



# Sierra Nevada Network River Hydrology Monitoring Protocol

## *Narrative Version 1.0*

Natural Resource Report NPS/SIEN/NRR—2017/1518



**ON THE COVER**

Protection Ranger John Anderson performing a discharge measurement at Boundary Creek in Devils Postpile National Monument.

Photograph by: Jennie Skancke

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Jennie Skancke,<sup>1</sup> Andrea Heard,<sup>1</sup> Leslie Chow,<sup>2</sup> Alice Chung-MacCoubrey<sup>1</sup>

<sup>1</sup>National Park Service  
Sierra Nevada Network Inventory & Monitoring Program  
47050 Generals Hwy  
Three Rivers, CA 93271

<sup>2</sup> National Park Service  
Sierra Nevada Network Inventory & Monitoring Program  
Yosemite Field Station  
P.O. Box 700  
El Portal, CA 95318

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# Standard Operating Procedures

The standard operating procedures (SOPs) are provided separately in the NPS Data Store at:  
<https://irma.nps.gov/DataStore/Reference/Profile/2243879>.

SOP 1. Streamgage Station Overviews

SOP 2. Training and Annual Schedule of Tasks

SOP 3. Procedures and Equipment for Station Visits

SOP 4. Methods for Streamflow Discharge Measurements

SOP 5. Safety Procedures

SOP 6. Acquiring Streamflow and Temperature Data from Streamgage Operators

SOP 7. Data Management

SOP 8. Data Analysis

SOP 9. Reporting

SOP 10. Quality Assurance Plan

SOP 11. Revising the Protocol



## Executive Summary

The National Park Service (NPS) Inventory & Monitoring (I&M) Program was established in 2000 as part of the Natural Resource Challenge, a long-term strategy to improve park management by increasing access to and reliance on high-quality scientific information. The Sierra Nevada Network (SIEN) is one of 32 I&M networks that will develop and provide scientifically credible information on the status and long-term trends in selected “vital signs”, or indicators of ecosystem condition. SIEN is comprised of four units: Devils Postpile National Monument (DEPO), Sequoia & Kings Canyon National Park (jointly administered units that are referred to as SEKI, or individually as SEQU and KICA), and Yosemite National Park (YOSE). The SIEN Vital Signs Monitoring Plan (Mutch et al. 2008) identified 13 high priority vital signs for which long-term monitoring protocols would be developed. This protocol captures the network’s surface water dynamics vital sign.

The overall goal of the SIEN I&M Program is to provide park managers with information needed to make decisions that will maintain the integrity of Sierra Nevada ecosystems. The monitoring objectives in this protocol are to report on long-term trends in surface water hydrology and water temperature of Sierra Nevada rivers. We will collect data from streamgages operated by network parks and other agencies, store these data in a central location, and produce analyses and reports for park managers. We will also share data and analysis results with academic researchers, state and federal agencies, and other cooperators. SIEN will provide support to parks operating protocol stations (three stations).

The primary focus of this protocol is the hydrology of rivers (i.e., streamflow timing and volume) in SIEN parks. SIEN will support operation of several stations and acquire discharge values from stations that are operated by other agencies, such as the U.S. Geological Survey and Southern California Edison Electric Company. We will use mean daily discharge values from each station to calculate a suite of hydrologic parameters by station (e.g., number of days to the onset of snowmelt). We have selected 14 existing stations for this protocol. The protocol has the flexibility to incorporate additional stations that meet SIEN objectives and criteria into our reporting. As a secondary objective, SIEN is monitoring water temperature at a subset (10) of the stations.

This protocol has two reporting products, hydrologic summaries of each year (produced on a biennial basis) and comprehensive status and trend reports (produced every four years). Biennial hydrologic status summaries will provide standardized information including hydrographs of daily mean discharge, low and high flow values, calculated snowmelt runoff statistics, temperature time series charts, and photographs. Long-term trend reports will include similar information as the hydrologic status reports with the addition of flow-duration curves, flood frequency analyses, and the assessment of trends in selected hydrologic and water temperature parameters.

This protocol narrative provides an introduction to river monitoring in the Sierra Nevada, articulates our monitoring goals and objectives, describes the sample design, and provides an overview of our monitoring approach (e.g. data management, analysis, reporting, personnel requirements, and budget). This protocol also includes standard operating procedures (SOPs) for implementing the

protocol and appendices that describe the protocol development process, power analyses, historic water data sets in SIEN, and recommendations for expanded monitoring.

## Acknowledgments

We would like to thank SIEN staff for their support, especially Sandy Graban who created the lovely maps in this protocol, and the authors of the SIEN lake monitoring protocol as it paved the way for the river monitoring protocol. Portions of the lake protocol have been duplicated here, including much of Appendix A.

Edward (Ned) Andrews provided an analysis and report on streamflow and snowpack status and trends that is the foundation for large portions of this document. Ned has been very generous with his time, explaining many of the data analysis methods that will be used for this protocol and answering long lists of questions.

Leigh Ann Harrod Starcevich and Stephanie Kane contributed the power analysis for this report which is included as Appendix C of this narrative.

We would like to acknowledge the water work group, who were among our greatest partners - Jim Roche at Yosemite and Annie Esperanza, Danny Boiano, and Harold Werner at Sequoia and Kings Canyon. This work group made the majority of the decisions that made this protocol come together. Despite limited funding for protocol development, the group members displayed remarkable dedication to the stewardship of park resources and served as powerful advocates for long-term monitoring. We also thank Harrison Forrester at Yosemite who, although not part of the formal work group, provided significant feedback, answered many questions, and shared existing SOPs.

We thank the following individuals in advance because our reports will depend upon data collected and provided by them: Dan Garrigue at Sierra Hydrographics; Kevin Skeen, John Melack, and Jim Sickman at the University of California; Derrik Tito at Southern California Edison, who has been so great digging up old records and explaining the ins and outs of the diversion system at SEKI; Dave Clow and Heidi Roop at the USGS and Jessica Lundquist at University of Washington, who have answered innumerable questions and provided excellent advice on a number of issues.

We also acknowledge and thank Frank Gehrke at the California Department of Water Resources and Bruce McGurk (formerly at Hetch Hetchy Water and Power) for their assistance and advice.

Some of the content for this protocol came from the San Francisco Network Streamflow Protocol (Fong et al. 2011) and the Southwest Alaska Network (SWAN) Freshwater Flow System Protocol. We thank Darren Fong and the SWAN staff for allowing us to adopt sections of their protocols.



## Terms and Acronyms

|       |                                                                |
|-------|----------------------------------------------------------------|
| ADCP  | Acoustic Doppler Current Profiler                              |
| CDEC  | California Data Exchange Center                                |
| CDWR  | California Department of Water Resources                       |
| CFS   | Cubic feet per second                                          |
| DEPO  | Devils Postpile National Monument                              |
| EPA   | Environmental Protection Agency                                |
| FGDC  | Federal Geographic Data Committee                              |
| HBN   | Hydrologic Benchmark Network                                   |
| HHWP  | Hetch Hetchy Water and Power                                   |
| I&M   | Inventory and Monitoring Division of the National Park Service |
| IPCC  | Intergovernmental Panel on Climate Change                      |
| IRMA  | Integrated Resource Management Applications                    |
| KICA  | Kings Canyon National Park                                     |
| KRWA  | Kings River Water Association                                  |
| MID   | Merced Irrigation District                                     |
| MRA   | Minimum Requirements Analysis                                  |
| NPS   | National Park Service                                          |
| NRDS  | Natural Resources Data Series                                  |
| NRR   | Natural Resources Report                                       |
| NWIS  | National Water Information System – Operated by the USGS       |
| OLS   | Ordinary Least Squares                                         |
| ORV   | Outstandingly Remarkable Value                                 |
| PEPC  | Planning, Environment and Public Comment                       |
| QA/QC | Quality Assurance/Quality Control                              |
| QAP   | Quality Assurance Plan                                         |

|         |                                                       |
|---------|-------------------------------------------------------|
| REST    | Representational State Transfer                       |
| SCE     | Southern California Edison Electric Company           |
| Scripps | Scripps Institution of Oceanography                   |
| SEKI    | Sequoia and Kings Canyon National Parks               |
| SEQU    | Sequoia National Park                                 |
| SIEN    | Sierra Nevada Network Inventory & Monitoring Program  |
| SNEP    | Sierra Nevada Ecosystem Project                       |
| SOP     | Standard Operating Procedure                          |
| SQL     | Structured Query Language                             |
| SWAN    | Southwest Alaska Network                              |
| UC      | University of California                              |
| US ACE  | United States Army Corps of Engineers                 |
| USGS    | United States Geological Survey                       |
| UCSB    | University of California, Santa Barbara               |
| VSMP    | Vital Signs Monitoring Plan                           |
| WRD     | Water Resources Division of the National Park Service |
| WY      | Water Year                                            |
| YOSE    | Yosemite National Park                                |

## Revision History Log

| Previous version # | Revision date | Revised by | Changes | Justification | Page #'s affected | New version # |
|--------------------|---------------|------------|---------|---------------|-------------------|---------------|
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**Note:** Add more rows as required to reflect new revisions.

This table reflects changes to this document. Version numbers will be incremented by one (e.g., Version 1.3 to Version 2.0) each time there is a significant change in the process and/or changes are made that affect the interpretation of the data. Version numbers will be incremented after the decimal (e.g., Version 1.6 to Version 1.7...1.10....1.21) when there are changes to grammar, spelling, or formatting, or minor modifications in the process that do not affect the interpretation of the data.



# 1. Background and Objectives

In 2000, the National Park Service (NPS) established the Inventory & Monitoring (I&M) Program to provide scientifically credible information on the status and long-term trends in “vital signs”, or indicators of ecosystem condition, with the overarching goal of supporting park management through increased access to and reliance on high-quality scientific information. The national I&M Program created 32 networks of parks that are linked by geography and shared natural resource characteristics. Within each network, parks are able to share budgets, staffing, and other resources to plan and implement an integrated program. NPS I&M networks share five common goals (Fancy et al. 2009):

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

Each network accomplishes I&M goals by conducting park-wide inventories and establishing a long-term vital signs monitoring program. Vital signs are physical, chemical, and biological elements and processes of park ecosystems that have been selected by each network “to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values” (Fancy et al. 2009). Each network will collect, organize, and make available natural resource data related to these vital signs and conduct and present results of analyses, syntheses, and modeling to better inform park managers and increase overall NPS institutional knowledge.

The Sierra Nevada Network (SIEN) comprises four units that are located within the Sierra Nevada mountain range: Devils Postpile National Monument (DEPO), Sequoia & Kings Canyon National Parks (jointly administered units that are referred to as SEKI, or individually as SEQU and KICA), and Yosemite National Park (YOSE). Collectively, these parks comprise over 657,980 hectares and range in elevation from 418 m in the Sierra foothills to 4,417 m at Mount Whitney, the highest point in the contiguous United States (Table 1). All SIEN parks are located, in their entirety, within California. I&M staff of the NPS Sierra Nevada Network (i.e., network staff) operate from offices embedded in network parks.

**Table 1.** Area, elevation and wilderness statistics for parks within the Sierra Nevada Network.

| Park Statistic         | DEPO        | SEKI      | YOSE      |
|------------------------|-------------|-----------|-----------|
| Size (hectares)        | 324         | 349,581   | 308,075   |
| Percent Wilderness (%) | 75          | >96       | 94        |
| Elevation Range (m)    | 2,200-2,500 | 418-4,417 | 610-3,998 |

The result of a three-phase process, the SIEN Vital Signs Monitoring Plan (VSMP), describes the rationale, basis, and plan for implementing this network's long-term ecological monitoring program (Mutch et al. 2008). The VSMP describes the collaborative process by which park staff, network staff, and numerous scientific partners from other organizations selected high priority vital signs for long-term monitoring. Park and network staff ranked vital signs using selection criteria that included significance to management, ecological importance, sensitivity to stressors, and strong linkages to other vital signs. These ranking results were then used to select SIEN's top thirteen vital signs that represent a balance of sensitive indicators that respond quickly to stressors and more integrative indicators.

Surface water dynamics was selected as one of the 13 high priority vital signs due to its widespread and significant influence on Sierra Nevada ecosystems, resulting ecological and economic significance, and susceptibility to anthropogenic stressors, especially climate change. This protocol also includes water temperature, one of the I&M core water quality monitoring measures. It is monitored at suitably equipped streamgages to compliment the hydrologic monitoring and provide another climate sensitive measure. Water temperature is a master variable controlling many physical, chemical, and biological processes within the aquatic ecosystem.

This river hydrology protocol describes the importance of and our approach to hydrologic monitoring of rivers (i.e., surface water dynamics) within SIEN. Of the six protocols to be implemented, this protocol was the last to be developed. Thus, its objectives and associated operational costs were constrained by the amount of funding remaining in the program budget, and it was not feasible to develop an extensive approach to monitoring hydrology with broad inferences across the network. Specific monitoring questions and objectives of this protocol were determined through an iterative process with the SIEN water work group, which includes staff from SEKI and YOSE, with input from the Resource Chiefs at SEKI and YOSE, and with input from the superintendent at DEPO (see Appendix E for a history of the protocol development). Recognizing that the SIEN lake protocol (Heard et al. 2012) addresses water chemistry for lakes at the network-level (i.e., the surface water chemistry vital sign), the above parties decided that the limited funds for this protocol would be focused on river hydrology (quantity and timing) (i.e., the surface water dynamics vital sign) in selected major watersheds.

This protocol employs a strategy that uses data from existing streamgage stations that are operated by other entities and have historic records. We will provide some operational and data management support for several gages that have been slated for abandonment by their current operators. We will

collaborate with park staff or other cooperators, wherever possible, to ensure long-term operation of selected stations. This protocol is intended to be a “living” document that will be modified as new data sources and information emerge and methodologies are refined.

The SIEN I&M Program provides valuable information about the status and trends of natural resources through long-term monitoring so that the parks may fully integrate natural resource monitoring and other science activities into the management processes of the National Park System, as laid out in the National Parks Omnibus Management Act (National Park Service 1998). The Act charges the Secretary of the Interior to "continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the National Park System". Park managers rely upon monitoring results to prioritize protection or restoration efforts and for scenario planning. Further, the Interagency Climate Change Adaptation Task Force (2011) has developed a national action plan to identify steps that federal agencies can take to improve management of freshwater resources in a changing climate. They have set the following national goal:

*Government agencies and citizens collaboratively manage freshwater resources in response to a changing climate in order to assure adequate water supplies, to protect human life, health and property, and to protect water quality and aquatic ecosystems.*

The action plan recognizes that many of the current policies and decision making tools used by resource managers rely on historic data. In a changing climate, complete and current data must be used along with predictive models to provide more accurate information to managers. With this protocol, SIEN will provide routine summaries of surface water status and trends to the parks and make the data available for use in predictive models that can provide valuable information for planning and management decisions.

### **1.1. Sierra Nevada Network Surface Water Monitoring**

Surface water dynamics in the Sierra Nevada encompasses not only streamflow, but also includes evapotranspiration, water supply to wetlands, water levels in lakes, and other components. Since comprehensive monitoring of all surface water dynamics throughout SIEN is beyond the scope and budget of our program, SIEN and park staff determined that separate protocols and objectives would be developed for lakes and rivers/streams and groundwater. Water quality is addressed by the lake protocol (Heard et al. 2012), which uses a spatially distributed sampling design to make inferences about water quality in high-elevation lakes across the network. The wetlands ecological integrity protocol (Gage et al. In prep.) examines groundwater hydrologic regime in fens and wet meadows throughout SIEN parks, in addition to monitoring associated plant and macroinvertebrate communities. This river hydrology protocol focuses on water quantity and timing including changes in hydrologic regimes. As a secondary objective, water temperature data is also collected at ten of the streamgage stations.

### **1.2. Rationale for Monitoring Rivers**

Sierra Nevada parks protect a diversity of water resources, including over 4,500 lakes and ponds, an estimated 3,450 km of mapped rivers and streams, as well as seeps, wet meadows, hot springs,

mineral springs, and karst springs. These water resources and associated aquatic and riparian habitats have high regional ecological value, supporting aquatic communities that account for 21% of vertebrate taxa and 17% of plant taxa in the Sierra Nevada (SNEP 1996a). The Sierra Nevada ecoregion, which includes SIEN watersheds, generates approximately \$2,200,000,000 in annual revenue. Water accounts for more than 60% of these dollars (SNEP 1996a). Primary water uses include irrigated agriculture, domestic water supplies, hydroelectric power, recreation, and tourism.

Rivers and streams are the primary means by which precipitation, including alpine snowpack, is delivered to ecosystems within the parks and to water users within and downstream of the parks. Human activities have and will continue to impact the flow regimes and water temperature in SIEN rivers and streams. Such threats drive the need for expanded and continued monitoring. Science-based information about the status and trends in surface water hydrology and temperature is vital to making informed management decisions within the parks and in California. Rivers are interactive components of their environment, as integrators of water, energy, nutrients, solutes, and pollutants from the landscape and atmosphere (Minshall et al. 1985). Accordingly, rivers serve as excellent sentinels of change on the surrounding landscape (Williamson et al. 2008).

Aquatic and riparian systems are the most altered and disturbed habitat type in the Sierra Nevada (SNEP 1996b) and will continue to be impacted by several key systemic stressors. The five stressors considered the greatest threats to Sierra Nevada parks include the loss of pre-Euroamerican fire regimes, non-native invasive species, air pollution, habitat fragmentation, and climatic change. These key stressors have been documented in SIEN parks and were identified by managers and researchers using a substantial supporting body of research (SNEP 1996a) and best professional judgment (National Park Service 1999). All of the above stressors except habitat fragmentation have significant impact on the parks' surface waters and aquatic life.

#### **1.2.1. *Sierra Nevada Hydrology***

SIEN parks are located on the western slope of the Pacific Crest in the Sierra Nevada mountains and span seven major watersheds, including, from north to south, the Tuolumne, Merced, San Joaquin, Kings, Kaweah, Kern, and Tule (Figure 1). 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. Although land area encompassed by SIEN parks range in elevation from 418 to 4,417 m, a large majority (86 percent of YOSE and 91 percent of SEKI) occurs above the rain-snow transition zone (average elevation of 1,800 m). Accordingly, SIEN watersheds have a snowmelt driven hydrologic system. The principal source of precipitation is snow in the winter that is later slowly released throughout the spring and dry summer seasons. Much of the snowmelt in the SIEN nourishes park ecosystems, such as the giant sequoia forests, and is returned to the atmosphere via evapotranspiration. The balance flows downstream in rivers and streams to serve as a primary source of water for domestic, commercial, and agricultural use throughout California.

