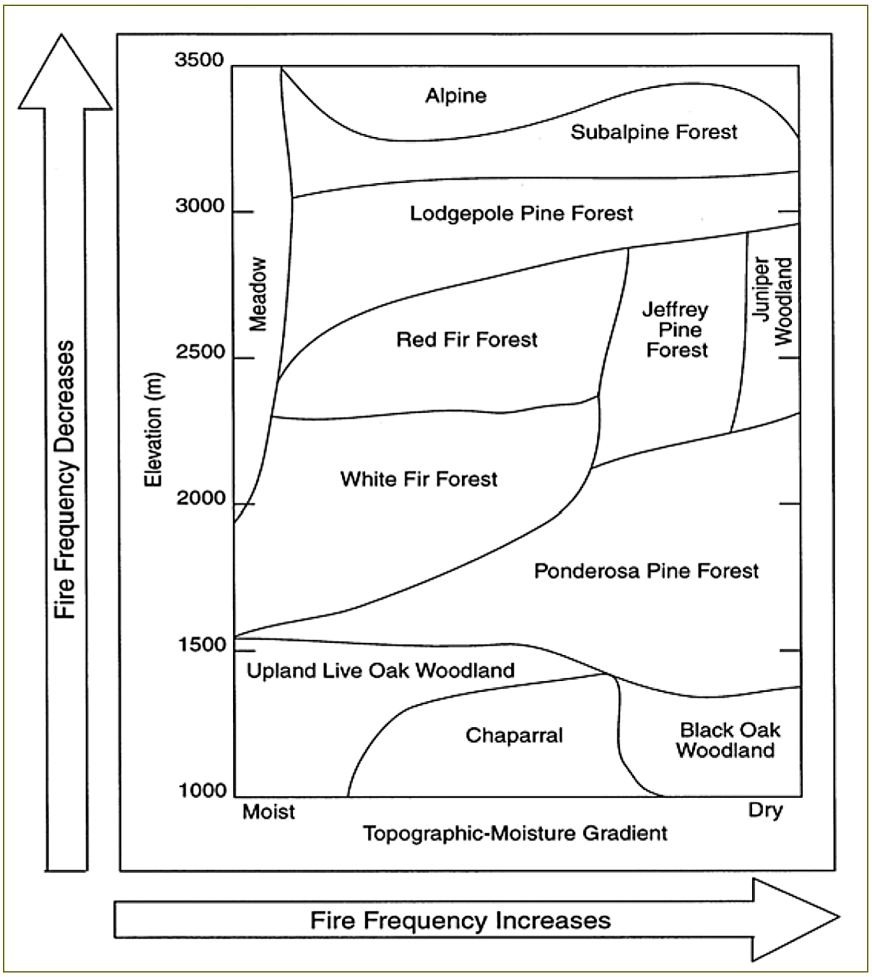



**Figure F–22.** The distribution of general vegetation types (Vankat 1982) and the relation of fire frequency to elevation, topographic, and moisture gradients in Sequoia National Park (Miller and Urban 1999c).

Attributes of pre-Euroamerican fire regimes can provide vital reference information for understanding changes in ecosystems over the last 150 years and in developing goals for the restoration of fire. The concept of a fire regime allows us to view fire as a multifaceted variable rather than a single event within an ecosystem (Whelan 1995). Thus areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability having both spatial and temporal attributes. Fire regimes are normally defined according to specific variables, including: (1) frequency, (2) magnitude (intensity, severity), (3) size, (4) season, (5) spatial distribution, and (6) type of fire (Gill 1975, Heinselman 1981). Fire regime characteristics may vary through time, and across the landscape,

in response to climatic variation, number of lightning ignitions, topography, vegetation, specific historic events, and human cultural practices (SNEP 1996).

A graphic overview of fire regime attributes and affected ecosystem properties is provided in Figure F–23. Fire regimes are also tightly linked to climatic variation (Swetnam 1993b). Predictions for increased fire severity and size in the Sierra Nevada with global warming (Torn and Fried 1992, Miller and Urban 1999a) suggest that monitoring fire regimes and their effects on the ecosystem will be essential in enabling managers to adapt to, and mitigate for, changing conditions.

### *Stressors*

#### *Altered Fire Regime—A Stressor*

As discussed earlier (see "Forest System Model", Figure F-21), altered fire regime is itself a stressor to Sierra Nevada ecosystems. Beginning in the 1860s, fire regime abruptly changed when human ignitions decreased (concomitant with decline of Native American populations), and cattle and sheep grazing reduced fuel loads (Parsons 1981, Swetnam 1993) (Vankat 1977). With the establishment of Sierra Nevada national parks in the late 19th and early 20th centuries, aggressive suppression of wildfires was initiated (Vankat 1977). In some forests, a pulse of tree reproduction followed the end of grazing: (1) seedlings became established in grazing-disturbed areas; (2) domestic animals no longer trampled or ate seedlings; and (3) fires were suppressed (Vankat and Major 1978).

Sierra Nevada montane forests are highly dependent on fire. Detailed fire histories obtained from fire scar sampling on tree trunks, logs, and snags (in white fir- and giant sequoia-) mixed conifer forests, demonstrate that fire return intervals in these forests prior to the mid 1860s ranged from 1 to 30 years, with the mean

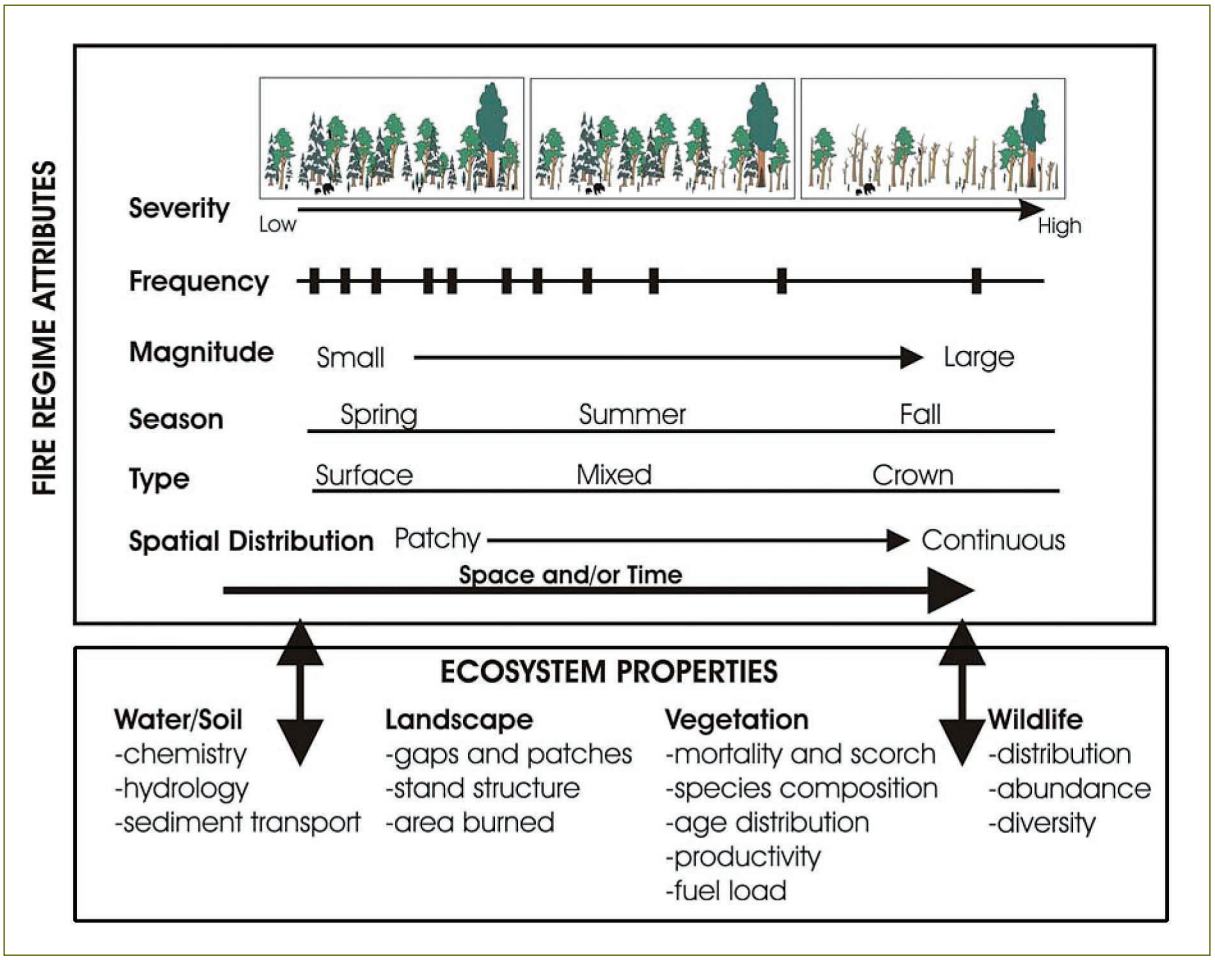



**Figure F–23.** Fire regime attributes and selected ecosystem properties influenced by fire (described in model narrative).

fire interval ranging from 10 years to a more conservative maximum mean of 16 years (Kilgore and Taylor 1979, Swetnam et al. 1992, Swetnam 1993, Caprio and Swetnam 1995, Swetnam et al. 1998, National Park Service 2003a).

A variety of studies suggest that past Sierran mixed conifer forests had lower tree density, and a very different demographic distribution of age classes—with lower fuel loads and greater landscape diversity of forest patches than current forests (Parsons and DeBenedetti 1979, Bonnicksen and Stone 1982, Vale 1987, Ansley and Battles 1998, Roy and Vankat 1999, Stephenson 1999)((Vankat and Major 1978). While many of the changes observed in forest structure and function are thought to primarily be a result of fire exclusion, they may also be related to warmer, moister conditions of the 20th century (Graumlich 1993, Scuderi 1993, Keeley and Stephenson 2000).

While the type of fire regime in white fir-mixed conifer forests (inclusive of giant sequoia groves) is often described as understory or low intensity surface fires, there is evidence from studies of forest age structure and post-fire giant sequoia growth response that low intensity fire interspersed with patchy high intensity fire is needed for successful recruitment of shade-intolerant giant sequoias seedlings (Harvey et al. 1980, Harvey and Shellhammer 1991, Stephenson et al. 1991b, Stephenson 1994, Mutch and Swetnam 1995). Stephenson (1994) estimates that a minimum of 0.1 ha gap size is needed for significant giant sequoia recruitment. In addition to favoring seedling establishment, patches of higher intensity fire result in release of more seeds from semi-serotinous giant sequoia cones. Other canopy dominants (sugar pine, Jeffrey pine) are dependent on gaps for effective regeneration, and the distribution of forest gap generated patches also likely has important effects on the distribution of wildlife (Keeley and Stephenson 2000). In general, a higher diversity of species composition, forest size structure, and landscape pattern occurs with a natural stand-thinning fire regime (Figure F–24).

Establishment of prescribed fire programs in Sierra Nevada parks in the 1960s resulted in substantial progress toward reducing fuel loads, and modifying stand structure to reduce tree densities in many areas (Kilgore 1973, Keifer et al. 1995, Keifer et al. 2000).

Lightning-caused fires cannot always be allowed to burn due to constraints of development, air quality restrictions, proximity of neighboring lands with commercial timber, human-made barriers to fire spread, and staffing restrictions during busy fire seasons. Thus management-ignited fires will need to continue to play a significant role in restoring historic fire regimes to park landscapes (Keeley and Stephenson 2000).

*See also, "Stressor Model," for a discussion of the effect of altered fire regime on vegetation and other ecosystem attributes.*

### *Fire and Nutrients*

Several Sierra Nevada studies have documented increases in stream solute concentrations after fire (Chorover et al. 1994, Williams and Melack 1997a, b, Heard 2005), probably due to increased runoff, changes in biogeochemical processes, and direct deposition of ash into waterbodies. Burning and decomposition of plant material, accelerated mineralization and erosion rates, and decreased nutrient uptake by vegetation also lead to increases in solute concentrations in soil solution (Raison 1979, DeBano et al. 1998). While many elements, particularly nitrogen, sulfur, and carbon, are converted to volatile compounds and ascend to the atmosphere (Covington and Sackett 1984, Caldwell et al. 2002), high concentrations of these elements are also left behind in ash layers and partially combusted organic material (Blank and Zamudio 1998). Fire may accelerate some losses of nutrients through combustion and leaching, but it also plays a critical role in supplying available nutrients to terrestrial and aquatic systems (St. John and Rundel 1976, Romme and Knight 1982, Hauer and Spencer 1998). Fire releases nutrients bound in above-ground organic matter, rendering them available in organic forms for plant and microbial uptake.

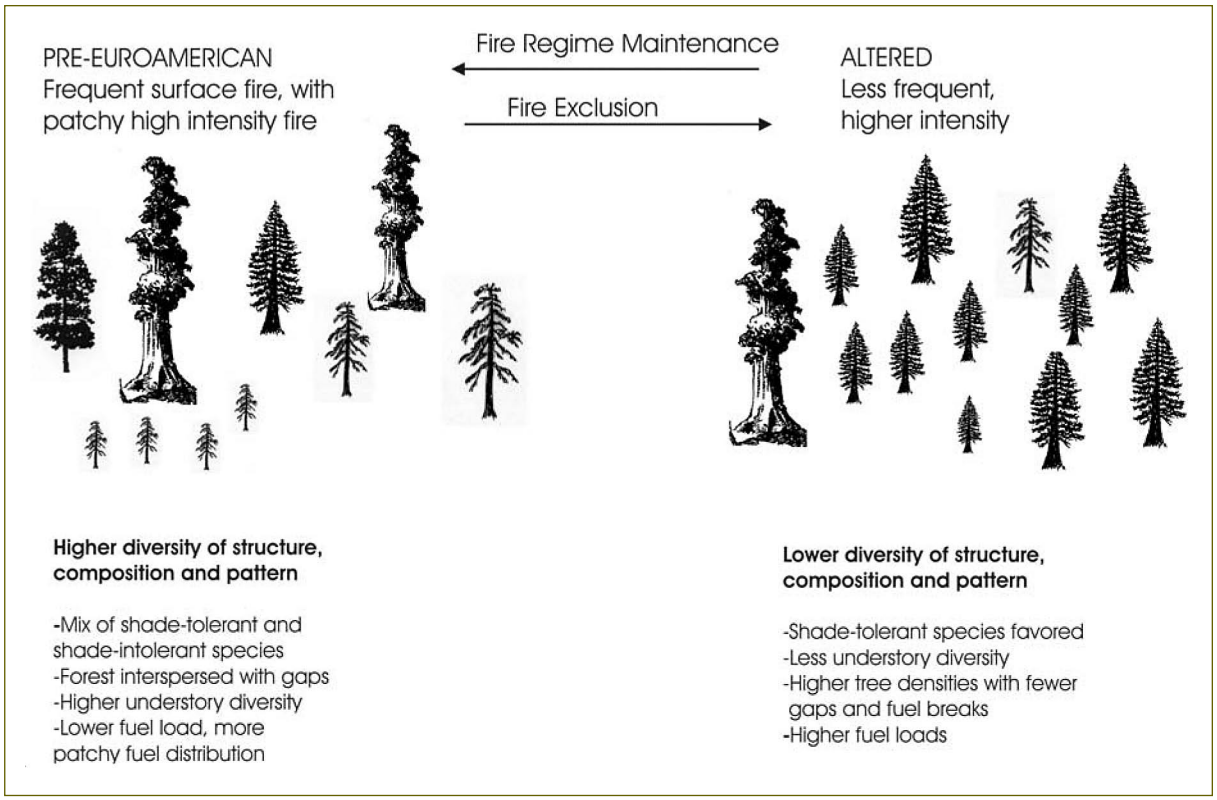



**Figure F–24.** Fire regime effects on white fir-mixed conifer forest structure, composition and pattern. Alteration of the fire regime, through fire exclusion, results in the types of changes indicated above for Sierra mixed conifer forests.

## *Fire Regime Attributes*

### *Fire Frequency*

Fire frequency is usually defined as the number of fires per unit time, or mean fire return interval (mean number of years between fires). General patterns of pre-Euroamerican fire frequencies are apparent at several scales within our parks. Variation exists locally, with specific site characteristics such as productivity, potential for ignition, or other factors influencing frequency. General patterns are also apparent at large scales. For example differences in fire frequency are observed in different vegetation types (Figure F- 25).

Additionally, on the west slope of the Sierra, frequencies (reconstructed using fire-scarred trees) show an inverse relationship between number of fires and elevation (Caprio and Swetnam 1995, Swetnam et al. 1998, Caprio 2000). Fire return intervals are longest at higher elevations, shortest in lower mixed conifer forest, and appear to again increase in time between fires in lower elevation grass-oak woodland and chaparral vegetation (Caprio and Swetnam 1995, Caprio and Lineback 1997). Additionally, within at least some watersheds strong differences in fire frequency exist between aspects, with fire frequencies being shorter on south aspects than on north aspects (Kilgore and Taylor 1979, Caprio 2000).

### *Fire Magnitude*

Fire magnitude characteristics, such as intensity and severity, also vary among vegetation types. Fire intensity is defined as the physical force (i.e., BTUs) of the fire per unit time (Pickett and White 1985). Severity refers to impact of the fire on organisms, communities, or ecosystems (e.g., basal area removed) (Sousa 1984, Pickett and White 1985). Fire severity is closely related to weather, fuel load, size and distribution of fuel and moisture content of fuel and soil (Wright and Bailey 1982). It is a common indicator of fire effects on vegetation. An inverse relationship is often observed between disturbance size and/or severity and disturbance frequency (Sousa 1984, Pickett and White 1985, Swetnam 1993).

At lower elevations, little is known about fire regimes in grasslands and oak woodlands due to (1) lack of fire scarred trees, and (2) replacement of nearly all native herbaceous communities by alien plants, following initiation of intense grazing in the 1860s (Dilsaver and Tweed 1991). However, descriptions of vegetation suggest that episodic fast-moving surface fires in flashy herbaceous fuels, during dry summer and fall seasons, probably played a role in these communities (Parsons 1981). Stand-replacing fire in chaparral communities today probably differs little from pre-Euroamerican characteristics, although frequencies have probably been altered. In much of the Sierra's sequoia-mixed conifer forest, fires were primarily non-stand replacing surface fires prior to Euroamerican settlement (Show and Kotok 1924, Kilgore and Taylor 1979, Warner 1980, Pitcher 1987, Caprio and Swetnam 1995). Fires in these areas were dominated by low to moderate severity, with high-severity generally restricted to localized areas (Stephenson et al. 1991). Fire in red fir forest was typically non-stand replacing, due to its fire resistant bark (Pitcher 1981, 1987). Fire in lodgepole pine was generally a patchwork of low-intensity surface fire, and higher-intensity crown fire, depending on specific burning conditions.

### *Fire Size*

The scale of fire prior to Euroamerican settlement was significantly different from that typically observed today. Both frequency of fire occurrence–and frequency of large spreading fire–was much greater than today or at any time in the last hundred years.

Estimates based on fire history data suggest that between 15,100 to 24,700 acres burned annually within the parks (Caprio and Graber 2000). However, because of the vagaries of climate or number of ignitions, actual number of acres burned in any given year could have been much greater, or smaller, than those averages.

Fire size was probably also related to overall landscape diversity patterns such as vegetation, fuel, and topographic complexity. In course-grained landscapes, such as the highly dissected, rocky, high country (upper Kern and Kings River drainages), fires probably tended to be smaller, with poor year-to-year synchrony. In contrast, fires were probably larger

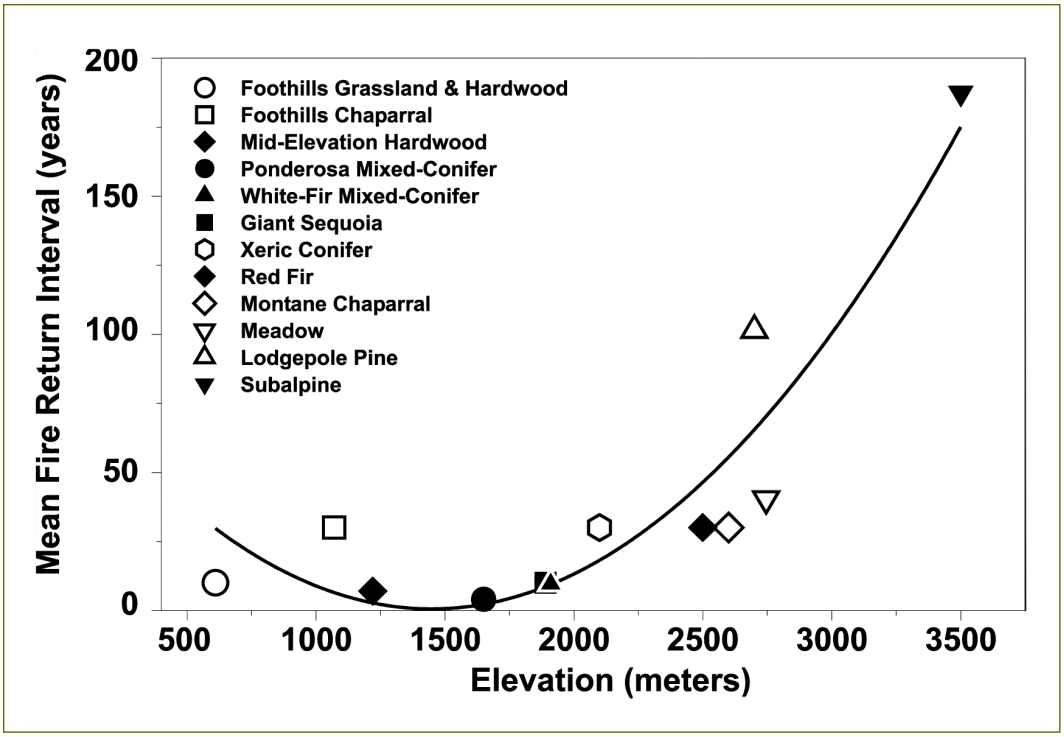



**Figure F–25.** Relationship between fire frequency and elevation, Sequoia and Kings Canyon National Parks (from Caprio and Lineback 1997).

and more synchronous in fine-grained watersheds, such as those found on the west side of the range. Burn patterns in these landscapes would be related to fire conductance among vegetation types and between drainages (Caprio 2003, National Park Service 2003a).

### *Season*

Season of fire occurrence can have important effects on vegetation and wildlife. Factors important in seasonality are fuel moisture content, phenology of vegetation, and life history patterns of wildlife. Vegetation and wildlife within particular ecosystems have generally adapted to fire within a particular window of time. However, changes in seasonality, outside the normal range of variability, may have adverse impacts. In the Sierra Nevada, pre-Euroamerican settlement fires generally occurred from summer through fall, based on analysis of seasonal positions of fire scars in tree rings (Swetnam et al. 1992, Caprio and Swetnam 1995). This is in agreement with current knowledge of contemporary lightning ignition and fire spread patterns (Show and Kotok 1924, Vankat 1985), Sequoia Kings Canyon and Yosemite fire records).

### *Fire Type*

Fire regime types range from no fire, to surface fires and crown fires, all with various combinations of fire types related to vegetation, fuel characteristics, weather and topography. Common fire regime types for major SIEN park vegetation communities can be broadly defined as: (1) short-interval, low-intensity surface fires, (2) moderate interval, stand-replacing fires, (3) variable-interval, variable-intensity surface fires, (4) long-interval, low-intensity surface fires, (5) long-interval, high-intensity surface fires, (6) long-interval, variable intensity fires, and (7) lack of fire.

### *Spatial Distribution of Fire*

The distribution of fire on the landscape at any given time is dependent upon many variables, including ignition source(s), topography, fuel continuity, structure and moisture; and weather conditions. Spatial distribution and pattern of fire are also dependent upon fire frequency and longer-term climate patterns. High fire frequency periods probably had small patchy fires and resulted in a fine-grained pattern in vegetation and fuels, while low fire frequency periods had wider spreading fires resulting in coarser-grained landscape patterns (Swetnam 1993b). Fire and forest dynamics modeling efforts for Sierra Nevada have suggested fire can increase heterogeneity in some forest characteristics (variability in species composition) and alter spatial heterogeneity (light regime within forest more variable with fire) (Miller and Urban 1999b). Fire suppression has likely resulted in more homogeneous forests, from fuel accumulation and increased density of understory trees (Vankat and Major 1978), creating forests more susceptible to larger, more severe fires.

### *Potential Fire Regime Indicators*

To monitor fire regimes as a process, landscape-scale monitoring of key attributes of fire regimes will be necessary. Fire severity, size, season and spatial distribution are all potential indicators that could be monitored using a combination of on-the-ground fire monitoring, remote-sensing, and GIS analysis. Some of these attributes are already being monitored in SIEN parks (National Park Service 2003a, 2004), and collaborative planning with park fire management will be needed to determine how our vital signs monitoring program can enhance and integrate with existing efforts. While the vital signs program does not propose to explicitly monitor fire effects on ecosystem properties, many of our selected vital signs (water chemistry, hydrology, forest stand population dynamics, bird populations) are affected by fire occurrence.

### *Vital Sign*

Monitoring of forest dynamics will need to be linked to monitoring fire regime and fire effects to enable effective interpretation of trends in tree population dynamics and largescale forest landscape changes in pattern and structure.

While mid-elevation mixed conifer forests occupy a large area and contain

focal species of interest for long-term monitoring (giant sequoia, sugar pine, Jeffrey pine), other forests of interest include those at the lower and upper elevation ranges, as these are areas that most likely to be sensitive to climatic change. Low-elevation forests in the Sierra Nevada are the most dynamic (i.e., highest turnover rates), and therefore may respond most quickly to environmental change (Stephenson and van Mantgem 2005). High elevation forests may respond more slowly to a given unit or pace of climatic change. Model projections suggest that climate may change more rapidly at high elevations in the Sierra than at low elevations (Knowles et al. 2006). Monitoring tree population dynamics and forest density at, and near, treeline also offers an opportunity to detect the beginnings of an upward shift in a highly climate-determined ecotone.

## Model: Non-native Invasive Plant Populations

### *Introduction*

Invasive species have the ability to alter the local environment, perpetuating their own existence at the potential expense of native species (Hobbs and Mooney 1998). The most destructive invasive plants can alter ecosystem processes, such as fire regimes (D'Antonio and Vitousek 1992, Brooks et al. 2004), nutrient cycling and soil chemistry (Ehrenfeld 2003), hydrological cycles (Blackburn et al. 1982), and sedimentation rates (Blackburn et al. 1982). In doing this, they have the potential to out-compete native species, lower native species recruitment, alter the community structure, and degrade or eliminate habitat for native animals (Bossard et al. 2000). Because of these effects (Figure F–26), and because of the number of extant taxa and populations, non-native invasive plants are one of the five major stressors affecting parks in the Sierra Nevada network.

Not all plant communities have been invaded by non-native plants. Furthermore, the qualities that make a plant community susceptible to colonization by non-native plants (i.e., invasibility) are not generally understood (Rejmanek and Richardson 1996)(see also Model: Invasive Plant–Susceptibility, below) . The primary interest in

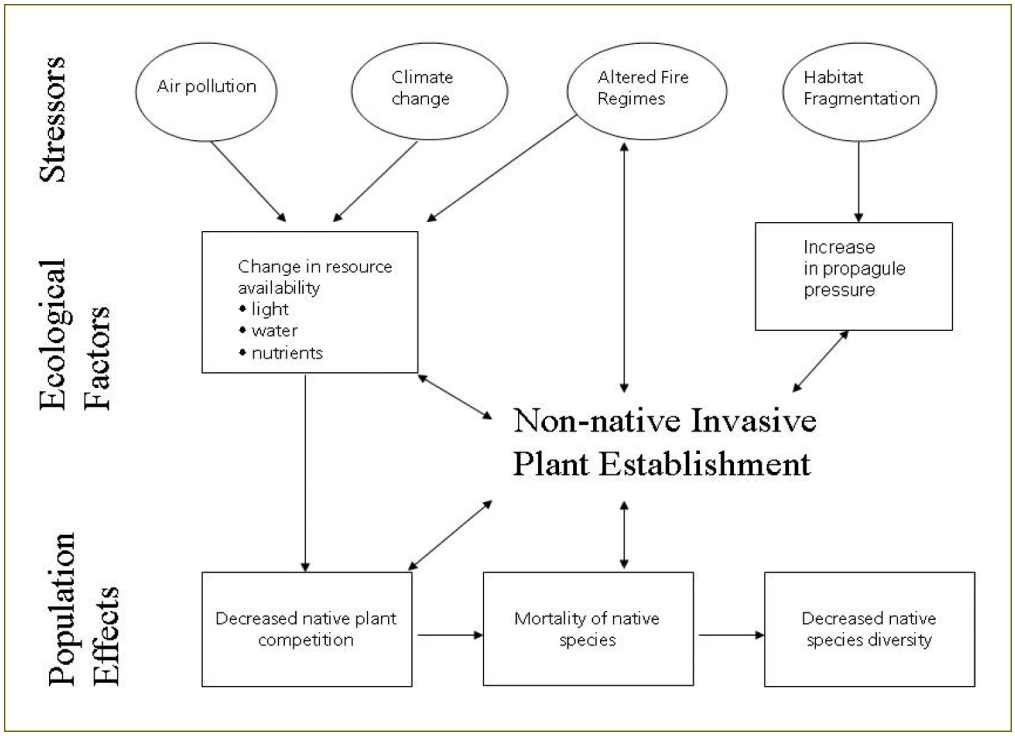



**Figure F–26.** Non-native Invasive Plant population conceptual diagram, depicting principle interactions of stressors and ecological factors.

monitoring nonnative invasive plants is to improve early detection of both new taxa that have not yet arrived in SIEN parks, and new populations of non-native species that already occur in parks.

Although there has been extensive research surrounding how and why exotic plants become invasive (Mack and D'Antonio 1998, Lonsdale 1999, Davis et al. 2000a), an allencompassing theory on invasion has yet to be developed. Several models of community invasibility are presented below (see companion conceptual models).

Studies examining individual characteristics of invasive species are limited in their applicability to all invasive plants, as it is unlikely that there will ever be a set of characteristics inclusive to all invasive species. On the ecosystem level, however, theories have been more encompassing. Many studies agree that a change in resources, such as water, light and nutrients, is a major cause of invasive plant establishment in an ecosystem. The theory of fluctuating resources (Davis et al. 2000) provides one of the most widely accepted models (Richardson and Pysek 2006). This model states that when there is a change in the amounts of resources, even the slightest amount, invasives can have an opportunity to take over a niche and enter the ecosystem. These changes can occur when there is a disturbance, such as heavy herbivory, erosion, or soil degradation; an increase in precipitation (a wetter year than average); or a eutrophication event (Davis et al. 2000). In addition, the presence of invasives can alter environmental conditions, such as altering biogeochemistry, and cause changes in the ecosystem to become more favorable for self-maintenance. This theory is explained in detail, below; see Model: Non-native Plants—Invasion Susceptibility.

Introduction of species into SIEN parks depends in part on whether surrounding communities (proximity of source) have been invaded, and on the vectors available to transport the plant (or its propagules) into our parks. Natural transport vectors, such as wind and animals, can move propagules. Plants or propagules may also be transported by human activities that import contaminated materials into the parks. These materials may include equipment, soil, sand, gravel, hay, straw, pack-stock dung, cultivated plants, car tires, and shoes. Once established inside parks, many of these same vectors can move the plants farther into the interior.

### *Status of Non-native Plants in Network Parks*

Currently, there are over 260 non-native species documented for SIEN parks—all are non-native, but not necessarily invasive (depending on definition used):

- SEKI—215 species (100 of which do not occur in YOSE)
- YOSE—160 species (45 of which do not occur in SEKI)
- DEPO—8 species

Research has been conducted in the Sierra Nevada examining invasive species' dynamics. Studies have looked at relationships between invasive plants and humandisturbed areas (Moore and Gerlach 2001, Gerlach et al. 2003), riparian areas (Kane et al. 2006), burned areas (Keeley et al. 2003, Klinger et al. 2006, Kaczynski 2007), and grazed areas (Keeley et al. 2003). There have also been species specific studies on *Cirsium vulgare* (Randall 1988) and *Bromus tectorum* (McGinnis and Keeley, unpublished). Our network contracted a study to model invasive species to predict where invasive species may be found–particulary those in naturally disturbed habitat–throughout the Sierra Nevada (Klinger and Underwood 2002, Underwood et al. 2004), the results of which were the impetus for the Kane et al. (Kane et al. 2006) and Kaczynski (Kaczynski 2007) studies listed above. Other studies have typically been sited in locations with anthropogenic disturbance, as humans are known to be important vectors for invasive plant dispersal (Gerlach et al. 2003). Elevation is known to have a strong effect on non-native invasive plant presence, with populations decreasing with increasing elevation.

A recent study modeling the relationship between non-native species and burned areas, examined various biotic and abiotic factors involved in non-native

species presence (Klinger et al. 2006). This study found that non-native species cover and richness were strongly positively correlated with slope and total herbaceous cover. Non-native invasive richness was strongly negatively correlated with elevation and cover of trees and shrubs. Invasive plants occurred more frequently than was expected in lower montane conifer plots (Klinger et al. 2006).

### Stressors

Researchers have identified four major systematic stressors in the Sierra Nevada Network parks that could promote establishment of non-native invasive plants (SNEP 1996). These include: (1) climate change, (2) altered fire regimes, (3) air pollution, and (4) habitat fragmentation. Non-native species, themselves, are the fifth systemic stressor.

#### *Climate change*

Effects of climate change include changing temperatures and changing amounts of precipitation. These effects contribute to a change in the overall resources (specifically water and nutrients) that are present in the ecosystem (Davis et al. 2000a). Some studies have shown that even a short-term increase in the amount of water in a system can lead to the long-term establishment of non-native invasives, specifically grasses (Dukes and Mooney 1999). Non-native invasive plants have proved to be very adaptable to changes in the ecosystems. A possible reason for this being that many of the worst non-native invasives are found to have very large and variable geographic ranges (Richardson and Pysek 2006). This adaptability has been seen on a regional scale, where yellow star thistle populations in coastal areas of California are characteristically different from populations farther inland (Maddox and Mayfield 1985).

#### *Altered Fire Regimes*

Historically, the Sierra Nevada ecosystems have had variable temporal scales of fire. Within the past century, the overall management strategy has been fire exclusion and suppression. However, within the past 30 years, reintroduction of fire has been a management goal within the SIEN parks. A dilemma exists with regards to the reintroduction of fire and its relationship with non-native invasive plants: allowing fire back into ecosystems may allow for more non-native invasives to establish, due to creating a site very conducive for establishment. It has been hypothesized that the altered fire regimes may have helped to keep non-native invasive populations low in certain ecosystems (Keeley 2001).

Due in part to the exclusion of fires, many of the mid-elevation conifer forests have been relatively free of non-native invasives. McGinnis and Keeley (unpublished) found that *Bromus tectorum* presence in *Pinus ponderosa* stands in Kings Canyon will be on a "boom and bust" cycle—when there is a fire that eliminates the litter layer, *B. tectorum* will establish, however when the litter layer builds up the *B. tectorum* can not survive. Populations of non-native invasives decrease as the years after the fire increase (Klinger et al. 2006). Recognizing that there is a relationship between non-native invasives and fire will assist managers in early detection of the species.

#### *Air pollution*

One consequence of air pollution is nitrogen deposition. Examining this in the context of the Davis et al. (2000) model, this increase can aid the establishment of non-native invasive plants. Increased levels of nitrogen favor faster-growing plants. Sierra Nevada has high rates of nitrogen deposition due to proximity to sources of high emissions and also an atmospheric inversion that occurs below an elevation of 1000 to 2000 meters (Fenn et al. 2003). The effects of increased CO2 concentrations and non-native invasive plants are still debated. However, non-native invasives that utilize C3 pathways for photosynthesis (see basic botany text) (ex. *B. tectorum*) have responded favorably to increased CO2 concentrations. Non-native invasives that utilize C4 and CAM pathways responded less predictably (Dukes and Mooney 1999). Increased CO2 levels

do stimulate overall growth in all plants and as a result can increase fuel loading, leading to more frequent and severe fires (Dukes and Mooney 1999).

### *Habitat fragmentation*

Anthropogenic effects within the parks (roads, corrals, campgrounds, trails) that fragment the landscape act as corridors for non-native invasive plants to travel farther into ecosystems. Gerlach et al. (2003) studied the presence of non-native invasives at these sites because randomly located sites across the landscape yielded few individuals. Habitat fragmentation surrounding the parks will also allow for the higher likelihood of invasion, due to an increase in propagule pressure.

## *Vital Sign*

In addition to being a "vital sign", as stated previously, non-native invasive plants are considered one of the five main stressors on SIEN park ecosystems. Their presence can have an effect on seven of the Network's 13 tier-1 vital signs.

Studies have shown a lag time between establishment of a non-native plant, to when it becomes invasive (Richardson and Pysek 2006). Thus, a plant that is not recognized as an invasive today may indeed be on the list in a few decades. As such, early detection of non-native invasive plants is a high priority. Control or eradication of a non-native invasive plant population, when it is of manageable size, is efficient, cost-effective, and protects resources.

Aspects of two monitoring protocols are proposed for SIEN parks: (1) one examines the status and trends of non-native plants and establishing better operational procedures for prioritization of management, and (2) the other looks at methods for early detection.

The monitoring of the status and trends of non-native invasive plants need to be dynamic. There are different levels of invasiveness—some species, such as dandelions, ranked lower in priority, while others, such as Himalayan blackberry ranked as high (Gerlach et al. 2003). With collaborators, the Network's Non-native Plant Workgroup is working on developing new ranking criteria and mechanisms for keeping the list current.

As mentioned above, dynamic ecological factors–particularly those affected by SIEN stressors–can modify the susceptibility of a community to invasion (Mack and D'Antonio 1998, Lonsdale 1999, Davis et al. 2000). We present details (narrative and conceptual models) regarding invasion susceptibility, below.

## *Sub-Model: Non-native Plant Populations — Invasion Susceptibility*

### *Introduction*

Sierra parks have been invaded by numerous non-native plant species. Some are wellknown invaders in other areas (e.g., cheatgrass—*Bromus tectorum* in the Great Basin), and consequently we know about their invasion ecology and effects on invaded ecosystems (Gerlach et al. 2003). Others have not been well investigated, and their effects are relatively unknown. Thus, we usually treat each invasive species as if it has a unique ecology. Not all plant communities have been invaded by non-native plants (Gerlach et al. 2003). In addition, the qualities that make a plant community susceptible to colonization by non-native plants (i.e., invasibility) are not generally understood (Rejmanek and Richardson 1996). Our primary interest in monitoring non-native plants is to improve early detection of both new taxa that have not yet arrived in SIEN parks and new populations of non-natives that already occur in parks.

Although the ecology of invasion has received much attention in the last several decades, we still lack an all-encompassing theory of invasion (Davis et al. 2000, Davis and Thompson 2000), nor is there agreement on the terminology of invasion (Davis and Thompson 2000); (Daehler 2001); (Rejmanek et al. 2002). Here, we adopt the terminology of (Richardson et al. 2000) to describe the process of naturalization and invasion by non-native plants. The conceptual model we present is based on that proposed by (Davis et al. 2000).

The process of invasion can be most

simply described as the sequential occurrence of three phases: introduction, naturalization, and invasion. Introduction means that the plant or its propagules have been transported across a significant geographical barrier. Many introduced plants may survive for short periods (called casuals or waifs) but do not persist unless repeatedly introduced. Naturalization occurs when introduced individuals reproduce regularly, overcoming any environmental or reproductive barriers, to establish a population sufficiently large that it is not subject to extinction by environmental variability. The length of time the population must persist to qualify as naturalized is not defined, but might be at least 25 years (see (Richardson et al. 2000), p. 99). Finally, invasion is the spread of the plant into areas distant from the site(s) of introduction. Invasion requires that the plant overcomes any barriers to dispersal in the new area, and can survive the abiotic environment as well as biotic interactions in the new area.

Introduction of species into the parks depends in part on whether surrounding communities (proximity of source) have been invaded, and on the vectors available to transport the plant (or its propagules) into the parks. Natural transport vectors, such as wind and animals, can move propagules into the parks. Plants or propagules may also be transported by human activities that import contaminated materials into the parks. These materials may include equipment, soil, sand, gravel, hay, straw, cultivated plants, car tires, and shoes.

Once propagules or plants of potentially invasive species have arrived in parks, their naturalization, and subsequent invasion, may occur. Alternatively, propagules or plants may arrive in the parks from surrounding areas in which the invasive species is already naturalized. Thus, introduction to the parks can be considered invasion.

Our conceptual model of invasibility describes the process by which an exotic species may become established in an otherwise natural plant community. The model focuses sequentially on the roles of resource availability, temporal fluctuations in resources, and differences among communities in invasibility.

### *Invasibility of a Community*

Below we describe scenarios influencing the invasibility of a community. For this model, (see Figure F–27), we consider the resources used by plants to be water, nutrients, and light (Davis et al. 2000). When resource uptake is very close to resource supply–the isoline– we expect competition to be strong and resource availability to be low. Thus, an invading plant would probably not persist. However, invasibility may increase if resources become more available. Resources can become more available either through an increase in supply (arrow A), a decrease in uptake (arrow B), or both. There are many factors that may change resource availability. Those that may be important for Sierra Nevada plant communities are listed in Table F–5.

Although the spatial extent of most of the factors in Table F-5 is very broad, some disturbances do act at local extents to decrease resource uptake. This might include natural perturbations such as gopher mounds and human-caused disturbances such as road edges and trails.

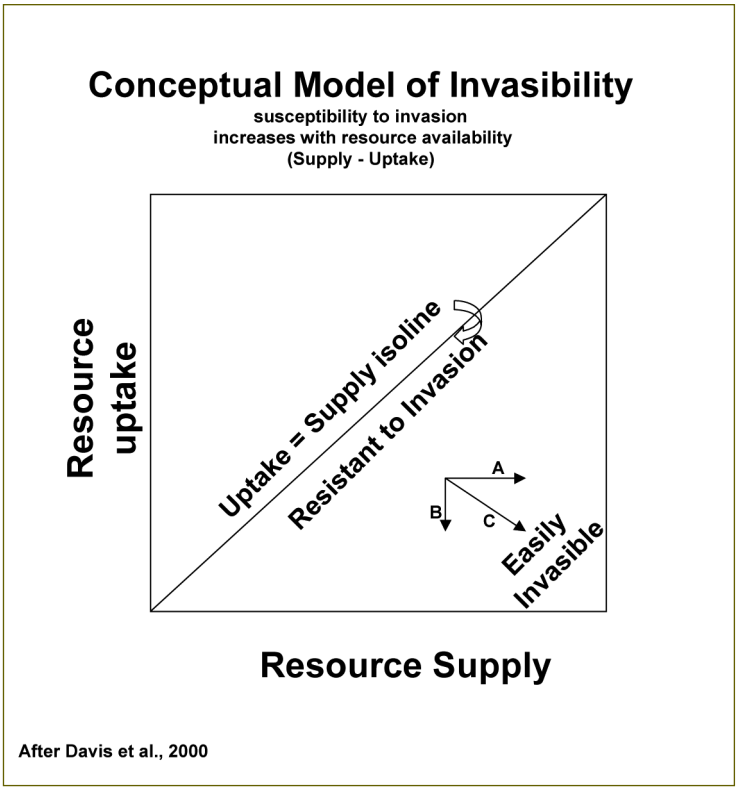



**Figure F–27.** Community invasibility: relationship to resource uptake and supply. After Davis et al. 2000.

**Table F–5.** Factors that result in changes in resource availability and subsequently in invasibility of plant communities.

| FACTORS THAT FAVOR AN INCREASE IN RESOURCE SUPPLY (ARROW A) | FACTORS THAT DECREASE RESOURCE UPTAKE (ARROW B) |
|---|---|
| • Increased precipitation—increased water supply | • Decreased precipitation—decreased water supply |
| • Climate change toward more moderate temperatures | • Climate change toward more extreme temperatures |
| • Fire—increased mineralization, reduced overstory (increased light on forest floor) | • Fire—kills or maims plants |
| • Nitrogen deposition––fertilizer effect | • Excess pollution––toxicity |
| | • Disturbance that kills or maims plants, e.g., increased herbivory, diseases, avalanches, grazing, floods |

### *Invasibility Windows*

As with factors that contribute to resource supply and uptake, resource availability usually fluctuates with time. Fluctuations in resource supply with season are likely to be overlain by shorter-term fluctuations due to local disturbances. Periods of greater resource availability typically lead to reduced competition, and thus represent "invasibility windows" for introduced species (Figure F–28). In this hypothetical example, uptake is near supply until a disturbance occurs that reduces uptake. This leaves a gap between supply and uptake for a period of time that defines an invasibility window.

Invasibility windows vary in magnitude (i.e., the difference between supply and uptake) and in length. Also, introduced species are likely to differ in the required thresholds of magnitude and length of the invasibility window necessary for the species to become naturalized. An invasible window for one species may not be for another species. In addition, if an introduced species requires resources at a higher level than are available in the invasibility window, it may not naturalize. For those introduced species that do naturalize, the frequency of occurrence of suitable invasibility windows must be sufficient for the species to complete the process of invasion by spreading to other sites. The spatial arrangement of these sites on the landscape may influence the ability of the species to spread (With 2002). For example, for a species that invades through disturbed habitats the extent and connectivity of these habitats must be sufficient to allow spread.

### *Invasibility and Plant Community Type*

An application to Sierra Nevada plant communities contrasts hypothetical scenarios for two different plant communities: (1) a low elevation annual grassland, and (2) a high elevation alpine fell-field (Figure F-29). The annual grassland community of the Sierra Nevada is already highly invaded, with new species continuing to naturalize. This community has relatively high resource supply and favorable growing conditions (except for the hot, dry summer season). A disturbance during the growing season that drastically reduces resource uptake can leave a large invasibility window. Hypothetically, a larger invasibility window should allow a larger number of species to exploit that window. In contrast, the alpine community has a much lower level of resource uptake and supply than an annual grassland. A disturbance during the growing season (Figure F–29) decreases resource uptake, but not by the magnitude found in an annual grassland. The invasibility window in the alpine community is small compared to the annual grassland; thus, few introduced species are able to exploit it.

This conceptual model of invasion has some deficiencies. Foremost among them, it does not accommodate interactions among species other than competition. For example, it does not account for introduced species that have deleterious effects on their neighbors (e.g., allelopathy–see (Bais et al. 2003). It also fails to generalize to animal invasions, although the model is suitable for some aspects of animal invasions. For example, some invasive animal species exhibit aggressive behavior, which is not included in this conceptual model.

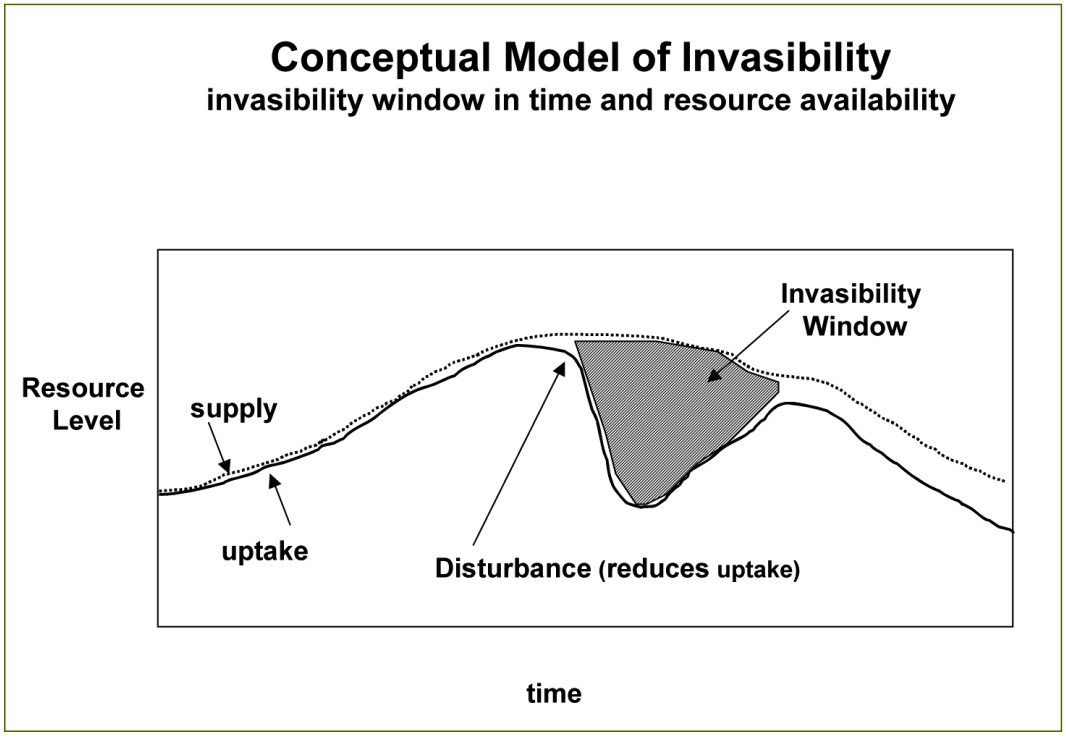



**Figure F–28.** Resource availability and windows of invasibility in time.

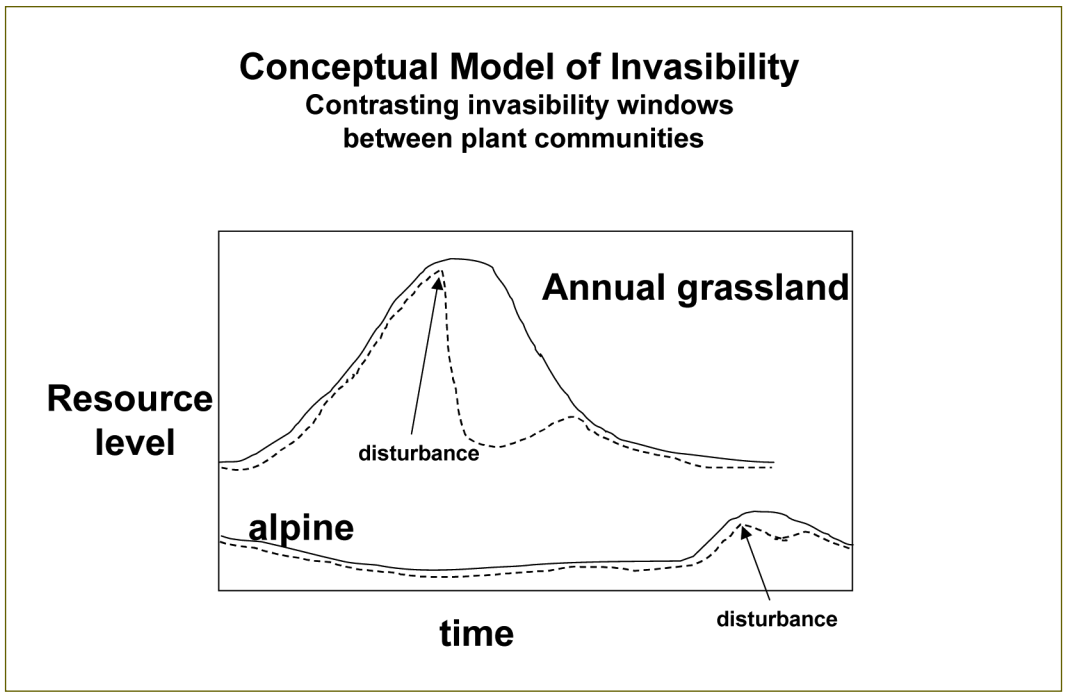



**Figure F–29.** Conceptual diagram of invasibility, contrasting two plant communities–annual grassland and alpine–that differ in resource levels.

## Model: Bird Populations

### *Introduction*

Sierra Nevada Network parks provide birds over 658,000 hectares (1,600,000 acres) of unusually diverse habitats, ranging from gently sloping foothill grasslands, through chaparral/oak woodland and giant conifer forests, up to windswept alpine wetlands and peaks. While none of the approximately 200 bird species that breed, winter, or migrate through the Sierra Nevada are unique, the key to its exceptional bird diversity is its extreme elevation gradient and corresponding habitat diversity. The western slope's elevation gradient spans over 14,000 feet–from the lower foothills to the top of Mt. Whitney–and supports the most diverse assortment of terrestrial habitats and birds in California (Beedy 1985).

Accordingly, our Mediterranean climate varies dramatically from the mild winters and hot dry summers that characterize the foothills, through wetter and cooler mid-elevations, up to harsh long winters and short summers in sub-alpine and alpine areas. Since birds are inextricably tied to the passage of seasons, species occupying different elevations follow radically different annual schedules. In recognition of the Sierra Nevada's bird diversity and critical breeding, stopover, and wintering habitats, Sequoia, Kings Canyon, and Yosemite National Parks, and a few other large areas in the Sierra Nevada, have been designated by the American Bird Conservancy as "Globally Important Bird Areas."

### *Status of Bird Populations*

Many populations of birds and other species are now threatened or endangered, or will likely become threatened soon, as a result of anthropogenic climatic and environmental changes (Terborgh 1989). The improved ability of scientists to document species population trends has led to long-term monitoring programs to monitor the health and status of populations, and to investigate the causes of observed population changes. North American Breeding Bird Survey data indicate that numerous bird species exhibit declining long-term population trends in the Sierra Nevada region. Data from the Sierra Nevada Network MAPS (Monitoring Avian Productivity and Survivorship) program in the parks' wetland habitats have shown declines in many breeding populations of birds. Analyses reveal negative trends in 13 species; and, adult birds of all species (pooled) represent a highly significant decrease, suggesting that populations of birds in Yosemite have been reduced by 23% over the last 13 years (Pyle et al. 2006). Over half the declining species exhibited low reproductive success, indicating that population dynamics on their Sierra Nevada breeding grounds is a limiting factor to these species' survival.

### *Stressors*

Researchers have identified five main categories of stressors faced by birds in Sierra Nevada Network parks (Figure F- 30) : (1) anthropogenic climate change (2) habitat fragmentation, loss, and insularization, (3) atmospheric pollution, (4) altered fire regime, and (5) invasive species (DeSante 1995, Graber 1996) SIEN Bird Workgroup 2006, pers. comm.).

#### *Anthropogenic Climate Change*

Over 140 studies have shown that global warming is correlated to biological change and several of these studies have revealed that as temperatures increase, the geographical ranges of numerous species have shifted poleward or moved to a higher elevation (Root et al. 2003, Root et al. 2005). Concurrent with these studies, the recent Grinnell resurveys across the Sierra Nevada detected many bird species ranging higher in elevation than observed 80 years earlier by Grinnell and his colleagues.

#### *Habitat fragmentation, Loss, and Insularization*

Habitat fragmentation and loss, including increasing exurban development with its concomitant increases in land conversion, is one of the biggest problems faced by birds today, and has contributed to the majority of species declines (Neotropical Migratory Bird Conservation Act 2000). The most endangered songbird in the Sierra Nevada, the Willow Flycatcher,

is rapidly disappearing because of land use practices (e.g., grazing, agriculture) that have denuded or destroyed their riparian habitat. Habitat degradation on a regional scale probably affects the viability of bird populations on relatively intact habitats managed inside the parks. Nearctic-Neotropical migratory passerine birds are exhibiting the most severe population declines because they face habitat destruction and degradation during migration stopover and on both wintering and breeding grounds.

### *Atmospheric Pollution*

The deposition of atmospheric pollutants in California's Sierra Nevada Mountains has resulted in the degradation of ecosystems (Duriscoe 1987, Unger 1989) and is thought to play a role in the declines of several wildlife populations (Davidson 2004, Fellers et al. 2004). Environmental pollutants, such as organophosphorous pesticides and ozone, travel upslope from the heavily developed San Joaquin and Sacramento Valleys due to prevailing winds (Zabik and Seiber 1993, LeNoir et al. 1999, Fancy and Gross 2004). The pollutants enter the Sierra Nevada ecosystem via wet and dry deposition, ultimately making their way into the food chain (LeNoir et al. 1999).

### *Altered Fire Regime*

The Sierra Nevada ecosystem was historically dependent upon frequent fire. Fire created complexity across the landscape by opening forests for shrub communities and creating snags, logs, and a varied-age plant structure - all critical features that support diverse and abundant wildlife. Fire exclusion from the Sierra Nevada has contributed to long-term shifts in habitat composition and structure (Gruell 2001) which has negatively affected a diversity of birds, for example, Olive-sided Flycatcher which favor open forest with snags and scattered trees, Brown Creeper and Pileated Woodpecker which rely on older forests with large-diameter trees, and Black-backed Woodpecker which depends on burned forest.

### *Invasive Species*

Invasive species include both introduced and native human commensal species that have expanded their range in the Sierra Nevada because of increased food supplies from stables, picnic areas, campgrounds, and residential areas. Introduced species, such as cavity nesting European Starling and House Sparrow, compete with native species for nest holes, and in some areas, such as Lee Vining Canyon, have reduced native populations of Violet-green Swallows, House Wrens, and Mountain Bluebirds (Leland and Carter 1985, Gaines 1988). Native human commensals (native pest species) have increased historically, both in extent of range and abundance (Marzluff 2005) and include nest predators, the Brown-headed Cowbird, and generalist species. Nest predators, such as Common Raven, Steller's Jay, and Western Scrub-Jay, take both eggs and young from nests. The nest parasite, Brown-headed Cowbird, lays their eggs in the nests of small songbirds such as vireos, flycatchers, and warblers, who raise the cowbird young usually at the expense of their own. Generalist species include American Robin, Northern Mockingbird, and blackbirds which are more numerous near campgrounds and residential areas and eventually may limit the size of other native songbird populations if food and nest sites become limited resources.

### *Vital Sign*

Birds are an appropriate indicator-species of local and regional change in terrestrial ecosystems because their ecology and biology integrates the effects of numerous stressors (Canterbury et al. 2000). Because of their high body temperature, rapid metabolism, and high ecological position on most food webs, birds are excellent integrators of the effects of local, regional and global environmental change on terrestrial ecosystems. Furthermore, their abundance and diversity in virtually all terrestrial habitats, diurnal nature, discrete reproductive seasonality, and intermediate longevity facilitate the monitoring of their population and demographic parameters (DeSante et al. 2005). Bird populations are a scientifically viable vital sign and surrogate for evaluation of network

ecosystem condition for several reasons:

- Birds occupy a wide diversity of ecological niches in the parks
- Birds are conspicuous, easily observable, and monitoring is cost effective
- As secondary consumers (i.e. insectivores), birds are sensitive indicators of environmental change
- By managing for a diversity of birds, most other elements of biodiversity are conserved and bird monitoring can prevent future listing of declining species by identifying problems and solutions early;
- Knowledge of the natural history of many bird species has a rich basis in literature
- All units in SIEN have a strong foundation of inventory data upon which to build future monitoring efforts
- Monitoring Avian Productivity and Survivorship (MAPS) has occurred at all parks for varying numbers of years and time periods, including at one station in Yosemite (Hodgdon Meadows) for 14 years

### *Measures*

In addition to population trends (distribution and abundance), effective management of birds should include assessment and monitoring of vital rates (primary demographic parameters) (DeSante et al. 2005). Environmental stressors and management actions affect vital rates directly, usually without time-lags. Vital rates are essential for understanding a) the stage of the life cycle where population change is being effected, b) health and viability of populations, and c) habitat quality (DeSante et al. 2005). DeSante et al. (2005) identified six vital rates upon which management should be based: (1) productivity, (2) survival of young, (3) recruitment of young, (4) annual survival of adults, (5) site fidelity, and (6) immigration. By identifying proximate demographic cause(s) of bird population changes, management guidelines may be formulated to reverse population declines and to evaluate the effectiveness of the management actions implemented.

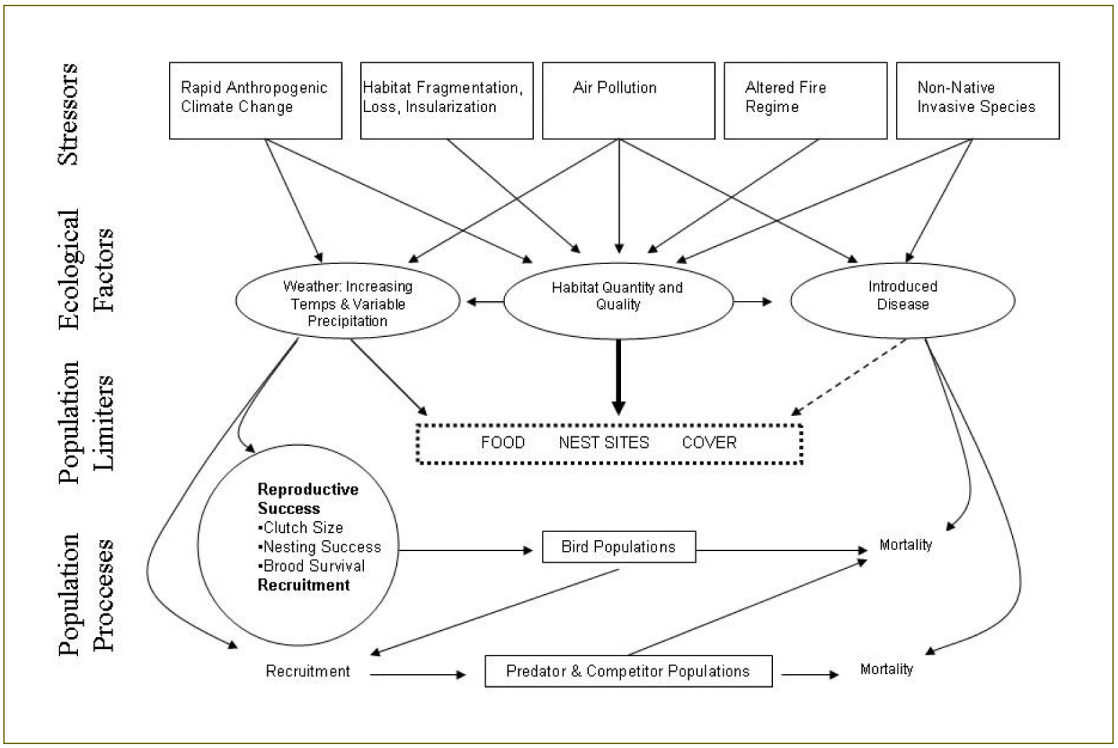



**Figure F–30.** Bird populations conceptual diagram, including principle interactions of stressors, ecological factors, population limiters, and population processes.

# LITERATURE CITED


Adam, D. P. 1981. Scanning electron micrographs of modern and late Holocene chrysomonad cysts from Harden Lake Meadow, Yosemite National Park, California. Open-File Report 81-0046, U. S. Geological Survey, Reston, VA.

Agee, J. K., R. H. Wakimoto, and H. H. Biswell. 1978. Fire and fuel dynamics of Sierra Nevada conifers. *Forest Ecology and Management* **1**:255-265.

Allen, E. B., P. E. Padgett, A. Bytnerowicz, and R. Minnich. 1988. Nitrogen deposition effects on coastal sage vegetation of southern California. A. Bytnerowicz, M. J. Arbaugh, and S. L. Schilling. International Symposium on Air Pollution and Climate Change Effects on Forest Ecosystems, Riverside, California, 25 February 2003.

Allen, T. F. H., and T. W. Hoekstra. 1992. Toward a Unified Ecology. Columbia University Press, NY.

Anderson, J. M. 2000. Food web functioning and ecosystem processes: problems and perceptions of scaling. Pages 3-24 *In* D. C. Coleman and P. F. Hendrix, editors. Invertebrates as webmasters in ecosystems. CABI Publishing, Oxon, UK.

Anderson, R. S. 1990. Holocene forest development and paleoclimates within the central Sierra Nevada, California. *Journal of Ecology* **78**:470-489.

Anderson, R. S. 1994. Paleohistory of a giant sequoia grove: The record from Log Meadow, Sequoia National Park. P. S. Aune. Proceedings of the Symposium on Giant Sequoias: Their place in the ecosystem and society. Vol. PSW-151.

Anderson, R. S., and S. J. Smith. 1991. Paleoecology within California's Sierra Nevada National Parks: An overview of the past and prospectus for the future. Proceedings of the Yosemite Centennial Symposium, El Portal, California.

Anderson, R. S., and S. J. Smith. 1994. Paleoclimatic interpretations of meadow sediment and pollen stratigraphies from California. *Geology* **22**:723-726.

Anderson, R. S., and S. J. Smith. 1997. Sedimentary record of fire in montane meadows, Sierra Nevada, California, USA: A preliminary assessment. Pages 313-327 *In* J. S. Clark, H. Cachier, J. G. Goldammer, and B. Stocks, editors. Sediment Records of Biomass Burning and Global Change. NATA ASI series, Springer-Verlag, Berlin.

Angerman, J. E., G. M. Fellers, and F. Matsumura. 2002. Polychlorinated biphenyls and toxaphene in pacific tree frog tadpoles (*Hyla regilla*) from the California Sierra Nevada, USA. *Environ Sci Technol* **21**:2209-2215.

Ansley, J. A. S., and J. J. Battles. 1998. Forest composition, structure, and change in an old-growth mixed conifer forest in the northern Sierra Nevada. *Journal of the Torrey Botanical Society* **125**:297-308.

Aston, L. S., and J. N. Sieber. 1997. Fate of summertime airborne organophosphate pesticide residues in the Sierra Nevada mountains. *Environ. Qual.* **26**:1483-1492.

Bailey, G. R. 1998. Ecoregions. In The Ecosystem Geography of the Oceans and Continents. Springer-Verlag, NY.

Bais, H. P., R. Vepachedu, S. Gilroy, R. M. Callaway, and J. M. Vivanco. 2003. Allelopathy and exotic plant invasion: From molecules and genes to species interactions. *Science* **301**:1377-1380.

Basagic, H. J. 2008. Twentieth century glacier change in the Sierra Nevada, California. MS. Portland State University, Portland, OR.

Battles, J. J., A. J. Shlisky, R. H. Barrett, R. C. Heald, and A. Diaz. 2001. The effects of forest management on plant species diversity in a Sierran conifer forest. *Forest Ecology and Management* **146**:211-222.

Beedy, E. C., and S. T. Granholm. 1985. Discovering Sierra birds: western slope. Yosemite Natural History Association and Sequoia Natural History Association.

Benedict, N. B., and J. Major. 1982. A physiographic classification of subalpine meadows of the Sierra Nevada, California. *Madrono* **29**:1-12.

Blackburn, W., R. Knight, and J. Schuster. 1982. Saltcedar influence on sedimentation in the Brazos river. *Journal of Soil and Water Conservation* **37**:298-301.

Blank, R. R., and D. C. Zamudio. 1998. The influence of wildfire on aqueous-extractable soil solutes in forested and wet meadow ecosystems along the eastern front of the Sierra-Nevada Range, California. *Journal of Wildland Fire* **8**:79-85.

Boiano, D. M., D. P. Weeks, and T. Hemry. 2005. Sequoia and Kings Canyon NationalParks, California: Water resources information and issues overview report. Technical Report NPS/NRWRD/NRTR 2005/333, National Park Service, Denver.

Bonnicksen, T. M., and E. C. Stone. 1978. An analysis of vegetation management to restore the structure and function of pre-settlement giant sequoia-mixed conifer forest mosaics. U.S. National Park Service, Sequoia and Kings Canyon National Parks, CA.

Bonnicksen, T. M., and E. C. Stone. 1982. Reconstruction of a presettlement giant sequoia mixed conifer forest community using the aggregation approach. *Ecology* **63**:1134-1148.

Bossard, C. C., J. M. Randall, and M. C. Hoshovsky. 2000. Invasive Plants of California's Wildlands. University of California Press, Berkeley, CA.

Bowman, W. D. 2000. Biotic controls over ecosystem response to environmental change in alpine trundra of the Rocky Mountains. *Ambio* **29**:396-400.

Bradford, D. F. 1989. Allotropic distribution of native frogs and introduced fishes in high Sierra Nevada lakes of California: Implication of the negative effect of fish introductions. *Copeia* **3**:775-778.