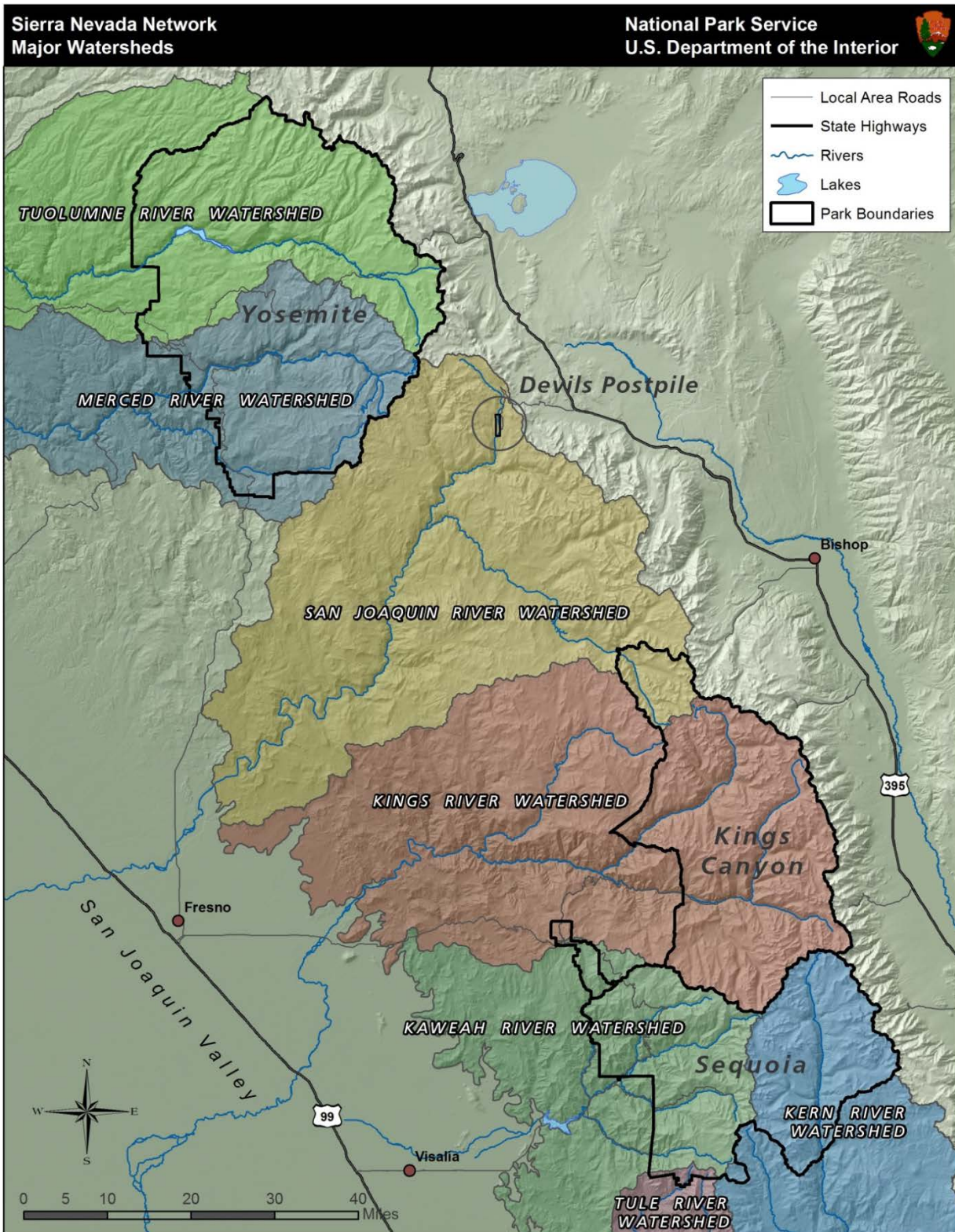


**Figure 1.** Sierra Nevada Network parks and major watersheds.

Hydrologic data, collected from networks of snow pillows, snow courses, precipitation gages, and streamgages are used by scientists and water managers to calculate a variety of hydrologic parameters and evaluate the quantity and timing of water delivery. Snow accumulation is measured and reported through an extensive network of snow monitoring sites (snow pillows and snow courses) by the California Department of Water Resources (CDWR). The CDWR and other water managers use data from snow courses and streamgages to develop and refine models to predict the timing and quantity of snowmelt, to develop hydrologic forecasts, and to better understand the water balance in watersheds. Because hydrology and climate are major drivers within ecosystems, observed and modeled changes in the hydrologic cycle may be used to better understand timing shifts in other ecosystem processes as well. These models need continued refinement and rely on both satellite data and manual measurements at snow courses and streamgages to contribute to the understanding of the relationship between snow cover, ablation, and streamflow.

Some of the precipitation received in a watershed, including rain and snow, runs off into rivers and streams and can be recorded at streamgages. The specific water yield in the Sierra Nevada varies by elevation. Streamgages measure water level (stage) and then discharge (flow) is computed using a stage-discharge relationship. Discharge is a volume and is often reported as cubic feet per second (cfs). A number of hydrologic parameters may be calculated from mean daily discharge data to illustrate the timing of runoff and reflect the form in which precipitation is received in watersheds (Table 2). Numerous studies have utilized streamflow records to document decreases in snow accumulation and earlier snowmelt (Stewart et al. 2005, Barnett et al. 2008). Since hydrology and climate are major drivers within ecosystems, these timing parameters may be used by managers to better understand timing shifts in other ecosystem processes.

**Table 2.** Derived mountain hydrology parameters that can serve as indicators of change in runoff timing.

| Hydrologic Parameter                                              | Management Significance                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| April-July discharge as percent of annual discharge (AMJJ/Annual) | Most of the snowmelt season occurs during the AMJJ period and these flows are the most important contribution to the annual streamflow, comprising 50-80 percent of the annual total (Stewart et al. 2005). A decrease in this value is indicative of reduced snowpack and/or a shift to more precipitation arriving as rain during other months of the year. Park ecosystems depend upon the slow release of snowmelt during the April-July period. |
| Onset of snowmelt                                                 | The date of the beginning of the spring prolonged snowmelt-driven streamflow. Rising temperatures may cause snowmelt to occur earlier in the year. This could lengthen the dry summer season and shift the timing of water delivery to park ecosystems.                                                                                                                                                                                              |
| Center of mass                                                    | This is the day of the year when half of the total annual discharge has occurred at a streamgage. The center of mass can be used as another indicator of snowmelt timing.                                                                                                                                                                                                                                                                            |

**Table 2 (continued).** Derived mountain hydrology parameters that can serve as indicators of change in runoff timing.

| Hydrologic Parameter                           | Management Significance                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Number of days to the 3-day high flow          | This is the number of days from October 1 to the highest consecutive 3-day discharge of the water year. Typically, the 3-day high flow occurs during the peak snowmelt runoff period, whereas the single day peak flow could result from a rainstorm. Similar to the center of mass and snowmelt onset, earlier 3-day high flows can indicate an earlier melt due to rising temperatures. Trends in earlier 3-day high flows in the SIEN were observed by Andrews (2012). |
| Winter low flows (3, 7, 10 or 14-day low flow) | The smallest value observed over 3, 7, 10 or 14 consecutive days. An increase in the volume of winter low flows would indicate that more precipitation is arriving in the form of rain during the winter months. The total volume of precipitation (and total annual discharge) may remain the same while the timing and form (rain vs. snow) may change. Park ecosystems would need to adapt to such shifts.                                                             |

Streamflow data are commonly displayed in hydrographs, which reflect responses in discharge to events such as rainstorms or snowmelt. Hydrographs usually represent the mean daily discharge over the course of the water year (WY), from October 1 through September 30. Figure 2 shows a typical hydrograph for a streamgage in SIEN (Happy Isles, YOSE). The snow water equivalent at a snow-pillow in the upper portion of the watershed is plotted on the second y-axis is (Tenaya Lake). The hydrograph reflects both small and large scale events, including a brief spike in discharge due to a rainstorm in November as well as the elevated discharge from May to June that corresponds with snowmelt in the upper watershed. Most often, the annual peak flow is tied to the peak snowmelt and occurs in May or June, although some of the largest storms and massive floods have occurred between November and February.

In the coming decades, climate change and variability will undoubtedly have profound effects on water resources in the Sierra Nevada and the ecosystems that have evolved within a snowmelt-driven hydrologic system. Changes have already been observed and are expected to continue (Knowles et al. 2006, IPCC 2007, Null et al. 2010). Barnett et al. (2008) predict a coming water crisis in the western United States, and their results show that “up to 60% of the climate-related trends of river flow, winter air temperature, and snow pack between 1950 and 1999 are human-induced.”

One of the most widely observed trends that will continue to have profound effects on the hydrologic cycle has been an increase in surface air temperatures. The Sierra Nevada has warmed 0.5 to 1.5 o C over the last 50 years (Mote et al. 2005). In the western U.S., some of the most notable effects of increased air temperatures on river dynamics occur through the effects of air temperature on snow accumulation and snowmelt. Air temperature influences the form in which precipitation falls, and warmer air temperatures raise the elevation of the rain-snow transition zone as is being observed in the mid-elevations of the Sierra Nevada. As this zone moves upward, more precipitation falls as rain rather than snow. At the higher elevations, increased snowpack has been observed due to higher precipitation levels (data from 1950-1997) (Mote et al. 2005, Andrews 2012). However, Stewart (2009) states that “with continued warming, increasingly higher elevations are projected to

experience declines in snowpack accumulation and melt that can no longer be offset by winter precipitation increases”.

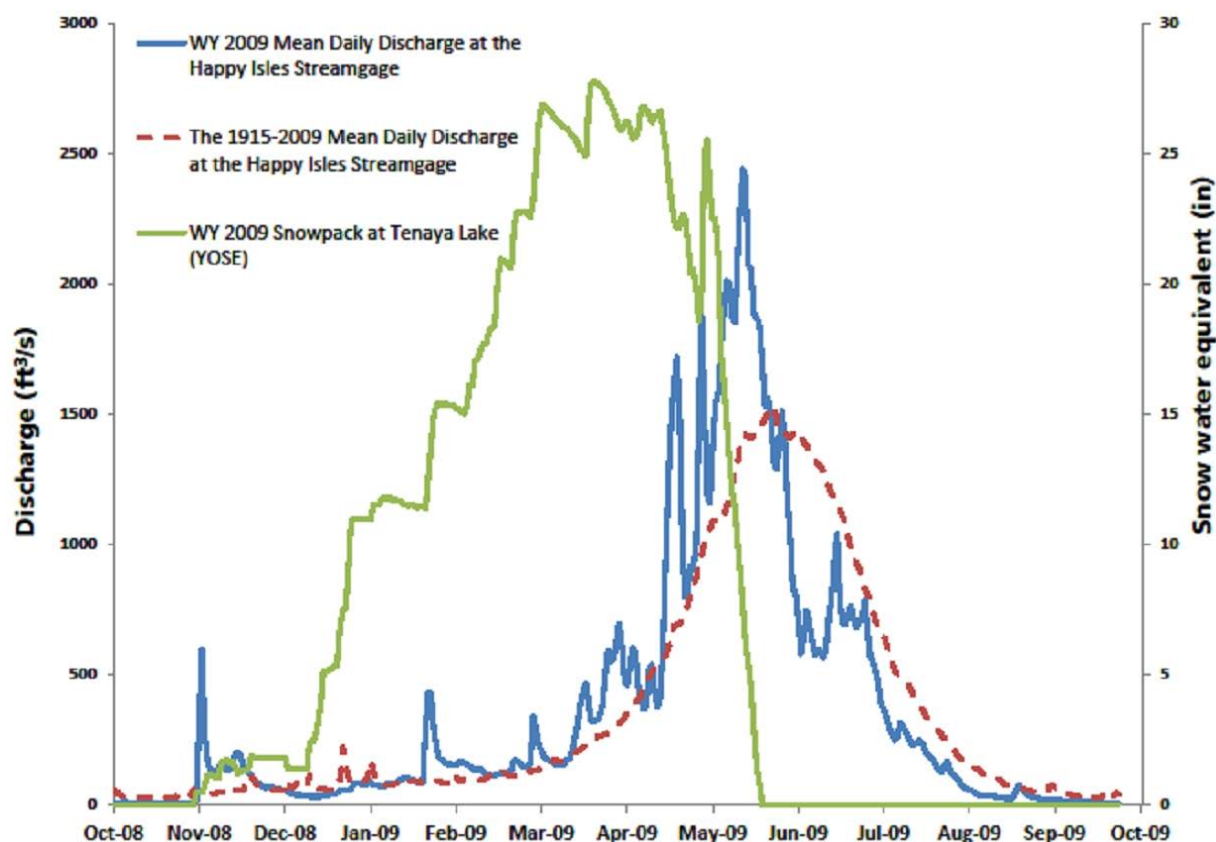


**Figure 2.** An example of the relationship between snow accumulation and snowmelt at the Tenaya Lake snow course in the upper Merced Watershed and discharge downstream at the Happy Isles streamgage. Note the dramatic increase in discharge (blue solid line) as snowpack rapidly melts (green solid line) in early May.

Researchers have documented hydrologic changes (earlier snowmelt runoff, reduced summer base flows, and decreased winter snowpack) in the Sierra Nevada and western U.S. and they predict further changes (Mote et al. 2005, Stewart et al. 2005). These changes and others, including wetter and more erratic winter flows, prolonged low summer flows, reduced soil moisture, and periodic drying of once perennial streams are depicted in the hydrograph in Figure 3. In the Sierra Nevada, annual precipitation, and consequently annual streamflow, are highly variable, commonly more so than in other parts of the U.S. Additionally, it is not uncommon for most of the annual water to be delivered in just a few large snow or rainstorms each year (Dettinger et al. 2011). Throughout SIEN and much of California, some of the largest floods have occurred during winter and spring rainstorms. This type of storm caused the floods that closed Yosemite Valley in Yosemite National Park in January 1997 and May 2005. Floods can be magnified in the winter and spring when high-altitude rains in the Sierra Nevada either melt or run off of an existing snowpack. Predictions for even greater variability in precipitation and streamflow along with more extreme events pose a dilemma for park managers and California water managers. Managers may no longer be able to

depend on the historic hydrologic system in which the majority of the precipitation for the year arrives and is stored as snow to be released throughout the summer. Greater variability in precipitation and less total snowfall could result in reduced summer low flows, the transition of river reaches from perennial to intermittent, reduced habitat for aquatic organisms, and decreased overall river productivity (Luce and Holden 2009).

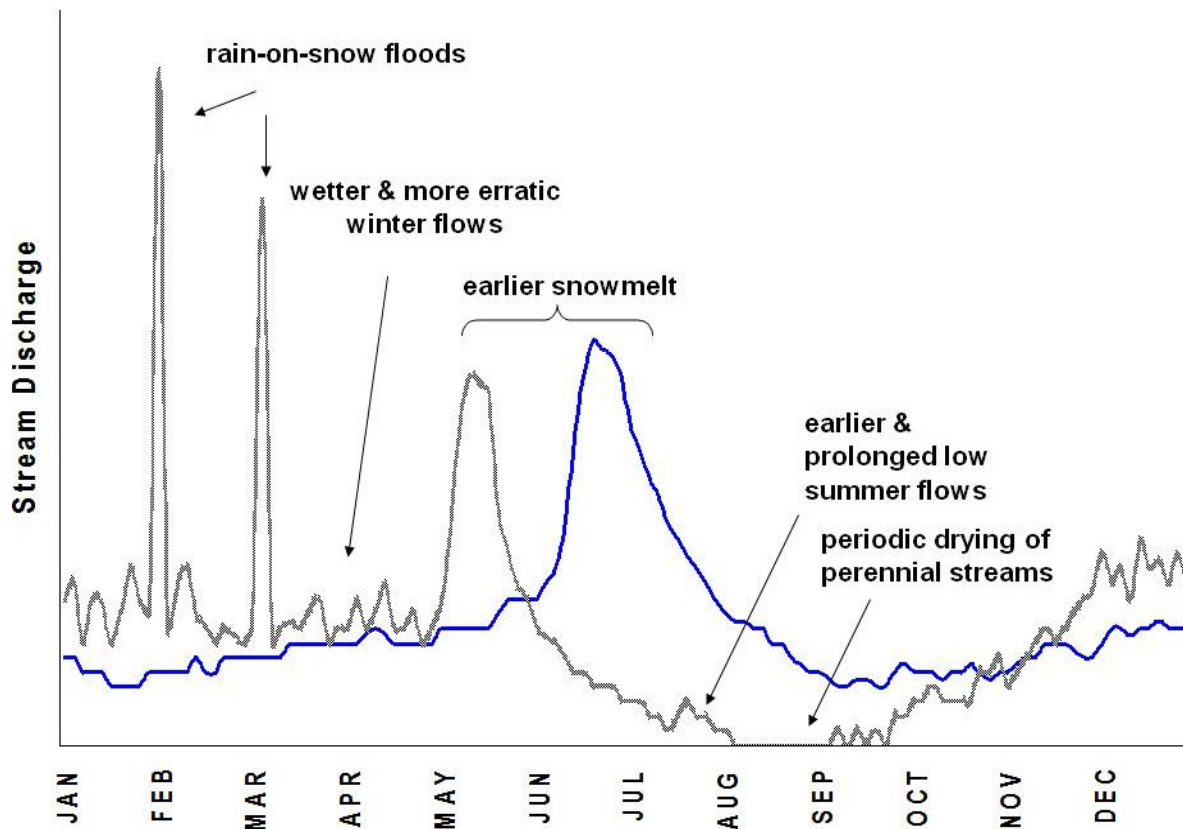


**Figure 3.** Hydrograph depicting changes in Sierra Nevada hydrology predicted to occur with shifting precipitation dynamics and climate warming. The blue line represents a typical historic hydrograph and the grey line illustrates the anticipated changes. Some of these changes have already been observed (Herbst 2008).