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, D. F., and M. S. Gordon. 1992. Aquatic amphibians in the Sierra Nevada: Current status and potential effects of acidic deposition on populations. Final Report ARBR93480.

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.

Bradley, R. S. 1985. Quaternary Paleoclimatology. Allen and Unwin, Boston.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of Invasive Alien Plants on Fire Regimes. *BioScience* **54**:677-688.

Brown, K. S., Jr., . 1997. Diversity, disturbance, and sustainable use of Neotropical forests: insects as indicators for conservation monitoring. *Journal of Insect Conservation* **1**:25-42.

Bytnerowicz, A., B. Godzik, K. Grodzinska, M. Krywult, A. Fraczek, M. Tausz, R. Alonso, D. Jones, R. Johnson, and N. Grulke. 2002. Summer-time distribution of air pollutants in Sequoia National Park, California. *Environmental Pollution* **118**:187-203.

Cahill, T. A., J. J. Carroll, D. Campbbell, and T. E. Gill. 1996. Air Quality. Sierra Nevada Ecosystem Project: final report to Congress UC Davis, Davis, CA.

Caldwell, T. G., D. W. Johnson, W. W. Miller, and R. G. Qualls. 2002. Forest floor carbon and nitrogen losses due to prescription fire. *Soil Science Society of American Journal* **66**:262-267.

California Energy Commission. 2003. Climate Change and California: Staff Report. California Energy Commission, Sacramento, CA.

Canterbury, G. E., T. E. Martin, D. R. Petit, L. J. Petit, and D. F. Bradford. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. *Conservation Biology* **14**:544-558.

Caprio, A. C. 1999. Research, inventory and monitoring: Mineral King Risk Reduction Project. Annual Report 1998, Sequoia and Kings Canyon National Parks, Three Rivers.

Caprio, A. C. 2000. Reconstructing attributes of pre-Euroamerican settlement fire at a watershed scale, Sequoia and Kings Canyon National Parks. 85th Ecol. Soc. Amer. Annual Meeting.

Caprio, A. C. 2003. Historic role of fire. *In* Fire and fuel management plan, Sequoia and Kings Canyon National Parks. National Park Service.

Caprio, A. C., C. Conover, M. Keifer, and P. Lineback. 2002. Fire management and GIS: A framework for identifying and prioritizing fire planning needs. N. G. Sugihara and M. E. Morales. Proceedings of the symposium: Fire in California ecosystems: Integrating ecology, prevention and management, San Diego, CA, Nov.17–20, 1997. Vol. 1.

Caprio, A. C., and D. M. Graber. 2000. Returning fire to the mountains: Can we successfully restore the ecological role of pre-Euroamerican fire regimes to the Sierra Nevada? D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin.

Proceedings: Wilderness Science in a Time of Change. Wilderness Ecosystems, Threats, and Management, Missoula, MT and Ogden, UT, May 23-27, 1999. Vol. RMRS-P-15-VOL-5.

Caprio, A. C., and P. Lineback. 1997. Pre-twentieth century fire history of Sequoia and Kings Canyon National Park: A review and evaluation of our knowledge. Fire in California Ecosystems: Integrating Ecology, Prevention, and Management, San Diego, CA, November 17-20.

Caprio, A. C., and P. Lineback. 2002. Pre-twentieth century fire history of Sequoia and Kings Canyon National Parks: A review and evaluation of our knowledge. N. G.

Sugihara, M. E. Morales, and T. J. Morales. Proceedings of the Symposium: Fire in California Ecosystems: Integrating Ecology, Prevention and Management, San Diego, CA, Nov.17-20, 1997. Vol. 1.

Caprio, A. C., and T. W. Swetnam. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. Pages 173-179 In J. K. Brown, R. W. Mutch, C. W. Spoon, and R. H. Wakimoto, editors. Proceedings of a Symposium on Fire in Wilderness and Park Management. USDA Forest Service Gen. Tech. Rep. INT-GRT-320.

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.

Chan , I. A. 1998. Aquatic macroinvertebrates of small streams in the Mineral King region of Sequoia National Park: Baseline communities and response to prescribed fire. MS Thesis. University of California, Berkeley, CA.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* **148**:1016-1037.

Chorover, J., P. M. Vitousek, D. A. Everson, A. M. Esperanza, and D. Turner. 1994. Solution chemistry profiles of mixed-conifer forests before and after fire. *Biogeochemistry* **26**:115-144.

Christensen, D. P. 1977. History of trout introductions in California high mountain lakes. A symposium on the management of high mountain lakes in California's national parks. California Trout, Inc., San Francisco.

CIRMOUNT Committee. 2006. Mapping new terrain: Climate Change and America's West. Report of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT). Pacific Southwest Research Station, Forest Service, US Dept. of Agriculture, Albany, CA.

Clark, J. S. 1988. Effect of climate change on fire regimes in northwestern Minnesota. *Nature*: **233-235**.

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

Cole, D. N., J. W. van Wagtendonk, M. P. McClaren, P. E. Moore, and N. K. McDougald. 2004. Response of mountain meadows to grazing by horses and mules: Yosemite National Park, California. *J. Range Management* **57**:153-170.

Coleman, D. C., and P. F. Hendrix, editors. 2000. Invertebrates as webmasters in ecosystems. CABI Publishing, Oxon, UK.

Convention on Biological Diversity. 2005. The Convention on Biological Diversity Handbook, 3rd Edition, http://www.biodiv.org/handbook/, Accessed November 30, 2006.

Cooper, D., E. C. Wolf, and R. Chimner. 2005. Hydrological and ecological analysis of the effects of groundwater pumping on water levels, fen carbon budget and vegetation, in Crane Flat, Yosemite National Park, California. Progress report Colorado State University, Fort Collins, CO.

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

Covington, W. W., and S. S. Sackett. 1984. The effect of a prescribed fire in southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. *Forest Science* **30**:183-192.

Coxwell, C. C., and C. E. Bock. 1995. Spatial variation in diurnal surface temperatures and the distribution and abundance of an alpine grasshopper. *Oecologia* **104**:433- 439.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change. *Annual Review of Ecology and Systematics* **23**:63-87.

Daehler, C. C. 2001. Two ways to be an invader, but one is more suitable for ecology. *Bulletin of the Ecological Society of America* **82**:101-103.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological guidelines and principles for managing the use of land. *Ecological Applications* **10:**639-670.

Datta, S., L. Hansen, L. McConnell, J. Baker, J. Pesticides and PCB contaminants in fish and tadpoles from the Kaweah River basin, California. *Bulletin of Environmental Contamination and Toxicology* **60**:829-836.

Datta, S., L. L. McConnell, J. E. Baker, J. LeNoir, and J. N. Seiber. 1998b. Evidence for atmospheric transport and deposition of polychlorinated biphenyls to the LakeTahoe Basin California-Nevada. *Environ Sci Technol* **32**:1378-1385.

Datta. S., L. Hansen, L. McConnell, J. Baker, J. LeNoir, and J. N. Seiber. 1998. Pesticides and PCB Contaminants in Fish and Tadpoles from the Kaweah River Basin, California. Bull. *Environ. Contam. Toxicol.* **60**:829-836.

Davidson, C. 2004. Declining downwind: Amphibian population declines in California and historical pesticide use. *Ecological Applications* **14:**1892-1902.

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

Davis, M. A., J. P. Grime, and K. Thompson. 2000a. Fluctuating Resources in Plant Communities: A General Theory of Invasibility. *Journal of Ecology* **88**:528-534.

Davis, M. A., and K. Thompson. 2000. Eight ways to be a colonizer; two ways to be an invader: a proposed nomenclature scheme for invasion ecology. Bulletin of the Ecological Society of America 81.

DeBano, L. F. 2000. The role of fire and soil heating on water repellency in wildland environments: A review. *Journal of Hydrology* **231-232**:195-206.

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. Fire's Effects on Ecosystems. John Wiley and Sons, Inc., New York.

DeBenedetti, S. H., and D. J. Parsons. 1984. Postfire succession in a Sierran subalpine meadow. *American Midland Naturalist* **111**:118-125.

Delwiche, C. C. 1970. The nitrogen cycle. *Scientific American* **223**:136-146.

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 J. R. Carlson. 2003. Coliform and pathologic bacteria in wilderness water, Sequoia and Kings Canyon National Parks. Informal Report, University of California, Davis School of Medicine, Davis, CA.

DeSante, D. F. 1995. The status, distribution, abundance, population trends, demographics, and risks of the landbird fauna of the Sierra Nevada mountains. Unpublished file report to the Siera Nevada Ecosystem Project, Davis, CA.

DeSante, D. F., P. Pyle, and D. R. Kaschube. 2005. The Monitoring Avian Productivity and Survivorship (MAPS) Program in Sequoia and Kings Canyon and Yosemite National Parks and Devil's Postpile National Monument: a comparison between time periods and locations. The Institute for Bird Populations, Pt. Reyes Station, CA.

Dettinger, M. 2005. Changes in Streamflow Timing in the Western United States in Recent Decades. Fact Sheet 2005-3018, US Geological Survey, Scripps Institution of Oceanography, La Jolla, CA.

Dettinger, M., K. Redmond, and D. Cayan. 2005. Winter Orographic-Precipitation Ratios in the Sierra Nevada—Large-Scale Atmospheric Circulations and Hydrologic Consequences. *Journal of Hydrometeorology* **5**:1102-1116.

Dettinger, M. D., D. R. Cayan, M. Meyer, and A. E. Jeton. 2004. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099. *Climatic Change* **62**:283-317.

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.

Dingman, S. L. 2002. Physical Hydrology, 2nd edition. Prentice-Hall, Engelwood Cliffs, New Jersey.

Drost, C., 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.

Dukes, J. S., and H. A. Mooney. 1999. Does global change increase the success of biological invaders? *Trends in Ecology and Evolution* **14**:135-139.

Dunne, J. A., J. Harte, and K. J. Taylor. 2003. Subalpine meadow flowering phenology responses to climate change: integrating experimental and gradient methods. *Ecological Monographs* **73**:69-86.

Dunne, T., and L. B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman and Company, San Francisco, CA.

Duriscoe, D. M. 1987. Evaluation of ozone injury to selected tree species in Sequoia and Kings Canyon National Parks, 1985 survey results. Air Quality Division, National Park Service, Denver, CO.

Duriscoe, D. M., and C. S. Duriscoe. 2002. Survey and monitoring of white pine blister rust in Sequoia and Kings Canyon National Parks. Final report on 1995-1999 survey and monitoring plot network. Three Rivers.

Duriscoe, D. M., and K. W. Stolte. 1989. Photochemical oxidant injury to ponderosa pine (*Pinus ponderosa* Laws.) and Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) in the national parks of the Sierra Nevada of California. R. K. Olson and A. S. Lefohn. Transactions: Effects of Air Pollution on Western Forests Anaheim, CA, Pittsburgh, PA.

Duriscoe, D. M., and K. W. Stolte. 1992. Decreased foliage production and longevity observed in ozone-injured Jeffrey and ponderosa pine in Sequoia National Park, California. Pages 663-680 *In* Tropospheric Ozone and the Environment II: Effects, Modeling and Control. Air and Waste Management Association, Pittsburgh, PA.

Ehrenfeld, J. G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. *Ecosystems* **6**:503-523.

Eilers, J. M., D. F. Brakke, D. H. Landers, and W. S. Overton. 1989. Chemistry of wilderness lakes in the Western United States. Environmental Monitoring and Assessment **12**.

Erman, D. C., E. D. Andrews, and M. Yodler-Williams. 1988. Effects of winter floods on fishes in the Sierra Nevada. *Canadian Journal of Fisheries and Aquatic Sciences* **45**:2195-2200.

Fancy, S., and J. Gross. 2004. Monitoring Natural Resources in our National Parks. http://science.nature.nps.gov/im/monitor/index.htm. Date Accessed: April, 2004.

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.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003. Ecological Effects of Nitrogen Deposition in the Western United States. *BioScience* **53**:404-420.

Fenn, M. E., M. A. Poth, J. Aber, J. S. Baron, B. T. Bormann, D. W. Johnson, D. Lemly, S. G. McNulty, D. F. Ryan, and R. Stottlemyer. 1998. Nitrogen excess in North American ecosystems: Predisposing factors, ecosystem responses, and management stratagies. *Ecological Applications* **8**:706-733.

Ferrell, G. M. 1996. The influence of insect pests and pathogens on Sierra forests. Pages 1177-1192 *In* Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University California, Centers for Water and Wildlands Resources, Davis, CA.

Fire and Resource Assessment Program. 1997. Bioregional Demographic Trends and Implications for Biodiversity. http://frap.cdf.ca.gov/projects/bioregional_trends/bioreg_pop.html.

Forman, R. T. T. 1997. Landscape Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, U.K.

Franklin, J. F., and J. A. Fites-Kaufmann. 1996. Assessment of late-successional forests of the Sierra Nevada, Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II: Assessments and Scientific Basis for Management Options. Wildland Resources Center Report No. 37, University of California, Davis.

Gaines, D. 1988. Birds of Yosemite and the East Slope. Artemesia Press Books, Lee Vining, CA.

Gerlach, J. D., Jr.,. 2004. The impacts of serial land-use changes and biological invasions on soil water resources in California, USA. *Journal of Arid Environments* **57**:365-379.

Gerlach, J. D., P. E. Moore, B. Johnson, D. G. Roy, P. Whitmarsh, D. M. Lubin, D. M. Graber, S. Haultain, A. Pfaff, and J. E. Keeley. 2003. Alien plant species assessment and management prioritization for Sequoia-Kings Canyon and Yosemite National Parks. Open File Report 02-170 U.S. Geological Survey: Carson City, Nevada.

Gill, A. M. 1975. Fire and the Australian flora: A review. *Australian Forestry* **38**:4-25.

Goldman, C. R., A. D. Jassby, and S. H. Hackley. 1993. Decadal, interannual and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **50**:1489-1496.

Gorham, E. 1991. Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* **1**:182-195.

Gotelli, N. J., and G. L. Entsminger. 2006. EcoSim: Null models software for ecology. Version 7. Acquired Intelligence Inc. & Kesey-Bear.

Graber, D. M. 1996. Status of terrestrial vertebrates. Pages 709-734 In Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis, CA.

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

Green, D. E., and C. Katarise-Sherman. 2001. Diagnostic histological findings in Yosemite toads (*Bufo canorus*) from a die-off in the 1970s. *Journal of Herpetology* **35**:92–103.

Grinnell, J., and T. I. Storer. 1924. Animal Life in the Yosemite. An account of the mammals, birds, reptiles, and amphibians in a cross-section of the Sierra Nevada. University of California Press, Berkeley.

Gross, J. E. 2005. Developing conceptual models for I&M Networks. Powerpoint presentation on: NPS I&M program conceptual model web page.

Gruell, G. E. 2001. Fire in Sierra Nevada forests: a photographic interpretation of ecological change since 1849. Mountain Press, Missoula, MT.

Hansen, A., and D. Gryskiewicz. 2003. Interactions between Heartland National and surrounding land use change: Development of conceptual models and indicators for monitoring. Final report to Heartland Network, National Park Service. Montana State University.

Harvey, H. T., and H. S. Shellhammer. 1991. Survivorship and growth of giant sequoia (Sequoiadendron giganteum (LINDL.) BUCHH.) seedlings after fire. *Madrono* **38**:14-20.

Harvey, H. T., H. S. Shellhammer, and R. E. Stecker. 1980. Giant Sequoia Ecology: Fire and Reproduction. Scientific Monograph Series USDI NPS, Washington, D.C.

Hauer, F. R., and C. N. Spencer. 1998. Phosphorus and nitrogen dynamics in streams associated with wildfire: A study of immediate and long-term effects. *International Journal of Wildland Fire* **8**:183-198.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, and J. H. Verville. 2004. Emissions pathways, climate change, and impacts on California. *National Academy of Sciences* **101**:12422-12427.

Heady, H. F., J. W. Bartolome, M. D. Pitt, G. D. Savelle, and M. C. Stroud. 1992. California prairie. Pages 313-335 *In* M. C. Coupland, editor. Ecosystems of the World: Natural Grasslands: Introduction and Western Hemisphere. Elsevier, New York, NY.

Heard, A., and L. S. Mutch. 2003. Summary of preliminary water resources vital signs scoping meeting for Sierra Nevada Network Parks. Unpublished report, Three Rivers, CA.

Heard, A. M. 2005. Effects of landscape scale prescribed fire on hydrology and stream chemistry. MS. Coloradao State University, Fort Collins, CO.

Heinselman, M. L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. Pages 7-57 *In* T. M. Mooney, T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners, editors. Proceedings of the conference: Fire regimes and ecosystem properties. USDA Forest Service, Honolulu, HI.

Helvey, J. D. 1980. Effects of a north central Washington fire on runoff and sediment production. *Water Resources Bulletin* **16**:627-634.

Hendry, G. W. 1934. The source literature of early plant introduction into Spanish America. *Agricultural History* **8**:64-71.

Herbst, D. B., E. L. Silldorff, and S. D. Cooper. 2003. The influence of introduced trout on the composition of native aquatic invertebrate communities in high Sierran streams of Yosemite National Park. Final report, The Nature Conservancy—Ecosystem research program, Grant Award #HO-CSD-050600-CA and the University of California Water Resourses Center, Grant Award #W-930.

Hobbs, R. J., and L. F. Huenneke. 1992. Disturbance, diversity and invasion: Implications for conservation. *Conservation Biology* **6**:324-337.

Hobbs, R. J., and H. A. Mooney. 1998. Broadening the extinction debate: population deletions and additions in California and Western Australia. *Conservation Biology* **12**:271-283.

Holmquist, J. G., and J. M. Schmidt-Gengenbach. 2004. Terrestrial invertebrates: functional roles in ecosystems and utility as vital signs in the Sierra Nevada. Report submitted to Sierra Nevada Network Inventory & Monitoring program, in partial fulfillment of: Cooperative Agreement H8R07010001and Task Agreement J8R07030011. University of California, White Mountain Research Station.

Holmquist, J. G., and J. M. Schmidt-Gengenbach. 2006. A pilot study study and assessment of the efficacy of invertebrates as indicators of meadow change in Sierra Nevada Network parks. 2004-2005 Final Report to Sierra Nevada Network Inventory & Monitoring program, in partial fulfillment of Cooperative Agreement H8R07010001 and Task Agreement J8R0730011. University of California, White Mountain Research Station.

Hopkins, P. S., K. W. Kratz, and S. D. Cooper. 1989. Effects of an experimental acid pulse on invertebrates in a high altitude Sierra Nevada stream. *Hydrobiologia* **171**:45-58.

Houghton, J. T., D. J. Ding, M. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson. 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, U.K.

Howarth, R. W., E. W. Boyer, W. J. Pabich, and J. N. Galloway. 2002. Nitrogen use in the United States from 1961-2000 and potential future trends. *Ambio* **31**:88-96.

Howat, I. M., and S. Tulaczyk. 2005. Climate sensitivity of spring snowpack in the Sierra Nevada. Geophysical Research-Earth Surface. 110 (F4).

Huffman, E. L., L. H. Mac Donald, and J. D. Stednick. 2001. Strength and persistence of fire-induced soil hydrophobicity under ponderosa and lodgepole pine, Colorado Front Range. *Hydrological Processes* **15**:2877-2892.

Inbar, M. M. T., and L. Wittenberg. 1998. Runoff and erosion processes after a forest fire in Mount Carmel, a Mediterranean area. Geomorphology 24:17-33. IPCC. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Portchester, New York.

IPCC. 2007. Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability. Summary for Policymakers.

IPPC. 2001. Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY.

Jennings, M. R. 1996. Status of amphibians. *In* D. University of California, editor. Sierra Nevada Ecosystem Project, Final Report to Congress, Davis, CA.

Jennings, M. R., and M. P. Hayes. 1994. Amphibian and reptile species of special concern in California. California Department of Fish and Game Technical Report, Inland fisheries division., Rancho Cordova, CA.

Jenny, H. 1941. Factors of Soil Formation. McGraw-Hill, New York.

Jovan, S., and B. McCune. 2005. Air-quality bioindication in the greater Central Valley of California, with epiphytic macrolichen communities. *Ecological Applications* **15:**1712-1726.

Kaczynski, K. 2007. Invasive species in Wilderness as a function of burn severity: A case study in Yosemite National Park, California. University of Colorado, Boulder, Boulder, CO.

Kane, J. M., S. K. Heath, and B. Kuhn. 2006. Non-native Vascular Plant Inventory of Riparian Areas in Yosemite National Park, California. PRBO Contribution #1335. PRBO Conservation Science, Petaluma, CA.

Kattelmann, R. 1990. Floods in the high Sierra Nevada, California, USA. Pages 311-318 *In* R. O. Sinninger and M. Monbaron, editors. Artificial Reservoirs: Water and Slopes, Publication 194. International Association of Hydrological Sciences, Wallingford, England.

Kattelmann, R. 1996. Hydrology and Water Resources. In Sierra Nevada Ecosystem Project, Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis, CA.

Kattleman, R., N. Berg, and B. McGurk. 1991. A history of rain-on-snow floods in the Sierra Nevada watersheds. *Proceedings, Western Snow Conference* **59**:138-141.

Keeley, J., and N. L. Stephenson. 2000. Restoring natural fire regimes to the Sierra Nevada in an era of global change. D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin. Wilderness science in a time of change: Wilderness ecosystems, threats and management, Missoula, MT. Vol. 5.

Keeley, J. E. 2001. Fire and invasive species in Mediterranean-climate ecosystems of California. Pages 81-94 *In* K. E. M. Galley and T. P. Wilson, editors. Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Managment. Proceedings of the Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Tall Timbers Research Station, Tallahassee, FL.

Keeley, J. E., D. Lubin, and C. J. Fotheringham. 2003. Fire and Grazing Impacts on Plant Diveristy and Alien Plant Invasions in the Southern Sierra Nevada. *Ecological Applications* **13**:1355-1374.

Keifer, M., A. C. Caprio, P. Lineback, and K. Folger. 2000. Incorporating a GIS model of ecological need into fire management planning. Proceedings of the Joint Fire Science Conference and Workshop, Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management, Boise, ID, June 14-16, 1999.

Keifer, M., P. M. Stanzler, and K. Folger. 1995. Fire effects monitoring in Sequoia and Kings Canyon National Parks. Proceedings: symposium on fire in wilderness and park management General Technical Report INT-GTR-320, USDA Forest Service, Ogden, UT.

Kilgore, B. M. 1973. The ecological role of fire in Sierran conifer forests: Its application to national park management. *Quaternary Research* **3**:496-513.

Kilgore, B. M., and H. H. Biswell. 1971. Seedling germination following fire in a giant sequoia forest. *California Agriculture* **25**:8-10.

Kilgore, B. M., and R. W. Sando. 1975. Crown-fire potential in a Sequoia Forest after prescribed burning. *Forest Science* **21**:83-87.

Kilgore, B. M., and D. Taylor. 1979. Fire history of a sequoia mixed-conifer forest. *Ecology* **60**:129-142.

Klinger, R., E. Underwood, and P. E. Moore. 2006. The role of environmental gradients in non-native plant invasion into burned areas in Yosemite National Park, California. *Diversity and Distributions* **12**:139-156.

Klinger, R., and E. C. Underwood. 2002. The Design of Sampling Protocols for an Inventory of Alien Plant Species in Burned and Riparian Areas in Yosemite National Park, California. University of California, Section of Evolution and Ecology, Davis.

Knapp, R. A. 2003a. Inventory of high-elevation waterbodies in Sequoia and Kings Canyon National Parks.

Knapp, R. A. 2003b. Yosemite Lakes Survey: 2000-2002. Sierra Nevada Aquatic Research Laboratory.

Knapp, R. A. 2005. Effects of nonnative fish and habitat characteristics on lentic herpetofauna in Yosemite National Park, CA. *Biological Conservation* **121**:265-279.

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.

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**:23-29.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in Snowfall versus Rainfall in the Western United States. *Journal of Climate* **19**:4545-4559.

Kratz, K. W., 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.

Leland, H. V., and J. L. Carter. 1985. Effects of copper on production of periphyton, nitrogen fixation and processing of leaf litter in a Sierra Nevada, California, stream. *Freshwater biology. Oxford* **15**:155-173.

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.

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

Lin, Y., and I. C. Jao. 1995. A Numerical Study of Flow Circulations in the Central Valley of California and Formation Mechanisms of the Fresno Eddy. *Monthly Weather Review* **123**:3227-3239.

Lonsdale, W. M. 1999. Global patterns of plant invasions and the concept of invasibility. *Ecology* **80**:1522-1536.

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.

Mac Donald, L. H., and J. D. Stednick. 2003. Forests and Water: A state-of-the-art review for Colorado. CWRRI Completion Report No. 196, Colorado State University, Fort Collins, CO.

Mack, M., and C. M. D'Antonio. 1998. Impacts of Biological Invasions on Disturbance Regimes. *Trends in Ecology and Evolution* **13**:195-198.

Mack, R. N. 1981. Invasion of *Bromus tectorum* L. into western North America: An ecological chronicle. *Agro-Ecosystems* **7**:145-165.

Maddox, D. M., and A. Mayfield. 1985. Yellow starthistle infestations are on the increase. *California Agriculture* **39**:10-12.

Manley, P. A., W. J. Zielinski, C. M. Stuart, J. J. Keane, A. J. Lind, C. Brown, B. L. Plymale, and C. O. Napper. 2000. Monitoring ecosystems in the Sierra Nevada: the conceptual model foundation. *Environmental monitoring and assessment* **64**:139-152.

Mann, M. E., R. S. Bradley, and M. K. Hughes. 1998. Global-scale temperature patterns and climate forcing over the past six centuries. *Nature* **392**:779-787.

Marzluff, J. M. 2005. Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. *Urban Ecosystems* **8**:157-177.

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

McClaren, M. P., and D. N. Cole. 1993. Packstock in Wilderness: Use, Impacts, Monitoring, and Management. United States Department of Agriculture—Forest Service.

McConnell, L. L., J. S. LeNoir, S. Datta, and J. N. Seiber. 1998. Wet deposition of current-use pesticides in the Sierra Nevada mountain range, California, USA. *Environmental Toxicology and Chemistry* **17**:1908-1916.

McCune, B., J. Grenon, and E. Martin. 2006. Lichens in relation to management issues in the Sierra Nevada national parks. Final report to Sierra Nevada Network Inventory & Monitoring Program. Cooperative Agreement No. CA9088A0008. Oregon State University, 45 p.

Meffe, G. K., and C. R. Carroll, editors. 1997. Principles of Conservation Biology 2nd edition. Sinauer Associates, Inc., Sunderland, MA.

Melack, J., and J. O. 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. International Association of hydrological Sciences, Wallingford, UK.

Melack, J. M., S. D. Cooper, T. M. J. Jenkins, L. Barmuta, S. Hamilton, K. W. Kratz, S. J., and C. R. 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 Contract Report to the California Air Resources Board A6-184-32, California Air Resources Board, Sacramento, CA.

Melack, J. M., J. O. Sickman, and A. Leydecker. 1998. Comparative analyses of highaltitude lakes and catchments in the Sierra Nevada: Susceptibility to acidification. Final Report, California Air Resources Board Contract A032-188, Santa Barbara, CA.

Melack, J. M., J. O. Sickman, and J. Schimel. 2002. Microbial and hydrological controls of nitrogen losses from alpine and chaparral ecosystems during seasonal transitions- research proposal. Proposal University California, Santa Barbara, Santa Barbara, CA.

Miller, C., N. E. Grulke, and K. W. Stolte. 1992. Air pollution effects on giant sequoia ecosystems. P. S. Aune. Proceedings of the symposium on giant sequoias: Their place in the ecosystem and society. Vol. PSW-151.

Miller, C., and D. L. Urban. 1999a. Forest pattern, fire, and climatic change in the Sierra Nevada. *Ecosystems* **2**:76-87.

Miller, C., and D. L. Urban. 1999b. Interactions between forest heterogeneity and surface fire regimes in the southern Sierra Nevada. *Canadian Journal of Forest Research*. **29**:113-135.

Miller, C., and D. L. Urban. 1999c. A model of surface fire, climate and forest pattern in the Sierra Nevada, California. *Ecological Modelling*. **114**:113-135.

Miller, D. M., T. C. Esque, D. R. Bedford, R. E. Webb, and D. L. Hughson. 2006. Conceptual Ecological Models-Draft, Appendix S. in Mojave Network Inventory and Monitoring Report. U.S. Geological Survey and National Park Service.

Miller, P. R. 1973. Oxidant-induced community change in a mixed-conifer forest. Pages 101-117 *In* J. A. Naegele, editor. Air pollution damage to vegetation, D.C.

Miller, P. R. 1996. Biological effects of air pollution in the Sierra Nevada. Sierra Nevada Ecosystem Project: final report to Congress, vol.III, Assessments, commissioned reports, and background information. Centers for Water and Wildlands Resources, University of California, Davis, CA.

Miller, P. R., S. L. Schilling, R. D. Wilborn, G. A.P., J. Wilborn, and N. E. Grulke. 1991. Ozone injury to important tree species of Sequoia and Kings Canyon National Parks. Final report to the Air Quality Division, National Park Service, Denver, CO.

Mitsch, W., and J. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, NY.

Moore, C. 2000. 1999 annual Sequoia watershed report. *In* 1999 annual fire report on research, monitoring and inventory. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Moore, P. E., and J. D. Gerlach. 2001. Exotic species threat assessment in Sequoia, Kings Canyon, and Yosemite national parks. D. Harmon. Crossing Boundaries in Park Management: 11th Conference on Reseach and Resource Management in Parks and on Public Land.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettermaier. 2005. Declining mountain snowpack in western North America. American Meterological Society.

Mutch, L. S. 2002. Devils Postpile National Monument vital signs workshop report, April 8-9, 2002. Unpublished report, Lee Vining, CA.

Mutch, L. S., and P. Lineback. 2001. Sequoia and Kings Canyon National Parks vital signs workshop report, April 13-16, 1999, Sequoia National Park. Unpublished report.

Mutch, L. S., and D. J. Parsons. 1998. Mixed conifer forest mortality and establishment before and after prescribed fire in Sequoia National Park, CA. *Forest Science*. **44**:341-355.

Mutch, L. S., and T. W. Swetnam. 1995. Effects of fire severity and climate on ringwidth growth of giant sequoia after burning. Proceedings: symposium of fire in wilderness and park management. General Technical Report INT-GTR-320, USDA Forest Service, Ogden, UT.

Mutch, L. S., and S. Thompson. 2003. Yosemite report, April 23-25, 2002. Unpublished report, Mariposa, CA.

Nash, T. H., and L. L. Sigal. 1999. Epiphytic lichens in the San Bernardino mountains in relation to oxidant gradients. Pages 223-234 *In* P. R. Miller and J. R. McBride, editors. Oxidant Air Pollution Impacts on the Montane forests of Southern California: A Case Study of the San Bernadino Mountains. Springer-Verlag, NY.

National Park Service. 1982. Natural resources management statement for Devils Postpile National Monument. National Park Service, Three Rivers, CA.

National Park Service. 1998. Baseline Water Quality Data Inventory and Analysis-Devils Postpile National Monument. Technical Report NPS/NRWRD/NRTR-98/189, National Park Service, Water Resources Division, Fort Collins, CO.

National Park Service. 2003a. Fire and fuels management plan: Sequoia and Kings Canyon National Parks. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2003b. Yosemite National Park Resources Management briefing package. Yosemite National Park, El Portal, CA.

National Park Service. 2004. Yosemite Fire Management Plan and Environmental Statement. Yosemite National Park.

National Park Service. 2006. Developing conceptual models of relevant ecosystem components. National Park Service Air Resources Division. 2003. Western Airborne Contaminants Assessment Project. Fact Sheet National Park Service Air Resources Division, Denver, CO.

National Research Council. 1995. Review of EPA's environmental monitoring and assessment program: Overall evaluation. National Resource Council, National Academy Press, Washington, D.C.

Neuman, M. J. 1990. Past and present conditions of back country meadows in Sequoia and Kings Canyon National Parks, Stock use and meadow monitoring program. Unpublished report Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Noon, B. R., T. A. Spies, and M. G. Raphael, editors. 1999. Conceptual basis for designing an effectiveness monitoring program. USDA Forest Service.

Parsons, D. J. 1981. The historical role of fire in the foothill communities of Sequoia National Park. *Madrono* **28**:111-120.

Parsons, D. J., and S. H. DeBenedetti. 1979. Impact of fire suppression on a mixedconifer forest. *Forest Ecology and Management* **2**:21-31.

Parsons, D. J., and T. J. Stohlgren. 1989. Effects of varying fire regimes on annual grasslands in the southern Sierra Nevada of California. *Madrono* **36**:154-168.

Parsons, D. J., A. C. Workinger, and A. M. Esperanza. 1992. Composition, structure and physical and pathological characteristics of nine forest stands in Sequoia National Park. Tech. Rep. NPS/WRUC/NRTR-92/50, USDI National Park Service, Western National Park Studies Unit, University of California, Davis, CA.

Patterson, M. T., and P. W. Rundel. 1989. Seasonal physiological responses of ozone stressed Jeffrey pine in Sequoia National Park. Pages 419-428 *In* R. K. Olson and A. S. Lefohn, editors. Transactions: Effects of Air Pollution on Western Forests, Anaheim, CA. Air & Waste Management Association, Pittsburgh, PA.

Patton, J. L. 2006. Draft report: The Grinnel resurvey project, Yosemite National Park. Museum of Vertebrate Zoology and Dept. of Integrative Biology, University of California, Berkeley, CA.

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. Springer-Verlag, New York.

Peterson, D. L., M. J. Arbaugh, V. A. Wakefield, and P. R. Miller. 1987. Evidence of growth reduction in ozone-injured Jeffery pine (*Pinus jeffreyi* Grev. and Balf.) in Sequoia and Kings Canyon National Parks. *JAPCA* **37**:906-912.

Phillips, O. L., T. R. Baker, L. Arroyo, N. Higuchi, T. J. Killeen, and W. F. Laurence. 2004. Pattern and process in Amazon tree turnover, 1976-2001. *Phil. Trans. R. Soc. Lond. B* **359**:381-407.

Pickett, S. T. A., and P. S. White. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, Inc.

Pitcher, D. 1981. The ecological effects of fire on stand structure and fuel dynamics in red fire forests of Mineral King, Sequoia National Park, California. M.S. Thesis. UC Berkeley.

Pitcher, D. 1987. Fire history and age structure in red fir forests of Sequoia National Park, California. *Canadian Journal of Forest Research* **17**:582-587.

Price, C., and D. Rind. 1991. Lightning activity in a greenhouse world. Proceedings of the 11th Conference of Fire and Forest Meteorology, Bethesda, MD.

Pyle, P., D. R. Kaschube, R. B. Siegel, and D. F. DeSante. 2006. The 2005 Annual Report of the Monitoring Avian Productivity and Survivorship (MAPS) Program in Yosemite National Park The Institute for Bird Populations, Point Reyes Station, CA.

Rachowicz, L. J., J. M. Hero, R. A. Alford, J. W. Taylor, and J. A. T. Morgan. 2005. The novel and endemic pathogen hypotheses: Competing explanations for the origin of emerging infectious diseases of wildlife. *Conservation Biology* **19**:1441-1448.

Rachowicz, L. J., J. M. Hero, R. A. Alford, J. W. Taylor, J. A. T. Morgan, V. T. Vredenburg, J. P. Collins, and C. J. Briggs. *In press*. The novel and endemic pathogen hypotheses: competing explanations for the origin of emerging infectious diseases of wildlife. Conservation Biology.

Rachowicz, L. J., R. A. Knapp, J. A. T. Morgan, M. J. Stice, V. T. Vredenburg, J. M. Parker, and C. J. Briggs. 2006. Emerging infectious disease as a proximate cause of amphibian mass mortality. *Ecology* **87**:1671-1683.

Rachowicz, L. J., and V. T. Vredenburg. 2004. Transmission of *Batrachochytrium dendrobatidis* within and between amphibian life stages. *Diseases of Aquatic Organisms* **61**:75-83.

Raison, R. J. 1979. Modification of the soil environment by vegetation fires with particular reference to N transformations: a review. *Plant and Soil* **51**:73-108.

Randall, J. M. 1988. Establishment and control of bull thistle (*Cirsium vulgare*) in Yosemite Valley. C. van Riper III, T. J. Stohlgren, S. D. Veirs, and S. C. Hillyer. Examples of Resource Inventory and Monitoring in  Proceedings of the 3rd Biennial Conference on Research in California's National Parks Davis, CA.

Ratliff, R. D. 1982. A meadow site classification for the Sierra Nevada, California. Gen. Tech. Rep PSW-60, USDA Forest Service.

Raub, W. B., A. Post, C. S. Brown, and M. F. Meier. 1980. Perennial ice masses of the Sierra Nevada, California, World Glacier Inventory. *IASH-AISH Publication* **126**:33-34.

Rejmanek, M., and D. M. Richardson. 1996. What Attributes Make Some Plant Species More Invasive. *Ecology* **77**:1655-1661.

Rejmanek, M., D. M. Richardson, M. G. Barbour, M. J. Crawley, G. F. Hrusa, P. B. Moyle, J. M. Randall, D. Simberloff, and M. Williamson. 2002. Biological invasions: Politics and the discontinuity of ecological terminology. *Bulletin of the Ecological Society of America* **83**:131-133.

Ricciardi, A., and J. B. Rasmussen. 1999. Extinction Rates of North American Freshwater Fauna. *Conservation Biology* **13**:1220-1222.

Richardson, D. M., and P. Pysek. 2006. Plant Invasions: Merging the Concepts of Species Invasiveness and Community Invasibility. *Progress in Physical Geography* **30**:409-431.

Richardson, D. M., P. Pysek, M. Rejmanek, M. G. Barbour, F. D. Panetta, and C. J. West. 2000. Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions* **6**:93-107.

Riggan, P. J., R. N. Lockwood, P. M. Jacks, and C. G. Colver. 1994. Effects of fire severity on nitrate mobilization in watersheds subject to chronic atmospheric deposition. *Environ Sci Technol* **28**:369-375.

Roman, C. T., and N. E. Barrett. 1999. Conceptual framework for the development of long-term monitoring protocols at Cape Cod National Seashore. USGS-Patuxent Wildlife Research Center.

Romme, W. H., and D. H. Knight. 1982. Landscape diversity: The concept applied to Yellowstone National Park. *Bioscience* **32**:664-670.

Root, T. L., D. P. MacMynowski, M. D. Mastrandrea, and S. H. Schneider. 2005. Human-modified temperatures induce species changes: Joint attribution. *National Academy of Sciences* **102**:7465-7469.

Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweigk, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature* **421**:57-60.

Roy, D. G., and J. L. Vankat. 1999. Reversal of human-induced vegetation changes in Sequoia National Park, California. *Canadian Journal of Forest Research* **29**:399- 412.

Rundel, P. W. 1969. The distribution and ecology of the giant sequoia ecosystem in the Sierra Nevada. Ph.D Dissertation. Duke University, Durham, NC.

Rundel, P. W. 1972. Habitat restriction in giant sequoia: The environmental control of grove boundaries. *American Midland Naturalist* **87**:81-99.

Rundel, P. W., D. J. Parsons, and D. T. Gordon. 1988. Montane and subalpine vegetation of the Sierra Nevada and Cascade Ranges. *In* M. G. Barbour and J. Major, editors. Terrestrial Vegetation of California. California Native Plant Society.

Saleska, S. R., J. Harte, and M. S. Torn. 1999. The effect of experimental ecosystem warming on CO2 fluxes in a montane meadow. *Global Change Biology* **5**:125-141.

Savage, M. 1994. Anthropogenic and natural disturbance and patterns of mortality in a mixed conifer forest in California. Canadian Journal of Forest Research **24**.

Schowalter, T. D. 2000. Insects as regulators of ecosystem development. In: CABI Publishing, Oxon, UK, p 99-114. Pages 99-114 *In* D. C. Coleman and P. F. Hendrix, editors. Invertebrates as webmasters in ecosystems. CABI Publishing, Oxon, UK.

Scuderi, L. A. 1993. A 2000-year tree ring record of annual temperatures in the Sierra Nevada Mountains. *Science* **259**:1433-1436.

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

Show, S. B., and E. I. Kotok. 1924. The role of fire in the California pine forests. U.S. Printing Office, Washington, D.C.

Sickman, J. O., and J. M. Melack. 1989. Nutrient limitation and effects of acidification on phytoplankton in Emerald Lake. Effects of atmospheric deposition on ecosystems in Sequoia National Park: ecological impacts to aquatic habitats. Final Report, U.S. National Park Service, Cooperative Agreement Order No. 8006-2-0002.

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* **48:**1885-1892.

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.

SNEP. 1996. Sierra Nevada Ecosystem Project: Final Report to Congress. 36 & 37, University of California, Center for Water and Wildlands Resources, Davis, CA.

Snyder, M. A., J. L. Bell, L. C. Sloan, P. B. Duffy, and B. Govindasamy. 2002. Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region. Geophysical Research Letters **29**.

Sousa, W. P. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* **15**:353-391.

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

Speare, R., and L. Berger. Global distribution of chytridiomycosis in amphibians. http://www.jcu.edu.au/school/phtm/PHTM/frogs/chyglob.htm

Spencer, C. N., K. O. Gabel, and F. R. Hauer. 2003. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. *Forest Ecology and Management* **178**:141-153.

St. John, T. V., and P. W. Rundel. 1976. The role of fire as a mineralizing agent in a sierran coniferous forest. *Oecologia* **25**:35-45.

Stephens, S. L. 1995. Effects of prescribed and simulated fire and forest history of giant sequoia (*Sequoiadendron giganteum*)—mixed conifer ecosystems of the Sierra Nevada, California. Ph.D. Dissertation. University of California, Berkeley, CA.

Stephens, S. L. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behavior in Sierra Nevada mixed-conifer forests. *Forest Ecology and Management* **105**:21-35.

Stephenson, N. L. 1987. Use of tree aggregations in forest ecology and management. *Environmental Management* **11**:1-5.

Stephenson, N. L. 1988. Climatic control of vegetation distribution: The role of the water balance with examples from North America and Sequoia National Park, California. Dissertation. Cornell University, Ithaca, NY.

Stephenson, N. L. 1994. Long-term dynamics of giant sequoia populations: Implications for managing a pioneer species. P. S. Aune. Proceedings of the symposium on giant sequoias: Their place in the ecosystem and society, Visalia, CA, 23-25 June 1992.

Stephenson, N. L. 1996. Ecology and management of giant sequoia groves. Sierra Nevada Ecosystem Project: Final report to Congress vol. II, Assesments and scientific basis for management options University of California, Centers for Water and Wildland Resources, Davis.

Stephenson, N. L. 1998. Actual evapotranspiration and deficit: Biologically meaningful correlates of vegetation distribution across spatial scales. *Journal of Biogeography* **25**:855-870.

Stephenson, N. L. 1999. Reference conditions for giant sequoia forest restoration: Structure, process and precision. *Ecological Applications* **9:**1253-1265.

Stephenson, N. L., D. J. Parsons, and T. W. Swetnam. 1991. Restoring natural fire to the sequoia-mixed conifer forest: should intense fire play a role. Proc. 17th Tall Timbers Fire Ecology Conference, Tall Timbers Research Station, Tallahassee, Florida, May 18-21, 1989.

Stephenson, N. L., and P. J. van Mantgem. 2005. Forest turnover rates follow global and regional patterns of productivity. *Ecology Letters* **8:**524-531.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario. *Climatic Change* **62**:217-232.

Stine, S. 1996. Climate, 1650-1850. Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and Scientific Basis for Manangement Options. University of California, Centers for Water and Wildland Resources, Davis, CA.

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

Stohlgren, T. J. 1988. Litter dynamics in two Sierran mixed conifer forests. II. Nutrient release in decomposing leaf litter. *Can. J. For. Res.* **18**:1136-1144.

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

Stolte, K. W., M. I. Flores, D. R. Mangis, and D. B. Joseph. 1992. Tropospheric ozone exposures and ozone injury on sensitive pine species in the Sierra Nevada of California. *In* Tropospheric Ozone and the Environment II: Effects, Modeling and Control. Air and Waste Management Association, Pittsburgh, PA.

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S. L. Rodrigues, D. L. Fischman, and W. R.W. 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. Baisan, A. C. Caprio, R. Touchan, and P. M. Brown. 1992. Treering reconstruction of giant sequoia fire regimes. Final report to Sequoia, Kings Canyon and Yosemite National Parks Coop. University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ.

Swetnam, T. W., C. H. Baisan, K. Morino, and A. C. Caprio. 1998. Fire history along elevational transects in the Sierra Nevada, California. Final report to Sierra Nevada Global Change Research Program Sequoia and Kings Canyon National Parks, USGS BRD Sequioa and Kings Canyon, and Yosemite Field Stations.

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.

Terborgh, J. W. 1989. Where have all the birds gone? Princeton University Press, Princeton, NJ.

Tiedemann, A. R., J. D. Helvey, and T. D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. *Journal of Environmental Quality* **7:**580-588.

Torn, M. S., and J. S. Fried. 1992. Predicting the impacts of global warming on wildland fire. *Climatic Change* **21**:257-274.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* **10**:171-198.

Underwood, E. C., R. Klinger, and P. E. Moore. 2004. Predicting patterns of non-native plant invasions in Yosemite National Park, California, USA. *Diversity and Distributions* **10**:447-459.

Unger, C. D. 1989. Analysis of summertime acid rain event in the Sierra Nevada. Air and Waste Management Association Symposium on Effects of Air Pollution on Western Forests, Anaheim, CA.

Urban, D. L., C. Miller, P. N. Halpin, and N. L. Stephenson. 2000. Forest gradient response in Sierran landscapes: The physical template. *Landscape Ecology* **15**:603-620.

Vale, T. R. 1987. Vegetation change and park purposes in the high elevations of Yosemite National Park, California. *Annals of the Association of American Geographers* **77**:1-18.

van Mantgem, P. J., N. L. Stephenson, M. Keifer, and J. Keeley. 2004. Effects of an introduced pathogen and fire exclusion on the demography of sugar pine. *Ecological Applications* **14**:1590-1602.

van Wagtendonk, J. W. 1985. Fire suppression effects on fuels and succession in shortfire-interval wilderness ecosystems. J. E. Lotan, B. M. Kilgore, W. C. Fischer, and R. W. Mutch. Proceedings—Symposium and Workshop on Wilderness Fire, 15-18 November 1983, Missoula, MT.

Vankat, J. L. 1970. Vegetation change in Dissertation. University of California, Davis, CA.

Vankat, J. L. 1977. Fire and man in Sequoia National Park. *Annals of the Association of American Geographers* **67**:17-27.

Vankat, J. L. 1982. A gradient perspective on the vegetation of Sequoia National Park, California. *Madrono* **29**:200-214.

Vankat, J. L. 1985. General patterns of lightining ignitions in Sequoia National Park, California. Proceedings of the symposium and workshop on wilderness fire General Technical Report INT-182, U.S. Forest Service, Intermountain Research Station, Ogden, UT.

Vankat, J. L. 2004. Montane and subalpine terrestrial ecosystems in the Southern Colorado Plateau Network—literature review and conceptual models. Vital Signs Monitoring Plan for the Southern Colorado Plateau Network: Phase II Report. Supplement I.

Vankat, J. L., and J. Major. 1978. Vegetation changes in Sequoia National Park, California. *Journal of Biogeography* 5.

Vitousek, P. M., J. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and G. D. Tilman. 1997. Human alteration of the global nitrogen cycle: causes and consequences. *Issues in Ecology* **1**:1-15.

Vitousek, P. M., and R. W. Howarth. 1991. Nitrogen limitation on land and in the sea: How can it occur? *Biogeochemistry* **13**:87-115.

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

Warner, T. E. 1980. Vegetation management plan for the Grant Tree area. Sequoia and Kings Canyon National Parks Management Report.

Wehausen, J. D. 2003. Draft recovery plan for the Sierra Nevada bighorn sheep (*Ovis canadensis californiana*). U.S. Fish and Wildlife Service, Region 1, Portland, OR.

Weldon, K. M., L. H. du Preez, A. D. Hyatt, R. Muller, and R. Seare. 2004. Origin of the amphibian chytrid fungus. *Emerging Infectious Diseases* **10**:2100-2105.

Whelan, R. J. 1995. The Ecology of Fire. Cambridge Univ. Press, Cambridge.

Whisenant, S. G. 1989. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Symposium on Cheatgrass Invasion, Shrub Die-Off and Other Aspects of Shrub Biology and Management USDA Forest Service, Las Vegas, NV.

Whitford, W. G. 2000. Keystone arthropods as webmasters in desert ecosystems. Pages 25-42 *In* D. C. Coleman and P. F. Hendrix, editors. Invertebrates as webmasters in ecosystems. CABI Publishing, Oxon, UK.

Williams, M. 1990. Understanding wetlands. Pages 1-41 *In* M. Williams, editor. Wetlands, A Threatened Landscape. Blackwell Publishers, Oxford.

Williams, M. R., and J. M. Melack. 1997a. 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. R., and J. M. Melack. 1997b. Effects of prescribed burning and drought on the solute chemistry of mixed-conifer forest streams of the Sierra Nevada, California. *Biogeochemistry* **39**:225-253.

Williamson, R. L., D. Spoto, R. Simonsen, F. Bravo, and J. Hendrickson. 1996. Yosemite National Park: Wawona Watershed Sanitary Survey. Department of Civil Engineering and Applied Mathematics, San Jose State University, San Jose, CA.

With, K. A. 2002. The landscape ecology of invasive spread. *Conservation Biology* **16**:1192-1203.

Woolfenden, W. B. 1996. Quaternary vegetation history. *Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options*. University of California, Centers for Water and Wildland Resources, Davis, CA.

Wright, H. A., and A. W. Bailey. 1982. Fire Ecology. John Wiley & Sons, Inc., N.Y.

Zabik, J. M., and J. N. Seiber. 1993. Atmospheric pesticides from California's Central Valley to the Sierra Nevada mountains. *Journal of Environmental Quality* **22**:80-90.

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix G: Identifying and Prioritizing Vital Signs*

Natural Resource Report NPS/SIEN/NRR—2008/072

Linda S. Mutch, Inventory & Monitoring Coordinator
Sierra Nevada Network, Sequoia & Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

Meryl Goldin Rose, Ecologist
Sierra Nevada Network Inventory & Monitoring Program
Yosemite Field Station
P.O. Box 700, El Portal, California 95318

Layout and design Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Mutch , L. S., and M. Goldin Rose. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix G. Identifying and prioritizing vital signs. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Contents

Overview ..... 271
Network-wide Prioritization Workshop ..... 276
Post-workshop Selection of Network Vital Signs ..... 277
Board of Directors Review ..... 279
Literature Cited ..... 281

## List of Tables

Table G-1. Sierra Nevada Network list of 86 vital signs ..... 273
Table G-2. Criteria applied to each of the 86 candidate vital signs ..... 275
Table G-3. Initial results of ranking of Sierra Nevada Network vital signs ..... 279
Table G-4. Reduced list of vital signs generated by network-wide prioritization ..... 280

## List of Figures

Figure G-1. Vital signs identification, prioritization, and selection process for the Sierra Nevada Network ..... 272

# Overview

"Vital sign" is defined in the NPS Inventory & Monitoring Program as "a subset of physical , chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values" (http://science.nature.nps.gov/im/monitor/).

Identifying and selecting vital signs for the Sierra Nevada Network (SIEN) Inventory and Monitoring Program has required a process of research, multi-disciplinary workshops, evaluation, and teamwork. Scientists, managers, administrators, numerous partner agencies, and many others throughout the Sierra Nevada Network have worked together to select and prioritize vital signs (Figure G-1). The current list of 34 candidate vital signs represents a balance of ecosystem driving variables (e.g., weather, climate) and response variables—communities and species (Bennett et al. 2006).

In Chapter 3 of the Vital Signs Monitoring Plan (Mutch et al. 2008) – the main document that this Appendix accompanies—we discuss the process used to select and prioritize candidate vital signs for the Sierra Nevada Network. Please see Chapter 3 for discussion and details. Several of the tables presented in Chapter 3 are duplicated in this Appendix for easier access.

In summary, the Sierra Nevada Network had three individual park-level workshops that involved park staff and scientists from universities and other agencies in identifying candidate lists of vital signs for each network park. Details of these workshops can be found in individual workshop reports (Mutch and Lineback 2001, Mutch 2002, and Mutch and Thompson 2003).

The Science Committee generated a "Network-wide" broad, comprehensive list of 86 vital signs (Table G-1) by refining the three individual park-based lists (i.e., combining similar vital signs, adding vital signs—for example, components of air and water resources—both of which are already being monitored within parks), reviewing the literature, and developing and refining conceptual models. Vital signs that are already part of established ongoing monitoring programs in SIEN parks, or nationally, were also noted and included where appropriate (e.g., wilderness use, night sky, soundscape).

A Sierra Nevada Network prioritization workshop (March 2005) led to the identification of a refined list of 34 candidate vital signs that represent an integrated approach to an overall monitoring program. Of these, seven vital signs relate directly to air and climate, two relate to geology and soils, seven relate to water, twelve relate to biological integrity, and six relate to ecosystem pattern and processes.

At the close of Phase II of development of our Monitoring Plan (September 2005), we had identified our top 13 vital signs for which it was feasible to proceed with protocol development. The Network has initiated protocol development (or refinement/enhancement where a vital sign is part of an extant monitoring program, e.g., surface water dynamics) (FY2005-2006). Protocol development includes detailed information related to monitoring each vital sign, including importance of monitoring the vital sign, monitoring objectives, sampling design, sampling metric(s), field data collection procedures, data management, staffing, and budget (Oakley et al. 2003).

As protocol development proceeds, the Network will be better able to make an informed decision on how many of the other key vital signs can be incorporated into long-term monitoring. For example, work has been conducted on "a synthetic review of mountain meadow ecosystem monitoring protocols" (Stevenson et al. 2006), and the results of this work are informing decisions on what metric(s) of wetland and meadow ecosystems will allow us to best monitor trends in the condition of these systems. Similar synthesis work has also been conducted on lichens (McCune et al.

2006), airborne contaminants (Western Airborne Contaminants Assessment Project- Landers et al. 2008), and atmospheric (Nitrogen) deposition (Clow et al. 2002, Sickman et al. 2003, Clow 2006, Heard and Sickman in progress).

During the network vital signs prioritization workshop and in the post-workshop vital signs selection process by the Science Committee, special attention was devoted to consideration of the five major stressors of ecological condition in the Sierra Nevada: (1) rapid anthropogenic climate change, (2) altered fire regimes, (3) non-native invasive species, (4) air pollution, and (5) habitat fragmentation and human use. Candidate network vital signs were evaluated in the context of their relevance to:

- National monitoring goals
- Network monitoring objectives
- Resources management needs
- Relationship to known anthropogenic stressors
- Information value regarding key ecosystems, communities, or processes
- Importance within the conceptual models of the Sierra Nevada

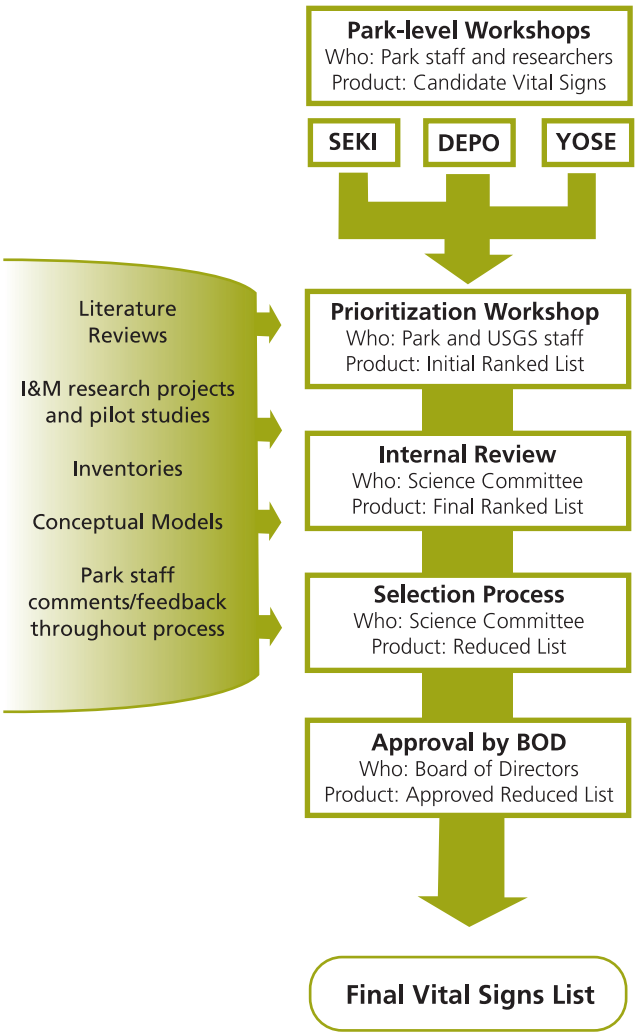



**Figure G-1.** Vital signs identification, prioritization, and selection process for the Sierra Nevada Network

**Table G-1**. Sierra Nevada Network List of 86 Vital Signs, in National Framework.

| NATIONAL VITAL SIGNS MONITORING FRAMEWORK | | |
|---|---|---|
| **Level 1 Category** | **Level 2 Category** | **SIEN Candidate Vital Sign *** |
| **Air and Climate** | Air Quality | Ozone |
| | | Wet and dry deposition |
| | | Visibility |
| | | Particulate matter |
| | | Air contaminants |
| | Weather and Climate | Weather-meteorological parameters |
| | | Snowpack |
| **Geology and Soils** | Geomorphology | Glacial features and processes |
| | | Hillslope features and processes |
| | | Streambank integrity |
| | | River/stream channel morphology |
| | Subsurface Geologic Processes | Cave/karst physical processes |
| | | Cave/karst features |
| | Soil Quality | Soil compaction |
| | | Soil chemistry |
| | | Soil organic matter |
| **Water** | Hydrology | Surface water dynamics-streams/rivers/springs/lakes |
| | | Surface water dynamics–wetlands |
| | | Groundwater dynamics |
| | Water Quality | Water chemistry–surface water |
| | | Water chemistry–groundwater |
| | | Water chemistry–springs |
| | | Toxics |
| | | Fecal bacteria |
| | | Aquatic vegetation–chemistry |
| | | Aquatic macroinvertebrates |
| | | Aquatic microorganisms |
| | | Suspended sediment |
| **Biological Integrity** | Invasive Species | Invasive/Alien plants |
| | | Invasive/Alien animals |
| | | Fishes–non-native |
| | Infestations and Disease | Animal diseases |
| | | Plant diseases |
| | Focal Species and Communities | Vegetation community composition and structure |
| | | Meadow vegetation communities |
| | | Alpine vegetation communities |
| | | Forest demography |
| | | Yellow pine populations |
| | | Foothill tree populations |
| | | Subalpine/treeline tree populations |

**Table G-1**. Sierra Nevada Network List of 86 Vital Signs, in National Framework, continued

| NATIONAL VITAL SIGNS MONITORING FRAMEWORK | | |
|---|---|---|
| **Level 1 Category** | **Level 2 Category** | **SIEN Candidate Vital Sign *** |
| **Biological Integrity, cont'd** | Focal Species and Communities, cont'd | Non-vascular plants |
| | | Phenology of plants and animals |
| | | Invertebrate biodiversity–meadows/wetlands |
| | | Cave invertebrates |
| | | Amphibians |
| | | Reptiles |
| | | Bird populations |
| | | Raptors–non-owl |
| | | Small mammals |
| | | Pika |
| | | Mid-sized carnivores |
| | | Bats |
| | | Mule deer |
| | | Mountain beaver |
| | | Snowshoe hare |
| | | Mountain lions |
| | | Fishes–fish assemblages |
| | | Wildlife communities–Yosemite Valley |
| | At-risk Biota | Bighorn sheep |
| | | California Spotted Owl |
| | | Great Grey Owl |
| | | Peregrine Falcon |
| | | Mountain yellow-legged frog |
| | | Western pond turtle |
| | | Yosemite toad |
| | | White pine populations |
| | | Giant sequoia populations |
| | | Selected rare plant taxa |
| | | Human/bear interactions |
| **Human Use** | Human Effects | Night sky darkness/light intrusion |
| | | Water consumption |
| | Consumptive use | Firewood consumption |
| | | Visitor use |
| | Visitor and Recreation Use | Backcountry use |
| | | Stock use and grazing |
| | | Volcanic feature degradation |
| | Fire | Vegetation community response to fire |
| | | Fuel dynamics |
| | | Fire regimes |

**Table G-1**. Sierra Nevada Network List of 86 Vital Signs, in National Framework, continued

| NATIONAL VITAL SIGNS MONITORING FRAMEWORK | | |
|---|---|---|
| **Level 1 Category** | **Level 2 Category** | **SIEN Candidate Vital Sign *** |
| **Human Use, cont'd** | Land Cover and Use | Landscape mosaics |
| | | Areal extent of meadows |
| | | Land use |
| | Soundscape | Soundscape |
| | Nutrient Dynamics | Biogeochemical cycling |
| | Productivity | Net primary productivity |
| | | Carbon storage |

* derived from park-level vital signs workshops

**Table G-2.** Criteria applied to each of the 86 candidate vital signs, including weighting applied to each criteria category for ranking purposes.

| Category (weight) | Criteria if *strongly* agree (score=1), otherwise (score=0) |
|---|---|
| **Ecological Relevance, Geographical Scope, Data Response & Sensitivity (60%)** | • There is a strong, defensible linkage between the vital sign and the ecological function or critical resource it is intended to represent. |
| | • The vital sign represents a resource or function of high ecological importance based on the conceptual models of the system and the supporting ecological literature. For example: |
| | Vital sign represents a species, community, process and/or place of high ecological importance. |
| | Vital sign is connected to multiple components or processes in the system. |
| | Vital sign has broad ecological scope—such as biodiversity, net primary productivity, biogeochemical cycling. |
| | • The vital sign has broad geographic scope—it occurs in at least two out of three network units (Devils Postpile, Sequoia & Kings Canyon, and Yosemite) and has broad spatial extent within the parks or across the region. |
| | • The vital sign is anticipatory. It can signify an impending change in the ecological system or in important resources. |
| | • The vital sign is sufficiently sensitive to small changes in linked or related resources or functions. |
| | • Baseline data exist within the region, and/or threshold values are specified in the literature that can be used to measure deviance from a desired condition. |
| **Management Relevance & Utility (40%)** | • There is an obvious, direct application of the data to key current or future management decisions. |
| | • Monitoring results are likely to provide early warning of resource impairment, and will thereby save park resources and money. |
| | • Data are of high interest to the public. |
| | • There is a direct application of the data to performance (GPRA) goals and long-term planning. |
| | • The vital sign is an extremely vulnerable or at-risk resource or process. |

## Network-wide Prioritization Workshop

At a two-day network-level vital signs prioritization workshop in April 2005, 40 participants from SIEN parks, divided into four subject-area work groups (physical resources, wildlife, vegetation, and ecosystem pattern&process/human use), ranked subsets of vital signs generated from the comprehensive list (Table G-1).

Detailed supporting information (justification) for each vital sign was provided, including a full description of the vital sign in context of the Network, stressors, management issues, potential monitoring questions, and others. A list of interdisciplinary criteria (Table J-2) and lively debate by team members was used to rank each vital sign. Because all vital signs ranked had some importance in the Network, a "strongly agree" (versus just "agree/yes") was necessary in order for a vital sign to receive a score of 1—otherwise the vital sign received a score of 0.

A database created by the Mojave Network (Kris Heister, Coordinator, and Craig Palmer, Data Manager) was modified by SIEN Data Specialist Rose Cook to be used at the SIEN workshop. A transcriber with computer recorded the vital sign's score directly into the database for each of the of the 4 work groups. The 86 vital signs were ranked by the four workgroups (wildlife=26 vital signs, vegetation=14, physical=28, landscape/human use=18).

A few additional ranking criteria (described below) were applied to each vital sign during the prioritization workshop. These were re-evaluated on their merit by the science committee post-workshop. After re-evaluation, the vital signs were mathematically re-ranked.

Re-evaluation factors included evaluation for redundancy, relevance, and "goodness of fit" (i.e., how well could the criterion be applied to the vital sign). Some criterion were easy to apply when the vital sign was a plant community or animal, but less applicable for stressor physical processes vital signs.

Where necessary, the work groups rescored a vital sign based on the new-or-reworded criterion. Original rankings for all vital signs have been maintained for future use, where-and-when appropriate.

Criteria that were modified or deleted are discussed individually as follows, along with reasoning therefore, with vital signs rescored where necessary

- "The vital sign has a high signal to noise ratio and does not exhibit large, naturally occurring variability." Vital signs were scored using this criterion, but the results were not included in the initial round of ranking—this criterion will have more applicability when specific measures for vital signs are determined (signal-to-noise will vary depending upon the metric).
- "The vital sign has broad geographic scope—it is relevant across the network parks and/or has regional significance." Some misunderstanding of the intent of this criterion occurred so it was revised and reapplied as follows: The vital sign has broad geographic scope—it occurs in at least 2 out of 3 network units (DEPO, SEKI, YOSE) and it has broad spatial extent in the parks or across the region. As re-described, a rare species evenly distributed across the parks would score a zero.
- "Reference conditions exist within the region, and/or threshold values are specified in the literature that can be used to measure deviance from a desired condition. Reworded to: "Baseline data" exist within the region....

Two criteria were decided to be very similar, and so they were combined as a single criterion, as follows: There is an obvious, direct application of the data to key current or future management decisions. If either criterion had received a "strongly agree", then "strongly agree" was applied in the ranking using the single criterion. The two original criteria that were combined are as follows: (1) "[t]here is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions", and (2) "[d]ata provide information needed for future management decisions."

The following criterion was deemed too similar to another and was removed from the scoring procedure: "[t]he vital sign will produce results that are interpretable for park managers, policy makers, research scientists, and the general public, all of whom should be able to recognize the implications of the vital sign's results for protecting and managing the parks' natural resources." Other criteria already applied concerns of the public and management decisions. We applied this criterion to reflect the concept of "interpretability. "

The following criterion was rewritten and applied more rigorously: "The vital sign is a vulnerable or at-risk resource or process and data on its status are needed to mitigate undesirable changes in species or communities (i.e., rapid declines of native species or increases in invasive species), or alterations of critical processes or ecosystem functions." The new criterion was rewritten and applied as follows: [t]he vital sign is a vulnerable or at-risk resource or process (a "strongly agree" was only applied if there was a sense of urgency, i.e., the resource or process is in obvious decline. An 'N/A' was applied to all non-native species vital signs.

Finally, "Legal Mandate" will be addressed with Science Committee or work groups as there are specific state and federal legislation, designations, and authorizations that define legal mandate, particularly where individual species are concerned.

## Post Workshop Selection of Network Vital Signs

Using the ranked results of the prioritization workshop (Table G-3), and comments and recommendations from workshop participants, the Science Committee examined the scores and, where necessary, reevaluated each vital sign based on scientific merit and context. For example, some vital sign–for which there was a overall lack of information and therefore inability to apply some criteria–received a low score (e.g., lichens, phenology) during the workshop, but nevertheless could be good indicators of ecosystem condition.

Finalization of the candidate vital signs list occurred through several subsequent meetings of the Science Committee—vital signs were categorized as follows

- Vital signs we consider to be good indicators of the larger ecosystem or resource condition (included in Table G-4).
- Vital signs that–although we do not consider them to be good indicators of the larger ecosystem (at least with information currently available)–are being considered as a candidate vital sign because they are themselves a resource we believe is important to monitor. Night sky, soundscape, visibility, cave biota and cave/karst physical processes are the five of these included in Table G-4.
- De-listed Vital Signs—those identified as weak "vital signs" or vital signs whose condition could be improved by straightforward management actions (e.g., stock use, visitor use, firewood consumption).