It is unlikely that hydrologic changes will occur homogeneously across all latitudes and elevations in the Sierra Nevada. Null et al. (2010) modeled possible hydrologic responses of Sierra Nevada watersheds to climate warming. Results suggested that northern Sierra Nevada watersheds are more vulnerable to decreased mean annual flows, while central and southern Sierra Nevada watersheds (i.e., SIEN watersheds) are more susceptible to earlier runoff timing. Accordingly, SIEN park ecosystems will likely be forced to adapt to longer and drier summers. Mid-elevations may be affected disproportionately relative to other elevations. Das et al. (2009) examined two hydrologic parameters associated with snowmelt and found that the strongest changes occurred at medium elevations (500-3,000 m) where warming has pushed temperatures from slightly below to slightly above freezing. As previously mentioned, observations and models suggest that the hydrologic cycle is being intensified, causing more frequent and extreme floods and droughts. Water managers outside

the parks are investigating and preparing for these types of hydrologic changes. For example, the Bureau of Reclamation is anticipating that earlier snowmelt and more rain resulting from warmer conditions may reduce the ability of current infrastructure to provide effective flood protection (Bureau of Reclamation 2011). To inform planning and management decisions, long-term data are crucial. Hannaford et al. (2011) noted “there is a growing need for observational data with which to discern any emerging trends in river flows and to compare these with future projections from climate models”.

Despite the importance of and need for hydrologic data within SIEN parks, the amount and availability of relevant data have been declining. Historically, hydrologic data in and near the parks have primarily been collected by researchers or agencies other than the NPS. Recognizing the need for hydrologic data to inform the state’s water management system and flood prediction efforts, the U.S. Geological Survey (USGS) and other agencies operated more than 30 streamgages in or within 20 miles of SIEN parks in the 1980s and 1990s. Since then, over half of these stations have been abandoned by their operators, primarily due to funding cuts. Furthermore, streamgages are commonly installed by an agency or researcher with their specific research or program needs in mind, and their data are not widely shared. Parks often do not have the time, staff, or resources to seek out and acquire data from disparate sources, and consolidate and analyze these data sets for trends in hydrologic parameters relevant to park management. This protocol will assist with the collection, management, and analysis of such data.

### **1.2.2. *Water Temperature***

Water temperature is a master variable controlling many physical, chemical, and biological processes. A few examples of processes water temperature affects include chemical reaction rates, dissolved oxygen concentrations, algal productivity, and health and reproduction of aquatic life. Stream water temperature is particularly sensitive to climate change. Continuous water temperature monitoring sensors are often collocated at streamgages and provide an opportunity to understand climate change effects on hydrology and water temperature. This protocol will increase our network of temperature monitoring sensors by adding temperature loggers to a few select streamgages and provide parks with water temperature summary and trend data from select set of stations.

## **1.3. Guidelines and Thresholds for Management**

### **1.3.1. *Wild and Scenic River Designations***

Portions of six of the seven major rivers in SIEN have been designated or determined to be eligible/suitable for wild, scenic, or recreational designation under the Wild and Scenic Rivers Act (Table 3). The designation includes identification of the rivers’ Outstandingly Remarkable Values (ORVs), which are river-related values that make a river unique and worthy of special protection. These values include aesthetic, recreational, biological, and hydrological features (Public Law 90-542; 16 U.S.C. 1271 et seq.). The Wild and Scenic Rivers Act requires protection of ORVs along designated reaches. In addition, no actions may be taken that could adversely affect the values that qualify a river for the national Wild and Scenic Rivers System, thus extending protection to rivers eligible for designation. Long-term hydrologic monitoring by SIEN on these rivers will inform the

parks' understanding of the status and trends and guide management decisions needed to protect the ORVs.

**Table 3.** Wild and Scenic River designation status for rivers in SIEN parks.

| <b>River</b>                     | <b>Park</b> | <b>Designation</b>                                                                                   |
|----------------------------------|-------------|------------------------------------------------------------------------------------------------------|
| Tuolumne                         | YOSE        | Wild and Scenic                                                                                      |
| Merced (Main Fork)               | YOSE        | Wild (upper segment), Scenic and Recreational (lower segment)                                        |
| Merced (South Fork)              | YOSE        | Wild (upper segment); Wild and Recreational (lower segment)                                          |
| San Joaquin (Middle Fork)        | DEPO        | Eligible/Suitable Wild and Scenic                                                                    |
| San Joaquin (South Fork)         | SEKI        | Eligible/Suitable Wild                                                                               |
| Kings (Middle Fork)              | SEKI        | Wild                                                                                                 |
| Kings (South Fork)               | SEKI        | Wild (upper segment); Recreational (lower segment)                                                   |
| Kaweah (Marble and Middle Forks) | SEKI        | Eligible/Suitable Wild (upper segment); Eligible/Suitable Recreational (lower segment)               |
| Kaweah (East Fork)               | SEKI        | Eligible/ Suitable Wild (upper and lower segments); Eligible/ Suitable Recreational (center segment) |
| Kaweah (South Fork)              | SEKI        | Eligible/Suitable Wild                                                                               |
| Kern (North Fork)                | SEKI        | Wild                                                                                                 |
| Tule                             | SEKI        | No status                                                                                            |

### **1.3.2. Minimum Flow Requirements for the Kaweah**

There are low minimum flow requirements on the Middle and Marble Forks of the Kaweah that must be monitored and maintained with respect to water withdrawals. In SEKI, Southern California Edison (SCE) has diverted water from the Middle and Marble Forks of the Kaweah River for power generation since 1907. An analysis was completed in 1980 (Jordan / Avant & Associates 1984) to determine the effects of the SCE diversions and to ensure that the minimum flow requirements laid out in the park-mandated special use permit were adequate to support healthy aquatic ecosystems downstream of the diversions. The report found that the diversions were not causing undue impacts, and the renewed special use permit established new minimum flow requirements. SCE operates multiple gages and reports the data to the park superintendent, as required by their special use permit, to ensure that they are maintaining the minimum flow requirements in the Kaweah. SCE also provides their streamflow data to SIEN for analysis and reporting. SIEN will examine the records and report any failures to comply with the minimum flow requirements, as described in Standard Operation Procedure (SOP) 9.

Minimum flow requirements are:

- Gage 227a (Marble Fork at Potwisha): Sept - Dec 1.5 cfs; Jan - Feb 6.0 cfs; March - June 9.0 cfs; Jul - Aug 6.0 cfs
- Gage 209 (Middle Fork near Potwisha): Sept - Dec 9.5 cfs; Jan - Feb 14 cfs; March - June 30 cfs; Jul - Aug 14 cfs

## **1.4. Monitoring Questions and Measurable Objectives**

### **1.4.1. Monitoring Questions**

As part of the vital signs selection process, park staff, network staff, and outside cooperators identified and prioritized resource-related questions of interest. Surface water dynamics encompasses a broad range of topics, and aspects are monitored through this river hydrology protocol as well as the lake protocol. Questions of interest identified in the Vital Signs Monitoring Plan with relevance to rivers include:

#### Surface Water Dynamics

- 1) 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)?
- 2) How are stream and river discharge rates and the timing and magnitude of peak flows changing?
- 3) How are water dynamics changing in response to climate change and fire regimes?

These questions help to define the context for why park and network staff selected surface water dynamics as a vital sign, while the objectives below provide the specific measures that will be used to monitor streamflow.

### **1.4.2. Measurable Objectives**

The focus of this protocol is on monitoring timing and quantity of streamflow and stream water temperature. Our approach toward achieving this goal is to acquire data from existing stations with long periods of record, to compile, analyze, and report on these data, and to support operation of a few selected stations. The hydrologic objective is the driver of the protocol (i.e., station selection and approach). Temperature is monitored opportunistically at stations that already include temperature sensors or stations where SIEN can add and maintain temperature sensors. The specific objectives of this protocol are as follows:

(1) Detect long-term trends in timing and volume of streamflow using fixed, continuous, water stage recording stations at existing streamgages in selected major watersheds of the SIEN. The SIEN will record, measure, and/or calculate the hydrologic measures listed below for each streamgage:

- Stage
- Discharge – instantaneous (measured), mean annual, instantaneous peak (annual), and highest and lowest daily mean (annual)
- Number of days to center of mass and onset of snowmelt
- Winter and summer 3, 7, 10 and 14-day low and high flow

- Number of days to winter and summer 7-day low flow
- Number of days to 3 and 14-day high flow
- Percent AMJJ/Annual flow.

(2) Detect long-term trends in stream water temperature using continuous temperature loggers at a subset (10) of the streamgages selected for hydrologic monitoring. The SIEN will record, measure, and/or calculate the temperature measures listed below for each site:

- Continuous 15-minute water temperature
- Daily mean water temperature
- Daily minimum water temperature
- Daily maximum water temperature

### **1.4.3. Monitoring Approach**

Constrained by limited funding and recognizing that many streamflow monitoring stations have been established in the SIEN through other research and monitoring programs, we achieved an approach that utilizes and builds upon existing infrastructure and data to address our monitoring questions and objectives. We will attain the above objectives by identifying existing stations that meet specific criteria to be included in the protocol (14 stations which are detailed in Chapter 2 and SOP 1). The majority of these stations are fully-maintained by other agencies. There are three stations that researchers have been maintaining that will be taken over collaboratively by SIEN and the parks. By supporting operation of stations that were abandoned by current operators or need additional support for them continue monitoring, we will ensure continued operation of stations with valuable historic records. We will compile existing hydrologic and temperature data from disparate sources into one central location, analyze, and report the data in a useful format to the parks and other audiences. This approach allows us to attain the largest sample size possible and capitalize on existing data sets to achieve our hydrologic objectives with a limited budget.

### **1.4.4. SIEN Vital Signs Integration and Linkages**

As each of the water dynamics-related protocols addresses specific components (lakes, wetlands, rivers) that are intricately connected via the hydrologic cycle, results from these protocols are linked, and data from one protocol may contribute to a greater understanding of the others and the hydrologic system overall (Heard et al. 2012, Gage et al. In prep.).

Surface water dynamics was selected as a priority vital sign in part because water is a physical driver of change in other resources, including plants, forest dynamics, birds, wetlands and amphibians, among others. Results from this protocol should have relevance to other monitoring projects in SIEN as changes in other ecosystem components may be correlated with changes in hydrology.

## **1.5. Major Watersheds of the Sierra Nevada Network**

Below is a brief overview of each of the major watersheds in the SIEN, including monitoring stations selected for this protocol. Appendix A of this protocol provides a summary of relevant surface water research and monitoring projects taking place in SIEN watersheds. In-depth summaries of SIEN

water resources information may be found in Heard and Stednick (2012) and Boiano et al. (2005). More information about the stations selected for this protocol can be found in Chapter 2 as well as SOP 1.

#### **1.5.1. Yosemite National Park**

Yosemite National Park contains the headwaters and significant portions of the Tuolumne and Merced watersheds. Portions of both rivers have been designated as Wild and Scenic Rivers and river management plans are in development by YOSE. Both the Tuolumne and Merced watersheds have been the subject of intensive collaborative research as part of the Yosemite Hydroclimate Project from the late 1990s to present. The project involves researchers from a number of universities and governmental organizations who undertook studies to better understand hydrology and climate in the park (Lundquist et al. 2003). A number of the studies paired meteorological stations with streamgages to better understand precipitation contributions, spatial dynamics, and intra-annual variation (Peterson et al. 2005). Seven of the fourteen stations included in this protocol are located in YOSE.

##### The Merced River Watershed

The headwaters of the Merced River watershed originate on the slopes of Mount Lyell and the Clark Range of the Sierra Nevada. The main stem flows through Little Yosemite Valley, past Half Dome, over Nevada and Vernal Falls and into the Yosemite Valley, the most heavily developed area of the park. The South Fork runs through the southern portion of the park and flows westward out of the park near Wawona, the park's south entrance. All of the famous waterfalls in Yosemite Valley meet the main stem of the Merced River on the Valley floor.

A large portion of the hydrologic and water quality monitoring in the watershed has been conducted by the USGS. The hydrology of the Merced River watershed is of high interest to a number of downstream water users such as the Merced Irrigation District (MID) which utilizes the water for both hydroelectric power and irrigation.

Three of the stations selected for this protocol are located in the greater Merced Watershed, two on the main stem and one on the South Fork (Figure 4). The USGS California Water Science Center operates two of the stations, Merced River at Happy Isles and Merced River at Pohono Bridge, located on the section of the Merced within Yosemite Valley. Sierra Hydrographics (a consulting company contracted by MID) operates the station on the South Fork Merced. There is an additional station on the Merced, the Merced above High Sierra Camp, that presently does not meet the SIEN River Hydrology Protocol criteria (described in section 2.2); however, we have recommended this station as an option for SIEN to improve and support if resources became available to expand monitoring (Appendix B). This station was formerly operated by USGS researcher Dave Clow (USGS Colorado Water Science Center) and more recently by Yosemite staff.

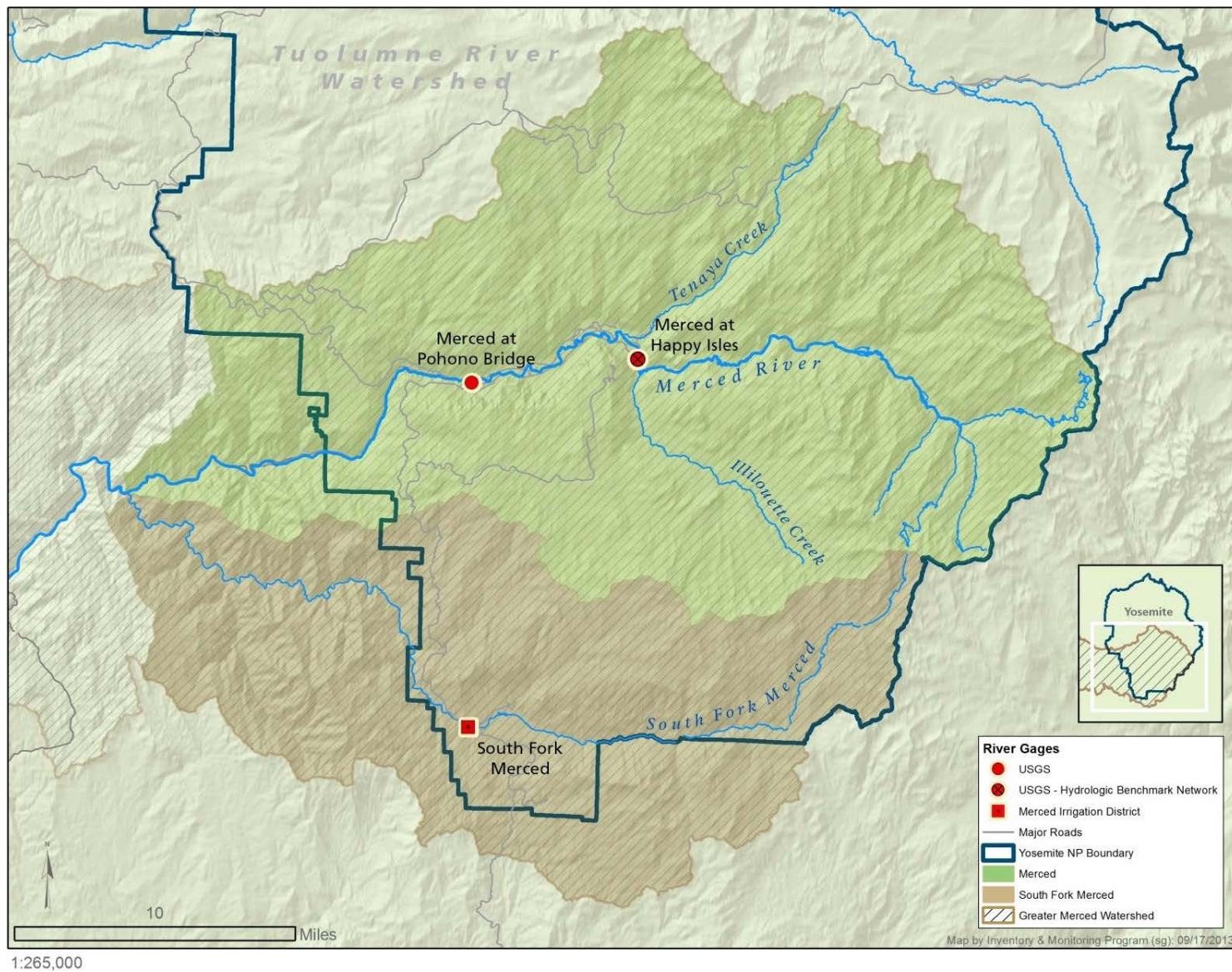


**Figure 4.** The Greater Merced watershed, streamgages (e.g., River Gages) included in this protocol, and station operators.

The streamflow records at the Merced River Yosemite Valley stations are among the longest in the nation, beginning in 1915 at the Happy Isles streamgage and in 1916 at Pohono Bridge. These long-term records are valuable to and widely used by researchers and water managers throughout California. The Happy Isles gage has a corresponding long-term water chemistry monitoring record (1967-present), collected as part of the USGS Hydrologic Benchmark Network (HBN). The HBN is designed to study status and trends in surface water chemistry in minimally affected basins and as a benchmark against which to compare changes in developed watersheds. The USGS performed an analysis of the water quality data in 2000 (Mast and Clow 2000).

#### The Tuolumne River Watershed

The headwaters of the Tuolumne River, the Dana and Lyell Forks, arise on the slopes of Mount Dana near Tioga Pass at the base of the Lyell snowfield and Maclure glacier. The Dana and Lyell Forks converge at Tuolumne Meadows to form the main stem which continues for 27 miles before ultimately flowing into 8-mile long Hetch Hetchy reservoir. Hetch Hetchy is the primary water source for the City of San Francisco.

Four of the stations selected for this protocol are located in the greater Tuolumne River watershed (Figure 5). Hetch Hetchy Water and Power (HHWP), which has a strong interest in understanding and predicting hydrologic dynamics in the watershed, funds the streamgage on the Tuolumne above Hetch Hetchy and operates a station on Falls Creek, which flows into the reservoir. HHWP also collaborates with YOSE and SIEN on a third station, the Tuolumne at Tioga Road Bridge, which is currently operated by YOSE, California Department of Water Resources, and several academic researchers. SIEN will analyze and manage the Tioga Bridge site data and rating curve. The highest elevation gaging station (9,615 ft) included in the protocol is the Lyell Fork of the Tuolumne, located upstream from the Tioga Bridge site and below MacClure glacier. This site was installed as part of a research project by Dave Clow (USGS) and is presently maintained by YOSE. Long-term funding for this site is uncertain, but SIEN and YOSE are working to secure funding, because information from high-elevation streamgages is sparse within the network and Sierra Nevada in general. In conjunction with stations at lower elevations, these data are particularly valuable for understanding the hydrology in contributing headwater basins and for investigating whether streamflow trends vary across an elevational gradient.