**Table G-3.** Intial results of ranking of SIEN vital signs (weighted 60:40––ecological: management significance, respectively)

| VITAL SIGN | SCORE | RANK |
|---|---|---|
| Fire Regimes | **1.000** | 1 |
| Bird Populations | 0.920 | 2 |
| Vegetation Community Response to Fire | 0.920 | 2 |
| Air Contaminants | 0.900 | 4 |
| Toxics | 0.900 | 4 |
| Weather—Meteorological Parameters | 0.900 | 4 |
| Surface Water Dynamics | 0.840 | 7 |
| Fuel Dynamics | 0.840 | 7 |
| Subalpine/Treeline Tree Populations | 0.840 | 7 |
| White Pine Populations | 0.840 | 7 |
| Snowpack | 0.820 | 11 |
| Mountain Yellow-legged Frog | 0.820 | 11 |
| Meadow Vegetation Communities | 0.820 | 11 |
| Ozone | 0.800 | 14 |
| Particulate Matter | 0.800 | 14 |
| Stock Use and Grazing | 0.800 | 14 |
| Invasive / Non-native Plants | 0.800 | 14 |
| Water Chemistry—Surface water | 0.760 | 18 |
| Amphibians | 0.760 | 18 |
| Biogeochemical Cycling | 0.760 | 18 |
| Water Consumption | 0.760 | 18 |
| Forest Demography | 0.760 | 18 |
| Wet and Dry Deposition | 0.740 | 23 |
| Bats | 0.740 | 23 |
| Macro-invertebrates—Wetlands | 0.740 | 23 |
| Landscape Mosaics | 0.740 | 23 |
| Mid-sized Carnivores | 0.720 | 28 |
| Backcountry Use | 0.720 | 28 |
| Giant Sequoia Populations | 0.720 | 28 |
| Bighorn Sheep | 0.700 | 31 |
| Fishes—Fish Assemblages | 0.700 | 31 |
| Water Dynamics - Wetlands | 0.680 | 33 |
| Groundwater Dynamics | 0.660 | 34 |
| Vegetation Community Comp. and Structure | 0.660 | 34 |
| Yellow Pine Populations | 0.660 | 34 |
| Plant Disease and Insects—non-native | 0.650 | 37 |
| Visibility | 0.640 | 38 |
| Peregrine Falcon | 0.620 | 39 |
| Great Grey Owl | 0.620 | 39 |
| Human-bear Interactions | 0.620 | 39 |

| VITAL SIGN | SCORE | RANK |
|---|---|---|
| Fishes—Non-native | 0.620 | 39 |
| Visitor Use | 0.620 | 39 |
| Land use | 0.600 | 44 |
| Streambank Integrity | 0.560 | 45 |
| Suspended Sediments | 0.560 | 45 |
| Areal Extent of Meadows | 0.560 | 45 |
| Foothill Tree Populations | 0.560 | 45 |
| California Spotted Owl | 0.560 | 49 |
| Yosemite Toad | 0.540 | 49 |
| Invasive / Alien Animals | 0.540 | 49 |
| Cave / Karst Features | 0.520 | 52 |
| Fecal Bacteria | 0.500 | 53 |
| Soil Compaction | 0.500 | 53 |
| Net Primary Productivity | 0.500 | 53 |
| Phenology (Plants, Animals) | 0.500 | 53 |
| Alpine Vegetation Communities | 0.500 | 53 |
| Aquatic Microorganisms | 0.480 | 58 |
| Glacial Features and Processes | 0.480 | 58 |
| Aquatic Macroinvertebrates | 0.480 | 58 |
| River / Stream Channel Morphology | 0.480 | 58 |
| Hillslope Features and Processes | 0.480 | 58 |
| Mountain Beaver | 0.480 | 58 |
| Mule Deer | 0.480 | 58 |
| Nonvascular Plants | 0.480 | 58 |
| Cave Invertebrates | 0.460 | 66 |
| Mountain Lion | 0.460 | 66 |
| Raptors - Non-owls | 0.460 | 66 |
| Selected Rare Plant Taxa | 0.440 | 69 |
| Soil Chemistry | 0.400 | 70 |
| Small Mammals | 0.400 | 70 |
| Reptiles | 0.380 | 72 |
| Pika | 0.380 | 72 |
| Cave / Karst Physical Processes | 0.360 | 74 |
| Animal Disease | 0.360 | 74 |
| Firewood Consumption | 0.360 | 74 |
| Western Pond Turtle | 0.340 | 77 |
| Soil Organic Matter | 0.300 | 78 |
| Aquatic Vegetation - Chemistry | 0.300 | 78 |
| Nightsky Darkness - Light Intrusion | 0.280 | 89 |
| Soundscape | 0.253 | 81 |

**Table G-3.** Intial results of ranking of SIEN vital signs, cont'd

| VITAL SIGN | SCORE | RANK |
|---|---|---|
| Plant Diseases and Insects-Native | 0.200 | 82 |
| Water Chemistry - Groundwater | 0.100 | 83 |
| Carbon Storage | 0.100 | 83 |
| Volcanic Feature Degradation | 0.100 | 83 |
| Water Chemistry - Springs | 0.080 | 86 |
| Snowshoe Hare | 0.080 | 86 |

## Board of Directors Review

Following Science Committee selection of recommended vital signs, the Coordinator provided the Board of Directors, or BOD, (who oversee the coordinator and provide guidance to the Network) the following for review:

- description of the selection process
- list of the proposed final vital signs, as selected by the Science Committee
- short description of each vital sign, including its meaning and significance

At a one-day meeting on 29 August 2005, the BOD approved the Science Committee recommendations as the Network's final vital signs. At this meeting, the Coordinator reviewed the three items noted above, including soliciting input and direction. The BOD provided helpful critiques and discussion and expressed much satisfaction with the collaborative process that SIEN undertook to create and refine the list.

Regarding the final vital signs list, the Network Coordinator requested that the BOD recognize that:

1. Minor changes to vital signs could be expected in the future.
2. As sampling protocol development commences during Phase III, some major changes may be requested for BOD approval, including addition or deletion of vital signs.
3. A strong possibility exists that the current list is outside the funding available through the Natural Resource Challenge.

At a December 5, 2006 Board of Directors meeting, the Board members indicated that their priorities for vital signs (and monitoring protocol development) and implementation are as follows:

1. highest priority—landscape dynamics, meadow ecological integrity (meadow/wetland water dynamics, meadow/wetland plant communities, macro-invertebrates–meadows/wetlands), and forest stand population dynamics;
2. high priority—lakes (water chemistry, surface water dynamics, amphibians), streams & rivers (water chemistry and surface water dynamics), weather & climate; and
3. lower priority—birds, and non-native invasive plants.

Based on these priorities, the SIEN staff and Science Committee will evaluate the timeline, available resources and expertise, and the proposed budget (Vital Signs Monitoring Plan, chapter 10, Mutch et al. 2008), and communicate to the Board revised budget and schedule alternatives associated with this prioritization, including the consequences for the timing of protocol implementation.

**Table G-4.** Reduced list of vital signs generated by Network-wide prioritization (workshop and science committee) and relevance to each park unit. Vital signs selected for protocol development in the next two years are bolded. See key below the table for symbol explanation.

| LEVEL 1 | LEVEL 2 | VITAL SIGN | DEPO | KICA | SEQU | YOSE |
|---|---|---|---|---|---|---|
| Air and Climate | Air Quality | Ozone | ✧ | ✧ | ● | ● |
| | | Airborne contaminants | ✧ | ✧ | ✧ | ✧ |
| | | Atmospheric deposition | ✧ | ✧ | ● | ● |
| | | Particulate matter | ✧ | ✧ | ● | ● |
| | | Visibility | ✧ | ✧ | ● | ● |
| | Weather and Climate | **Weather and climate** | + | ● | ● | ● |
| | | **Snowpack** | + | ● | ● | ● |
| Geology and Soils | Geomorphology | Stream channel morphology | ✧ | ✧ | ✧ | ● |
| | Subsurface Geologic Processes | Caves/karst physical processes | - | ● | ✧ | ✧ |
| Water | Hydrology | **Surface water dynamics** | ● | + | + | + |
| | | **Wetland water dynamics** | + | + | + | + |
| | Water Quality | **Water chemistry** | + | + | + | + |
| | | Toxics | ✧ | ✧ | ✧ | ✧ |
| | | Snow chemistry | ✧ | ✧ | ✧ | ✧ |
| | | Macro-invertebrates | ✧ | ✧ | ✧ | ✧ |
| | | Microorganisms | ✧ | ✧ | ✧ | ✧ |
| Biological Integrity | Invasive Species | Non-native invasive plants | - | + | + | + |
| | Focal Species or Communities | Selected plant communities | ✧ | ✧ | ✧ | ✧ |
| | | Forest dynamics | + | + | + | + |
| | | Phenology | ✧ | ✧ | ✧ | ✧ |
| | | Wetland plant communities | + | + | + | + |
| | | Amphibians | - | + | + | + |
| | | Birds | + | ● | ✧ | ● |
| | | Macro-invertebrates (wetlands) | + | + | + | + |
| | | Cave biota | ✧ | ✧ | ✧ | ✧ |
| | | Bats | ✧ | ✧ | ✧ | ✧ |
| | | Meso-carnivores | ✧ | ✧ | ✧ | ✧ |
| Landscapes (Ecosystem Pattern and Processes) | Fire and Fuel Dynamics | Fire regimes | ● | + | + | + |
| | | Fire effects on plant communities | ● | ● | ● | ● |
| | Landscape Dynamics | Landscape Dynamics | + | + | + | + |
| | Viewscape | Night sky | ✧ | ✧ | ✧ | ✧ |
| | Soundscape | Soundscape | ✧ | ✧ | ✧ | ✧ |
| | Nutrient Dynamics | Biogeochemical cycling | ✧ | ✧ | ✧ | ✧ |
| | Energy Flow | Net primary productivity | ✧ | ✧ | ✧ | ✧ |

Legend:
+ Vital signs that the Network will use to develop protocols and implement monitoring, using funding from the vital signs or water quality monitoring programs.
● Vital signs that are monitored by a network park, another NPS program, or by another federal or state agency using other funding. The Network will collaborate with these other monitoring efforts.
✧ High-priority vital signs for which monitoring will likely be done in the future, but which cannot currently be implemented because of limited staff and funding.
- Vital sign does not apply to park, or for which there are no foreseeable plans to conduct monitoring.

Bennett, A. J., W.L. Thompson, and D.C. Mortenson. 2006. Vital signs monitoring plan. Southwest Alaska Network, National Park Service, Anchorage, AK. 140 pp.

Clow, D.W. 2006. Nitrogen deposition monitoring in Yosemite National Park using resin collectors. Unpublished report, U.S. Geological Survey, Denver, CO.

Clow, D. W., R. G. Striegl, M. Nanus, M. A. Mast, D. H. Campbell, and D. P. Krabbenhoft. 2002. Chemistry of selected high-elevation lakes in seven national parks in the western United States. *Water Air and Soil Pollution* **2**:139-164.

Landers, D.H., S.L. Simonich, D.A. Jaffe, L.H. Geiser, D.H. Campbell, A.R. Schwindt, C.B. Schreck, M.L. Kent, W.D. Hafner, H.E. Taylor, K.J. Hageman, S. Usenko, L.K. Ackerman, J.E. Schrlau, N.L. Rose, T.F. Blett, and M.L. Erway. 2008. The Fate, Transport, and Ecological Effects of Airborne Contaminants in Western National Parks (U.S.A.). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, OR.

McCune, B., J. Grenon, and E. Martin. 2006. Lichens in relation to management issues in Sierra Nevada national parks. Final report to Sierra Nevada Network Inventory & Monitoring program. Cooperative Agreement No. CA9088A0008 between Oregon State University and the National Park Service, Corvallis, OR. 45 p.

Mutch, L. S. 2002. Devils Postpile National Monument vital signs workshop report, April 8-9, 2002. Unpublished report, Lee Vining, CA.

Mutch, L. S., and P. Lineback. 2001. Sequoia and Kings Canyon National Parks vital signs workshop report, April 13-16, 1999. Unpublished report, Three Rivers, CA.

Mutch, L. S., and S. Thompson. 2003. Yosemite National Park vital signs workshop report, April 23-25, 2002. Unpublished report, Mariposa, CA.

Mutch, L. S., M. Goldin Rose, A. M. Heard, R. R. Cook, and G.L. Entsminger. 2008. Sierra Nevada Network: vital signs monitoring plan. Natural Resource ReportNPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, CO.

Oakley, K. L., L. P. Thomas, and S.G. Fancy. 2003. Guidelines for long-term monitoring protocols. *Wild. Soc. Bull.* **31**:1000-1003.

Sickman, J.O., J. M. Melack, and D.W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* **48**:1885-1892.

Stevenson, K.M., M. Barbour, and S. Haultain. 2006. Mountain meadow monitoring across the western United States: A synthesis with implications for monitoring vital signs in Devils Postpile, Kings Canyon, Sequoia and Yosemite National Parks. Final Report in fulfillment of Task Agreement J8C07050013 under CESU Coop. Agreement H8C07030001. University of California, Davis, CA and NPS Inventory & Monitoring Program, Sierra Nevada Network, Three Rivers, CA. 85 pp.

# Sierra Nevada Network
# Vital Signs Monitoring Plan

## *Appendix H: Protocol Development Summaries*

Natural Resource Report NPS/SIEN/NRR—2008/072

Meryl Goldin Rose[1], Linda S. Mutch[1], Andrea M. Heard[1], Athena Demetry[2], Bill Kuhn[3], and Harold Werner[2]

[1] Sierra Nevada Network
(Devils Postpile National Monument,
Sequoia & Kings Canyon and Yosemite National Parks)
47050 Generals Highway
Three Rivers, CA 93271

[2] Division of Resources Management and Science,
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271

[3] Division of Resources Management & Science
Yosemite National Park
5083 Foresta Road, P.O. Box 700
El Portal, California 95318

Layout and design Barbara BC Gleason/BGleason Design & Illustration, LLC.

September 2008

U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Fort Collins, Colorado

Please cite this appendix as:

Mutch, L. S., M. Goldin Rose, A. Demetry, B. Kuhn, and H. Werner. 2008. Sierra Nevada Network vital signs monitoring plan: Appendix H. Protocol development summaries. Natural Resource Report NPS/SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

# Contents

Protocol: Birds. ..... 287
Protocol: Early Detection of Invasive Plants ..... 293
Protocol: Forest Dynamics ..... 299
Protocol: Lakes ..... 307
Protocol: Landscape Dynamics ..... 317
Protocol: Wetlands Ecological Integrity. ..... 325
Protocol: Rivers and Streams. ..... 337
Protocol: Weather and Climate ..... 341

# Protocol: Birds

## Parks Where Protocol Will be Implemented

Devils Postpile National Monument (DEPO)
Sequoia and Kings Canyon National Parks (SEKI)
Yosemite National Park (YOSE)

## Vital Signs Addressed by Protocol

Birds

## Justification

Increasingly, birds are seen as appropriate indicator species of local and regional change in terrestrial ecosystems. The Sierra Nevada Network parks—Sequoia and Kings Canyon National Parks (SEKI), Yosemite National Park (YOSE), and Devils Postpile National Monument (DEPO)—together provide over 1,600,000 acres of habitat for over 200 species of birds, including many neotropical migrants. Critical breeding, stopover, and wintering grounds occur from lands adjacent to the parks and monument to land as far south as Patagonia. SEKI, YOSE, and a few other large habitat areas in the Sierra Nevada have been designated by the American Bird Conservancy as Globally Important Bird Areas (IBA). Analysis of North American Breeding Bird Survey data indicates that numerous bird species exhibit declining long-term population trends in the Sierra Nevada region.

Bird Monitoring is the only Sierra Nevada Network (SIEN) vital sign that would monitor multiple species across the entire elevational gradient.

## Background Information

Researchers have identified eight potential Sierra-wide risks faced by Sierra Nevada birds: livestock grazing, logging, fire suppression, exurban development, increased recreational use, pesticide use, habitat destruction and degradation on wintering grounds, and large-scale climate change (DeSante 1995; Graber 1996). Data from the MAPS (Monitoring Avian Productivity and Survivorship) program suggest that populations of numerous species are declining in Yosemite, and that the majority of those declines appear to be tied to low productivity (presumably resulting from factors occurring in the park where breeding habitat is found), rather than low survival on wintering grounds (DeSante et al. 2005). Birds generally occupy a high position on the food web, and they provide important ecological functions such as seed dispersal and insect predation, making them good indicators of change in ecosystems.

Because of their high body temperature, rapid metabolism, and high ecological position on most food webs, birds are excellent indicators of the effects of local, regional, and global environmental change on terrestrial ecosystems. Furthermore, their abundance and diversity in virtually all terrestrial habitats, diurnal nature, discrete reproductive seasonality, and intermediate longevity facilitate the monitoring of their population and demographic parameters (DeSante et al. 2005).

Bird populations provide an attractive vital sign and provide the opportunity for detailed evaluation of network ecosystem condition because birds (1) occupy a wide diversity of ecological niches in the parks and (2) are conspicuous and easily observable.

In addition, (1) knowledge of the natural history of many bird species has a rich basis in literature, (2) all units in SIEN have a strong foundation of inventory data upon which to build future monitoring efforts, and (3) monitoring of avian productivity and survivorship has occurred at all parks for varying numbers of years and time periods. Monitoring Avian Productivity and Survivorship (MAPS) programs have been operating in Sierra Nevada Parks for many years, and at one station in Yosemite for 17 years.

Forest birds throughout the Sierra Nevada face numerous potential stressors and changes, including pollution and pesticide up-drift from the Central Valley, increasing exurban development (Duane 1999) with its concomitant increases in land

conversion, habitat fragmentation, facilitation of Brown-headed Cowbird parasitism, and long-term shifts in habitat composition and structure resulting from fire exclusion (Helj 1994; Chang 1996; Gruell 2001), projected climate change (Lenihan et al. 2003, Hayhoe et al. 2004), and recent decisions by the USDA Forest Service to increase timber harvest and forest thinning efforts to reduce fuels.

## Specific Monitoring Questions and Objectives

### *Monitoring Objectives*

Our bird monitoring protocol addresses three of eleven broad monitoring objectives eveloped for the Network's long-term monitoring program:

1. Document rates and types of change in animal communities in response to changes in landscape characteristics, biotic interactions, and human use
2. Understand the ecological relationships between terrestrial landscape elements and animal distributions
3. Monitor trends in the distribution and abundance of focal species

### *Monitoring Questions*

The Sierra Nevada Network Bird Workgroup established broad monitoring questions at its first meeting in FY2006. However, after continued investigation of other Network approaches and experiences (discussed below, Protocol Development & Status), the workgroup realizes that Network-wide and park-level inference may not be feasible because the parks are so large—their size presents logistical issues and financial challenges associated with sampling remote locations (excepting Devils Postpile). Further, because of the topographic complexity of our parks, it may be necessary and efficient to focus on specific bird habitats (e.g., foothill oak woodland, subalpine meadow, white fir forest, riparian) or species thought most affected by the stressors affecting Network parks. Monitoring questions were refined during early 2007, as follows:

1. Detect trends in the density of those landbird species monitored well by point counts, throughout accessible areas of SIEN parks during the breeding season
2. Track changes in breeding-season distribution of landbird species throughout accessible areas of SIEN parks.

## Potential Measures

Density, relative abundance, diversity as a function of habitat type, and, possibly, productivity & survivorship, in limited locations.

## Basic Approach

In FY2004-2005, before a formal Bird Workgroup was established, the Sierra Nevada Network contracted with The Institute for Bird Populations (IBP) to make general recommendations for avian monitoring sample design alternatives for monitoring (1) trends at the landscape level, and (2) trends in subalpine meadows (Siegel and Wilkerson 2005). Data from avian inventories, Monitoring Productivity and Survivorship (MAPS), and Breeding Bird Surveys were used to provide a preliminary assessment of power to detect population trends using a landscape-level monitoring program, and an assessment using meadow monitoring. In addition, Breeding Bird Survey data were used to assess which habitats are under-sampled by existing Sierra Nevada-wide bird monitoring efforts. Preliminary implementation budgets were also provided.

In FY2006, the network established a formal Bird Workgroup (comprising park and network staff) to establish broad avian monitoring objectives. In addition, a contract was established with IBP to facilitate decision-making and develop SIEN's bird monitoring protocol. In January 2007, the workgroup met (with IBP and several additional outside experts with experience monitoring birds in the Sierra) to refine monitoring objectives, devise an approach to protocol development, and–in light of the previous two decisions–determine feasibility and value of continuing the collection MAPS data.

## Protocol Development & Status

The Institute for Bird Populations will apply its extensive experience developing and refining a bird monitoring protocol for the North Coast Cascades Network (NCCN).

## Tentative Sampling Methods & Design

The SIEN bird monitoring protocol will follow that of NCCN, and will therefore consist of Variable Circular Plot (VCP) (Siegel et al. 2007) methodology at points along transects (spatial) at the three large park units of SIEN, including an array or riparian design at DEPO. Numerous discussions of the costs and benefits of different types of bird monitoring programs (e.g., MAPS versus VCP), conducted elsewhere, was again recapped at this meeting (in addition to discussions over the past several years), and the group feels confident that the above-method will best achieve SIENs monitoring objectives. Reasoning: the current predicted 70% change in snowpack will cause significant change in habitats, which argues for a spatial design (i.e., VCP).

The Bird Workgroup decided to include an explicit statement in the monitoring protocol to include MAPS monitoring—as an important component of a comprehensive SIEN bird monitoring protocol—while noting (and understanding) that it is currently an unfunded part of bird monitoring in SIEN. Members of the Bird Workgroup are committed to finding additional funding to continue the MAPS program in SIEN.

NCCN and Terrastat Consulting performed power analyses and found the following: 4% per annual change in a park is detectable after 15-20 yrs for 20+ species (Siegel et al. 2007). IBP is confident that SIEN data would meet or exceed this power. Because of this, the Bird Workgroup decided that power analyses of our current data (inventory) are unnecessary; instead, power analysis of the data would be conducted after five years of SIEN data (monitoring) had been collected.

## Principal Investigator, NPS Lead, Workgroup Members, and Collaborators

**NPS Lead**
Meryl Rose, Ecologist
Sierra Nevada Network
meryl_rose@nps.gov

**Workgroup Members**
Sara Stock, Wildlife Biologist
Yosemite National Park

Steve Thompson,
Branch Chief, Wildlife Biology
Yosemite National Park

Harold Werner,
Wildlife Ecologist
Sequoia and Kings Canyon National Parks

## Collaborators

Dr. Rodney Siegel
(PI, Protocol Development)
Institute for Bird Populations
Pt Reyes Station, CA 94956
rsiegel@birdpop.org

Leigh Ann Harrod, Statistician
University of Idaho

Tom Gardali
PRBO Conservation Science

Bob Wilkerson
Institute for Bird Populations

## Schedule (protocol development)

| | |
|---|---|
| April 2006 | Define broad bird monitoring objectives |
| July 2006 | Establish contract with Institute for Bird Populations (IBP) |
| Winter 2006-2007 | IBP facilitates workgroup refinement of monitoring and sampling objectives |
| April 2007 | Database development (review/modify NCCN for SIEN) |
| April 2007 | IBP begins drafting of Bird Monitoring Protocol |
| June 2007 | Draft sample design complete |
| September 2007 | Draft protocol complete (for YOSE & SEKI) |
| September 2007 | Meet with PI to discuss sample design for DEPO |
| January 2008 | Final protocol to peer review |

## Budget*

| | |
|---|---|
| $24,800 | Contract with IBP (Tasks 1-4, above) |
| $5,000 | Statistical assistance (U of Idaho Cooperative Agreement) |
| $15,500 | In-kind Park Staff Time |

**No additional funds for protocol testing or implementation are available, at the current time (Spring 2007).*

# Literature Cited Birds Protocol


Chang, C. 1996. Ecosystem response to fire and variations in fire regimes. Pages 1071-1100 *In:* Sierra Nevada Ecosystem Project, final report to Congress, Vol. II: assessments and scientific basis for management options. Wildland Resources Center Report No. 37, Univ. of California, Davis, CA.

DeSante, D.F., P. Pyle and D.R. Kaschube. 2005. The Monitoring Avian Productivity and Survivorship (MAPS) program in Sequoia and Kings Canyon and Yosemite National Parks and Devils Postpile National Monument: A comparison between time periods and locations. The Institute for Bird Populations, Pt. Reyes Station, CA. 34 pp + tables.

Duane, T.P. 1999. Shaping the Sierra: Nature, Culture and Conflict in the Changing West. University of California, Berkeley, CA.

Graber, D. M. 1996. Status of terrestrial vertebrates. Pages 709-734 *In*: Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis, CA.

Gruell, G.E. 2001. Fire in Sierra Nevada forests: A photographic interpretation of ecological change since 1849. Mountain Press, Missoula, MT.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, and J. H. Verville. 2004. Emissions pathways, climate change, and impacts on California. *National Academy of Sciences* **101**:12422-12427.

Heath, S.K. 2004. Bird monitoring in montane meadow and riparian habitats of Devils Postpile National Monument: Final report 2002-2004.

Hejl, S.J. 1994. Human induced changes in bird populations in coniferous forests in western North America during the past 100 years. *Studies in Avian Biology* **15**: 232-246.

Lenihan, J.M., R. Drapek, D. Bachelet, and R.P. Neilson. 2003. Climate change effects on vegetation distribution, carbon, and fire in California. *Ecological Applications* **13**: 1667-1681.

Institute for Bird Populations. 1990–2004. Annual Reports of the Monitoring Avian Productivity and Survivorship (MAPS) Program in Yosemite National Park

Siegel, R.B. & D.F. DeSante. 2002. Establishing a Southern Sierra Meadows Important Bird Area: Results from Meadow Surveys at Stanislaus, Sierra, and Sequoia National Forests, and Yosemite and Sequoia/Kings Canyon National Parks; Appendix One in Avian Inventory of Yosemite National Park (1998-2000). 91 pp.

Siegel, R.B., and D.F. DeSante. 2002 . A bird inventory of Yosemite National Park. The Institute for Bird Populations, Pt. Reyes Station, CA.

Siegel, R.B. & R.L. Wilkerson. 2005. Sample Design for Avian Monitoring Alternatives *In:* Sierra Nevada Network Parks. The Institute for Bird Populations, Pt. Reyes Station CA. Report submitted under Contract #P2130-04-04. 74 pp.

Siegel, R.B. and R.L. Wilkerson. 2004. Landbird Inventory for Devils Postpile National Monument. Final Report. Cooperative Agreement No. H9471011196. The Institute for Bird Populations, Pt. Reyes Station, CA. 39 pp.

Siegel, R.B. and R.L. Wilkerson. 2005. Landbird Inventory for Sequoia and Kings Canyon National Parks (2003-2004). Final Report. Cooperative Agreement No. H9471011196. The Institute for Bird Populations, Pt. Reyes Station, CA. 237 pp.

Siegel, R.B., R.L. Wilkerson, K.J. Jenkins, R.C. Kuntz II, J.R. Boetsch, J.P. Schaberl, and P.J. Happe. 2007. Landbird monitoring protocol for national parks in the North Coast and Cascades Network: US Geological Survey Techniques and Methods 2-A6. 200 pp.

# Protocol: Early Detection of Invasive Plants

## Parks Where Protocol will be Implemented

Devils Postpile National Monument (DEPO)
Sequoia & Kings Canyon (SEKI)
Yosemite National Parks (YOSE)

## Vital Signs Addressed by Protocol

Non-native Invasive Plants

## Justifications/Issues being addressed

Invasive non-native plants can bring about significant changes in park ecosystems by changing structural attributes of native plant communities (physiognomy, species composition, genetic diversity) and the processes that support them (fire, nutrient cycling, hydrology, soil erosion, decomposition) (MacDonald et al. 1988). There are over 200 non-native plant taxa in Sierra Nevada Network (SIEN) parks, and new introductions continue to occur. Many of these taxa are invasive, or a threat to native plant and animal communities—they compete for space and resources, and often do not meet the same habitat needs of animals as do native plants.

The Network hosted a workshop focused on developing and prioritizing monitoring objectives for invasive non-native plants in May 2005, and the primary monitoring interests identified for the Inventory and Monitoring program involved early detection and trends monitoring. The first protocol we will develop is early detection monitoring. Vast areas of the network parks are free of invasive plants, and all parks' highest invasive plant management priorities are to prevent new introductions to these weed-free areas, to detect new introductions early in the invasion process, and to provide rapid eradication response. By definition, early detection monitoring focuses on locating spatially rare events, so standard sampling procedures may not be effective. To narrow the search frame and be most effective with limited funds, others have narrowed the list of target species for searching, modeled the highest potential habitat for target species, modeled the highest probability areas for new introductions based on invasion vectors or plant community characteristics, or used adaptive sampling. To assist park managers and Inventory and Monitoring staff with this complex problem, regional NPS staff and the USGS are collaborating to develop an early detection handbook.

## Specific Monitoring Questions and Objectives to be Addressed by the Protocol

### *Monitoring Questions*

1. What non-native species are present in the parks and how do these species change over time?
2. What non-native species not currently present in the parks most threaten native ecosystems?
3. What are the priority non-native species for early detection monitoring based on ecological impacts, invasiveness potential, and distribution?
4. Are new species, or new populations of species already present in the parks, establishing in weed-free areas, high-value resource areas, or naturally-disturbed areas?

### *Monitoring Objectives*

1. Periodically review park weed management databases and update NPSpecies with new taxa not yet vouchered and documented. From NPSpecies, update each park's non-native species list, using a defined set of criteria for inclusion, and evaluate changes.
2. Create and periodically update a "watch list" of species that are not present in the parks but are known to exist in the region or to have the potential to become problematic in the region.
3. Create and periodically update early detection monitoring priorities for species in lists one and two using a transparent, documented system.

4A. Compile and periodically update polygons of weed-free areas, high-value resources areas, and naturally-disturbed areas, from a defined set of criteria, using existing information.

4B. Within the polygons defined in Objective 4A, detect (1) watch-list species, and (2) new populations of priority species already present in the parks through either (a) complete search/census, or (b) sampling within search frames narrowed by selection criteria based on vectors, environmental factors, and other susceptibility measures.

4C. Expand scope of personnel searching for watch-list species by developing SOPs and training materials to be included in other I&M protocols, in wilderness ranger duties, and in other park staff and volunteer efforts as appropriate.

## Basic Approach

Comprehensive early detection protocols will be developed following the publication of the NPS/USGS "Early Detection of Invasive Plant Species Handbook," anticipated in 2007/2008. In the meantime, SOPs for Objectives 1, 2 have been developed; Objective 3 will begin in the Fall-Spring of 2007-2008 (these are not likely to change with the publication of the Early Detection Handbook). These products will move us closer to full development of early detection protocols and will be helpful to management in the interim.

*Objective 1:* Create criteria and SOPs by which each park's non-native plant species list will be periodically updated from NPSpecies. For example, a park may have 160 non-native species if the vouchered, naturalized species list is extracted from NPSpecies. However, if waifs, cultivars, landscape plantings, extirpated species, un-vouchered observations, or specimens keyed to genus are included, a park may have many more non-native taxa. A non-native plant species list is very dynamic, and the criteria used to extract the list and track changes needs to be defined. In addition, invasive plant crews may identify new species but not collect a voucher specimen, or collected vouchers may languish in an office without being verified and added to NPSpecies. A periodic effort to collect voucher specimens, verify plant identifications, and add to NPSpecies are part of this protocol.

*Objective 2:* Create SOPs to produce and periodically update a "watch list" of species that are not present in the parks but are known to exist in the region or to have the potential to become problematic in the region. We will research how other parks have created watch lists, modify their SOPs if appropriate, speak with adjacent land managers, and search priority species lists for surrounding regions. An updated (2008 and beyond) watch list will be created based on this SOP.

### *Assessment Protocol to Prioritize Non-native Plant Species for Early Detection and Rapid Response.*

The majority of questions that make up our assessment criteria have been drawn from natureserve's invasive species assessment protocol (Morse, Randall et al. 2004). Morse and colleagues suggested that a combination of high ecological impact, low current distribution, and high potential distribution, should indicate a high priority for early detection.

We have expanded on this basic premise in order to derive the early-detection ranks. Our protocol is in the form of a database, and was designed to leverage existing vegetation data from SIEN parks. To assess a species of interest, the database synthesizes information from published sources and datasets. The database also provides a means to update a suite of species periodically.

We have also developed a protocol to develop and update watchlists of species that have not yet invaded these parks, but have the potential to do so. The criteria are based on the proximity and similarity of habitats of current infestations, and their tendency to be invasive in natural ecosystems.

For *Objective 3*, we will create SOPs to produce and periodically update a prioritization for early detection of species in lists one and two. Published species prioritization systems such as Hiebert and Stubbendieck's Alien Plants Ranking System (APRS 2000), NatureServe/TNC's Invasive Species

Assessment Protocol (Morse, Randall et al. 2004), or the California Invasive Plant Inventory (Warner, Bossard et al. 2003), will be reviewed, compared, and one chosen and modified. Species prioritizations for early detection monitoring may be different from (and use different criteria than) species prioritizations for management. The result will be a list of target species for early detection monitoring that will include two classes of target species: (1) new populations of species already present in the parks, (2) species new to the parks (i.e., "watch list" species). A 2006 or 2007 prioritization will be created based on this SOP.

### *Projects Conducted in Support of Early Detection and Protocol Development*

We commissioned a report describing the procedures for the development of a sampling protocol for inventorying alien plant species in wildfire and riparian areas (in Yosemite National Park). The inventory has two purposes: (1) to provide data for an analysis of general patterns of distribution and abundance of alien species in wildfire and riparian areas, and (2) to create a baseline dataset to compare future surveys with (i.e., monitoring). It was the initial step in developing a formal monitoring protocol for alien speices in wildfire and riparian areas.(Klinger and Underwood 2002; Underwood, Klinger et al. 2004). Subsequent to the underlying theme of this report, we undertook the following two projects.

In 2005, we supported an inventory project for invasive non-native plants in riparian habitat within Yosemite. This project will refine knowledge of vegetation conditions—specifically alien invasive plant species presence—in areas subject to natural disturbance, specifically riparian habitat. The final report include correlation analyses (for all pertinent physical, biological, and environmental variables (Kane, Heath et al. 2006). Results will provide a baseline against which changes in distribution and abundance of selected species could be measured and will assist vegetation management staff with prioritization of individual populations and sites for control or eradication efforts.

In 2006, we supported pilot monitoring efforts already underway in SEKI and YOSE related to early detection of invasive plants in burned areas, a subset of Objective 4. In YOSE, Kristin Kaczynski and Dr. Susan Beatty of University of Colorado at Boulder and in SEKI, Nate Bensen and Jeff Morisette of NASA Goddard Space Flight Center are working on projects to narrow the search frame within burned areas to successfully and efficiently detect target non-native plants after fire.

The objectives of the Kaczynski and Beatty project in YOSE are to determine:

1. If there is a relationship between fire severity and the density, frequency, and percent cover of invasive species in wilderness areas of Yosemite National Park
2. If remote sensing is a feasible option for early detection of invasive plants after fire in remote locations (e.g., National Park wilderness)

The result will be a predictive evaluation/model of the probability of encountering an invasive plant population based on fire severity and habitat characteristics, and a evaluation of the feasibility of using remote sensing for early detection in Sierra burned areas (Kaczynski 2007).

The report from NASA Goddard is pending completion of the project.

### Non-native Plants

Sample designs for non native plant monitoring will be geared towards early detection. We will review and implement, where possible, results of the publication of the NPS/USGS "Early Detection of Invasive Plant Species Handbook," anticipated in 2007.

In the meantime, SIEN is developing products necessary to fulfill development of early detection monitoring protocols and to conduct Handbook recommendations: (1) periodic update of each park's non non-native plant species list, (2) a scheme for prioritization for early detection of specific species on SIEN park lists (above), (3) creation of a "watch list" of species not currently present in the parks but known to

exist in the region or to have the potential to become problematic in the region, and (4) continued support for two monitoring projects already underway in SEKI and YOSE related to early detection of invasive plants in burned areas (these projects are being conducted by cooperators at University of Colorado and NASA Goddard Space Flight Center).

### Principal Investigators and NPS Lead

Athena Demetry (lead),
Restoration Ecologist
Sequoia and Kings Canyon National Parks

### Workgroup Members

Brent Johnson, Botanist
Yosemite National Park

Meryl Rose, Ecologist
Sierra Nevada Network

### Cooperators

Colorado University, Boulder

NASA Goddard Space Flight Center

University of Colorado, Fort Collins

Bradshaw Consulting

PRBO Conservation Science, Point Reyes, CA

Additional cooperators in protocol development: to be identified in 2007.

### Development Schedule, Budget, and Expected Interim Products

2005

Riparian PRBO

2006

- Review early detection literature (internal)
- Develop SOPs for Objectives 1 (internal)
- Develop SOPs for Objectives 2 and 3 and implement SOPs

  a) Contract with Ginger Bradshaw Kelleher ($20,000)
- Pilot early detection strategies in burned areas

  b) Support Kaczynski and Beatty study in YOSE on detecting invasive plants after fire

  c) Support NASA pilot project in SEKI on a support system for NPS decisions on fire management activities and invasive plant species control

2007

- Create SOP for objectives 4A and 4C – funds obligated in FY2006.
- Write protocol narrative, background, and objectives
- Identify cooperator for developing sampling design and field methods
- Cost: $20,260

*2008

Following publication of NPS & USGS Early Detection Handbook:

- Develop sampling design
- Develop field methods
- Develop data management protocols
- Develop analysis and reporting protocols
- Draft protocol for internal review
- Estimated Cost: $40,000

*2009

Final protocol for peer review

**Funds to fully develop this protocol may not be available as it received low priority by the Board of Directors in FY2007. At this time, we will only be able to develop a few Non-native Plant Early Detection SOPs to implement as part of other protocols and as part of our data management program.*

Kaczynski, K. 2007. Invasive species in Wilderness as a function of burn severity: A case study in Yosemite National Park, California. University of Colorado, Boulder, CO. MS Thesis.

MacDonald, L.A.W., D.M. Graber, S. DeBenedetti, R.H. Groves, and E.R. Fuentes. 1988. Introduced species in nature reserves in Mediterranean-type climatic regions of the world. *Biological Conservation* 44: 37-66.

Morse, L. E., J. M. Randall, N. Benton, R. Hiebert, and S. Lu. 2004. An Invasive Species Assessment Protocol: Evaluating Non-Native Plants For Their Impact On Biodiversity. Version 1. NatureServe, Arlington, VA.

Warner, Peter J., Carla C. Bossard, Matthew L. Brooks, Joseph M. DiTomaso, John A. Hall, Ann M. Howald, Douglas W. Johnson, John M. Randall, Cynthia L. Roye, Maria M. Ryan, and Alison E. Stanton. 2003. Criteria for Categorizing Invasive Non-Native Plants that Threaten Wildlands. Available online at www.cal-ipc.org and www.swvma.org. California Invasive Plant Council and Southwest Vegetation Management Association. 24 pp.

# Protocol: Forest Dynamics

## Parks Where Protocol Will be Implemented

Sequoia & Kings Canyon (SEKI)
Yosemite (YOSE)
Devils Postpile (DEPO)—perhaps, depending on species monitored

## Vital Signs Addressed by Protocol

Forest Population Dynamics

## Justification/Issues Being Addressed

Sierra Nevada montane and subalpine coniferous forests comprise one of the largest and most economically important vegetation regions in California (Rundel, Parsons et al. 1988). They are very complex in composition, structure and function (Franklin and Fites-Kaufmann 1996). We are most interested in monitoring forest dynamics, i.e., birth, growth and death rates of trees, because they are sensitive to changes in the two major drivers in the Sierra Nevada–climate and fire regimes. These two drivers are subject to substantial alteration by human impacts, and in these altered states can act as stressors on forest systems.

## Background Information

Recent research results suggest that forest dynamics may already be showing effects of climatic changes. Forest turnover rates (defined as the average of tree mortality and recruitment rates) have been increasing in tropical Amazonia (Phillips et al. 2004) and in the Sierra Nevada (Stephenson and van Mantgem 2005). In the Sierra Nevada, a possible cause for this more rapid forest turnover rate is that summers have been getting warmer and drier. Snowpack has been decreasing over most of the West in recent decades (Mote et al. 2005) and spring stream flow has been occurring earlier (Stewart et al. 2004).

A variety of studies suggest that past Sierra mixed conifer forests had lower tree density and very different demographic distribution of age classes—with lower fuel loads and greater landscape diversity of forest patches than current forests (Vankat and Major 1978; Parsons and DeBenedetti 1979; Bonnicksen and Stone 1982; Vale 1987; Ansley and Battles 1998; Roy and Vankat 1999; Stephenson 1999). While many of the changes observed in forest structure and function are thought to be primarily due to fire exclusion, they may also be related to warmer, moister conditions of the 20th century (Graumlich 1993; Scuderi 1993; Keeley and Stephenson 2000).

Simulation models of climate change suggest that predicted warmer temperatures will alter water availability due to changes in type of precipitation and timing of snowmelt in the Sierra Nevada (Knowles and Cayan 2001; Dettinger et al. 2004). In addition to direct effects of reduced moisture availability and higher temperatures on forest dynamics, climatic change will also interact strongly with other stresses affecting forests. These include such things as: air pollution (e.g., N deposition, increasing atmospheric $CO^2$), non-native invasive species (including pathogens), land-use change (including habitat fragmentation), and altered fire regimes.

While there are other aspects of forest vegetation we will consider monitoring (e.g., lichen communities), we focus primarily on forest tree population dynamics because:

1. There is a successful track record of doing this kind of work already in these parks and a wealth of baseline data to build upon (USGS Global Change Research Program, NPS Fire Effects program).
2. Forest tree population dynamics data are interpretable and changes are often closely tied to drivers and/or stressors whose effects we seek to better understand (fire, climate, pollution and non-native species).
3. Trees comprise a keystone life form, creating the array of microclimates and habitats that entrain other ecosystem components and processes (such as wildlife and hydrology).

Additionally, USGS Research Ecologist Nate Stephenson makes these points regarding the importance of monitoring forest dynamics:

- Forests provide humans with irreplaceable resources and services.
- Climatic change will profoundly affect forests.
- Forests may profoundly affect climatic change (because they sequester the majority of the terrestrial biosphere's carbon, affect surface albedo and the hydrologic cycle, etc).

## Specific Monitoring Questions and Objectives

The Sierra Nevada Network identified a set of broad monitoring objectives and questions for the Phase I and Phase II Monitoring Plans (Mutch et al. 2005). These questions provide the context as to why we care about forest dynamics, although we may not be able to answer them without more specific research projects aimed at determining the causes for changes we observe from monitoring tree populations. We have not yet determined if we have the resources to monitor in more than one or two forest types, nor have we yet identified varying objectives for more intensively monitored index sites vs. less intensively monitored, more spatially extensive sites. We have identified the highest priority species for long-term monitoring, but analysis of existing data will help inform us about what the cost will be to take a broader (more species) vs. a more focused (one or two species) approach.

### *Monitoring Questions*

- How are the dynamics (establishment, growth and death rates) of tree populations changing in response to changes in climate?
- How do the structure, composition, and distribution of plant communities change in response to variation in climate, fire regime, and human activities?
- How is net primary productivity changing in aquatic and terrestrial systems in relation to changes in climate, fire regime, and human activities?
- How are increasing levels of ozone (and other pollutants) affecting vegetation? Are concomitant changes in fatal insect attacks or tree population dynamics (recruitment and death rates) occurring?

### *Monitoring Objectives*

Species initially identified as highest priority: (1) giant sequoia, (2) sugar pine, and (3) whitebark pine.

*Tree population dynamics:*

- Determine trends in populations of selected tree species (birth, growth, death rates); growth form, if monitoring whitebark pine
- Monitor trends in causes of tree death
- Monitor trends in white pine blister rust prevalence in five-needle pine populations

## Basic Approach

A small work group of USGS and NPS staff members from Sierra Nevada parks and the I&M program was formed to define the monitoring objectives, identify existing datasets that could be resources for power analysis and sample design, determine the approach for protocol development and seek a collaborator for assistance with data analysis and, possibly, protocol development.

At the initial meeting, we prioritized the list of focal species for demographic monitoring that came from the network vital signs workshops (giant sequoia, sugar pine, whitebark pine, ponderosa pine, lodgepole pine, oak woodlands) and narrowed to three species. In order of priority, they were giant sequoia, whitebark pine and sugar pine. Later, we decided we should find a collaborator to analyze existing data to determine sample sizes and sampling intervals needed for detection of trends (such as, 80% chance of detecting 20% change) before we narrow our focus prematurely. A range of alternatives would be investigated (different forest types, different sampling intervals, etc.). This information would then be used to work with a statistician (e.g., Julie Yee of USGS or Leigh Ann Starcevich, Cooperator through the Univ. of Idaho) on a sample design and determine how many forest types and/or species we could monitor.

We identified the following datasets that could be used for analyses:

- Forest demography (most useful)—USGS-BRD (SEKI, YOSE)
- Fire effects—NPS (all parks)
- Lambert/Stohlgren giant sequoia data (SEKI)
- Harvey et al. giant sequoia seedling data (SEKI)
- Giant sequoia tree inventory maps––revisit random areas to determine mortality (SEKI, maybe YOSE)
- White pine blister rust survey data—Duriscoe and USFS (SEKI)

Another task will be to review existing protocols from networks or other agencies (USFS) to determine if there are useful approaches that would meet some of our objectives. The North Coast/Cascades Network (NCCN) forest protocol (Woodward et al. 2009) may have some approaches (sample design, SOPs, database, etc.) that will be helpful to us. The USGS –WERC Sequoia and Kings Canyon Field Station has been doing forest demographic monitoring for many years, and has long-term data, analyses, publications, and approaches that will inform SIEN's protocol development. Finally, the Whitebark Pine Ecosystem Foundation has developed methods for surveying and monitoring whitebark pine stands and blister rust that we will review to determine if their methods will help address our objectives (Tomback et al. 2004).

To address our monitoring objectives, a plot-based approach that tracks individually marked trees will be needed. The following paragraphs are the rationale and considerations for this approach from Nate Stephenson.

The rationale for plot-based monitoring of individually-identified trees is simple. First, the approach gives precise measures of forest composition and structure for change detection. Second, and perhaps more important, it is the only approach that can hope to yield the information needed to develop models capable of forecasting or predicting future changes. Specifically, plot-based monitoring of individually-identified trees yields species-specific demographic rates and growth rates, and sheds light on their controls. Demographic rates determine numbers of trees, while growth rates determine sizes of trees. Together, species-specific numbers and sizes of trees precisely define forest composition and structure. Therefore prediction requires mechanistic understanding of environmental controls of species-specific demographic rates and growth rates.

Experience has proven other ground-based approaches to be less useful. For example, if trees are not individually identified, plot-based approaches effectively become repeated inventories rather than monitoring. Changes in forest structure and composition can still be detected, but all ability to determine demographic rates and growth rates (hence all ability to develop mechanistic models) is lost. Additionally, as empirical data from tropical forests have demonstrated, substantial parallel changes in mortality and recruitment (hence carbon cycling and other aspects of forest function) can occur with little change in forest structure and composition.

Establishment of plot-based monitoring of individually-identified trees is associated with several considerations, as follows.

Tradeoff between plot size and number. A tradeoff exists between precision (having a few large plots that give a precise picture of forest dynamics at a few sites) and accuracy (having more, smaller plots that sample more of the landscape). Experience in both tropical and temperate forests indicates that having more, smaller plots is most useful for addressing the sorts of questions posed here. Experience further indicates that minimum useful plot size often is in the range of 0.5 to 1 ha.

Nested plots. In multi-cohort forests, small trees usually far outnumber large trees. It may therefore sometimes be useful to sample a larger area for large trees than for small trees. However, experience shows that for analysis and interpretation, simplicity of design is quite important.

Minimum tree size sampled. Commonly, the minimum diameter at breast eight (dbh) of trees sampled is 10 cm (especially in exceptionally dense

tropical forests). However, the smallest trees in a forest are usually both the most abundant and most dynamic, meaning that monitoring of smaller trees is critical to derive mechanistic understanding. We recommend monitoring trees of all sizes, including seedlings (see below).

Seedlings. Forests, because they are physically dominated by large trees that live for centuries, are notorious for sometimes having a fair bit of inertia to environmental changes. Seedlings often are more vulnerable to environmental changes than large trees, so that the first signals of environmentally-induced forest change may appear as changes in seedling growth and dynamics. Thus, seedlings should also be monitored, usually in smaller nested plots.

Plot locations. If natural environmental gradients are available (such as elevational or soil fertility gradients), understanding of forest dynamics and change will often advance most quickly if plots are arrayed along the gradients as "natural experiments." *[The NPS I&M program will require that we have a sample design that defines a target population and allocates plots in a random or systematic way to allow inference to that entire population. General Random Tessellation Stratification, or GRTS (Stevens and Olsen 2004), is one approach that I&M networks are using for ensuring spatially balanced sample sites, and we will consider that approach with a statistician as a means of allocating plots across the target areas or populations.]*

Frequency of observation. The most common interval for forest plot monitoring is about five years. Longer intervals tend to create problems, such as tree tags being engulfed by rapidly-growing trees, overwhelming amounts of new recruitment accumulating, and loss of temporal resolution tying forest changes to environmental changes. However, five-year measurement intervals are usually too long to accurately determine probable causes of tree deaths and to confidently link forest changes to certain short-term stresses (like a one- or two-year drought), thereby limiting mechanistic understanding.

A strong case can be made for annual monitoring (especially for seedlings), but the extra labor needed usually means that fewer total plots can be monitored.

While plot-based monitoring of individually-identified trees offers the only reasonable means of gaining a mechanistic understanding of forest dynamics (hence predictive ability), by itself it is not sufficient. First, its relatively labor-intensive nature limits it to a tiny fraction of the landscape. Second, it does not adequately measure forest function (though it can provide estimates of aboveground biomass dynamics). Hence, other approaches are also needed.

Other approaches include monitoring of change in forest mosaics at the landscape level using remote sensing and monitoring forest function (carbon exchange between forest systems and atmosphere) using eddy flux towers. The latter is not feasible at this time for the I&M program to pursue due to problems with cost and methodology as well as the "footprint" on the landscape of such structures. To pursue landscape objectives, the forest group will need to work with the landscape group.

We will work with the SIEN Data Manager to develop the data management plan for the protocol, including standard operating procedures for field data collection, database design, data archiving, delivery, and reporting.

## Principal Investigators

### *Current work group members*

Lead (2006-2008): Linda Mutch, Network Coordinator

New lead (2009-2010): Shawn McKinney, SIEN Ecologist

Tony Caprio, SEKI Fire Ecologist

Gus Smith, YOSE Fire Ecologist

Nate Stephenson, USGS-WERC Sequoia & Kings Canyon Field Station Research Ecologist

### *Others who have participated:*

MaryBeth Keifer, PWR Fire Ecologist

Adrian Das, Ecologist, USGS-WERC Sequoia & Kings Canyon Field Station

### *Cooperators*

University of Idaho—power analysis and sample design; USGS-WERC Sequoia and Kings Canyon Field Station (data prep for power analysis, protocol oversight and internal review); others—to be determined.

## Development Schedule, Budget, and Expected Interim Products

Protocol development was on-hold for several years while staff were working on developing other protocols (wetlands, landscape dynamics).

**Table 1:** DRAFT forest dynamics protocol development schedule

| DATE | DEVELOPMENT |
|---|---|
| January 2006 | Establish draft protocol monitoring objectives and PDS |
| January 2009 | Update PDS to reflect new work group members |
| May 2009 | Re-convene work group and more narrowly define focal forest type for monitoring |
| Aug–Oct 2009 | Assemble datasets for power analysis, do literature review for focal forest types (5-needle pines), and initiate power analyses |
| Nov 2009–Jan 2010 | Do power analyses and develop sample design alternatives to present to Science Committee |
| Feb–Apr 2010 | Draft protocol narrative and SOPs |
| May 2010 | Internal and informal review |
| Jun–Jul 2010 | Field-testing/revision |
| Aug 2010 | Peer review |
| Summer 2011 | Implementation |

**Table 2**. Budget for Protocol Development

| PERSON | COST | DESCRIPTION |
|---|---|---|
| Shawn McKinney | $40,000 | Lead |
| Linda Mutch, Les Chow | $10,000 | Assistance with protocol narrative sections and selected SOPs |
| Leigh Ann Starcevich—University of Idaho | $15,000 | Analyze existing data—power analysis, sample design |
| Work group members | $10,000 | Data compilation, protocol guidance and review, SOP assistance |

# Literature Cited: Forest Dynamics


Ansley, J. A. S., and J. J. Battles. 1998. Forest composition, structure, and change in an old-growth mixed conifer forest in the northern Sierra Nevada. *Journal of the Torrey Botanical Society* **125**:297-308.

Bonnicksen, T. M., and E. C. Stone. 1982. Reconstruction of a presettlement giant sequoia mixed conifer forest community using the aggregation approach. *Ecology* **63**:1134-1148.

Dettinger, M. D., D. R. Cayan, M. Meyer, and A. E. Jeton. 2004. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099. *Climatic Change* **62**:283-317.

Franklin, J.F. and J.A. Fites-Kaufmann. 1996. Assessment of late-successional forests of the Sierra Nevada, Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II: Assessments and Scientific Basis for Management Options. Wildland Resources Center Report No. 37, University of California, Davis, CA.

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

Keeley, J., and N. L. Stephenson. 2000. Restoring natural fire regimes to the Sierra Nevada in an era of global change. D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin. Wilderness science in a time of change: Wilderness ecosystems, threats and management, Missoula, MT. Vol. 5.

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**:23-29.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettermaier. 2005. Declining mountain snowpack in western North America. American Meterological Society.

Mutch, L. S., A. Heard, M. Rose, and S. Martens. 2005. Vital Signs Monitoring Plan, Phase II Report, Sierra Nevada Network. National Park Service, Three Rivers, CA.

Parsons, D. J., and S. H. DeBenedetti. 1979. Impact of fire suppression on a mixed-conifer forest. *Forest Ecology and Management* **2**:21-31.

Phillips, O. L., T. R. Baker, L. Arroyo, N. Higuchi, T. J. Killeen, W. F. Laurance, and e. al. 2004. Pattern and process in Amazon tree turnover. *Phil. Trans. R. Society. Lond.* **B 359**:381-407.

Roy, D. G., and J. L. Vankat. 1999. Reversal of human-induced vegetation changes in Sequoia National Park, California. *Canadian Journal of Forest Research* **29**:399-412.

Rundel, P. W., D. J. Parsons, and D. T. Gordon. 1988. Montane and subalpine vegetation of the Sierra Nevada and Cascade Ranges. *In* M. G. Barbour and J. Major, editors. Terrestrial Vegetation of California. California Native Plant Society.

Scuderi, L. A. 1993. A 2000-year tree ring record of annual temperatures in the Sierra Nevada Mountains. *Science* **259**:1433-1436.

Stephenson, N. L., and P. J. van Mantgem. 2005. Forest turnover rates follow global and regional patterns of productivity. *Ecology Letters* **8**:524-531.

Stephenson, N. L. 1999. Reference conditions for giant sequoia forest restoration: Structure, process and precision. *Ecological Applications* **9**:1253-1265.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario. *Climatic Change* **62**:217-232.

Tomback, D.F., R.E. Keane, W.W. McCaughey, and C. Smith. 2004. Methods for surveying and monitoring whitebark pine for blister rust damage and infection. Whitebark Pine Ecosystem Foundation, Missoula, MT.

Vale, T. R. 1987. Vegetation change and park purposes in the high elevations of Yosemite National Park, California. *Annals of the Association of American Geographers* **77**:1-18.

Vankat, J. L., and J. Major. 1978. Vegetation changes in Sequoia National Park, California. Journal of Biogeography 5.

Woodward, A., S.A. Acker, K. Jutten, J.R. Boetsch, M. Biven, R. Rochefort, C.C. Thompson, and L. Whiteaker. 2009. Forest vegetation monitoring protocol for the North Coast and Cascades Network. Natural Resource Report NPS/NCCN/NRR-2009/XXX. National Park Service, Ft. Collins, CO.

# Protocol: Lakes

## Parks Where Protocol Will be Implemented

Sequoia & Kings Canyon (SEKI) and Yosemite (YOSE)

## Vital Signs Addressed by Protocol

Water chemistry
Surface water dynamics
Amphibians

## Justification

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

## Background Information

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

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

The parks' aquatic ecosystems are subjected to natural and anthropogenic disturbances that have the potential to modify the systems and degrade water resources. Some of the biggest threats to Sierra Nevada lakes are the systemic stressors, which occur at regional and ecosystem scales. These include loss of pre-Euroamerican fire regimes, non-native invasive species, air pollution, habitat fragmentation, and rapid anthropogenic climatic change (SNEP 1996; Sequoia and Kings Canyon National Parks 1999). Aquatic systems are also impacted by localized stressors that threaten relatively small areas or specific water bodies; these include visitor use impacts, small dams and diversions, or abandoned mines.

Water resources are critical components of the parks' ecosystems and indicators of aquatic and terrestrial ecosystem condition. Hydrological and water chemistry measures are good indicators of aquatic and terrestrial ecosystem condition and trend because they reflect changes within the larger watershed. High-elevation lakes of the western United States are especially sensitive to change because the waters are oligotrophic and have a low buffering capacity. Sierra Nevada lakes have

some of the lowest acid neutralizing capacity (ANC) concentrations in the western U.S. (Eilers et al. 1989). Changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes have been previously detected and attributed to increased nitrogen and phosphorous inputs (Goldman et al. 1993, Sickman et al. 2003).

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

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

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

The Yosemite toad is endemic to the high Sierra Nevada. It has disappeared from more than 50% of the sites where it was known to occur historically. Overall status for Pacific tree frogs is undetermined, but data suggests decline in certain areas. Although research is still ongoing to fully explain the species' decline, it is well-documented that introduced fish, which predate on tadpoles, and the disease chytridiomycosis are two of the primary causes. Other evidence suggests that pesticides and climate change may also be contributing factors.

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

## Specific Monitoring Questions and Objectives

### *Monitoring Questions*

The Sierra Nevada Network identified a set of broad monitoring objectives and questions for the Phase I and Phase II Monitoring Plans (Mutch et al. 2005). We used these to guide us in defining the specific monitoring objectives. Lake monitoring, in conjunction with the other indicators, will provide information

that will help the network answer these questions. SIEN's broad monitoring questions that pertain to the lake onitoring protocol include:

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

### *Monitoring Objectives*

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

### *Survey Sites*

- Detect long-term trends in lake water chemistry for Sierra Nevada Network lakes.
  - Temp, pH, sp. conductance, dissolved oxygen, acid neutralizing capacity
  - Major ions: Ca, Na, Mg, K, Cl, $SO_4$
  - Nitrate, dissolved organic nitrogen, total dissolved nitrogen
  - Total dissolved phosphorus
  - Particulate nitrogen, particulate phosphorus, particulate carbon
- Characterize Sierra Nevada Network lakes.
- Determine the proportion of Sierra Nevada Network lakes above threshold values for selected constituents.
- Detect long-term trends and abundance of high-elevation anurans, particularly mountain yellow-legged frog, Yosemite toad, and Pacific treefrog for Sierra Nevada Network lakes.

### *Index Sites*

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

### Potential Measures

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

Surface-water dynamics: lake outlet discharge lake elevation, lake volume,

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

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

## Protocol Development & Status

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

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

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

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

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

To complement long-term monitoring data, we would like to collect sediment cores for diatom analyses. This would provide information on historical nitrogen loading to SIEN lakes and help us identify threshold conditions. After the core protocol is developed we will be discussing how to best accomplish this component—it is likely we will need to seek additional funding.

## Tentative Sampling Methods & Design

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

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

The Network and others working in large mountainous landscapes have

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

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

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

Index sites will be used to monitor sites of particular interest, based on existing research and monitoring, accessibility or demonstrated sensitivity to certain stressors.. These index sites will be visited more frequently, for instance once or twice a month, from spring through fall. Additional instrumentation will be used at index sites so that continuous data collection is possible.

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

### *Amphibians*

SIEN's science committee has decided that fiscal and logistical limitations necessitate the exploration of integration of amphibian monitoring with lake chemistry monitoring. We do not know if this will meet our amphibian monitoring or sampling objectives. We are also working with our statistician to see if–and at what level–integration can be achieved. Most lake measures will be collected in the late summer into fall; this precludes some amphibian sampling, as tadpoles and adults may be less abundant and detectable (e.g., *Hyla*). However, we have not yet conducted data analyses to assess the practicality of integration. For example, if feasible we will include lakes with a history of long-term amphibian monitoring in the lake index sites, which will be sampled throughout the season.

Our current target population includes populations (historic and extant) of mountain yellow-legged frog (*Rana muscosa*), Yosemite toad (*Bufo canorus*); and Pacific treefrog (*Hyla regilla*) in SEKI and YOSE. Decisions for sampling amphibians in DEPO have not been made; only one of our target species (Pacific treefrog) occurs there.

Details regarding sample design and probability of inclusion for amphibian

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

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

## Principal Investigators

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

## NPS Leads

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

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

Sierra Nevada Network Water Resources and Amphibian Work Groups
Danny Boiano, Aquatic Ecologist
Sequoia and Kings Canyon National Parks
Danny_Boiano@nps.gov

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

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

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

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

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

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

## Cooperators*

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

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

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

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

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

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

*Other cooperators may be identified.

## Development Schedule, Budget, and Expected Interim Products

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

**Table 3:** Lake Protocol development schedule

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

# Literature Cited: Lake Protocol


Boiano, D. M., D. P. Weeks, and T. Hemry. 2005. Sequoia and Kings Canyon National Parks, California: Water resources information and issues overview report. Technical Report NPS/NRWRD/NRTR 2005/333, National Park Service, Denver, CO.

Brown, C. 2001. Population and habitat monitoring for mountain yellow-legged frog and Yosemite toad: Study plan review and approval. USDA Forest Service, Sonora, CA.

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**:1171.

Clow, D. W., and J. K. Sueker. 2000. Relations between basin characteristics and stream water chemistry in alpine/subalpine basins in Rocky Mountain National Park, Colorado. *Water Resources Research* **36:**49-61.

Eilers, J. M., D. F. Brakke, D. H. Landers, and W. S. Overton. 1989. Chemistry of wilderness lakes in the Western United States. Environmental Monitoring and Assessment 12.

Eilers, J. M., P. Kanciruk, R. A. McCord, W. S. Overton, L. Hook, D. J. Blick, D. F. Brakke, P. E. Kellar, M. S. DeHaan, M. E. Silverstein, and D. H. Landers. 1987. Characteristics of lakes in the Western United States. Volume II. Data Compendium for Selected Physical and Chemical Variables. EPA-600/3-86/054b, U. S. Environmental Protection Agency, Washington, DC.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003. Ecological effects of nitrogen deposition in the western United States. *Bioscience* **53**:404-420.

Fenn, M. E., M. A. Poth, J. Aber, J. S. Baron, B. T. Bormann, D. W. Johnson, D. Lemly, S. G. McNulty, D. F. Ryan, and R. Stottlemyer. 1998. Nitrogen excess in North American ecosystems: Predisposing factors, ecosystem responses, and management stratagies. *Ecological Applications* **8**:706-733.

Goldman, C. R., A. D. Jassby, and S. H. Hackley. 1993. Decadal, interannual and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **50**:1489-1496.

Melack, J. M., J. O. Sickman, and J. Schimel. 2002. Microbial and hydrological controls of nitrogen losses from alpine and chaparral ecosystems during seasonal transitions- research proposal. Proposal University California, Santa Barbara, Santa Barbara, CA.

Mutch, L. S., A. Heard, M. Rose, and S. Martens. 2005. Vital Signs Monitoring Plan, Phase II Report, Sierra Nevada Network. National Park Service, Three Rivers, CA.

Rachowicz, L. J., R. A. Knapp, J. A. T. Morgan, M. J. Stice, V. T. Vredenburg, J. M. Parker, and C. J. Briggs. 2006. Emerging infectious disease as a proximate cause of amphibian mass mortality. *Ecology* **87**:1671-1683.

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

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* **48**:1885-1892.

SNEP. 1996. Sierra Nevada Ecosystem Project: Final Report to Congress. 36 & 37, University of California, Center for Water and Wildlands Resources, Davis, CA.

Stohlgren, T. J. 1988. Litter dynamics in two Sierran mixed conifer forests. II. Nutrient release in decomposing leaf litter. *Can. J. For. Res.* **18**:1136-1144.

# Protocol: Landscape Dynamics

## Parks where protocol will be implemented

Yosemite (YOSE)
Sequoia & Kings Canyon (SEKI)
Devils Postpile (DEPO)

## Vital Signs Addressed by Protocol

Landscape mosaics
Fire regime
Snow cover
Phenology
Forest patch dynamics

## Justification

Remote sensing of land use patterns offers a relatively rapid and cost effective method to assess large and small spatial scale changes in the landscape.

There are a variety of major factors threatening the integrity of Sierra Nevada ecosystems. Regional science has identified climate change (anthropogenic), altered fire regimes, non-native invasive species, air pollution, and habitat fragmentation as the five primary threats to Sierran systems (SNEP 1996). With a rapidly expanding human population and a steeply rising projection in the state's population size, these threats are likely to only increase in scope and severity. In particular, the Sierra Nevada foothills are projected to be heavily impacted by future development. Climate change is also predicted to play an increasingly important and serious role in California, posing a significant threat to the existence and persistence of native ecosystems and species (California Energy Commission 2003; Hayhoe et al. 2004). Decades of fire suppression and predicted climate shifts are likely to bring dramatically altered fire dynamics to the Sierra Nevada.

## Background Information

Remote sensing has been used for almost two decades to assist in answering a variety of ecological and landscape questions and issues. These include land cover classification, ecosystem function, change detection, and monitoring process such as flooding and disease spread (Kerr and Ostrovsky 2003; Ager and Owens 2004). Land cover and its spatial patterns are key aspects of ecological monitoring. Landscape patterns and the patchwork of vegetation communities integrate biotic and abiotic factors in their structure and composition. Thus, remote sensing can detect changes in both the land cover type and in the variability of particular land cover types (such as vegetation). Although not the canary-in-a-coalmine, changes in plant community health, composition, extent, and spatial arrangement as well as changes in snow cover and timing can reflect changes in climate, biotic interactions, fire regimes, or anthropogenic forces.

There are two primary justifications for wanting to monitor the change in landscape dynamics (including fire) over time:

1. To document the change where and when it occurs. This information can then be applied to respond to crises or to direct managers to areas of heightened concern. Remote sensing provides techniques and data to allow for the preparation of scientific responses to environmental change.
2. To use data to build models of predicted future landscape mosaic patterns. This will allow managers to prepare for and then manage for ecosystem changes that are likely to affect processes, systems, and individual species.

Fire has played a pivotal role in shaping ecosystems and landscapes in the Sierra Nevada for many millennia (Davis and Moratto 1988; Smith and Anderson 1992; SNEP 1996; Anderson and Smith 1997). It affects numerous aspects of ecosystem dynamics such as soil and nutrient cycling, decomposition, succession, vegetation structure and composition, biodiversity, insect outbreaks, and hydrology (Kilgore 1973, SNEP 1996).

From the late 1890s through 1960s, Sierra Nevada park and national forest personnel attempted to suppress all fires, and these efforts met with a fair degree of success. Consequently, numerous ecosystems that had evolved with frequent fires have since experienced prolonged periods without fire (Swetnam

et al. 1992; Swetnam 1993; Caprio and Graber 2000; Caprio et al. 2002; Caprio and Lineback 2002). In 1968 (Sequoia & Kings Canyon) and 1970 (Yosemite), NPS staff began prescribed burning. After more than 30 years of prescribed fires, significant progress has been made, though park efforts are far from restoring natural fire regimes at the landscape level (e.g., (Caprio and Graber 2000; National Park Service 2004).

Climate change and associated predicted changes in fire extent, severity, and occurrence are expected to be the primary drivers of landscape change in the Sierra Nevada in the foreseeable future. The altered fire regimes that have resulted from fire exclusion are currently considered one of the most important stressors on our natural systems. Therefore, it is imperative that we document and understand how climate change will affect fire regimes which will in turn to help interpret changes in plant community composition, structure and function; water chemistry and dynamics; and animal populations' abundance and distribution.