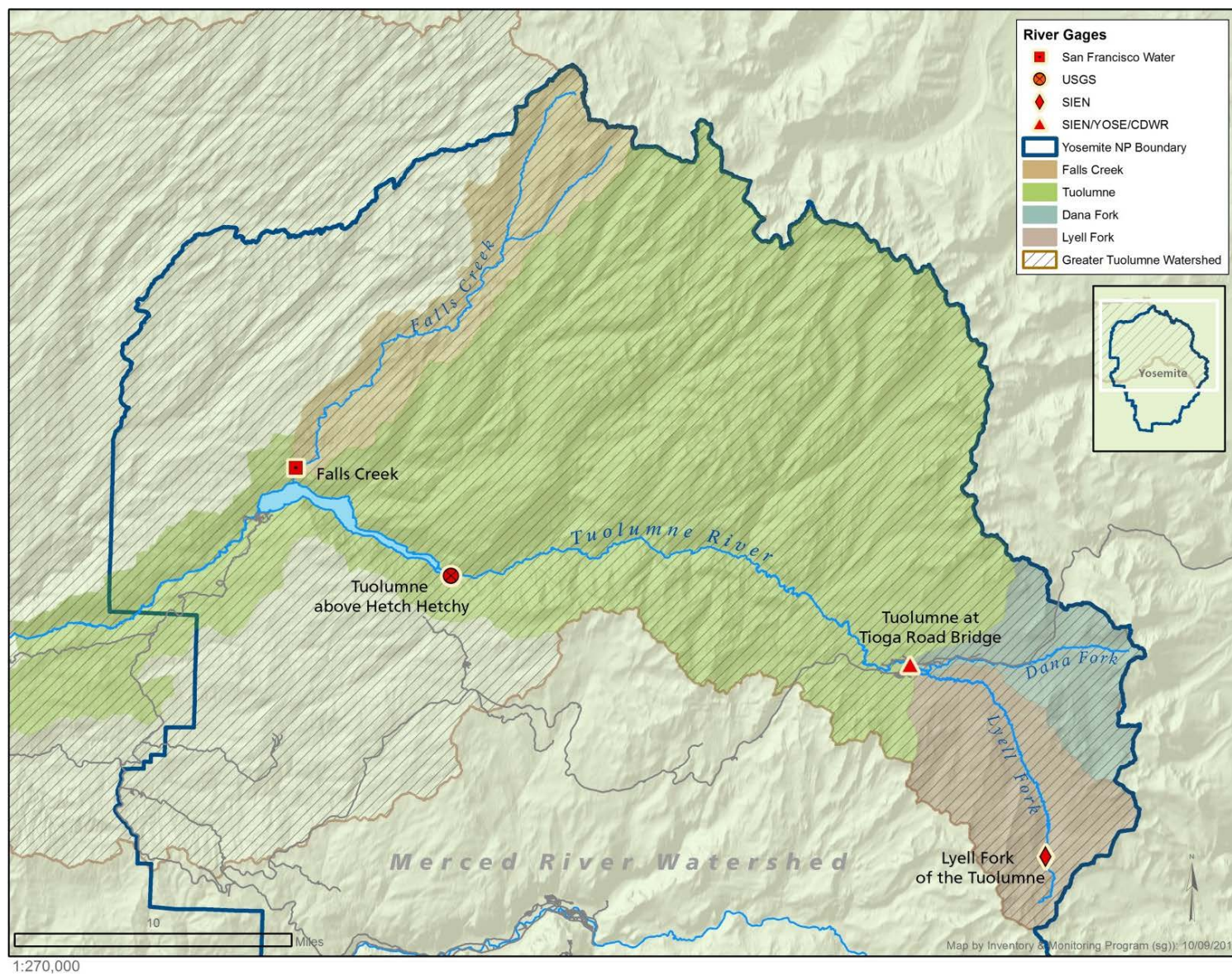


**Figure 5.** The Greater Tuolumne watershed, streamgages included in this protocol, and station operators.

### **1.5.2. Devils Postpile National Monument**

#### The Middle Fork of the San Joaquin River Watershed

Approximately 3.5 miles of the Middle Fork of the San Joaquin River is within DEPO, and includes one waterfall, Rainbow Falls, that is a popular attraction for visitors. Multiple segments of the river within and adjacent to DEPO have been classified as eligible/suitable for designation as a Wild and Scenic River.

In 2009, DEPO cooperated with the USGS to install a streamgage on the river near the northern boundary of the park (Figure 6). The station is now jointly funded by DEPO and SIEN. Prior to the installation of this station, hydrologic monitoring was limited to water level, which was collected as part of the Soda Spring Meadow meteorological station that is operated by Scripps Institution of Oceanography and the California Department of Water Resources. In conjunction with the meteorological station, the streamgage provides valuable long-term information about hydrologic dynamics in DEPO and the Middle Fork of the San Joaquin. These data can be used by DEPO for scenario planning and to better understand dynamics in other resources, such as meadows.

DEPO staff conduct monthly water quality monitoring at three locations on the San Joaquin River as well as two tributaries. Water quality monitoring visits include discharge measurements when possible. These data are stored in an NPSTORET database at DEPO.

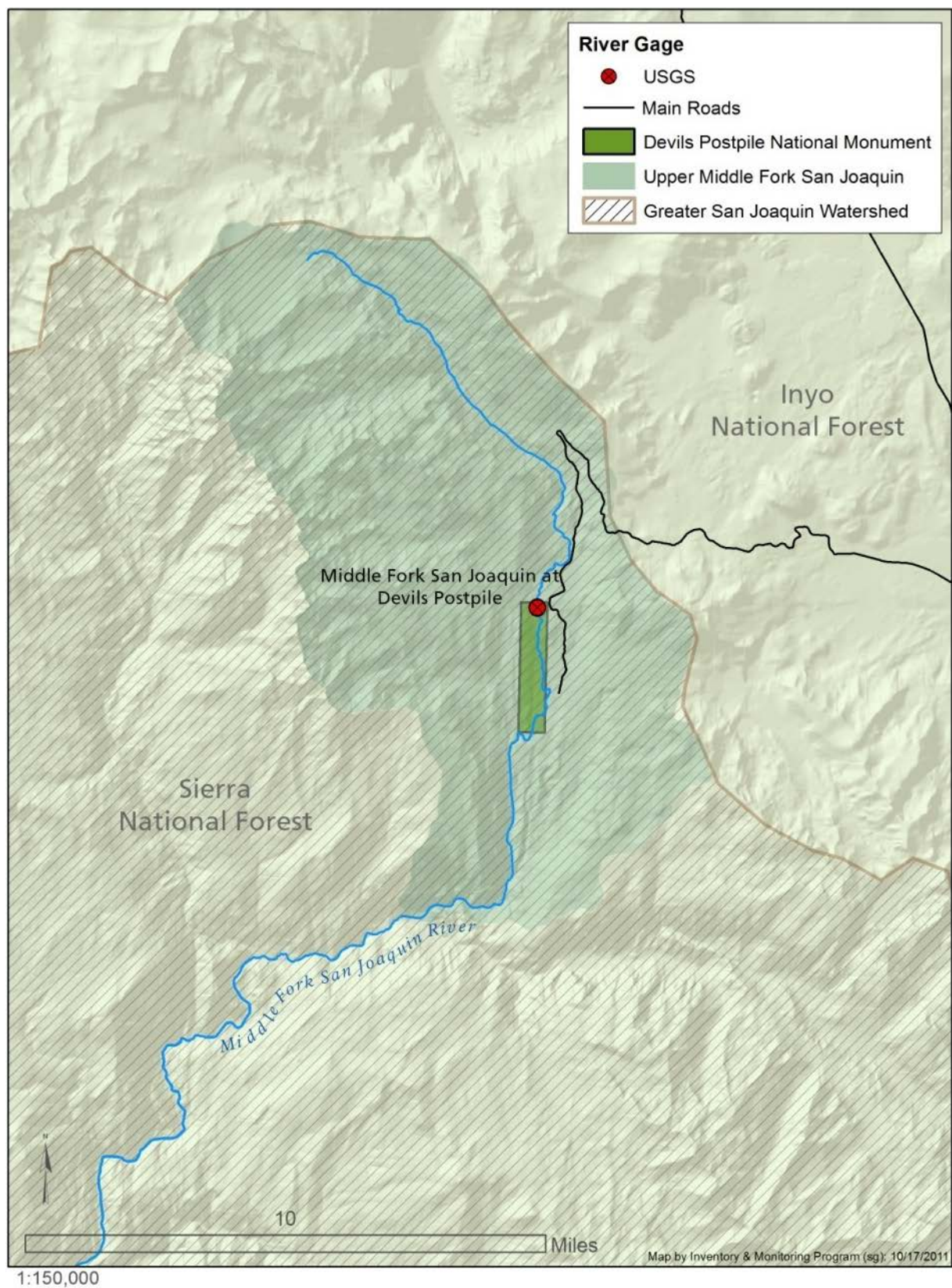


**Figure 6.** The Middle Fork of the San Joaquin watershed and the Devils Postpile streamgage.

### **1.5.3. *Sequoia and Kings Canyon National Parks***

Portions of the Middle and South Fork Kings, South Fork San Joaquin and North Fork Kaweah River watersheds are located in Kings Canyon National Park (KICA). Sequoia National Park (SEQU) includes portions of all forks of the Kaweah River, the upper Kern River, and a small portion of the Tule River. Portions of the Kern River (46.5 km), Middle and South Forks of the Kings River, and Middle, Marble, East and South Forks of the Kaweah River have been determined eligible/suitable or designated as Wild and Scenic Rivers. SEKI has prepared a General Management Plan/Wild and Scenic River Management Plan to address resource management issues, development, and user capacities (National Park Service 2007).

#### The Kings River Watershed

The Middle and South Forks of the Kings River originate in KICA, merge west of the park, and then join the North Fork above Pine Flat Reservoir, which was constructed in 1954 by the United States Army Corps of Engineers (US ACE). The US ACE measures the Kings River discharge above Pine Flat Dam and well outside the park. Until recently, there were no existing streamgages on the North, Middle or South Fork Kings that could provide hydrologic information about the portions of the watersheds within the park. In 2016, the Kings River Water Association (KRWA), through a grant from CDWR, installed a streamgage on the South Fork Kings River above Roaring River in KICA (Figure 7). KRWA is initially contracting with Sierra Hydrographics to perform maintenance and discharge measurements, as well as develop the rating curve. Later, perhaps after three or four years, KRWA staff will fully operate the station.

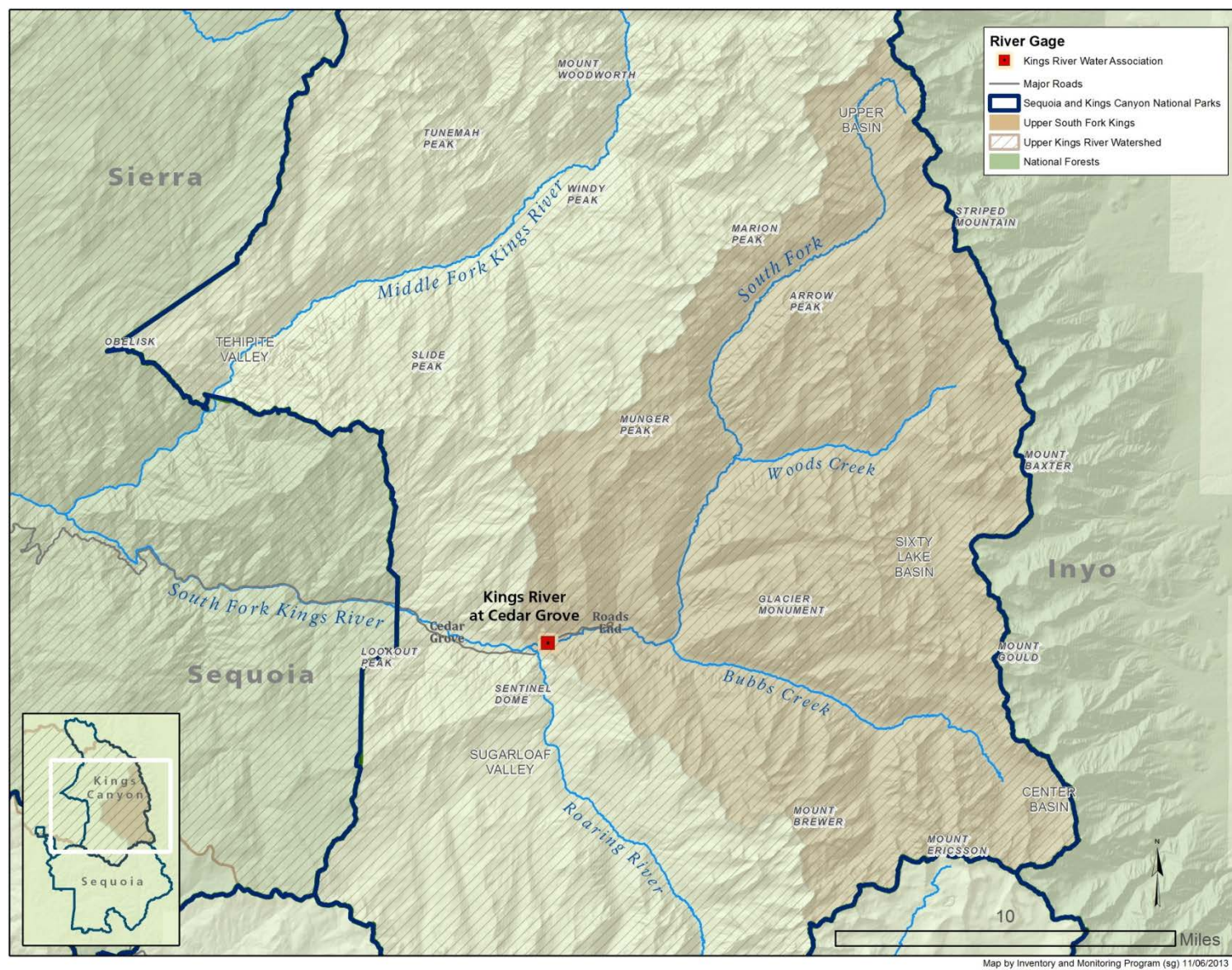


**Figure 7.** The South Fork Kings River watershed and proposed monitoring station selected for this protocol.

### The Kaweah River Watershed

All five forks of the Kaweah River, the North, Marble, Middle, East, and South, originate in SEQU. The Marble and Middle Forks join in SEQU, while the other forks merge downstream of the park boundaries (Figure 8). The main stem of the river flows into Lake Kaweah, a reservoir operated by the US ACE. A hydroelectric project, operated by the Southern California Edison Company (SCE), diverts water from the Middle, Marble, and East Forks of the Kaweah River. A schematic of the diversions and information about the project are included in Appendix D of this protocol.

Four of the 14 stations included in this protocol are located in the Kaweah River Watershed, and three of the four are operated by SCE. The fourth streamgage is located on the upper Marble Fork and is operated as a cooperative effort between the USGS, SEKI, SIEN, and the University of California (UC). This station, Marble Fork above Tokopah Falls, was installed by UC researchers John Melack and Jim Sickman in 1993 as part of a larger basin-wide research project. The station was added to the USGS HBN in 2003. Water chemistry samples are primarily collected by SEKI and SIEN staff (not as part of this protocol, but as part of the USGS monitoring program).

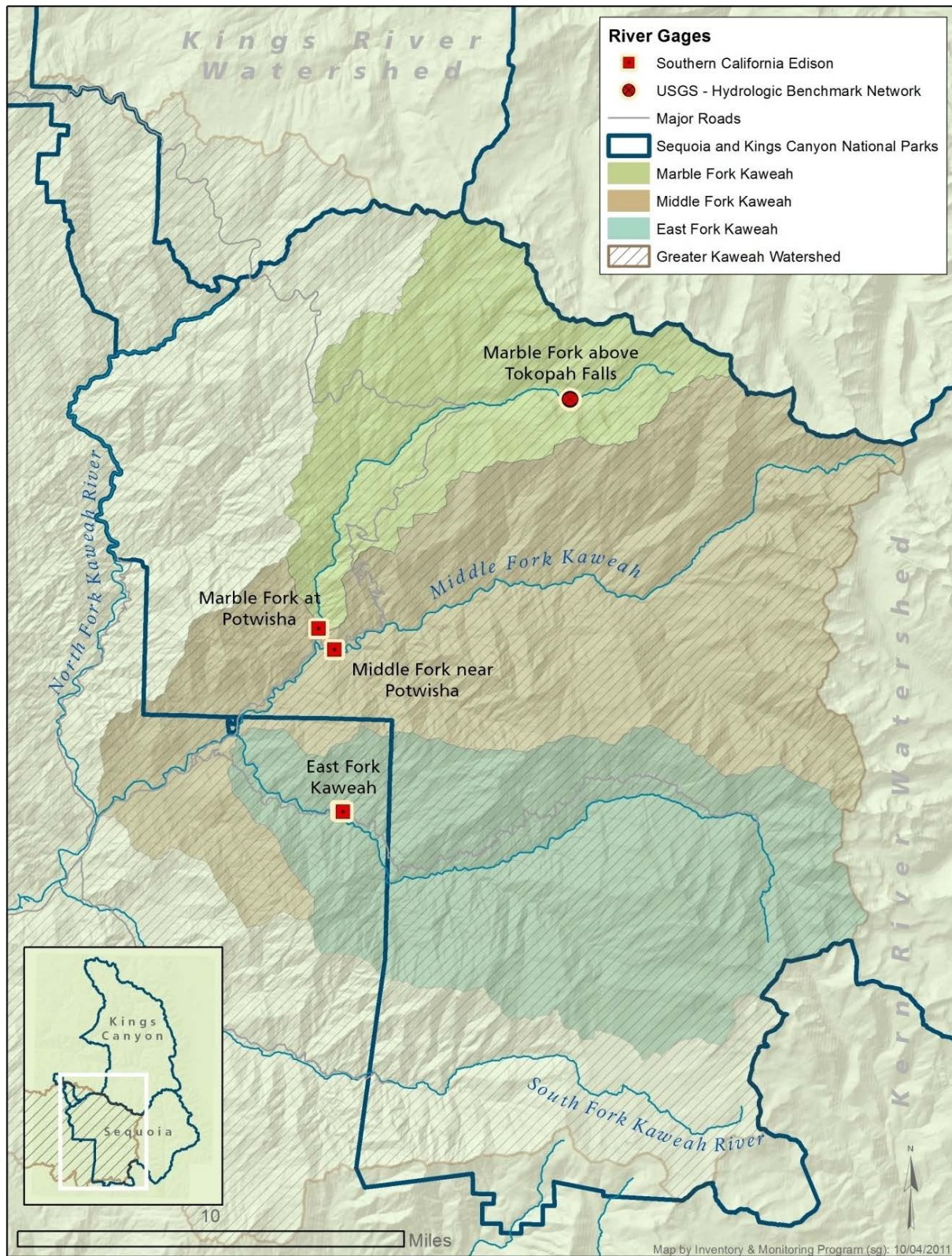


**Figure 8.** The Greater Kaweah River watershed, monitoring stations selected for this protocol, and station operators.

### The Kern River Watershed

The Kern River is the southernmost watershed in SIEN. The Kern headwaters originate from some of the highest peaks in the Sierra Nevada, including Mt. Whitney, the highest peak in the contiguous U.S. (Figure 9). Given the high elevations, steep terrain and lack of nearby roads, the Kern is one of the most difficult rivers to access in SIEN and hydrologic data are sparse. A single gaging station, the Kern River near Kernville, is located in the Kern River watershed well downstream of the park boundary. The station is located in Sequoia National Forest and operated by SCE. Although it is located some distance outside the park boundary, this station still provides valuable information about the streamflow timing and volume in the watershed and thus is included in the protocol. As the southernmost watershed, the Kern may not exhibit the same hydrologic response to climate change as those in the central and northern Sierra. For example, Andrews (2012) found that trends in decreasing snow water content that were observed at many of the lower elevation snow courses in the Sierra Nevada were not observed at the higher elevations in the southern Sierra Nevada. Therefore, watersheds with a greater percentage of area at high elevation, such as the Kern, may not exhibit the same hydrologic response to climate change as those with less high elevation land area. Null et al. (2010) found that the Kern watershed was the most resilient of all Sierra Nevada watersheds to the effects of climate warming during modeling exercises. Data from the Kern River streamgage may prove particularly valuable for understanding how southern Sierra watersheds, which have a higher percentage of total land area at high elevation, respond to climate warming compared to those in the central Sierra, which have more area at lower elevations.

### The Tule River Watershed

The headwaters of the Tule River are in SEQU, although very little of the watershed is in the park. There are currently no long-term streamgages in the watershed.

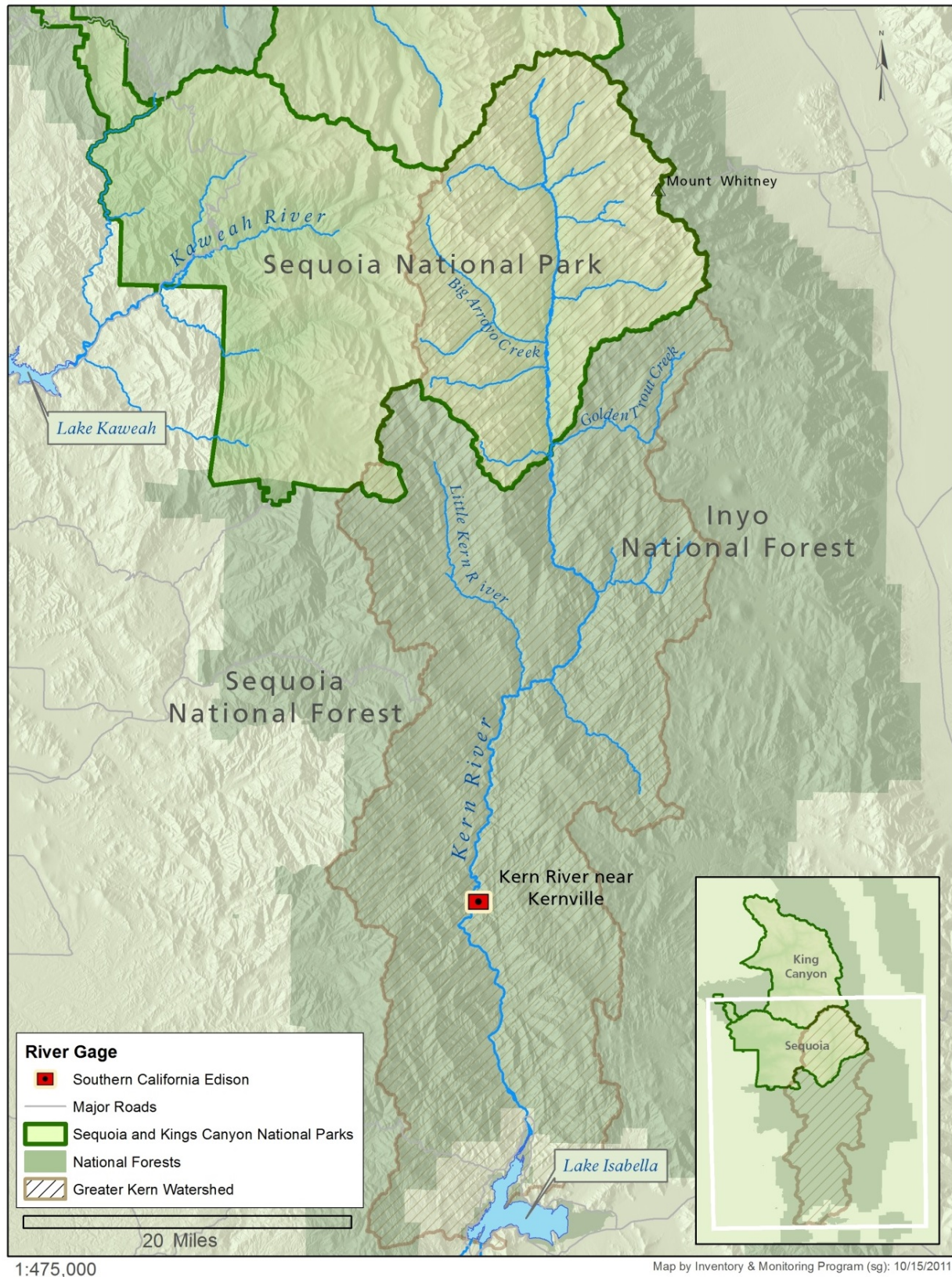


**Figure 9.** The Kern River watershed and Kern River streamgauge



## 2. Sampling Design

Monitoring-related sampling designs typically fall into three broad categories: census, probabilistic, and judgment. Census monitoring designs sample all units within a target population (e.g., all lakes within a park) and are rare due to the level of sampling effort and costs involved. The use of probabilistic designs has increased in recent years among natural resource monitoring programs because they ensure that the sample unit represents a random sample of the target population, thus allowing inference from sample to the target population. The judgment sample design focuses on specific sample units that are selected based on expert judgment or specific selection criteria.

Water resource monitoring programs commonly use more than one design, depending on the management question being asked. Judgment sampling is a common monitoring design for surface water monitoring among state, federal, and citizen monitoring programs, is recommended by the Environmental Protection Agency (EPA) (1997), and is used by the USGS National Water Quality Assessment Program and the Washington State streamflow monitoring program (Butkus 2005). Judgment sampling is commonly used for hydrologic monitoring because it is difficult to obtain suitable stream reaches using a random selection process. Locations typically are selected using the best professional judgment to ensure that a site is representative of a particular sub-watershed and has specific characteristics, such as stream bank and channel characteristics that are stable over time, stream size and slope that are conducive to discharge measurements, and relatively easy access. Probabilistic sampling would be extremely difficult to implement because the design would likely select numerous sites that do not have the specific characteristics suitable for a streamgage. The limitation of the judgment sample design is that data cannot be used to make statistical inference beyond the individual streamgage locations.

### 2.1. Monitoring Approach

The focus of this protocol is the timing and quantity of streamflow with a secondary objective of monitoring water temperature trends. The desired target population is rivers in mid to large size watersheds in SIEN parks. We have chosen to use a judgmental sample design that relies on existing stations because i) a probabilistic sampling design to establish new streamgage locations is not logistically or financially feasible and ii) the use of existing streamgage locations allows us to take advantage of and build upon historic records. Hydrologic measures commonly have high variability and signal-to-noise ratio compared to many other ecological indicators, which makes long-term records especially valuable for trend analyses. We will compile, analyze, and report on data from selected existing stations and may support additional stations if their current operators are no longer able to do so (Table 4).

**Table 4.** The 14 gaging stations included in this protocol.

| Station Name                                   | Park / Watershed                      | Start Date       | Elevation (ft) | Current Operator     | Long-term operator   | Temperature Sensor | Notes                                                                           |
|------------------------------------------------|---------------------------------------|------------------|----------------|----------------------|----------------------|--------------------|---------------------------------------------------------------------------------|
| Tuolumne River above Hetch Hetchy              | YOSE / Upper Tuolumne                 | 2006             | 3,850          | USGS                 | USGS                 | Yes                | USGS operation is funded by HHWP                                                |
| Tuolumne River at Tioga Road Bridge*           | YOSE / Upper Tuolumne                 | 2002             | 8,583          | YOSE, SIEN           | YOSE, SIEN           | Yes                | Station also has turbidity. Operation funded by HHWP.                           |
| Tuolumne River - Lyell Fork below Maclure Cr.* | YOSE / Upper Tuolumne                 | 2001             | 9,615          | YOSE, SIEN, USGS     | YOSE, SIEN           | Yes                | —                                                                               |
| Falls Creek                                    | YOSE / Falls Creek (greater Tuolumne) | (1915-1983) 2010 | 5,350          | HHWP                 | HHWP                 | Yes                | —                                                                               |
| Merced River at Pohono Bridge                  | YOSE / Merced                         | 1916             | 3,862          | USGS                 | USGS                 | No                 | —                                                                               |
| Merced River at Happy Isles                    | YOSE / Merced                         | 1915             | 4,017          | USGS                 | USGS                 | Yes                | HBN water quality station                                                       |
| South Fork Merced River at Wawona              | YOSE / Merced                         | (1911-1921) 2007 | 3,960          | Sierra Hydrographics | Sierra Hydrographics | Yes (SIEN HOBO**)  | Funded and contracted by the Merced Irrigation District                         |
| Middle Fork of the San Joaquin in DEPO*        | DEPO / San Joaquin                    | 2009             | 7,580          | USGS                 | USGS                 | Yes (SIEN HOBO)    | USGS operation is funded by DEPO and SIEN. DEPO and SIEN provide field support. |
| Kern River near Kernville                      | SEKI / Kern                           | 1960             | 3,620          | SCE                  | SCE                  | No                 | —                                                                               |
| Kaweah River Middle Fork near Potwisha         | SEKI / Kaweah (Middle Fork)           | 1950             | 2,190          | SCE                  | SCE                  | Yes (SIEN HOBO)    | Not used for trend analysis                                                     |
| Kaweah River Marble Fork above Tokopah Falls   | SEKI / Kaweah (Marble Fork)           | 1992             | 8,616          | USGS, UCSB           | USGS, UCSB, SEKI     | Yes                | HBN water quality station                                                       |

\*Stations where SIEN will provide support

\*\*SIEN will install HOBO temperature loggers at some sites where temperature is currently not monitored.

HHWP= Hetch Hetchy Water and Power. SCE= Southern California Edison. KRWA = Kings River Water Association. UCSB= U. Calif. Santa Barbara

**Table 4 (continued).** The 14 gaging stations included in this protocol.

| Station Name                         | Park / Watershed            | Start Date | Elevation (ft) | Current Operator | Long-term operator | Temperature Sensor | Notes                                                 |
|--------------------------------------|-----------------------------|------------|----------------|------------------|--------------------|--------------------|-------------------------------------------------------|
| Kaweah River Marble Fork at Potwisha | SEKI / Kaweah (Marble Fork) | 1951       | 2,210          | SCE              | SCE                | No                 | Calculated values used for annual status reports only |
| Kaweah River – East Fork             | SEKI / Kaweah (East Fork)   | 1952       | 2,700          | SCE              | SCE                | No                 | —                                                     |
| SF Kings abv Roaring R               | SEKI / Kings                | 2016       | 5,000          | KRWA             | KRWA               | Yes                | —                                                     |

\*Stations where SIEN will provide support

\*\*SIEN will install HOBO temperature loggers at some sites where temperature is currently not monitored.

HHWP= Hetch Hetchy Water and Power. SCE= Southern California Edison. KRWA = Kings River Water Association. UCSB= U. Calif. Santa Barbara

The advantages of using existing streamgages are that locations have already been expertly selected, equipment has already been purchased and installed, rating curves that describe the stage-discharge relationship have been developed, and historic data are available. We initially considered the possibility of installing new stations in areas that are not well represented or re-installing stations that had been removed. However, it was not possible to find stations that met all of our selection criteria and fit within our budget and staffing plan. Installation of new stations would have been expensive and time-consuming because the development of rating curves requires frequent visits in the initial years (i.e., up to 10 years) in order to obtain discharge measurements over a wide range of streamflows. After the initial years of operation and if a relatively stable reach has been selected, the stage-discharge relationship will not change much, and fewer measurements are required to check for shifts in the rating curve. By selecting existing stations, we are able to achieve greater efficiency with our time and budget because we are able to build upon existing rating curves and make fewer station visits. Further, when performing trend analyses, most hydrologists prefer stream discharge records that exceed 30 years so that decadal oscillations in precipitation (averages about 11 years) can be incorporated in the analyses. The incorporation of existing stations into our sampling design allows us to examine some records for trends immediately and other records significantly sooner than if we were installing new stations.

By adopting this sampling design, we are not able to represent all watersheds of interest and will not be able to make statistical inference to all watersheds across the network. Our analyses and conclusions will be largely catchment-specific. Our network of stations provides information about the timing and quantity of precipitation received in the watershed upstream of each station. The selected stations may be considered sentinels of change across SIEN. Further, Andrews (2012) found excellent coherence with mean annual discharge among stations in mid-sized watersheds throughout SIEN, even those separated by considerable distance and on opposite sides of the Sierras. When similar significant trends, such as an earlier snowmelt onset, are observed at multiple stations throughout the network, such findings warrant management consideration and may indicate areas for further investigation through modeling or targeted research.

We have the opportunity to explore hydrologic relationships within the context of “nested watersheds”, within the Tuolumne and Merced watersheds. The agencies that installed and operate existing gages selected station locations based on a nested watershed approach. A nested watershed approach involves selecting multiple stations within a watershed, whereby the larger watershed contains multiple smaller catchments or “sub-watersheds”. Here, sub-watershed refers to the area that contributes runoff to the streamgage, rather than the typical definition where a sub-watershed is delineated at the point where a smaller stream joins a larger one. Stations that occur farther downstream and at lower elevations have progressively larger contributing areas. Thus, the contributing area and hydrology of each streamgage can be examined within the context of the next larger (or smaller) watershed. Ecosystems often show non-linear responses along altitudinal gradients to changes in environmental parameters, such as temperature (Becker et al. 1997). This may be particularly relevant in the Sierra Nevada, where the greatest response to a warming climate is likely to be seen at mid-elevations around the rain/snow transition. A nested watershed approach allows us

to examine hydrologic trends from stations at a variety of elevations as well as explore intra-watershed variation and contributions.

Due to the possibility of future budget cuts and shifting agency priorities, it is possible that one or more of the stations selected for this protocol may be abandoned by their operator or need additional support in the future. While we cannot assume operation of most of the stations selected for this protocol, there are specific stations that we have the interest and capacity to support over the long-term. For example, SIEN could not assume operation of the streamgage above Hetch Hetchy Reservoir on the Tuolumne River because discharge measurements and access to the site requires a boat, which SIEN cannot afford to purchase, maintain, or operate. SIEN is best suited to provide coordination, technical support, some limited field assistance, data management, and analysis support. Additional streamgage stations across the network are highly desirable, and we would welcome data from new or additional stations. However, given budget constraints, SIEN itself cannot add to the existing network of stations.

Stations included in the protocol will be re-evaluated every other year in conjunction with the reporting cycle to ensure they still meet protocol criteria. Any stations not meeting protocol criteria will be excluded from the analyses and reporting. New stations may also be evaluated at this time and added to the protocol if they meet criteria and are deemed of value by the SIEN Physical Scientist and the water workgroup.

## **2.2. Station Selection**

We began our station selection process by identifying all operating streamgages in SIEN. We also identified gage locations that were no longer in operation, where we would have the opportunity to build upon an existing rating curve and data if the station were put back into operation.

Many agencies, universities, and other organizations have been involved in hydrologic monitoring in and near SIEN. They have established streamgages for a variety of objectives, most of which have focused on water supply or short-term research rather than long-term monitoring. Data from nearly all streamgages can be used to achieve our long-term monitoring objectives as long as the data are of high quality. Data quality classifications and procedures are discussed in the Quality Assurance Plan (SOP 10). We assume all stations selected for this protocol have acceptable data quality because operators follow established USGS procedures. For the most part, where the primary objective is to predict and measure water supply, stations have been placed at low elevations and have a large contributing area, whereas stations installed for research purposes are more widely distributed and may be located at higher elevations in a watershed. Regardless of their primary objective, all operators rely upon the following criteria to select an appropriate streamgage location:

- 1) **Streamgages should be within a suitable reach.** A reach is a stretch of stream or river between any two points. The best reaches for streamgages are relatively straight (between bends) for a length that is at least 20 times the width of the stream. The reach should be as stable as possible. Reaches that are primarily bedrock are much more stable than those with less rock and more soil along the banks and channel bottom. The major source of uncertainty in measured streamflow for natural channels is change in channel dimensions, which can be caused by bed scour/deposition,

bank erosion, vegetation changes, and debris deposition. Thus, frequent streamflow measurement and stage-discharge relationship adjustments are required to minimize the uncertainty in measured streamflow data from unstable channels. The reach should not be overly steep because when velocity head is high (when there is a steep gradient and turbulent flow), because depth is a poor predictor of velocity and it is difficult to maintain an accurate stage-discharge relationship. Finally, the total flow is confined to one channel at all stages, and no flow bypasses the site as subsurface flow.