Attributes of pre-Euroamerican fire regimes can provide vital reference information for understanding changes in ecosystems over the last 150 years and in developing goals for the restoration of fire. The concept of a fire regime allows us to view fire as a multi-faceted variable rather than a single event within an ecosystem (Whelan 1995). Thus, areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability that can have both spatial and temporal attributes. Fire regimes are normally defined according to specific variables including frequency, magnitude (intensity, severity), size, season, spatial distribution and type of fire (Gill 1975; Heinselman 1981). These fire regime characteristics can vary through time and across the landscape in response to climatic variation, number of lightning ignitions, topography, vegetation, specific historic events and human cultural practices (SNEP 1996).

The National Parks of the Sierra Nevada (Yosemite, Kings Canyon, Sequoia, and Devils Postpile) together have established a large proportion of the central and southern Sierra Nevada as federally protected areas. Together they help to protect one of the nation's and the world's most biotically unique and diverse locations. Consistently, the California Floristic Province (of which the Sierra Nevada is a part) is identified as a global biodiversity hotspot (Meyers et al. 2000; Whittaker 2005) where large concentrations of endemic species are threatened by loss of, or degradation of habitat. In accordance with this level of global biodiversity, resource managers of the Sierra Nevada Network parks must use any and all methods available to document and assess impacts to these federal protected lands. Information can be collected from the ground or remotely using satellites or aircraft. Remote sensing of land use patterns offers a relatively rapid and cost effective method to assess large and small spatial scale changes in the landscape.

## Specific Monitoring Questions & Objectives

The Sierra Nevada Network (SIEN) has a landscape protocol work group that identified the following primary onitoring objectives:

1. Determine how vegetation type and cover is changing over time. Use remote sensing data and technology to detect changes in vegetation type and cover from a baseline on a 5-10 year interval.
2. As often as necessary, use remote sensing to detect the extent and severity of fire events and incorporate these into change detection maps. This detection will occur in every year there is at least one fire of significant size (to be determined).
3. Determine how snow cover within the parks is changing both inter-annually and intra-annually. The objective is to monitor how snow cover duration may be changing over time and how it is changing within the season (e.g., detect if timing of the initiation or melt of snow cover is changing over time.). This will be monitored on a 2-5 year interval.
4. Determine probable causation of changes detected in vegetation type and cover based on pilot studies of

past disturbance events including fire and insect damage.

5. Determine changes in the distribution and abundance of vegetation and land cover classes over time. Metrics of patterns including total area, number of patches, mean patch size, mean inter-patch distance, and overall patch class diversity will be used to characterize and track changes in landscape dynamics.
6. Determine changes in vegetation health or condition over time. Various remote sensing derived metrics of vegetation health can be used to monitor how vegetation health may be changing. These include Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Fraction of Photosynthetically Active Radiation (FPAR), and Leaf Area Index (LAI), and possibly others. These metrics can be used in conjunction with the normally derived vegetation type and cover change detection to monitor vegetation condition. This will be monitored on a 2-5 year interval.
7. Using the change detection analysis, determine how vegetation phenology is changing over time. Phenology can include leafout, leaf senescence, and vegetation growth or activity (as detected with metrics such as NDVI). The objective is to determine how vegetation types are responding to changes in climate and other disturbances (i.e., is growing season expanding?).

In addition to the seven objectives outlined above, we would like to explore the potential of using remote sensing to help monitor other aspects of the landscape. These secondary objectives would assist in the monitoring of other "vital signs" that are or will be slated for long term monitoring in the SIEN.

These secondary objectives will have the advantage of extensive field validation data that will be collected as part of the monitoring effort of the other vital signs. These data will be valuable for informing change detection analysis.

Secondary objectives include:

8. Use finer scale remotely sensed imagery (e.g., 5-10m) monitor the changes in forest patch dynamics over time. This would focus on a few important vegetation classes or communities dominated by significant species. The objective would be to monitor how overall cover and patch dynamics (e.g., total cover, mean size, inter-patch distance) is changing.
9. Use remote sensing to monitor the presence and spread of a small number of non-native plant species. This would require fine resolution imagery (1-5m).
10. Monitor changes in the extent and number of meadows as well as their vegetation composition and health. This would require finer resolution imagery as many meadows are small (< 100m across). The desire is to monitor how meadows may be shrinking or disappearing across the landscape, and how the vegetation community may be changing.
11. Monitor how the timing of ice-over and ice-out of lakes is changing inter-annually in response to climate change. This also would require fine resolution imagery (1-5m) as many lakes are also small.

## Basic Approach

The protocol objectives, above, were developed by two separate work groups, both comprised of NPS and USGS staff members: a landscape dynamics workgroup and a fire regimes workgroup. Objectives were developed and prioritized for these two vital signs separately, and in October 2006, the two groups met together to merge the objectives from the groups into one protocol. From this date on, we plan to proceed with one protocol development approach.

A cooperative agreement with the Oregon State University has been established (FY 2007-2008) to assess SIEN's landscape monitoring objectives in relation to appropriate remote sensing technologies and methods and existing relevant datasets, to determine which objectives can feasibly be pursued given anticipated resources, and to test and develop a protocol that meets local needs for landscape change monitoring. This will include providing alternatives for acquiring the expertise needed to process and interpret remote-sensing imagery.

## Protocol Development & Status

SIEN and cooperators at OSU will conduct a workshop during FY2008 with the Sierra Nevada Network's "landscape work group", other interested stakeholders in the parks, and National Aeronautics and Space Laboratory, Ames Research Center (NASA-Ames) collaborators to provide an overview of approaches developed or in-progress for other networks, to frame SIEN monitoring objectives in the context of remote sensing approaches, and to determine which objectives are the most feasible to pursue with available resources.

*Phase 1* of this project will rely on transfer of existing tools and related protocols developed for the North Coast and Cascades Network (NCCN) and Southwest Alaska Network (SWAN) from the cooperators to the SIEN. These tools have been (and continue to be) developed and tested at other western park networks and should be readily transferable to the SIEN (after a set of pilot studies). Both draft and final protocols based on these existing tools will be developed for the SIEN as a part of this phase. Existing protocols developed for NCCN and SWAN will likely not meet all of the SIEN remote sensing monitoring objectives. Therefore, Phase 1 will also involve, as a set of additional pilot studies, development of new tools to more fully address the complete set of SIEN remote sensing monitoring objectives. A report describing these new tools and their potential for addressing the fuller set of SIEN remote sensing monitoring needs will be provided.

*Phase 2* of this project will include an additional period of technology transfer, in which cooperator time will be devoted to helping SIEN personnel implement the protocols developed during Phase 1 of this project. If additional funds are available, Phase 2 will also involve further development and testing of (and writing of protocols for) the fuller set of remote sensing monitoring tools tested and reported on in Phase 1. Attachment I further describes the project and contains a more detailed study plan.

## Tentative Sampling Methods & Design

Our goals will require monitoring the landscape on varying time scales, depending upon the question asked. For longer term questions such as changes to overall landscape patterns, we will take the approach of monitoring landscape dynamics on a longer term time scale (5-10 years). This basic landscape dynamics monitoring will involve a comparative spectral analysis between imagery from time 1 and time 2. Only those areas that are identified as having a significant spectral change will be remapped. The most appropriate imagery is likely to be Landsat Thematic Mapper (TM) at a resolution of 30 meters. This imagery should be available free of cost to the National Park Service.

Once areas that have experienced spectral change are identified, either ground truthing and/or use of high resolution aerial photography will be used to verify those changes. This methodology has been used for a variety of applications with success (e.g., Oetter et al., 2000). Depending upon availability and cost, digital orthophotoquads (DOQQs) may also be used at this step. Field work conducted through other protocols (such as Forest Dynamics) may be used to verify spectral changes identified in the analysis. One possibility is to use the inventory of the Forest Inventory Assessment plots that are maintained and periodically monitored by the US Forest Service. A final step of the process will be to assign causality to the identified change, if possible.

There are two approaches that could be pursued in the process of change detection. One would be to conduct a detection of change in the patterns of the landscape within the parks will be based upon existing base maps such as recent vegetation maps. All four vegetation maps are highly detailed and should be sufficient for use as a base map. Once landscape changes are identified, the vegetation base map would then be updated as necessary. The other approach would be to map change only based on spectral differences between time one and time two TM imagery.

This is the method chosen by the North Coast/Cascades Network (NCCN). This method is not tied to an original base map and so this may present some difficulties with translating the spectral changes to the physical reality of what exists on the landscape. It is likely that we will apply the first approach.

In addition to an analysis of landscape change, we want to analyze changes in the mosaics of landscape units. This will involve an analysis of the landscape patterns that characterize the composition, extent, and spatial arrangement of land cover and vegetation units. Metrics will allow us to analytically measure change within the landscape. Metrics of spatial pattern can be generated using a combination of analysis ool in ESRI's ArcGIS and others such as FRAGSTATS. These metrics will include:

1. Composition (the variety and abundance of distinct patch types)
    a) Proportional abundance of each type
    b) Richness: total number of patch types
    c) Evenness: the relative abundance of different patch types
    d) Diversity: a composite of richness and evenness (e.g., Shannon Weaver)
2. Spatial Configuration
    a) Patch characteristics (size shape): mean, max, variance
    b) Spatial relationships: nearest neighbor, clustering, dispersion, connectivity
    c) Contrast: differences among patch types
    d) Corridors

We will want to focus a considerable amount of the effort on monitoring changes in metrics of forest/vegetation health over time, in conjunction with the change detection analysis (every 5-10 years). Metrics derived from the TM imagery such as NDVI, FPAR, and LAI can be calculated to detect alterations in the health and/or composition of the vegetation.

Currently, Sequoia, Kings Canyon, and Yosemite have existing fire management programs that new fire extent annually and calculate fire return interval and have recently begun to determine fire severity within the boundaries of burn areas using Landsat imagery. Efforts of this protocol will aim to complement, not duplicate, the fire monitoring program within the parks. The Sierra Nevada Network, with its Science Committee and protocol work groups, will need to determine whether it has the resources to enhance and build upon existing fire regime monitoring efforts in Sierra Nevada parks, or whether it will need to limit its role to synthesizing and helping make more available already existing data.

Some of our objectives will require the purchase of imagery with a much finer scale (less than 5m). Questions such as meadow health and extent, timing of lake ice-out, phenological timing, and invasive plants extent will require finer scale imagery. This imagery does come with a greater cost and the monitoring objective will have to be prioritized if and when funds are not sufficient to answer all questions. This fine scale imagery may cost thousands to tens of thousands of dollars for the four SIEN parks as imagery may need to be purchased for several times throughout the year. A complete cost-benefit analysis would need to be written to help in protocol objective prioritization.

Other protocols to be implemented within the Sierra Nevada Network also have identified a potential need for remote sensing to assist is achieving their goals. These include monitoring extent and health of meadows, detecting and monitoring invasions by non-native plants, and forest condition and patch dynamics. Although the parks currently have a program to monitor the annual extents and timing of fires, additional remote sensing analyses can assist to monitoring vegetation change following fire.

Many of the details of the change detection methods will be taken from the NCCN vegetation monitoring protocols. The US Forest Service and the California Department of Forestry and Fire Protection (CDF) have also instituted a change detection program for forests

in the Sierra Nevada that is tailored to detecting changes to the cover of conifer and hardwood forests over time (Fisher et al., 2004) but does not take a broader look at landscape mosaic patterns and dynamics. The landscape mosaics protocol will be implemented to complement the USFS and CDF change detection program and to take advantage of their output.

### Principal Investigator, NPS Lead, Workgroup Members, and Collaborators

This protocol development will be accomplished by cooperators at Oregon State University and NASA-Ames in collaboration with Sierra Nevada Network scientists, both within the NPS and the USGS.

#### *NPS Leads*

Bill Kuhn, GIS Specialist & Landscape Ecologist, Yosemite
Bill_Kuhn@nps.gov

Linda Mutch, Coordinator, Inventory & Monitoring Program
Sierra Nevada Network
Linda_Mutch@nps.gov

#### *Workgroup Members*

Tony Caprio, Fire Ecologist
Sequoia & Kings Canyon

Karen Folger, Fire GIS Specialist
Sequoia & Kings Canyon

Andi Heard, Physical Scientist
Sierra Nevada Network

MaryBeth Keifer Fire Ecologist
NPS Pacific West Region

Jen Hooke, Fire Ecologist, Yosemite

Pat Lineback, GIS Coordinator
Sequoia & Kings Canyon

Dr. Leland Tarnay,
Air Quality Specialist, Yosemite

Dr. Jan van Wagtendonk,
Research Forester
USG—Western Ecological Research Center, Yosemite Field Station

Kent van Wagtendonk,
Fire GIS Specialist, Yosemite

### External cooperators

Drs. Zhiqiang Yang, Robert Kennedy and Warren Cohen, Laboratory for Applications of Remote Sensing in Ecology (Oregon State University and USFS Pacific Northwest Research Station)

Dr. Rama Nemani and Dr. Forrest Melton
NASA Ames Research Center

| DEVELOPMENT SCHEDULE, BUDGET AND EXPECTED INTERIM PRODUCTS | |
|---|---|
| Finalize protocol objectives and PDS | Fall 2006 |
| Task Agreement with OSU | Summer 2007 |
| Workshop with work group and cooperators | Fall 2007 |
| Workshop report and Study Plan | Winter 2008 |
| Draft protocol SOPs complete | August 2009 |
| Draft protocol narrative complete | August 2009 |
| Protocol finalized for peer review | January 2010 |

| BUDGET | |
|---|---|
| **FISCAL YEAR 2006** | Landscape Ecologist for 2 pp (one to I&M) @ $2634/pp = $5268 |
| **FISCAL YEAR 2007** | Protocol development task agreement (PNW CESU, Oregon State Univesity~ $100,000 |
| | YOSE Landscape Ecologist Bill Kuhn for 3 pp -- $8,300 |
| **FISCAL YEAR 2008** | YOSE Landscape Ecologist Bill Kuhn for 4 pp $11,500 |
| | Other costs associated with protocol completion- TBD |
| | Imagery costs—TBD |

# Literature Cited


Ager, A. A., and K.E. Owens. 2004. Characterizing Meadow Vegetation with Multitemporal Landsat Thematic Mapper Remote Sensing. USDA Forest Service Report. Portland, OR.

Anderson, R. S., and S. J. Smith. 1997. Sedimentary record of fire in montane meadows, Sierra Nevada, California, USA: A preliminary assessment. Pages 313-327 *In*: J. S. Clark, J.S., H. Cachier, J. G. Goldammer, and B. Stocks, editors. Sediment Records of Biomass Burning and Global Change. NATA ASI series, Springer-Verlag, Berlin.

Caprio, A. C., C. Conover, M. Keifer, and P. Lineback. 2002. Fire management and GIS: A framework for identifying and prioritizing fire planning needs. *In*: N. G. Sugihara and M. E. Morales (Eds). Proceedings of the symposium: Fire in California ecosystems: Integrating ecology, prevention and management, San Diego, CA, Nov.17-20,1997. Vol. 1.

Caprio, A. C., and P. Lineback. 2002. Pre-twentieth century fire history of Sequoia and Kings Canyon National Parks: A review and evaluation of our knowledge. *In*: N. G. Sugihara, M. E. Morales, and T. J. Morales (Eds). Proceedings of the Symposium: Fire in California Ecosystems: Integrating Ecology, Prevention and Management, San Diego, CA, Nov.17-20, 1997. Vol. 1.

Caprio, A. C., and D. M. Graber. 2000. Returning fire to the mountains: Can we successfully restore the ecological role of pre-Euroamerican fire regimes to the Sierra Nevada? *In*: D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin (Eds). Proceedings: Wilderness Science in a Time of Change—Vol. 5 Wilderness Ecosystems, Threats, and Management, Missoula, MT and Ogden, UT, 1999 May 23-27. Vol. RMRS-P-15-VOL-5.

California Energy Commission. 2003. Climate Change and California: Staff Report. California Energy Commission. Sacramento, CA. 46 pp.

Davis, O. K., and M. J. Moratto. 1988. Evidence for a warm dry early Holocene in the western Sierra Nevada of California: Pollen and plant macrofossil analysis of Dinkey and Exchequer Meadows. *Madrono* **35**:132-149.

Fisher, L., M. Rosenberg, L. Mahon, L. Zhangfeng, B. Maurizi, P. Longmire, and S. Shupe. 2004. Monitoring land cover changes in California: California land cover mapping and monitoring program. USDA Forest Service Report. Sacramento, CA.

Gill, A. M. 1975. Fire and the Australian flora: A review. *Australian Forestry* **38**:4-25.

Hayhoe, K. D. C., C.B. Field, P.C. Frumhoff et. al. 2004. "Emissions pathways, climage change, and impacts on California." *Proceedings of the National Academy of Sciences* **101**(34): 12422-12427.

Heinselman, M. L. 1981. Fire intensity and frequency as factors in the distribution and structure of norhtern ecosystems. Pages pp. 7-57 in 594 pp. *In*: T. M. Mooney, T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners, editors. Proceedings of the conference: fire regimes and ecosystem properties. Dec. 11-15, 1978, Honolulu, Hawaii. USDA Forest Service, Honolulu, HI.

Kerr, J.T., and M. Ostrovsky. 2003. From space to species: ecological applications for remote sensing. *Trends in Ecology and Evolution* **18**(6): 299-305.

Kilgore, B. M. 1973. The ecological role of fire in Sierran conifer forests: Its application to national park management. *Quaternary Research* **3**:496-513.

Meyers, N., R.A. Mitterneier, C.G. Mittermeier, G.A.B Da Fonseca, and J. Kent. 2000. "Biodiversity hotspots for conservation priorities." *Nature* **403**: 853-858.

Mutch, L., A. Heard, M. Rose, and S. Martens. 2005. Vital Signs Monitoring Plan, Phase II Report, Sierra Nevada Network. National Park Service, Three Rivers, CA.

National Park Service. 2003. Fire and fuels management plan. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

National Park Service. 2004. Yosemite Fire Management Plan and Environmental Impact Statement. Yosemite National Park.

Oetter, D. R., W.B. Cohen, M. Berterretche, T.K. Maiersperger, and R.E. Kennedy. 2000. Land cover mapping in an agricultural setting using multiseasonal Thematic Mapper data. *Remote Sensing of the Environment* **76**: 139-155.

Smith, S. J., and R. S. Anderson. 1992. Late Wisconsin paleoecologic record from Swamp Lake, Yosemite National Park, California. *Quaternary Research* **38**:91-102.

SNEP. 1996. Sierra Nevada Ecosystem Project: final report to Congress. Summary. University of California, Davis, CA.

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

Swetnam, T. W., C. H. Baisan, A. C. Caprio, R. Touchan, and P. M. Brown. 1992. Tree-ring reconstruction of giant sequoia fire regimes. Final report to Sequoia, Kings Canyon and Yosemite National Parks Coop. Agreement No. DOI 8018-1-0002, University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ.

Whelan, R. J. 1995. The Ecology of Fire. Cambridge Univ. Press, Cambridge.

Whittaker, R. J. 2005. Conservation Biogeography: assessment and prospect. *Diversity and Distributions* **11**(1): 3-23.

# Protocol: Wetlands Ecological Integrity

## Park Where Protocol will be Implemented

Yosemite National Park (YOSE)
Devils Postpile National Monument (DEPO)
Sequoia and Kings Canyon National Parks (SEKI)

## Vital Signs Addressed by Protocol

Wetland water dynamics
Wetland plant communities
Macro-invertebrates (wetland)

## Justification

Wetlands[1] (often referred to as "meadows" in the Sierra Nevada) are diverse and complex ecosystems that vary widely in character and composition, though occupying only a small fraction of the land surface of the Sierra Nevada (Benedict and Major 1982; Ratliff 1982; Kaczynski 2007). Wetlands form in catchments where soils are saturated or flooded for at least a portion of the year. Wetlands occur in basins, on slopes, along streams, and adjacent to lakes and ponds. Sierra Nevada meadows range in size from small patches to large expanses, such as Tuolumne Meadow in Yosemite National Park. Most Sierra Nevada wetlands occur above snowline, where snowmelt provides moisture during the summer growing season. In addition to surface flow, moisture enters wetlands from streams and from sub-surface flows that are forced to the surface by local geomorphology. Wetlands have varying levels of moisture, both temporally and spatially, reflecting the relative availability of water during the summer growing season.

## Background Information

Sierra Nevada wetland vegetation is dominated by perennial graminoids, which reflect the relatively short growing season of the middle and high elevations. Key genera include *Carex, Deschampsia, Calamagrostis, Juncus, Danthonia*, and *Eleocharis*, with species composition of individual wetlands determined by local moisture regime and soil characteristics. Annual productivity of wetland graminoids is closely tied to the amount and timing of winter snows as well as changes in length of growing season associated with such fluctuation; when late lying snows shorten the growing season, productivity declines accordingly. In some wetlands with higher moisture availability,, mosses are also important, forming mats and hummocks under favorable conditions. Woody plants are generally excluded from wetlands because of seasonally saturated soils. However, willows (*Salix* spp.) are frequently found along stream channels and often form patches within wetlands. Lodgepole pine, *Pinus contorta*, with a high tolerance for saturated soils, is commonly encountered in and adjacent to wetlands. Lodgepole pine take hold during dry years and give way to wetland vegetation under wetter conditions in a dynamic cycle of invasion and retreat.

Wetlands provide critical breeding and foraging habitat for a suite of animal species. Recent work by (Holmquist and Schmidt-Gengenbach 2005; Holmquist and Schmidt-Gengenbach 2006) in the Sierra Nevada parks demonstrated the importance of wetlands as breeding grounds for invertebrates, which form the energetic basis of many food chains. Many insects breed in wet meadows, then disperse into adjacent forests and woodlands as the season progresses (Holmquist and Schmidt-Gengenbach 2005). Wetland invertebrates also serve as pollinators for montane and high elevation plants. A number of bird species, such as the rare willow flycatcher, use wetlands for foraging, nesting, or both. Mule deer take advantage of the cover provided by

1 For purposes of this protocol, wetlands included are primarily palustirne emergent wetlands, and may include extensive areas of palustrine scrub-shrub (primarily willows, Salix sp.), and/or palustrine forested (primarily lodgepole pine, *Pinus contorta*, or aspen, *Populus tremuloides*)—wetland taxonomy of Cowardin et al (1979). Using terminology defined in Mitsch and Gosselink (1993, page 32), these wetlands consist primarily of wet meadows, but also include fens, marshes, and small patches of swamp. Marshes associated with the edge of lakes and ponds are excluded from this protocol, but the protocol includes riparian areas within wetlands.

montane wetland vegetation by hiding their fawns in dense vegetation. Small mammals, such as ground squirrels, pocket gophers, and voles feed on meadow vegetation, and play a significant role in soil perturbation. Animals such as frogs, toads, and shrews frequent the moist vegetation and stream channels.

As wetlands, wet meadows provide important ecological and cultural functions. Some of the functions described by Mitsch and Gosselink (1993) and Williams (1990) that might apply of the Sierra Network meadows include: (1) influencing regional water-flow regimes including flood mitigation by intercepting and slowing the release of water to streams, (2) improving water quality by removing nutrients and toxic materials, (3) sediment trapping, (4) sources for some of the highest productivity in the world, (5) important habitat for wildlife, and (6) aesthetic values to the people that visit them. Peat-accumulating wetlands in their natural condition remove and store carbon. If altered, such as by drainage, the process would reverse contributing to atmospheric carbon dioxide through oxidation (Gorham 1991). Wetlands play an important role in the nitrogen and sulfur cycles. In the anaerobic reducing environments of wetland soils, nitrogen in nitrate, ammonia, and organic nitrogen is returned to the atmosphere as N2, and sulfur is converted to hydrogen sulfide (Gosselink and Maltby 1990; Mitsch and Gosselink 1993). This helps mitigate some of the nutrient deposition from air pollution. Wet meadows provide unique intersection of terrestrial and aquatic, aerobic and anaerobic conditions.

Wetlands are susceptible to the same stressors that affect the Sierra Nevada parks as a whole. Climate change has the potential to shift the species composition of mountain meadows through changes in the timing and amount of snowmelt and subsequent alteration of the underlying hydrology of local systems. Experimental manipulations in the Rocky Mountains demonstrate that increased temperatures can lead to a general drying down of mountain wetlands, subsequent invasion by woody species such as sagebrush, influence carbon fluxes (Saleska et al. 1999), and cause shifts in timing of flowering of wetland species (Dunne et al. 2003).

Although Sierra Nevada high elevation weltands have so far proven to be relatively resistant to invasion by non-native plants (Gerlach 2004), wetlands in the lower montane are demonstrably susceptible to invasion by the non-native Kentucky blue grass (*Poa pratensis*), which now dominates some heavily grazed wetlands in Sequoia and Kings Canyon National Parks (Neuman 1990; Gerlach et al. 2003; Gerlach et al. 2004). Dandelion (*Taraxacum officinale*), a common invader of mountain wetlands worldwide, is also frequently encountered in disturbed wetlands and riparian areas of the Sierra, especially in those that are heavily grazed.

Serious invasive invertebrates have not been reported in any of the wetlands of Sierra Nevada parks yet, but invertebrate research in these meadows is in its infancy. The New Zealand mud snail, *Potamopygrus antipodarum*, occurs both east and west of the Sierra Nevada parks, and could easily become established in meadow streams, transported on the boots or waders of anglers or perhaps as hikers back-flush their water filters. As the climate warms, Argentine ants, *Linepithema humile*, could invade wetlands, displacing native ants and altering ecosystem processes like seed dispersal and plant pollination. One introduced species, an earwig from Europe, *Forficula auricularia*, has been collected in the meadow at Devils Postpile National Monument (Holmquist pers. com.).

The parks' receive considerable input from agricultural pesticides (Cory et al. 1970; Zabik and Seiber 1993; Aston and Sieber 1997; Datta et al. 1998a; Datta et al. 1998b; McConnell et al. 1998; McConnell et al. 1999; LeNoir et al. 1999; Angerman et al. 2002) A growing body of scientific evidence suggests that the pesticides may be impacting wetland amphibians (Sparling et al. 2001; Fellers et al. 2004). Further, there exists an inverse relationship between pesticide use and downwind occurrence of frog populations (Davidson 2004). Pesticides,

herbicides, and other contaminants could also be impacting invertebrate populations (Curry 1994; Cilgi and Jepson 1995; Scholtz and Kruger 1995; Longley and Sotherton 1997; Clay and Riedell 1998; Ellsbury et al. 1998; Stewart 1998), especially at the higher trophic levels.

Several new diseases could alter native vertebrate populations within wetlands as well as other park habitats. A recently emerging pathogenic fungus, *Batrachochytrium dendrobatidis*, which causes chytridiomycosis, has reached Sierra Nevada aquatic environments, including the wet meadows and marshes. The disease has caused widespread decimation of the mountain yellow-legged frog, *Rana muscosa*. The genetic data suggests that *B. dendrobatidis* is new to the area (Rachowicz et al. 2005). West Nile virus has reached the Sierra Nevada, and the recently discovered avian-adapted influenza A subtype H5N1 is anticipated to reach the western hemisphere soon. These diseases have potential to alter meadow bird populations in and around meadows and interrupt ecosystem processes in which birds play a role.

Nitrogen pollution from atmospheric deposition has the potential to affect productivity of wetland vegetation, and depending on seasonal timing, may affect aquatic organisms such as algae and invertebrates.

Although fire can impact wetlands directly when vegetation is dry enough to burn, such events do not appear to lead to long-term changes (DeBenedetti and Parsons 1984). More long-lasting impacts are seen when stand-removing fires in adjacent forests are followed by increased flooding and surface erosion. This can lead to the deposition of sands and gravels during storm events and thus return the wetland vegetation to an earlier successional stage. This process can be important to the establishment of willows (Argus per. com.). Fire has also been shown to alter ant assemblage structure in fens (Ratchford et al. 2005). Fire can also maintain wetland edges (Norman and Taylor 2005).

Wetland invertebrates are especially sensitive to fragmentation by trail corridors, with declines in species abundance and diversity observed as much as 2 m away from trail treads in seemingly undisturbed vegetation (Holmquist and Schmidt-Gengenbach 2004). As a result, broad scale impacts can be exacerbated by local disturbances.

During the mid-1800s and into the early 1900s, most Sierra Nevada wetlands were grazed, in some cases severely, by cattle and sheep. Many park wetlands continue to be grazed by recreational and administrative pack stock, and this activity has a suite of known impacts to meadows such as soil compaction, erosion, trampling of vegetation, and changes in plant species composition (Ratliff 1985; Stohlgren, DeBenedetti et al. 1989; McClaran and Cole 1993; McClaren and Cole 1993; Moore et al. 2000). Recent research in Yosemite National Park suggests that even moderate levels of such grazing can have a measurable effect on wetland productivity (Cole et al. 2004).Though the sample size was small, Holmquist (unpublished data) found differences among invertebrate communities between grazed and ungrazed wetlands in the Rock Creek area of Sequoia National Park. Elsewhere, studies have shown that grazing of grasslands affects small mammals (Grant et al. 1982; Keesing 1998; Matlack et al. 2001) and ground-nesting birds (Dobkin et al. 1998; Pavel 2004).

## Specific Monitoring Questions and Objectives Addressed by the Protocol

### *Monitoring questions*

1. Are hydrologic processes (e.g., duration, depth, timing of surface and groundwater) in wetlands changing?
2. Is the structure of wetland vegetation (e.g., composition, plant species abundance, standing crop, ground cover) changing?
3. Is the composition, abundance, or trophic structure of aquatic or terrestrial invertebrate communities changing in wetland ecosystems?
4. Are introduced species (plants,

invertebrates, vertebrates) expanding or declining in wetlands?

5. Are observed changes in flora and/or fauna correlated with changes in hydrologic patterns?
6. Do observed changes in geomorphic processes correlate with changes in flora and fauna?
7. Is wetland condition changing as reflected in changes in hydrology, vegetation, fauna and/or overall biodiversity or productivity?
8. Is human use visually altering Sierra Nevada wetlands?

### *Monitoring Objectives*

1. Determine temporal changes in species composition and abundance of wetland vascular and non-vascular flora, including changes in exposed bare ground.
2. Determine temporal changes in the composition and relative abundance of above-ground wetland invertebrate populations at the level of Family (Order when necessary for efficiency) except for identifying ants to species.
3. Determine temporal changes in hydrology including the duration, depth, and timing of surface and ground water.
4. Document temporal changes in coarse measures of anthropogenic influences to wetlands.

For each of the objectives, the protocols will be designed to detect at least a 20 percent decadal change with 80 percent power. These numbers may change somewhat after power analyses are completed.

## Potential Measures

Wetland water dynamics: duration, depth, timing of surface and ground water,ground water pH and electrical conductance, water chemistry, stream condition (if present), soil compaction, evidence of recent depositional events into the meadow, evidence of small mammals.

Wetland plant communities: presence/absence, rate of spread for taxa not being managed,frequency, abundance and distribution of native plants in relation to changes in the same measures for non-native plants in selected communities, native & non-native species ratios and non-native species abundance in selected communities.

Macroinvertebrates: community composition of wetland macro-invertebrates, distribution and relative abundance of wetland macro-invertebrates.

*See, also, discussion of measures in more detail below (Protocol Development & Status).*

## Protocol Development & Status

*The field protocol is being tested in Yosemite National Park (summer 2007): wells and plots are being installed (N=60 sites), including several (N=6) index (sentinel) sites. A full complement of data are being collected for the following vital signs: hydrology (surface and groundwater dynamics), wetland plant communities, and invertebrates. Depending on the number of sites installed in summer 2007and assessment of data in power analyses, site installation will continue in Yosemite and Sequoia & Kings Canyon (summer 2008).*

The Sierra Network (SIEN) wetlands ecological integrity protocol will emphasize the measurement of vascular and non-vascular floristic composition, invertebrate populations, and hydrology to document wetland condition and change. The hydrology drives the natural ecology of the wetlands systems and serves as a covariate for interpreting other wetlands measures. Vegetation provides the productivity, physical structure, and wildlife habitat (along with water) for the wetland community. Vascular and non-vascular vegetation facilitates water quality maintenance, supports a wide variety of fauna, and provides long-term response to environmental change. Wetlands invertebrates are the predominant in terms of abundance and species richness) wetlands fauna and provide a rapid response to environmental change caused by various stressors. Invertebrates include representatives of several trophic levels and are important food resources and processors of organic

material, represent a crossroads for ecological flows (e.g., aquatic-terrestrial), are easy to sample quantitatively, and are sensitive to a variety of stresses and in turn are capable vectors for cascading disturbances (Holmquist and Schmidt-Gengenbach 2004).

The work will utilize two complementary and integrated types of monitoring sites: (1) extensive, randomly selected long-term monitoring sites, and (2) more temporally intensive measures at judgment-selected sites that will provide more complete information and serve as index sites for the extensive sampling. The first type will allow valid statements of condition and long-term trend at the network scale. The index sites will track shorter term dynamics, link to existing long term monitoring and potentially allow more explicit interpretation of the network-scale information. The index sites could also become the focal points for related research projects.

## Tentative Sampling Methods & Design

The target population for inference on wetlands ecological integrity includes approximately 12,000 wetlands in SEKI and YOSE; only a single wetland complex occurs in DEPO.The general approach for selecting wetlands for monitoring will be as follows. First a watershed classification will be developed using the GIS layers that collectively characterize the diversity of SIEN watersheds, especially with regard to the watersheds' potential influence on meadow development and ecology. Spatial data to form the basis for the classification may include maps of bedrock geology, extent of Pleistocene glaciation, and climate (or a surrogate for climate). We will use the selected spatial data to determine the proportion of each watershed that has distinctive surficial geology, glaciated vs. non-glaciated areas, and the primary source of precipitation (e.g., snowmelt dominated, snowmelt and rain dominated, or primarily rain dominated).

The data for each watershed will be analyzed using cluster analysis, and a watershed classification would be developed based upon physical characteristics that are known to influence the abundance and types of wetlands occurring (Winters et al. 2003). A second tier of watershed classification might include stressor predictors (e.g., distance from the Central Valley, drainage orientation (rain shadow effects), grazing intensity, backpacker density, etc). The cluster analysis will be used to identify major types (estimate 6-8) of watersheds in SIEN. We will then randomly choose two or three watersheds of each type for wetland analysis using a two-stage GRTS design.