- 2) **Streamgages should be accessible.** Streamgages require equipment that must be transported to the site. Further, it is necessary to visit a streamgage multiple times throughout the year to download data from the logger and collect discharge measurements. Discharge measurements on large rivers may need to be done from bridges, with a boat or via a cable-way. Accessibility allows for more frequent discharge measurements, which contribute to a better stage-discharge relation and higher quality data. Stations are occasionally placed in remote locations away from roads, resulting in site visits that require more time.

By selecting an appropriate location, operators ensure higher data quality because they are able to collect high quality discharge measurements and frequently check the accuracy of the rating curve. We selected 14 stations (seven in YOSE, six in or near SEKI, and one in DEPO) for which we will acquire, archive, and analyze data and report the results (Table 4). Three of the 14 stations are partially supported by SIEN. We identified multiple stations in the network that met the criteria to be included in this protocol, but required additional support to continue long-term. Given our limited funds, we were able to select three stations that SIEN could lend support to long-term. These stations are cooperatively managed by SIEN and the parks. Park support is critical for their long-term operation. The sites were selected using the following prioritization criteria:

- Builds upon an existing network of stations to achieve a nested watershed design. As previously mentioned, some stations have been established in SIEN based on a nested watershed design, and we will take advantage of this approach where possible.
- Has an existing record that would be valuable to continue.
- Is reasonably accessible or if it is far from a road, we have the equipment and capacity to perform discharge measurements at that location.
- Is within a major (mid or large size) watershed or sub-watershed. Whereas Andrews (2012) found good coherence among stations in mid-sized basins throughout SIEN, small watersheds are likely to exhibit more variability. Therefore, gages on streams in smaller sub-watersheds are less likely to contribute to a better understanding of hydrologic trends throughout the network and any results from such stations would be more limited to the station.
- Fills a significant data gap.

Over time, streamgages are likely to be installed in SIEN parks by researchers, the parks, or other organizations. SIEN will evaluate these streamgages according to the following criteria to determine whether we are able to assist with their operation and/or if it is worthwhile to incorporate them into our data management and reporting processes:

- The station is likely to be operated over a long-period of time so the data would provide more than a snapshot of the status at that location.
- The quality of the data is known to be high and metadata are available.
- Stations are located in mid to large watersheds and the data would provide relevant information to the park about river hydrology. Stations on small streams would likely not be incorporated.

### **2.2.1. Station Specifics for SIEN Involvement**

#### Stations Supported by SIEN

We identified three stations that SIEN will support (referred to as SIEN-supported). Two are within YOSE and one is at DEPO (Table 5). Although we have performed initial screenings as described above to select the stations, we have not had an opportunity to carefully examine the rating curves and historic records for the station on the Lyell Fork of the Tuolumne. During the initial years of protocol implementation, SIEN will explore and confirm that data collected at this station are of an appropriate quality to meet our objectives. The primary obstacle toward the stations meeting our objectives would be ice effect on the gage or the inability to capture flows at the high end of the rating curve. Ice-affected data could result in periods of unusable data and prevent the calculation of the mean daily discharges which are used to calculate the hydrologic statistics selected for trend analysis. If the station does not meet SIEN objectives it will be removed from the sampling design.

- Lyell Fork of the Tuolumne River below Maclure (YOSE) – The site was initially a research gage installed by Dave Clow (USGS) and YOSE in 2001. The gage is currently maintained by Yosemite physical science staff. The YOSE staff are responsible for site visits during the snow-free accessible months of the year (approximately June – September). The station is not accessible in the winter. SIEN will provide technical support as needed and manage the data in cooperation with YOSE.
- The Tuolumne River at Tioga Road Bridge (YOSE) – This site was originally installed as a research site for the hydroclimate monitoring network. It also has strong support, including financially, by HHWP. YOSE staff are responsible for monthly station visits during the snow-free accessible season. SIEN will provide technical support as needed and manage the data in cooperation with YOSE.
- The Middle Fork San Joaquin (DEPO) – The USGS is the primary operator of this station and performs station visits from mid-February to mid-June (i.e., during late winter and high flows). DEPO staff are responsible for station visits from mid-June to mid-February. SIEN’s role is to provide technical assistance. This station is accessible by road in the summer, but requires ski access during winter. The site is jointly funded by SIEN and DEPO.

**Table 5.** SIEN's level of involvement at SIEN-supported streamgages.

| Station Name                           | SIEN Level of Involvement                                                                  |
|----------------------------------------|--------------------------------------------------------------------------------------------|
| Lyell Fork of the Tuolumne             | Provide technical assistance; manage and analyze data, including the rating curve.         |
| Tuolumne River at Tioga Rd Bridge      | Provide technical assistance; manage and analyze data, including the rating curve.         |
| Middle Fork of the San Joaquin at DEPO | Fund 50 percent of the cost for USGS to operate the station; provide technical assistance. |

#### Marble Fork of the Kaweah at Potwisha

The Marble Fork of the Kaweah at Potwisha warrants further explanation as it was included in the protocol exclusively to monitor minimum flow requirements and will not be included in trend analyses. This streamgage was operated by SCE from 1951 to 2002. In 2002, SEKI and SCE determined that the station was a safety hazard to visitors and the data were unreliable due to modifications of the river channel by visitors recreating in the area. The infrastructure was removed, and SCE now reports a calculated value using data from streamgages on the Middle Fork and Main Fork of the Kaweah (see Appendix D for a diagram of gages and the formula used by SCE). The calculated value serves as validation that SCE is meeting the minimum flow requirement as defined in SCE's use permit. The accuracy of the calculated values compared to the historic measured values has not been quantified. Therefore, we determined that the data are not suitable for trend analysis. However, we are including the site in the hydrologic status reports because monitoring low flows and SCE compliance are important to SEKI.

### **2.3. Selected Measures**

Parameters selected for the river hydrology protocol reflect SIEN's overall approach to monitor resource condition by using parameters that most strongly affect or reflect ecosystem function and are sensitive to multiple stressors, including future and unknown threats.

Stage data are collected nearly continuously, usually at 15-minute intervals, at all streamgages. The stage data are used to calculate continuous discharge across the period of record, and discharge data are used to calculate hydrologic parameters that reflect the quantity and timing of streamflow (Table 6). Rating curves are used to convert stage measurements into discharge. To develop the rating curve, instantaneous discharge and stage measurements are collected simultaneously across a range of streamflows to establish the relationship between stage and discharge. After establishing the rating curve, stage and discharge measurements are collected periodically to improve and update the rating curve. The mean daily and mean annual discharges are calculated from the continuous record of 15-minute stage data.

**Table 6.** Hydrologic parameters measured or calculated for SIEN reports.

| <b>Parameter</b>                                                       | <b>Measured or Calculated</b> | <b>Procedure</b>                                                                                                                             |
|------------------------------------------------------------------------|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Water level                                                            | Measured                      | Collected by logger at 15-minute intervals                                                                                                   |
| Instantaneous discharge                                                | Measured                      | Direct measurement, salt solution, dye tracer, or indirect measurement by survey of the cross section (1 to 15 measurements annually)        |
| Mean daily discharges                                                  | Calculated                    | Calculated using 15-minute discharge                                                                                                         |
| Instantaneous peak discharge                                           | Measured or Calculated        | Projected from rating curve to match the peak water level and/or measured using discharge measurement methods                                |
| Mean and total annual discharge                                        | Calculated                    | The annual total is the sum of the daily means (for the water year) and the "mean annual" is the total divided by 365 (or 366 in leap years) |
| April, May, June, July percent of annual flow (AMJJ/Annual)            | Calculated                    | Total discharge measured during April – July / Total discharge for the water year                                                            |
| Days to runoff center of mass (CM – also referred to as Center Timing) | Calculated                    | The number of days from the beginning of the water year (Oct 1) to the date when half the total annual water year discharge has occurred     |
| Days to onset of snowmelt                                              | Calculated                    | The number of days from January 1 to when the cumulative departure from the mean flow is most negative. See Lundquist et al. (2004).         |
| 3, 7, 10, and 14 day high flow                                         | Calculated                    | The highest mean daily flows over 3, 7, 10 and 14 consecutive days (within the water year – Oct 1 to Sept 30)                                |
| 3, 7, 10, and 14 day winter and summer low flow                        | Calculated                    | The lowest mean daily flows over 3, 7, 10 and 14 consecutive days.<br>Winter = December through February<br>Summer = July through September  |
| Days from Oct 1 to the winter and summer 7-day low flow                | Calculated                    | Count of days to the summer 7-day low flow                                                                                                   |
| Days from Oct 1 to 3-day and 14-day high flow                          | Calculated                    | Count of days to the 3 and 14 day high flows                                                                                                 |
| Water temperature                                                      | Measured                      | Collected by logger at 15-minute intervals                                                                                                   |
| Mean daily and mean annual water temperature                           | Calculated                    | Calculated using 15-minute temperature data                                                                                                  |
| Daily and annual minimum and maximum water temperature                 | Calculated                    | Calculated using 15-minute temperature data                                                                                                  |

Water temperature data are also collected continuously, usually at 15-minute intervals. Mean, minimum, and maximum water temperature statistics are calculated from these data.

All parameters are based on the water year (WY) – October 1 through September 30. Some parameters, such as peak snowmelt runoff and center timing, are reported in number of days from the start of the water year and others, such as days to onset of snowmelt, are reported as the number of days from the start of the calendar year.

Stage and discharge measurements will be recorded and reported in English units, which is the USGS standard. Temperature will be reported in Celsius. Guidance on measurement precision and reporting accuracy is included in the Quality Assurance Plan (SOP 10).

## **2.4. Power and Trend Analysis**

Starceвич and Kane completed a trend and power analysis using historic data from two long-term streamgages in SIEN (see Appendix C). The report examines long-term trends for 18 calculated hydrologic parameters on the Kern and Merced Rivers. Status, trend, and variance component estimates from the long-term data were used to conduct a power analysis. Power analysis provides a reality check on project goals and objectives and an *a priori* understanding of the ability and confidence with which one can detect trends over time. Power analysis results provide guidance for future trend analyses and interpretation of results. Plots of the historic data from the two stations indicate that some of the metrics have substantial year-to-year variation that can differ between rivers.

### **2.4.1. Methods**

Trends were examined using the t-test derived from a linear mixed model for trend (VanLeeuwen et al. 1996, Piepho and Ogutu 2002), the Kendall tau-b test (Higgins 2004), and a reduced ordinary least squares (OLS) model. The power of the parametric and nonparametric trend tests is examined with a Monte Carlo power simulation. The most recent estimates of status and estimates of residual error from the individual river analyses are used with the year-to-year variation estimates from the across-river analyses to simulate the populations of interest under known levels of trend. Note that variance components are taken from different trend analyses so that total variance may be overestimated. This approach is considered conservative but useful given the large impact of the year-to-year variation on the power to detect trend (Urquhart and Kincaid 1999). The simulated data are combined with the historic data for a complete data record for the trend test, but trend is imposed only on the simulated data. Simulated trends showed increases, except in cases where the historic data indicated a significant decreasing trend. The two-sided parametric and nonparametric trend tests are conducted and compared against a Type I error level of 0.10. A total of 1,000 iterations are used to assess the power of each test as the proportion of times the test results in a correct rejection of the null hypothesis.

### **2.4.2. Results**

Trend test results are discussed in-depth in Appendix C. Overall, trends in the eighteen metrics describing flow conditions in the Merced and Kern Rivers were detectable with at least 80% power within a reasonable monitoring period. If an increasing annual trend of 1% is observed during the next 100 years, the power to detect this trend would exceed 80% within 20 to 40 years for most outcomes. An annual trend of 4% would be detected with at least 80% power in no more than 20 years for all of the outcomes examined. Only the outcome measuring percent of total flow occurring between April and July exhibited high power for both rivers. None of the other outcomes consistently performed with higher or lower power than the rest. Power for the Kendall tau-b test of trend is generally higher than that of the linear mixed model when the residual variation is relatively large for an outcome.

### 3. Field Methods

This protocol uses data from existing stations for analysis and reporting. Most stations are operated by other entities and a select few will be supported by a combination of SIEN staff, park staff, and cooperators. This chapter addresses methods to be performed at the SIEN-supported sites, including periodic visits to perform discharge measurements, station improvements and regular maintenance, safety considerations, and procedures for QA/QC of data. These procedures are presented in greater detail in each of the SOPs (Table 7). The field SOPs were written by SIEN or adapted from previously published I&M protocols. There have been discussions within Water Resources Division (WRD) about developing standardized field protocols that I&M networks can adopt. If and when these SOPs are developed, SIEN will incorporate them into this protocol.

**Table 7.** Standard Operating Procedures pertinent to field operations.

| SOP | Title and Description                                                                                                                                                                                                                                                                                            |
|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     | <b>Procedures and Equipment for Station Visits</b>                                                                                                                                                                                                                                                               |
|     | The Procedures and Equipment for Station Visits SOP describes equipment maintenance, field visit procedures, post-visit activities, station improvements and maintenance, station surveys and datum corrections, and HOBO temperature logger visits.                                                             |
|     | <b>Methods for Streamflow Discharge Measurements</b>                                                                                                                                                                                                                                                             |
|     | The Methods for Streamflow Discharge Measurements SOP describes procedures for quantitative and semi-quantitative discharge measurements. These include direct measurements using a current meter, FlowTracker or acoustic Doppler current profiler (ADCP), salt dilutions, and the float method.                |
|     | <b>Safety Procedures</b>                                                                                                                                                                                                                                                                                         |
|     | The Safety SOP describes roles and responsibilities, training standards, backcountry travel, and field communication procedures. It describes basic river monitoring safety and provides checklists, Job Hazard Guidelines, contact information, and forms for personnel who are involved with field activities. |
|     | <b>Quality Assurance Plan</b>                                                                                                                                                                                                                                                                                    |
|     | The Quality Assurance Plan (QAP) describes quality assurance and quality control objectives and procedures. It covers measurement quality objectives, data generation and acquisition, and assessment and oversight.                                                                                             |

#### 3.1. Routine Station Visits to SIEN-supported Sites

The objectives of station visits are to record site conditions, download loggers, check recording equipment for drift, collect a discharge measurement, and perform site maintenance or improvement as needed. The DEPO site will be visited every 4-6 weeks year round. Station visits to the SIEN-supported stations in YOSE will not occur during the winter because the stations are too difficult to access in the snow. The station will be visited as late as safely possible in the fall, then as early as safely possible in the spring. During the snow free season, the stations will be visited approximately monthly.

Station visits begin with adequate preparation in the office, including inspection and preparation of equipment, evaluation of conditions, and other tasks, and end with proper maintenance and storage of data files and equipment. Figure 10 is a generalized work-flow of the tasks that should be completed prior to, during, and following a station visit and are based on instructions found in SOPs 3, 4, and 5.

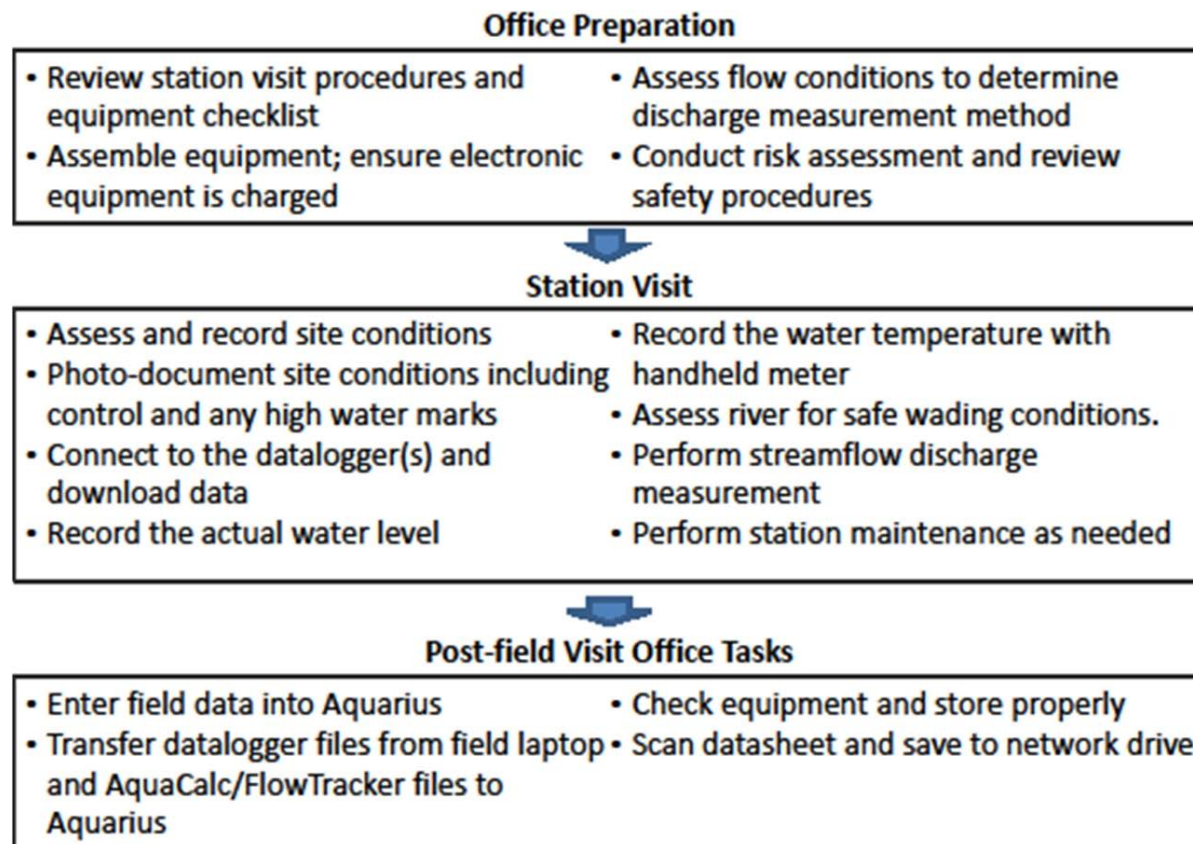


**Figure 10.** A generalized workflow for office preparation and procedures for streamgage station visits. See SOPs 3, 4, and 5 for more details. An overview is also described in the paragraphs below.

Office preparation includes assembly of field equipment and safety gear (SOP 3), review of safety procedures (SOP 5), and an estimation of flows at the site(s) to be visited. An estimation of flow is needed to determine the safest and most suitable method for discharge measurement (i.e., wading during lower flows or dye tracer during high flows). Although not all SIEN gages have real-time data available via satellite, it is possible to view some stations online to get a general sense of whether flows are rising, falling, or remaining steady. We can use data from these online gages to assess conditions at those that are not online because major rivers and tributaries exhibit similar streamflow timing throughout SIEN. For example, if the stage has been rising for multiple days at the Tuolumne River at Tioga Rd Bridge, it can be assumed that streamflow at the Lyell Fork station, which is further up in the watershed, would be too high for wading.

During station visits, the following actions will be performed:

- 1) Photo documentation of site conditions
- 2) Water level and discharge measurement
- 3) Instantaneous water temperature measurement for quality control checks of the continuous temperature sensor
- 4) Datalogger downloads
- 5) Maintenance or repair actions as needed

All streamgages that SIEN supports will record both stage and water temperature. Station visit procedures include an instantaneous measurement near the continuous water temperature sensor. The purpose of the instantaneous temperature measurement is not for analysis purposes, but rather to check for drift in the sensor and apply corrections to the continuous temperature data after it is uploaded to Aquarius (see SOP 7). Additional data to be recorded on the datasheet include information about the streamgage data download and streamflow discharge measurement data (see SOP 3).

### **3.1.1. Discharge Measurements**

During routine station visits, discharge measurements are performed and qualitative descriptions of the discharge measurement site such as cross-section and control conditions are recorded on the datasheet prior to the measurement. During any visit, selection of the appropriate method will depend on the site, water depth and velocity, and access conditions (see SOPs 3 and 4 for guidance on method selection). Each of these methods requires specific specialized equipment and procedures. For the most part, discharge will be measured quantitatively using established USGS procedures (Turnipseed and Sauer 2010). The primary quantitative methods that will be used at SIEN-supported sites include: i) salt dilutions, ii) dye tracer method, iii) wading, and iv) ADCP. Indirect and bridge board measurements are also available methods that could be considered if conditions warrant them. However, technical support will be required as it is beyond the scope of this protocol to describe these two methods. The most commonly used methods during safe wading flows are wading using vertical axis current meters (pygmy and Price AA), FlowTrackers, and salt dilutions. Dye tracers and the ADCP are used during high flows. Semi-quantitative discharge estimates may also be made using floats under extreme high flow conditions and indirect discharge measurements can be used to estimate discharge based on a surveyed high flow channel cross-section and the longitudinal slope of the channel. No estimate of subsurface flows will be done under this monitoring protocol.

For direct measurements, a cross-section of the stream is chosen and the stream is divided into panels or sections. The width, depth, and velocity of each section are then recorded and individual discharge measurements per section are computed. Total stream discharge is the sum of individual discharge measurements in each section and is recorded in  $\text{ft}^3/\text{s}$  or cfs. The current meter and FlowTracker measure velocity at a single point. Discharge measurements are based on the mean vertical velocity obtained from each measured section, which is derived from depth-integrated measurements within the vertical profile (Figure 11).

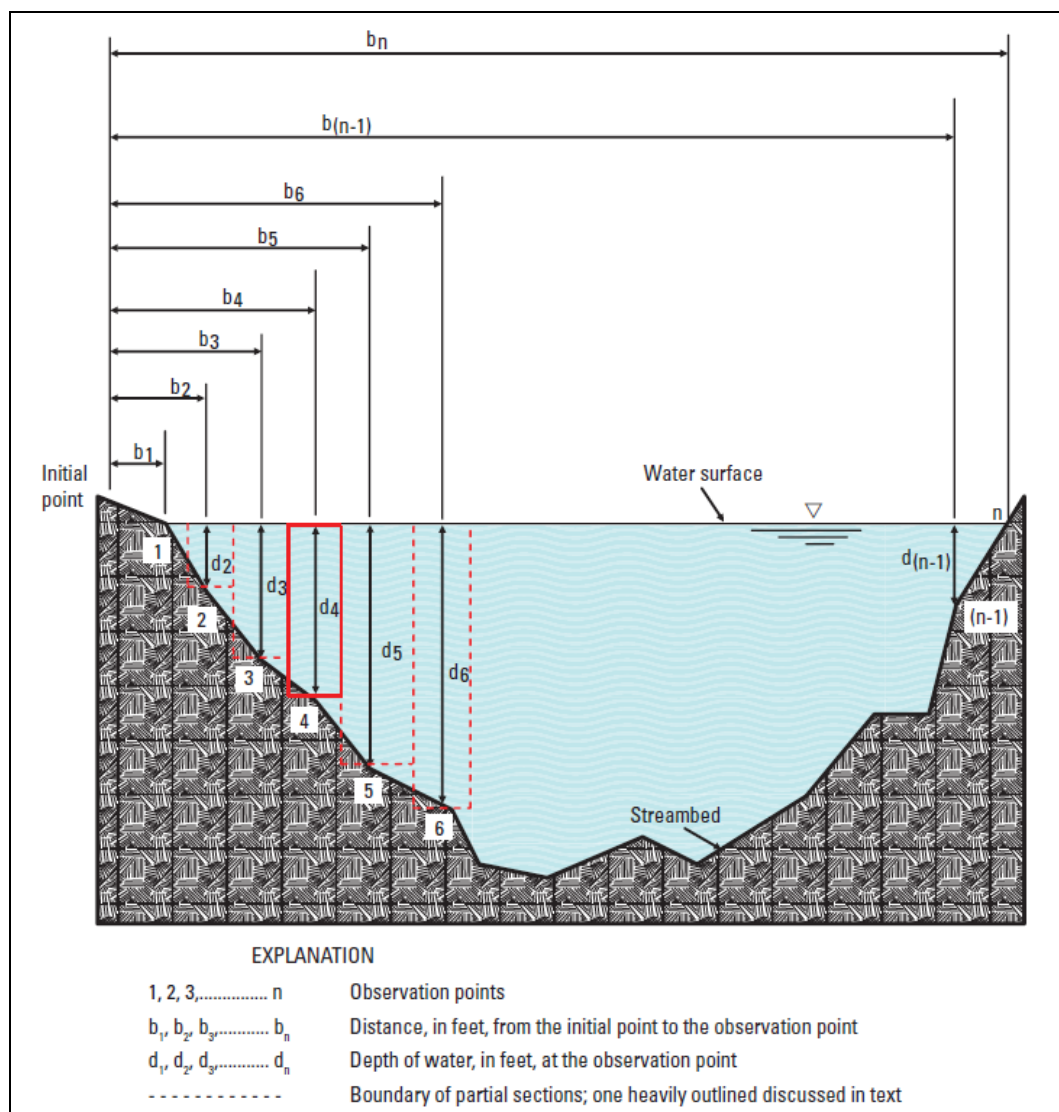


**Figure 11.** Definition sketch of the current meter midsection method of computing cross-section area for discharge measurements (Turnipseed and Sauer 2010).

For salt dilutions, we will be using the slug method (Moore 2004, 2005). A reach of stream is selected where the length is determined based on the estimated discharge (higher flows require a longer reach). A salt solution of known conductivity, is released into the river at the upstream location and the time is recorded. At the downstream location, the electrical conductivity of the river is recorded at periodic time intervals (e.g., 5 seconds) for the period of time required to capture the increase and subsequent decline in conductivity from the injected salt. The salt concentration, electrical conductivity measurements, and mass balance principles are used to calculate the discharge (Moore 2005).

The primary discharge method at DEPO will be wading measurements using vertical axis current meters with an AquaCalc data recorder. USGS will perform high flow measurements from a downstream bridge using acoustic Doppler methods. The primary discharge method at the Lyell Fork

of the Tuolumne will be salt dilutions due to the steep gradient and uneven stream bed (Appendix F). Wading measurements using the FlowTracker will be conducted one to two times per summer as a QA/QC comparison. The primary method at Tioga Bridge is wading using the FlowTracker during wadable flows and ADCP during high flows.

The water depth at the staff plate or reference point is measured prior to and following each discharge measurement (Sauer and Turnipseed 2010). The stage should be recorded multiple times during the discharge measurement if it is rapidly changing. Field personnel should be familiar with the measurement device sensitivities and accuracy associated with stage and velocity measurements as detailed in SOP 10. Each SIEN station has either a staff plate with permanent numbers from which the water level can be read from a distance as seen in Figure 12, or a marker from which the water level can be recorded by measuring down or up from the top of the marker (Figure 13). The white enamel staff plate in Figure 12 is not as compatible with the NPS wilderness requirements due to its high visibility; therefore a temporary post has been used at several stations until permanent low visibility markers can be approved and installed.



**Figure 12.** Typical staff gage with numerical gradations for reading water depth, the Tuolumne River at Tioga Road Bridge streamgage.



**Figure 13.** Temporary marker for measuring water depth at the Lyell Fork below Maclure streamgage.

## **3.2. Station Improvement and Maintenance**

### **3.2.1. SIEN-supported Stations**

Generally, SIEN streamgages consist of i) a datalogger, ii) a pressure transducer, iii) a marker or staff plate to manually measure water level, and iv) power for the station (usually a solar panel and trickle charge battery). See completed station descriptions on the SIEN network (J:\sien\monitoring\_projects\rivers\data\metadata) for current information on each of the SIEN-supported gages. The gages in the Tuolumne watershed that SIEN will be involved with also include continuous temperature sensors and satellites for real-time data transmission. During the initial years of implementation we will make improvements to stations to facilitate long-term operation. The primary improvements needed are the installation of permanent markers at each site to establish a datum and better infrastructure to secure the streamgage cables and sensors. The gage and staff plate, or reference marker from which water level is measured, are surveyed to the permanent marker when it is installed.

Periodic surveys are performed to determine the stability of the streamgage and corroborate any shifts that may have occurred to the stage-discharge relationship. Level surveys require at least two people, one of which must have experience with the methods that are detailed in Kenney (2010).

Periodic repairs and calibrations of station equipment will be performed as per manufacturer's recommendations.

Over time, we will need to repair or replace equipment at SIEN-supported stations. Many of our stations will experience freezing conditions; thus, we must utilize equipment that will work best in such conditions. Further, we must choose equipment that is of good quality, but not so expensive that we cannot afford to replace it periodically. There are many equipment options for stream gaging at a wide range of prices. Campbell Scientific dataloggers are widely used for streamgages and are the primary type used at SIEN stations. Campbell Scientific carries nearly all the equipment needed for a complete streamgage including pressure transducers and water chemistry sensors.

#### Permitting and Compliance

Permitting processes are required to ensure that our activities comply with park regulations and the Wilderness Act. The respective parks take the lead on permitting and compliance. The YOSE requirements involve i) submitting a research permit, ii) submitting a Minimum Requirements Analysis (MRA) and working with the park to modify our actions and the MRA until it is approved, and iii) inputting all information to the Planning, Environment and Public Comment (PEPC) database. The research permit is renewed annually. DEPO's compliance process is through SEKI and primarily involves submitting an MRA. Annual research permits are not required by DEPO for internal NPS projects.

#### **3.2.2. *Water Temperature***

Water temperature is measured by collaborators at seven of the 14 stations and by SIEN at the three SIEN-supported stations (Table 4). To increase temperature monitoring across the network, we have installed HOBO temperature loggers at an additional two non SIEN-supported stations (Table 4), where the operator has agreed to allow a temperature logger to be added.



## 4. Data Collection and Acquisition

This protocol relies upon data that are i) collected at SIEN-supported stations and ii) collected by other operators and then acquired by SIEN. Here, we describe the types of data that are collected or acquired and summarize the collection and acquisition procedures. SOPs 6 and 7 contain detailed procedures for acquiring and managing data from cooperators.

Data used for analysis and reporting will come from multiple sources that fall into three general categories: data collected at streamgages supported by SIEN, data downloaded from the USGS National Water Information System (NWIS) server, and data obtained through an annual request to another agency, contractor, or researcher. The data sources and the kinds of data they provide are briefly summarized below. Acquisition processes for current and historic data for the protocol's 14 streamgages are presented in Table 8.

SIEN-supported gages in Yosemite (DEPO data are managed by USGS and acquired by SIEN through NWIS):

- 15-minute stage and water temperature data downloaded from dataloggers during station visits
- Instantaneous discharge measurements collected during station visits
- Instantaneous stage and temperature data collected during station visits (used to calibrate equipment drift)
- Level survey data

Data downloaded from NWIS for stations operated or reviewed by USGS (seven stations) (note that some, but not all, SCE station records are reviewed and published to NWIS):

- Daily mean discharge
- Annual peak discharge
- Annual instantaneous low flow
- Water temperature data (where available)

Data obtained by annual request from stations operated by other agencies, contractors, or university researchers (five stations):

- Daily mean discharge
- Annual peak discharge
- Annual instantaneous low flow
- Water temperature (where available)

**Table 8.** Streamflow gaging stations, operators, and data retrieval processes.

| Station                                      | Operator(s)                                                  | Historic Data Source                                                                                | Process for Acquiring Current Data                          |
|----------------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| Tuolumne River above Hetch Hetchy            | USGS (funded by HHWP)                                        | NWIS                                                                                                | Download from NWIS                                          |
| Tuolumne River @ Tioga Rd Bridge             | YOSE, SIEN                                                   | Jessica Lundquist (Univ. of Washington) will send 15-minute, daily means, and rating curves to SIEN | Sites operated and data managed by YOSE and SIEN            |
| Lyell Fork of the Tuolumne below Maclure Cr. | SIEN                                                         | Dave Clow (USGS) will send 15-minute, daily means, and rating curves to SIEN                        | Sites operated and data managed by YOSE and SIEN            |
| Falls Creek                                  | HHWP                                                         | 1915-1983 from NWIS                                                                                 | HHWP will send data to SIEN (annually)                      |
| Merced River @ Pohono Bridge                 | USGS                                                         | NWIS                                                                                                | Download from NWIS                                          |
| Merced River @ Happy Isles                   | USGS                                                         | NWIS                                                                                                | Download from NWIS                                          |
| South Fork Merced River at Wawona            | Sierra Hydrographics (funded by MID)                         | 1958-1968 from NWIS                                                                                 | Sierra Hydrographics will send data to SIEN (annually)      |
| Middle Fork of the San Joaquin in DEPO       | USGS, DEPO, SIEN                                             | NWIS                                                                                                | Download from NWIS                                          |
| Kern River near Kernville                    | SCE                                                          | NWIS                                                                                                | Download from NWIS                                          |
| Kaweah River Middle Fork near Potwisha       | SCE                                                          | SCE                                                                                                 | SCE Hydrographer will send data to SIEN (annually)          |
| Kaweah Marble Fork above Tokopah Falls       | USGS and UC                                                  | UC (PIs: Melack and Sickman) will send daily means to SIEN                                          | UC (PIs: Melack and Sickman) will send data to SIEN         |
| Kaweah River Marble Fork at Potwisha         | SCE                                                          | SCE                                                                                                 | NWIS                                                        |
| Kaweah River – East Fork                     | SCE                                                          | NWIS                                                                                                | Download from NWIS                                          |
| The Kings River at Cedar Grove               | Kings River Watershed Assoc. and CA Dept. of Water Resources | Not applicable                                                                                      | Kings River Water Assoc. will send data to SIEN (annually). |

A general overview of the data types, acquisition, collection, and processing is illustrated in Figure 14. Much of this program's data management occurs within the multi-faceted Aquarius software platform which is explained in the following chapter and SOP 7. Data from the Tuolumne streamgages supported by SIEN will include river stage and water temperature recorded at 15-minute intervals by automated dataloggers and instantaneous discharge measurements collected during periodic station visits. In the field, continuous data are downloaded from the datalogger to a mini-laptop computer. Instantaneous flow measurement data are recorded digitally by the AquaCalc,

FlowTrackers, and ADCP, and, as a back-up, are also recorded on a paper data sheet. Salt dilution data are recorded on field data sheets. Upon return to the office, the files from the laptop, AquaCalc, and/or FlowTracker are transferred to the SIEN file server and stored as read-only versions. Salt dilution data are entered from field data sheets to an Excel spreadsheet. The data are uploaded, edited, and stored in Aquarius (software and database used by SIEN – see Section 5).

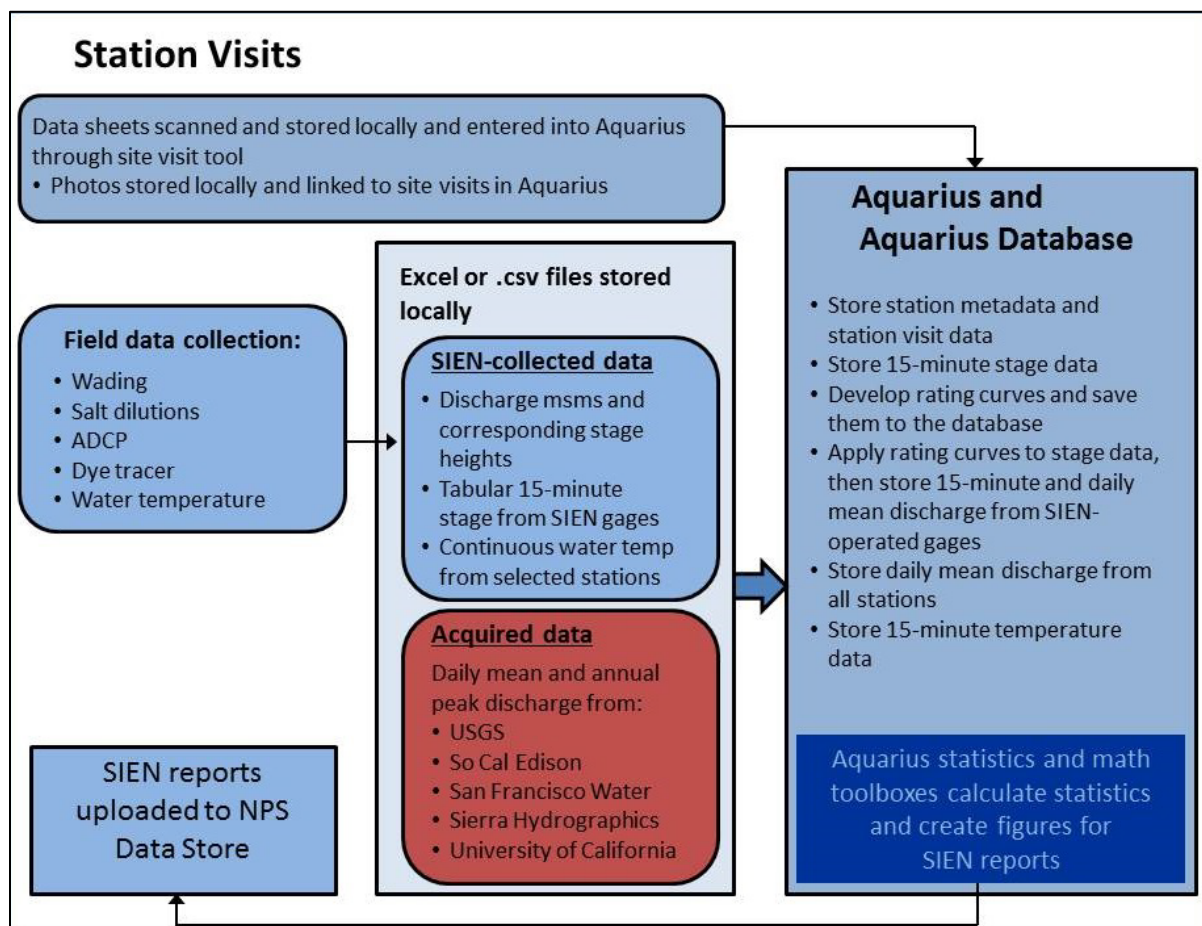


**Figure 14.** Representation of data sources, types, processing mechanisms, and storage locations used for this protocol. An overview is also provided in the paragraphs before and after this image.