Within randomly-selected watersheds, we will use the wetlands on the National Wetlands Inventory (NWI) maps using the classification of Cowardin, et al. (1979) as a starting point. In the southern Sierra Nevada, only two thirds of the NWI sites are correctly classified as palustrine emergent (meadows), but most of the errors were palustrine scrub-shrub (willows; Werner 2004). The scrub-shrub wetlands may be of interest to this monitoring. Additional accuracy will be achieved utilizing Network vegetation maps. The classification of SIEN wetlands will resemble the classification present in Carsey et al. (2003), which is based upon principles of the hydrogeomorphic (HGM) approach to wetland analysis (Brinson 1993), and an HGM classification by Cooper (1998). Wetlands in NWI maps, as well as the Inventory and Monitoring Program vegetation mapping data, will be reanalyzed using natural color aerial photographs, and each wetland polygon will be preliminarily classified as riparian, marsh, wet meadow or fen. This monitoring effort will focus on wet meadows and fens, and may include marshes, meadow riparian areas, palustrine scrub-shrub and palustrine forests associated with each site. The classification will provide a means of subdividing wetlands that occur in SIEN parks into a few major types that can be mapped within randomly selected watersheds. We would then randomly choose two or three wetland complexes of each type in each watershed (the second stage of the GRTS design) for monitoring.

At each wetland complex selected for long term monitoring, aerial photographs, and field inspection

of the site will be used to refine the map of the major wetland types and communities occurring at each site. In many mountain environments, several wetland types (e.g., fens, wet meadows and riparian areas) can occur within the same wetland polygon, and may be fed by different water sources. Each will have distinctive hydrologic regimes, vegetation, and wetland functions. Within each wetland site, the major communities will be identified and sampling site(s) selected. An unbiased design or mechanism will be developed for selecting these final sites within each community type. Index sites will receive one or more ground water monitoring wells. At extensive sites, only water table measurements will be taken. The location for vegetation and invertebrate sampling will be based on the ground water measurement locations and will stay within the community represented by the water table measurements.

Extensive sites will be visited annually, each summer, based on hydrologic cycle. Index sites will be used to monitor sites of particular interest—chosen based on accessibility, history of research at the site, ability to install instrumentation because site is not subject to Wilderness Act concerns, etc.. Survey seasons and scope are limited by spring snow, stream crossings, weather, and so on. Survey site protocols will follow established methods for assessing vegetation composition and structure along with the necessary supporting habitat information (especially ground water dynamics, select soil and water physiochemistry, and habitat structure).

Index site protocols will include all survey site methods, plus additional continuous monitoring of ground water dynamics and water physiochemistry, again using established methodology. Index sites will be visited more frequently, from mid-May through October. These sites will be used to estimate inter-annual variability (e.g., vertebrates).

Both quadrat and transect data are available to inform plot sample size approximation and power analysis of wetland vegetation. We have several years of invertebrate data from our work supporting development of this monitoring protocol. Our existing data provide a baseline for variability of a site; we have some data to inform spatial variability. We may have some well and vegetation data to inform power to detect trend.

## Principal Investigators and NPS Lead

Protocol development, field monitoring implementation and data analysis will be done collaboratively through a cooperative agreement with Colorado State University and with the University of California, White Mountain Research Station.

### *NPS Lead*

Harold Werner, Wildlife Ecologist
Sequoia & Kings Canyon
Harold_Werner@nps.gov

### *Workgroup Members*

Lisa Acree, Botanist
Yosemite

Sylvia Haultain, Vegetation Ecologist
Sequoia & Kings Canyon

Peggy Moore, Research Ecologist
USGS–Western Ecological Research Center, Yosemite Field Station

### *Principal Investigators (Cooperators)*

Dr. David J. Cooper
(plant communities and hydrology)
Colorado State University, Forest, Range, Watershed Stewardship Department
Fort Collins, CO
davidc@cnr.colostate.edu

Dr. Jeff Holmquist (invertebrates)
University of California, White Mountain Research Station
jholmquist@ucsd.edu

### *Other Cooperators*

Dr. Kathren Murrell Stevenson, Meadow Ecologist

Meryl Rose, Ecologist
Sierra Nevada Network Inventory & Monitoring Program

Leigh Ann Starcevich and Dr. Kirk Steinhorst, Statisticians, University of Idaho

## Development Schedule, Budget,

### and Expected Interim Products

Planning for protocol development is in progress. Decisions regarding the final design should occur during a field trip during the week of July 24 in Yosemite National Park or shortly thereafter. Preparation of the draft protocol SOPs is targeted to begin September 11, 2006 with review completed by December 11, 2006. The draft SOPs will be implemented during the summer of 2007 with an evaluation completed by October 1, 2007. The SOP for data management will be prepared during the fall and winter of 2007-2008 and before March 30, 2008. Preparation of the protocol narrative and revision of SOPs is targeted for April 28, 2008. The final draft will be applied during the summer of 2008. Following evaluation of the 2008 field season during September 2008, the draft protocol will be fine-tuned and targeted for completion by May 2009. External costs are expected to be about $10,250 in FY06, $51,346 in FY07, and $41,484 in FY08 ($103,080 total) for the vegetation and hydrology components and an additional $24,704 in FY06, $43,410 in FY07, and $43,410 in FY08 ($111,524 total) for the invertebrate components.

# Literature Cited: Wetlands Ecological Integrity Protocol


Allen-Diaz, B. H. 1991. Water table and plant species relationships in Sierra Nevada meadows. *American Midland Naturalist* **126**:30-43.

Angerman, J. E., G. M. Fellers, and F. Matsumura. 2002. Polychlorinated biphenyls and toxaphene in pacific tree frog tadpoles (*Hyla regilla*) from the California Sierra Nevada, USA. *Environ Sci Technol* **21**:2209-2215.

Aston, L. S., and J. N. Sieber. 1997. Fate of summertime airborne organophosphate pesticide residues in the Sierra Nevada mountains. *Environ. Qual.* **26**:1483-1492.

DeBenedetti, S. H., and D. J. Parsons. 1984. Postfire succession in a Sierran subalpine meadow. *American Midland Naturalist* **111**:118-125.

Benedict, N. B., and J. Major. 1982. A physiographic classification of subalpine meadows of the Sierra Nevada, California. *Madrono* **29**:1-12.

Brinson, M. 1993. A hydrogeomorphic classification for wetlands. U.S. Army corps of Engineers, Waterways Experiment Station, Vicksburg, MS. USA. Technical Report WRP-DE-4.

Datta, S., L. Hansen, L. McConnell, J. Baker, J. LeNoir, and J. N. Seiber. 1998a. Pesticides and PCB contaminants in fish and tadpoles from the Kaweah River basin, California. *Bulletin of Environmental Contamination and Toxicology* **60**:829-836.

Datta, S., L. L. McConnell, J. E. Baker, J. LeNoir, and J. N. Seiber. 1998b. Evidence for atmospheric transport and deposition of polychlorinated biphenyls to the Lake Tahoe Basin California-Nevada. *Environ Sci Technol* **32**:1378-1385.

Dunne, J. A., J. Harte, and K. J. Taylor. 2003. Subalpine meadow flowering phenology responses to climate change: integrating experimental and gradient methods. *Ecological Monographs* **73**:69-86.

Carsey, K., D. Cooper, K. Decker, D. Culver, G. Kittel. 2003. Statewide wetlands classification and characterization. Colorado Natural Heritage Program. Colorado State University, Fort Collins, CO

Cilgi T., and P. Jepson. 1995. Pesticide spray drift into field boundaries and hedgerows: toxicity to non-target Lepidoptera. *Journal of Environment and Pollution* **87**:1-9.

Cooper, D. 1998. Classification of Colorado's wetlands for use in HGM functional assessment. A first approximation. Colorado Department of Natural Resources, Colorado Geological Survey, Denver, CO 80203.

Cowardin, L. W., V. Carter, F.C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Biological Service Program, U.S. Fish and Wildlife Service, FWS/OBS 79/31. Office of Biological Services, Fish and Wildlife Service, U.S. Department of Interior, Washington, D.C.

Cole, D. N., J. W. van Wagtendonk, M. P. McClaren, P. E. Moore, and N. K. McDougald. 2004. Response of mountain meadows to grazing by horses and mules: Yosemite National Park, California. *JRange Management* **57**:153-170.

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

Curry, J. P. 1994. Grassland invertebrates: ecology, influence on soil fertility, and effects on plant growth. Chapman and Hall, London.

Davidson, C. 2004. Declining downwind: Amphibian population declines in California and historical pesticide use. *Ecological Applications* **14**:1892-1902.

Dobkin, D., A. Rich, and W. Pyle. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. *Conservation biology* **12**:1523-1739.

Ellsbury, M. M., J. E. Powell, F. Forcella, W. D. Woodson, S. A. Clay, and W. E. Riedell. 1998. Diversity and dominant species of ground beetle assemblages (Coleoptera: Carabidae) in crop rotation and chemical input systems for the northern Great Plains. *Annals of the Entomological Society of America* **91**:619-625.

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.

Gerlach, J. D. J., P. E. Moore, B. Johnson, D. G. Roy, D. M. Whitmarsh, D. M. Lubin, D. M. Graber, S. Haultain, A. Pfaff, and J. Keeley. 2003. Alien Plant Species Threat Assessment and Management Prioritization for Sequoia-Kings Canyon and Yosemite National Parks. Open File Report 02-170, U.S. Geological Survey, Carson City, NV.

Gorham, E. 1991. Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecolological Applications* **1**:182-195.

Gosselink, J. and E. Maltby. 1990. Wetland losses and gains. Pp 296-322. *In*: Wetlands, a threatened landscape (M. Williams, ed). Blackwell Publishers, Oxford, UK.

Grant, W.E., E.C. Birney, N.R. French, and D.M. Swift. 1982. Structure and productivity of grassland small mammal communities related to grazing-induced changes in vegetative cover. *J Mammalogy* **63**:248-260

Holmquist, J. G. 2004. Terrestrial invertebrates: functional roles in ecosystems and utility as vital signs in the Sierra Nevada. Report submitted to Inventory and Monitoring Program in partial fulfillment of Cooperative Agreement H8R07010001 and Task Agreement J8R07030011, White Mountain Research Station, University of California, Bishop, CA.

Holmquist, J. G., and J. M. Schmidt-Gengenbach. 2004. User-mediated meadow fragmentation in Yosemite National Park: effects on invertebrate fauna. Final Report to the Yosemite Fund.

Holmquist, J. G., and J. M. Schmidt-Gengenbach. 2005. Interim report: A pilot study on the efficacy of invertebrates as indicators of meadow change in Sierra Nevada Network parks. Report submitted to Inventory and Monitoring Program in partial fulfillment of Cooperative Agreement H8R07010001 and Task Agreement J8R07030011, White Mountain Research Station, University of California, Bishop, CA.

Jones, W.M. 2004. Using Vegetation to Assess Wetland Condition: a multimetric approach for temporarily and seasonally flooded depressional wetlands and herbaceous-dominated intermittent and ephemeral riverine wetlands in the northwestern glaciated plains ecoregion, Montana. Report to the Montana Department of Environmental Quality and the U.S. Environmental Protection Agency. Montana Natural Heritage Program, Helena, MT. 34 pp. plus appendices.

Keesing, F. 1998. Impacts of ungulates on the demography and diversity of small mammals in central Kenya. *Oecologia* **116**:381-389.

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.

Longley, M., and N. W. Sotherton. 1997. Factors determining the effects of pesticides upon butterflies inhabiting arable farmland. *Agriculture, Ecosystems, and Environment* **61**:1-12.

Matlack, R, D. Kaufman, and G. Kaufman. 2001. Influence of Grazing by Bison and Cattle on Deer Mice in Burned Tallgrass Prairie. *The American Midland Naturalist* **146**:361-368.

McClaran, M. P., and D. N. Cole. 1993. Packstock in Wilderness: Use, Impacts, Monitoring, and Management. Gen. Tech. Rep. INT-301. Ogden, UT: USDA For. Service, Intermountain Research Station. 33p.

McConnell, L. L., J. S. LeNoir, S. Datta, and J. N. Seiber. 1998. Wet deposition of current-use pesticides in the Sierra Nevada mountain range, California, USA. *Environmental Toxicology and Chemistry* **17**:1908-1916.

Mitsch, W. and J. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, New York.

Moore, P.E., D.N. Cole, J.W. van Wagtendonk, M.P. McClaran, and N. McDougald, 2000. Meadow response to pack stock grazing in Yosemite wilderness: integrating research and management. *USDA Forest Service Proceedings RMRS-P-15*, Vol.5, Fort Collins, CO:160-163.

Neuman, M. J. 1990. Past and present conditions of back country meadows in Sequoia and Kings Canyon National Parks, Stock use and meadow monitoring program. Unpublished report Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Norman, S. P. and A. H. Taylor. 2005. Pine forest expansion along a forest-meadow ecotone in northeastern California, USA. *Forest Ecology and Management* **215**: 51-68.

Pavel, V. 2004. The impact of grazing animals on nesting success of grassland passerines in farmland and natural habitats: a field experiment. *Folia Zool.* **53**:171-178.

Ratchford, J.S., S.E. Wittman, E.S. Jules, A.M. Ellison, N.J. Gotelli, and N.J. Sanders. 2005. The effects of fire, local environment, and time on ant assemblages in fens and forests. *Diversity and Distributions* **11**:487-497.

Ratliff, R. D. 1982. A meadow site classification for the Sierra Nevada, California. Gen. Tech. Rep PSW-60, USDA Forest Service.

Ratliff, R. D. 1985. Meadows in the Sierra Nevada of California: state of knowledge. Berkeley, CA:U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. Gen. Tech. Rep. PSW-84. 52 p.

Rachowicz, L. J., J-M. Hero, R.A. Alford, J.W. Taylor, J. A. T. Morgan, V. T. Vredenburg, J. P. Collins, and C. J. Briggs. 2005. The Novel and Endemic Pathogen Hypotheses: Competing Explanations for the Origin of Emerging Infectious Diseases of Wildlife. *Conservation Biology* **19**:1441-1448.

Saleska, S. R., J. Harte, and M. S. Torn. 1999. The effect of experimental ecosystem warming on CO2 fluxes in a montane meadow. *Global Change Biology* **5:**125-141.

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

Scholtz, C. H., and K. Krüger. 1995. Effects of invermectin residues in cattle dung on dung insect communities under extensive farming conditions in South Africa. Pp 465-471, *In* Insects in a Changing Environment (Harrington, R. and N. E. Stork, eds.). Academic Press, London.

Stewart, D. A. B. 1998. Non-target grasshoppers as indicators of the side-effects of chemical locust control in the Karoo, South Africa. *Journal of Insect Conservation* **2**:263-276.

Stohlgren, T., S. DeBenedetti, and D. Parsons. 1989. Effects of herbage removal on productivity of selected high-sierra meadow community types. *Environmental Management* **13**:485-491.

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

Williams, M. 1990. Understanding wetlands. Pp 1-41 *In* Wetlands, a threatened landscape (M. Williams, ed). Blackwell Publishers, Oxford, UK.

Winters, D. B. Bohn, D. Cooper, et al. 2003. Conceptual framework and protocols for conducting broad scale aquatic, riparian and wetland ecological assessments. USDA Forest Service, Rocky Mt. Research Station.

Zabik, J. M., and J. N. Seiber. 1993. Atmospheric transport of organophosphate pesticides from California's Central Valley to the Sierra Nevada mountains. *Journal of Environmental Quality* **22**:80-90.

# Protocol: Rivers and Streams

## Parks Where Protocol Will be Implemented

Devils Postpile National Monument (DEPO)
Sequoia and Kings Canyon National Parks (SEKI)
Yosemite National Park (YOSE)

## Vital Signs Addressed by Protocol

Water chemistry
Surface-water dynamics

## Justification

Water quantity and quality are critical components of the parks' ecosystems and indicators of aquatic and terrestrial ecosystem condition. Hydrological and water quality parameters are good indicators for detecting ecological change because they reflect changes within the larger watershed. Ecological changes following a disturbance (natural or anthropogenic) may occur locally in the area affected or may be detected downstream. Changes may be detected immediately following one disturbance or may not be detected until multiple disturbances have occurred. Therefore, analyzing water quality parameters at different spatial and temporal scales can be a useful tool in detecting change at the watershed scale.

## Background Information

Sierra Nevada Network (SIEN) parks protect over 4,500 lakes and thousands of kilometers of rivers and streams that have some of the highest water quality in the Sierra Nevada. The parks' ecosystems are subjected to natural and anthropogenic disturbances that have the potential to modify the systems and degrade water resources. Managers and researchers, using the findings from the Sierra Nevada Ecosystem Project (SNEP 1996), identified five important systemic stressors to Sierra Nevada systems: (1) loss of pre-Euroamerican fire regimes, (2) non-native invasive species, (3) air pollution, (4) habitat fragmentation, and (5) rapid anthropogenic climatic change (Sequoia and Kings Canyon National Parks 1999). The stressors with the greatest impact on the parks' flow regimes and water quality are altered fire regimes, air pollution, and climate change. Park aquatic ecosystems are also susceptible to localized stressors which include visitor use impacts, small dams and diversions, park infrastructure (i.e., sewage treatment plants, roads), and abandoned mines.

Over 100 years of fire suppression polices have altered fire regimes in the Sierra Nevada Network parks. Potential effects on water resources from a lack of fire are reduced stream flows, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994; Williams and Melack 1997; Hauer and Spencer 1998; Moore 2000). Less frequent but higher severity wildfires have the potential to impair water resources by increasing flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978; Helvey 1980; Riggan et al. 1994; Mac Donald and Stednick 2003).

High elevation lakes and streams in the Sierra Nevada are oligotrophic, have a low buffering capacity, and sensitive to change from atmospheric deposition of nutrients, toxic substances, and acids (Goldman et al. 1993; Leydecker et al. 1999; Davidson and Shaffer 2002; Sickman et al. 2003).

It has been predicted that even a modest temperature increase (2.5 °C) from global climate change will significantly alter hydrologic processes. The most pronounced changes are earlier snowmelt runoff, reduced summer base flows and soil moisture, (Dettinger et al. 2004), a lower snowpack volume at mid-elevations (Knowles and Cayan 2001), and increased flooding, including rain-on-snow events. The water infrastructure in California was built under the assumption that the Sierra Nevada snowpack would act as a temporary reservoir for the State's water and release it slowly during the spring and early summer months. Changes in precipitation type and timing will result in longer and drier summers with less water available for ecosystems and regional economic uses during the months it is most needed. Water quality would be threatened by increased flooding and erosion and lower summer flows.

## Specific Monitoring Questions and Objectives

We will identify specific river and stream monitoring objectives in fall 2009.

## Basic Approach

We assembled a small work group, consisting of network and park resources staffs, to determine objectives and outline protocol development strategies for the two water resource vital signs—surface water dynamics and water chemistry. In December 2005, the work group decided that a good strategy would be to separate water resources monitoring into two protocols: (1) Lakes and (2) Rivers and Streams. The Lake monitoring protocol is under-development; the final protocol will be ready for peer review in spring 2008. The Rivers and Streams protocol development will begin in fall 2009. We have few details for this protocol development summary because our staff is focusing on the lake monitoring protocol this year.

## Protocol Development & Status

Will begin late 2009.

## Potential Measures

### *Streams and Rivers*

pH, dissolved oxygen, specific conductance, temperature, major ions, acid neutralizing capacity, nitrate, dissolved organic nitrogen, total dissolved nitrogen, total dissolved phosphorus, particulate nitrogen, particulate carbon, particulate phosphorus, stream discharge (peak flow/low flow/water yield), qualitative estimate of flow relative to bank full.

## Tentative Sampling Methods & Design

Will be determined by the Sierra Nevada Network Water Resources Work Group (late 2007–2008).

## Principal Investigators

The protocol development strategy and cooperators will be determined by the Sierra Nevada Network Water Resources Work Group in 2007.

### *NPS Lead*

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

### *Sierra Nevada Network Water Resources Work Group*

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

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

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

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

NPS—WRD Contact
Gary Rosenlieb, Hydrologist
National Park Service—
Water Resources Division
Gary_Rosenlieb@nps.gov

## Development Schedule, Budget, and Expected Interim Products

The stream protocol development will begin in fall 2009. The water resources work group will determine the specific monitoring objectives, development strategy, and timeline at that time. The protocol is tentatively scheduled to be ready for peer-review in fall/winter 2010.

**Table 3:** Rivers and Streams Protocol development schedule

| DATE | DEVELOPMENT |
|---|---|
| Fall 2009 | Begin protocol development |
| Fall/Winter 2010 | Submit for peer-review |
| Summer 2011 | Implement protocol |

# Literature Cited: Rivers and Streams Protocol


Chorover, J., P. M. Vitousek, D. A. Everson, A. M. Esperanza, and D. Turner. 1994. Solution chemistry profiles of mixed-conifer forests before and after fire. *Biogeochemistry* **26**:115-144.

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

Dettinger, M. D., D. R. Cayan, M. Meyer, and A. E. Jeton. 2004. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099. *Climatic Change* **62**:283-317.

Goldman, C. R., A. D. Jassby, and S. H. Hackley. 1993. Decadal, interannual and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **50**:1489-1496.

Hauer, F. R., and C. N. Spencer. 1998. Phosphorus and nitrogen dynamics in streams associated with wildfire: a study of immediate and long-term effects. *International Journal of Wildland Fire* **8**:183-198.

Helvey, J. D. 1980. Effects of a north central Washington fire on runoff and sediment production. *Water Resources Bulletin* **16**:627-634.

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**:23-29.

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

Mac Donald, L. H., and J. D. Stednick. 2003. Forests and Water: A state-of-the-art review for Colorado. CWRRI Completion Report No. 196, Colorado State University, Fort Collins, CO.

Moore, C. 2000. 1999 annual Sequoia watershed report. *In* 1999 annual fire report on research, monitoring and inventory. Sequoia and Kings Canyon National Parks, Three Rivers, CA.

Riggan, P. J., R. N. Lockwood, P. M. Jacks, and C. G. Colver. 1994. Effects of fire severity on nitrate mobilization in watersheds subject to chronic atmospheric deposition. *Environ Sci Technol* **28**:369-375.

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

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. *Limnology and Oceanography* **48**:1885-1892.

SNEP. 1996. Sierra Nevada Ecosystem Project: Final Report to Congress-Summary. University of California, Davis, Davis, CA.

Tiedemann, A. R., J. D. Helvey, and T. D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. *Journal of Environmental Quality* **7**:580-588.

Williams, M. R., and J. M. Melack. 1997. Effects of prescribed burning and drought on the solute chemistry of mixed-conifer forest streams of the Sierra Nevada, California. *Biogeochemistry* **39**:225-253.

# Protocol: Weather and Climate

## Parks Where Protocol Will be Implemented

Devils Postpile National Monument (DEPO)
Sequoia & Kings Canyon (SEKI)
Yosemite National Parks (YOSE)

## Vital Signs Addressed By Protocol

Weather
Climate
Snowpack

## Justification

Climatic forces are a major driver of Sierra Nevada ecosystems. Current patterns of vegetation, water dynamics, and animal distribution in the Sierra are determined largely by cumulative effects of past and present climates. Not surprisingly, anthropogenic climate change is the stressor that is predicted to have the most pronounced effects on Sierra Nevada ecosystems. Weather and climate was one of the top ranked vital signs for our network. The primary reasons the Sierra Nevada Network selected weather and climate are (1) changes in local and regional climate patterns will cause change in park ecosystems and resources of concern; (2) weather data will be used to explain patterns observed in other indicators (i.e., surface water dynamics, meadows, birds); and (3) partnership and cost leveraging opportunities with other agencies and universities.

## Background Information

The last several decades in the Sierra Nevada were among the warmest of the last millennium (Graumlich 1993). Paleoecological records show the early and middle Holocene (ca. 10,000 to 4,500 years ago) was a period of generally higher global summer temperatures (perhaps by 2° C) and prolonged summer drought in California. During this period, fire regimes and vegetation community composition of Sierra Nevada forests differed from those of today (including some species combinations that no longer exist) (Anderson 1990; Anderson and Smith 1991; Anderson 1994; Anderson and Smith 1994; Anderson and Smith 1997).

Human-influenced temperature patterns are significantly associated with discernible changes in plant and animal phenological traits (Root et al. 2005). Global warming is likely to shift habitats to higher elevations. Some organisms with limited mobility or specific habitat needs (e.g., amphibians) may not be able to move or survive such habitat shifts and could be locally extirpated. Consequently, species diversity may decline. Some habitats (e.g., high alpine) may shrink dramatically or disappear entirely, leading to irreversible loss of some species (e.g., Clark's Nutcracker)

It has been predicted that even a relatively modest mean temperature increase (2.5 °C) would significantly alter hydrologic processes. The most pronounced changes would probably be earlier snowmelt runoff, reduced summer base flows and soil moisture (Dettinger et al. 2004; Dettinger 2005), a lower snowpack volume at mid-elevations (Knowles and Cayan 2001), and increased winter and spring flooding (Dettinger et al. 2004). High spring run-off flows in many western streams begin a week to almost three weeks earlier than they did in the mid 20th century (Cayan et al. 2001; Dettinger 2005). Glacial extent in the Sierra Nevada has declined markedly in the past several decades (Basagic 2008). If the current trends continue, the "natural reservoirs" provided by snowpack will become progressively less useful for water resources management, flood risk may change in unpredictable ways, and Sierra Nevada ecosystems will experience increasingly severe summer-drought conditions (Dettinger 2005; Dettinger et al. 2005; Mote et al. 2005).

Global climate change is also likely to exacerbate three other systemic stressors: altered fire regime, air pollution, and non-native species. Some models predict future climate change will be accompanied by increased lightning strikes at latitudes spanned by the Sierra Nevada (Price and Rind 1991). Compounding the increase in wildfire ignitions, extreme weather conditions such as drought are likely to result in fires burning larger areas, being more severe,

and escaping containment more frequently (Torn and Fried 1992; Miller and Urban 1999). Warm temperatures create the perfect conditions for the production of "smog," or ground-level ozone. Global warming is therefore likely to make air pollution problems (e.g., ozone) worse. A warmer climate would allow certain species—for example, those species unable to get a stronghold because of cold temperatures—to thrive and reproduce.

## Specific Monitoring Questions and Objectives

We will identify specific monitoring objectives in fall 2007. In the interim, we have identified project-oriented objectives for both weather inventory and monitoring that we ill focus on in the next year:

1. Assist Dr. Kelly Redmond and Western Regional Climate Center (WRCC) staff with the weather station inventory
2. Assess current climate monitoring, which includes identifying data gaps and determining 'high priority' sites for the parks and vital signs monitoring. Determine if we want to add instrumentation to existing sites, make data more available or real-time, or assist with maintaining of sites. Assess need for and feasibility of adding new stations in the parks
3. Develop protocol and Standard Operating Procedures for the Devils Postpile new meteorological station. These will be incorporated into the larger climate monitoring protocol
4. Develop an interpretive sign for the new Devils Postpile meteorological station
5. Determine the role that I&M will have in analyses, summaries, reporting, and delivery of meteorological data
6. Coordinate micro-scale weather monitoring across vital signs, depending on the needs of other work groups (e.g., if several protocols include collecting parameters such as air temp and RH at their plots, lakes, etc., then the type of equipment and protocols should be consistent.)

## Potential measures

Weather and climate: precipitation, temperature, wind speed, wind direction, solar radiation, relative humidity, soil moisture, soil temperature.

Snowpack: snow depth, snow cover, snow water equivalent, timing of snowmelt.

## Basic Approach

The first climate monitoring project that the network was involved in was the installation of a new meteorological station in Devils Postpile National Monument. The monument had no current weather monitoring. The purchasing, installation, and management of the station were a cooperative effort between the Sierra Nevada Network, California Department of Water Resources-Cooperative Snow Surveys, Scripps Institute of Oceanography, and US Geological Survey.

The climate work group will focus on the above six objects over the next year. Overviews of how these individual objectives will be accomplished are as follows:

1. Andi Heard (SIEN physical scientist), with input from park and USGS staff, will assist the Western Regional Climate Center with the weather inventory project. This will involve providing information on weather station metadata as requested by WRCC.
2. Assessing Network climate monitoring needs and objectives will be accomplished through a Cooperative Ecosystem Unit (CESU) agreement with Dr. Kelly Redmond at WRCC. This agreement began in October 2006.
3. The protocol and Standard Operating Procedures for the Devils Postpile meteorological station are being primarily developed by Dr. Daniel Cayan (Scripps/USGS) and student Martha Coakley (UC San Diego) with contributions from Frank Gehrke (Calif. Cooperative Snow Surveys) and Douglas Alden (Scripps). Annie Esperanza and Andi Heard are the NPS contacts and are also contributing content to the protocol.
4. Deanna Dulen and staff will take the lead on developing an interpretive sign for the meteorological station. The exhibit will be installed in 2007.

5. Defining I&M's role in climate monitoring will be ongoing. The current projects, particularly the climate assessment project, will inform this process.
6. As needed, the climate work group will provide support to other work groups for small scale (i.e., plots, lakes) weather monitoring.

## Protocol Development & Status

Although, the above-mentioned projects will feed into the climate monitoring protocol, most of the protocol development will not begin until sometime in 2007, when he climate work group will identify specific monitoring objectives and a detailed protocol development strategy. Meteorological monitoring in the parks is currently conducted by several divisions within the National Park Service and multiple outside agencies. The work group will be working with cooperators to best determine how the Inventory and Monitoring Program can contribute to the existing meteorological monitoring infrastructure. We will be looking for opportunities to collaborate with other agencies in the short-term to develop the protocol and for the long-term to continue meteorological monitoring in the parks.

## Tentative Sampling Methods & Design

Unlike most other vital signs, various measures of SIEN park climate have been monitored for the last century. Currently, an existing network of monitoring stations is maintained by a variety of state and federal agencies and universities within and adjacent to the parks. Most existing sites were selected using best professional judgment of that time; changes to existing sites would severely compromise existing legacy climate data from these stations. Our basic approach involves a detailed analysis of existing climate monitoring stations to determine whether they provide adequate sampling of spatial and temporal variability and adequate data for strata of management interest or scientific importance. We will use the results of this analysis to determine how the Network can best contribute to the current system.

Specific monitoring objectives and protocol development strategy will be determined by the Sierra Nevada Network Climate Work Group.

## NPS Lead

Andi Heard, Physical Scientist
Sierra Nevada Network
559-565-3786
Andi_Heard@nps.gov

### *Sierra Nevada Network Climate Work Group*

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

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

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

Lee Tarnay, Air Quality Specialist
Yosemite National Park
Lee_Tarnay@nps.gov

### *Cooperators*

Kelly Redmond, Regional Climatologist/
Deputy Director
Desert Research Institute/Western
Regional Climate Center

Frank Gehrke, Chief
California Cooperative Snow Surveys

Dan Cayan, Researcher
Scripps Institute of Oceanography/USGS

## Development Schedule, Budget, and Expected Interim Products

In 2006 and 2007, several projects were initiated that will directly inform the Weather and Climate monitoring protocol. These include the weather inventory, climate monitoring assessment, and Devils Postpile weather station protocol development projects. In summer/fall 2009, we will determine the strategy and timeline for fully developing the protocol. In FY2005, the network put $20,000 towards the purchase and installation of a new meteorological station at Devils Postpile. In FY06, $32,000 were put towards climate related projects, including the Climate Monitoring

Assessment agreement with the Western Regional Climate Center, an interpretive exhibit for the new Devils Postpile meteorological station, and SOP development for the Devils Postpile station (Table H-5).

**Table 2:** Weather and Climate Protocol development schedule

| DATE | DEVELOPMENT |
|---|---|
| Spring 2006 – Winter 2007 | DEPO protocol development |
| Summer 2007 | Weather inventory complete |
| October 2007–September 2008 | Climate monitoring assessment |
| August 2009–May 2010 | Protocol development |
| June 2010 | Protocol peer review |

**Table :** Budget for FY06 and FY07 Climate Projects

| WHAT? | WHO? | AMOUNT |
|---|---|---|
| Climate Assessment | WRCC | $24,000 |
| Wayside Exhibits | DEPO | $3,150 |
| DEPO Protocol | Scripps | $4,000 |

# Literature Cited: Weather and Climate Protocol


Anderson, R. S. 1990. Holocene forest development and paleoclimates within the central Sierra Nevada, California. *Journal of Ecology* **78**: 470-489.

Anderson, R. S. 1994. *Paleohistory of a giant sequoia grove: The record from Log Meadow, Sequoia National Park*. Proceedings of the Symposium on Giant Sequoias: Their place in the ecosystem and society, USDA Forest Service Gen. Tech. Rep.

Anderson, R. S. and S. J. Smith. 1991. Paleoecology within California's Sierra Nevada National Parks: An overview of the past and prospectus for the future. Proceedings of the Yosemite Centennial Symposium, Yosemite Association, El Portal, CA.

Anderson, R. S. and S. J. Smith. 1994. Paleoclimatic interpretations of meadow sediment and pollen stratigraphies from California. *Geology* **22**: 723-726.

Anderson, R. S. and S. J. Smith. 1997. Sedimentary record of fire in montane meadows, Sierra Nevada, California, USA: A preliminary assessment. *Sediment Records of Biomass Burning and Global Change*. J. S. Clark, H. Cachier, J. G. Goldammer and B. Stocks. Springer-Verlag, Berlin, NATA ASI series. **151**: 313-327.

Dettinger, M. 2005. Changes in Streamflow Timing in the Western United States in Recent Decades. US Geological Survey, Scripps Institution of Oceanography, La Jolla, CA.

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.

Miller, C. and D. L. Urban. 1999. A model of surface fire, climate and forest pattern in the Sierra Nevada, California. *Ecological Modelling*. **114**: 113-135.

Price, C. and D. Rind. 1991. *Lightning activity in a greenhouse world*. Proceedings of the 11th Conference of Fire and Forest Meteorology, Society of American Foresters, Bethesda, MD.

Torn, M. S. and J. S. Fried. 1992. Predicting the impacts of global warming on wildland fire. *Climatic Change* **21**: 257-274.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS D—046, September 2008

**National Park Service**
**U.S. Department of the Interior**

**Natural Resource Program Center**
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™