The records from all stations that the USGS operates or reviews are available online through NWIS. We will use the Representational State Transfer (REST) service provided by the USGS Daily Values Site Web Service to acquire data from NWIS. The REST service accepts a query in the form of a URL and returns a data set based on conditions and filters that specify the path to the data, the station of interest, the desired statistic, and the start and end dates of the data you are seeking. The data are returned in WaterML1.1 (an XML schema) by default, a format that can be displayed and manipulated in Aquarius. Because the query is executed on the fly the data are always the most recent version. These procedures are described in SOP 6.

Data from stations operated by other agencies, contractors, and universities that are not available through NWIS are obtained by request from the operator. Contact information for operators is in SOP 1. Initially, all historic data are acquired, imported, and saved to the database. In subsequent years, only data from the most recent water year are requested. These data are acquired as Excel files that are saved as comma separated values (.csv) files and imported into Aquarius. Aquarius provides the ability to define the structure of the imported data and easily save it to the Aquarius database. Data from several of the stations are posted to the CDWR online data repository, the California Data Exchange Center (CDEC). The CDEC site posts data in real time to provide information to water users throughout the state. These data are qualified as preliminary and should not be acquired by SIEN. Rather, SIEN will acquire a quality checked data set from the operator of each station. SOP 6 includes instructions for requesting data, naming and saving the files locally. SOP 7 includes instructions for importing and managing the files within Aquarius.

## 5. Data Management

This chapter describes our general approach to data management and outlines the data management procedures that take place after data have been collected by SIEN or acquired from other station operators. The best way to understand this process is by examining the data management life-cycle illustrated in Figure 15. Individual elements of the data management life-cycle are described in more detail in the Standard Operating Procedures listed in Table 9. There have been discussions within WRD about developing standardized data management protocols that I&M networks can adopt. If and when these SOPs are developed, SIEN will incorporate them into this protocol.

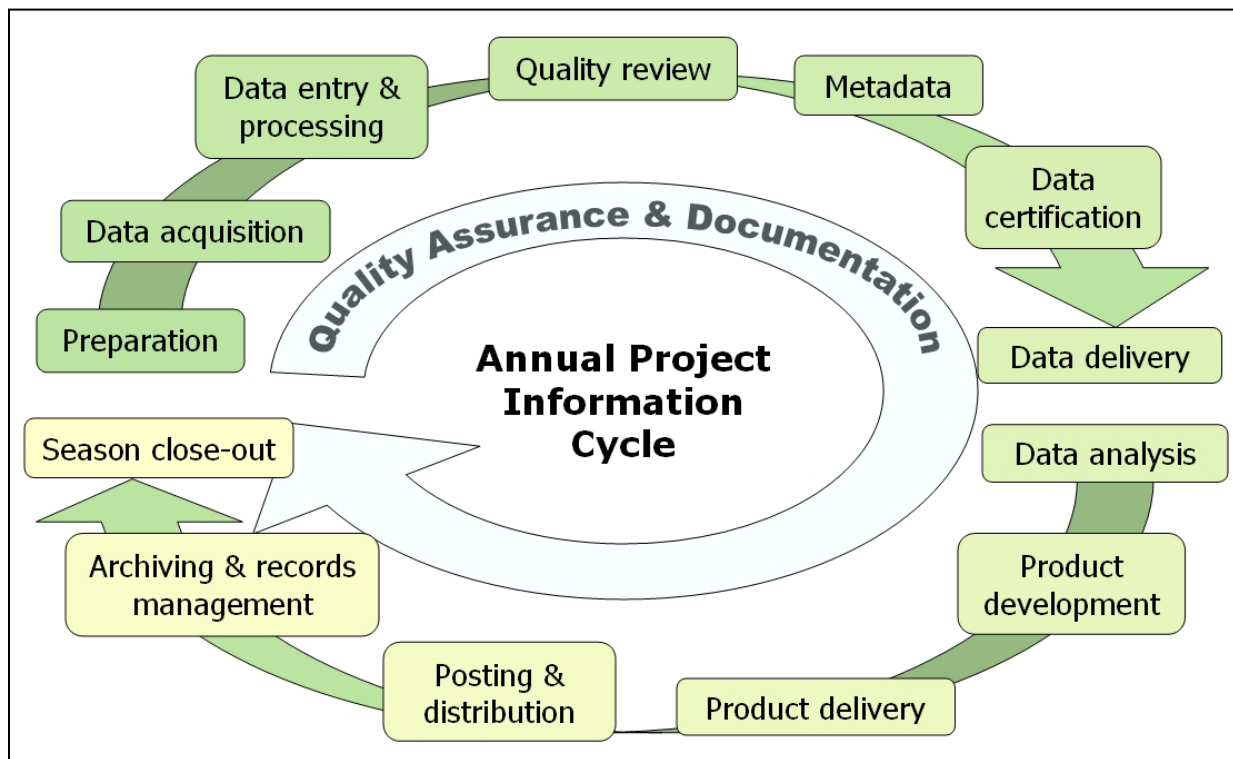


**Figure 15.** Steps in the data and project information cycle from data acquisition to archiving. Figure from the North Coast and Cascades Network (Siegel et al. 2007).

A standardized, systematic approach to data management is an essential part of any monitoring program. The objectives of data management are to ensure that data are stored and transferred accurately, secured from loss or damage, and made available to decision makers in a timely and understandable manner (Peterson et al. 1995). In order for this program to meet these objectives, a management plan is needed to ensure data quality, interpretability, security, longevity and availability. The SIEN Data Management Plan (Cook and Lineback 2008) describes the network's approach to data management.

**Table 9.** Standard Operating Procedures pertinent to data management activities.

| SOP | Title and Description                                                                                                                                                                                                                                                                                                                                                                                          |
|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     | Acquiring Streamflow and Temperature Data from Streamgage Operators                                                                                                                                                                                                                                                                                                                                            |
|     | This SOP contains procedures for acquiring summarized streamgage and temperature data for those stations that are not supported by SIEN.                                                                                                                                                                                                                                                                       |
|     | Data Management                                                                                                                                                                                                                                                                                                                                                                                                |
|     | This SOP includes an introduction to the Aquarius software and database and explains how Aquarius will be utilized for many of the data management procedures associated with this protocol. It includes instructions for entering field data, importing tabular time series files, correcting time series data, establishing and managing rating curves, and applying rating curves to continuous stage data. |
|     | Quality Assurance Plan                                                                                                                                                                                                                                                                                                                                                                                         |
|     | The Quality Assurance Plan describes quality assurance and quality control objectives and procedures. It covers an overview of data management, documentation, records management and review.                                                                                                                                                                                                                  |

Data take on different forms during various phases of a project, and are maintained in different places as they are acquired, processed, documented, analyzed, reported, and distributed. Here, we outline the data management activities and the software used to store and process data for analyses and summary reports. Effective data management requires a comprehensive project information management strategy that is detailed and structured within an annual cycle, designed for refinement as needed, and is sustainable throughout the lifecycle of the protocol. Primary responsibility for this project's information management resides with the SIEN Physical Scientist and Data Manager, but is not effectively implemented without the assistance of other network and park staff and cooperators.

### **5.1. Aquarius Software and Database**

The Aquarius software and database used by the SIEN river hydrology monitoring protocol reside on servers located in Lakewood, CO and managed by the NPS-WRD. The Aquarius software is accessed via remote desktop connection (Windows Terminal Services) to a server that hosts WRD's five concurrent-user license. There are two platforms within Aquarius, Springboard and Whiteboard, that can be used to access the Aquarius database. Springboard is the primary platform we will utilize and Whiteboard will be used for a few specific tasks where it performs better. Implemented within Microsoft SQL Server, the Aquarius database is based on Aquatic Informatics' proprietary schema that is optimized to handle continuously collected data. The schema is available from WRD and Aquarius and also stored locally on the SIEN network (J:\sien\monitoring\_projects\rivers\data\tabular\Aquarius\schema). In the event that Aquarius software is no longer available (e.g., they go out of business) the data can be accessed via an application programming interface (API) (Luce and Holden 2009, Aquatic Informatics Inc. 2016b, a). The NPS Aquarius system is managed by WRD's Data Manager (currently Dean Tucker - Dean\_Tucker@nps.gov). He and NRSS IT staff are responsible for archiving and backup procedures. NPS specific introductory/overview documents and videos can be accessed at <http://nrdata.nps.gov/programs/water/Aquarius/AquariusVideos.htm>.

Aquarius (<http://aquaticinformatics.com>) is a software platform designed to simplify the management and analysis of time-series data. It consists of Aquarius Server for managing data and Aquarius Workstation, for data processing. Springboard, the primary user interface SIEN will use to access the Aquarius Server, provides tools to import and store gaging station metadata, record and annotate field sampling events, manage associated time series data sets, and develop, maintain, and apply rating curves. SIEN will also utilize tools available via the Whiteboard interface to calculate hydrologic statistics. Aquarius Server automation allows the user to set up different types of notifications such that user-defined rules or automatic notifications and alerts can be issued. Aquarius Server also controls the user's interaction with the Aquarius database. The Aquarius Data Portal provides a mechanism to furnish approved time series data to the public via the Internet.

Aquarius's central concept is the monitoring location, to which time series, rating curves, field visit information, and other data are attributed (Figure 16). Each monitoring location has associated metadata such as geospatial data, information about benchmarks at the gage, and equipment. All time series data must be associated with an established monitoring location. Stations and associated data and metadata within Aquarius are accessible to other park and network Aquarius users. This will allow for comparison and data sharing among all the NPS units, with associated metadata stored in the same system.

AQUARIUS Springboard - Internet Explorer

http://np2300fcvgett1/AQUARIUS/Springboard/Default.asp

AQUARIUS Springboard

Location Folders

- All Locations
- Recent Locations

- Gulf Coast Network
- Heartland Network
- Kaloko-Honokohau National Hist
- Klamath Network
- Mid-Atlantic Network
- Mojave Desert Network
- National Capital Region Network
- North Cascades National Park
- Northeast Coastal and Barrier Ne
- Northeast Temperate Network
- Northern Colorado Plateau Netw
- Northern Great Plains Network
- Pacific Island Network
- Point Reyes National Seashore
- Presidio of San Francisco
- Redwood National Park and State
- Rocky Mountain National Park
- Rocky Mountain Network
- San Francisco Bay Area Network
- Shenandoah National Park
- Sierra Nevada Network
- Sonoran Desert Network
- Southeast Alaska Network
- Southeast Coast Network
- Southern Colorado Plateau Netw
- Southwest Alaska Network
- Upper Columbia Basin Network
- Upper Delaware Scenic and Recr
- Whiskeytown National Recreation
- Wind Cave National Park
- Yosemite National Park
- My Locations

Locations

Drag a column here to group by that column

| Location Identifier           | Location Name                                                                | Location Type          | Folder            |
|-------------------------------|------------------------------------------------------------------------------|------------------------|-------------------|
| DEPO_SCRIPPS_Wx_station       | DEPO_SCRIPPS_Wx_station                                                      | Meteorological Station | Climate           |
| SIEN_SEQU_KAWEEAFK_C          | East Fork Kaweah - Combined Flows                                            | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KAWEEAFK_D          | East Fork Kaweah Diversion                                                   | Canal Drainage         | Rivers Monitoring |
| SIEN_SEQU_KAWEEAFK_R          | East Fork Kaweah River                                                       | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_TUOLFACK            | Falls Creek                                                                  | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KERNKERN            | Kern River Near Kernville                                                    | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KERNKERN_C          | Kern River near Kernville, combined flows of Kern River and Kern River No. 3 | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_TUOLLYFK            | Lyll Fork of the Tuolumne below Maclure Creek                                | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KAWEMATO            | Marble Fork Kaweah above Tokopah Falls                                       | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KAWEMAPO_R          | Marble Fork Kaweah at Potwisha - Calculated                                  | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KAWEMAPO_R_Historic | Marble Fork Kaweah River at Potwisha-Measured Historic                       | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_MERCHISC            | Merced River above High Sierra Camp                                          | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_MERCPBR             | Merced River at Pohono Bridge                                                | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_MERCHAIS            | Merced River Happy Isles Gaging Station                                      | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KAWEMIFK_C          | Middle Fork Kaweah combined flows                                            | River/Stream           | Rivers Monitoring |
| SIEN_SEQU_KAWEMIFK_D          | Middle Fork Kaweah Diversion                                                 | Canal Transport        | Rivers Monitoring |
| SIEN_SEQU_KAWEMIFK_R          | Middle Fork Kaweah near Potwisha                                             | River/Stream           | Rivers Monitoring |
| SIEN_DEPO_SAJOMIFK            | Middle Fork of the San Joaquin at DEPO                                       | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_MERCSFRK_Historic   | South Fork Merced - Historic                                                 | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_MERCSOFK            | South Fork of the Merced at Wawona                                           | River/Stream           | Rivers Monitoring |
| SIEN_YOSE_TUOLHEHE            | Tuolumne River above Hetch Hetchy                                            | River/Stream           | Rivers Monitoring |

Visits Log

No location selected

Total locations: 920

About Logged in: Ichow

AQUARIUS TIME-SERIES™ SOFTWARE

**Figure 16.** Screenshot of the Aquarius Springboard showing the starting point for establishing locations and uploading and managing data.

## **5.2. Data Processing and Storage**

As outlined in previous chapters, data are collected or acquired by SIEN from a number of sources and in a variety of formats. After data have been acquired or collected, they are uploaded to the Aquarius database and processed using procedures specific to the data type in preparation for analysis and reporting. An overview of data processing procedures by data type is included here.

### **5.2.1. Stage and Discharge Data from SIEN-supported Gages**

Instantaneous discharge and stage measurements that are collected and continuous water level data that are downloaded during station visits are stored on the network drive as read-only files immediately upon returning to the office. Instructions for the file naming, file formats, and network file folder location are described in SOP 3. The instantaneous discharge and stage measurements are uploaded to Aquarius and used for rating curve development. The Data Correction toolbox is used to apply drift correction or remove outlying values. Aquarius preserves the original values and allows the user to turn on/off corrections as desired to produce final values. The standard procedures for the majority of the discharge data computations that SIEN will perform have been developed and published by the USGS in Rantz and others (1982), Kennedy (1983) and USGS (2006). These documents and other resources are located on the SIEN server at:

J:\sien\monitoring\_projects\rivers\Resources\ProtocolResourcesAndTraining.

### **5.2.2. Mean Daily Discharge from Streamgages Operated or Reviewed by USGS**

As described in the previous chapter, data from streamgages that are operated or reviewed by the USGS are posted to the USGS NWIS website. Mean daily discharge data are acquired directly from NWIS using the RESTful protocol service built into Aquarius version 3.5. (see SOP 1 for the sites and web links to the data and SOP 6 for detailed instructions on acquiring the data). Stations created in Aquarius are linked to the corresponding station in the NWIS system. Aquarius retains the web-service link and accesses the data from the source system upon request. No further processing of the data will be required until they are analyzed along with SIEN-collected data.

### **5.2.3. Mean Daily Discharge from Other Streamgage Operators**

Mean daily discharge data are acquired and stored as read-only Excel spreadsheets following procedures described in SOP 6. The data are then saved as .csv files and uploaded to Aquarius using the Append Logger File Tool within Aquarius Springboard. When files are appended via the Aquarius Springboard, they are automatically saved in the database. The data do not require any further processing until they are analyzed along with SIEN-collected data.

### **5.2.4. Continuous Water Temperature Data**

Temperature data are uploaded to Aquarius in a similar manner as the 15-minute water level data (SOP 7). Upon upload, the data are linked to a station and any instantaneous measurements are input using the Site Visit toolbox. The Data Correction toolbox is used to apply drift correction or remove outlying values. Aquarius preserves the original values and allows the user to turn on/off corrections as desired to produce final values.

### 5.3. Metadata Procedures

Aquarius Springboard provides the ability to include some basic station metadata in the Location Manager. However, the database does not currently allow for entry of all metadata required by the Federal Geographic Data Committee (FGDC) Metadata Standard and the National Biological Information Infrastructure Biological Data Profile. Meeting these standards is prerequisite for uploading data to the NPS Data Store. Aquarius is working with the USGS to incorporate these metadata standards but the effort will take one to two years. In the interim, SIEN will develop an ArcGIS geodatabase that documents the locations of all the streamgages identified in this protocol. We will use the geodatabase to store FGDC compliant spatial metadata for each station. The geodatabase will be backed up by the SIEN Data Manager along with all SIEN data.

### 5.4. Quality Assurance and Quality Control

SIEN will follow data quality assurance and quality control objectives and protocols described in *SOP 10: The Quality Assurance Plan* to ensure scientific credibility. The ultimate success of a monitoring program depends on the quality of the data collected and used in decision-making. Quality assurance (QA) is the application of procedures that reduce bias and improve precision, accuracy, comparability, and sensitivity. The quality assurance procedure begins with study design, and is in place throughout data collection, analysis, integration, and storage (National Park Service 1992). Quality control (QC) is the application of specific procedures in sampling and analysis to ensure that precision and accuracy of results are built into the monitoring effort. Precision is the degree to which repeated measurements of a quantity vary from one measurement to another when no true change has occurred. Accuracy is the degree to which measurements differ from a true value (Peterson et al. 1995). Three factors influence the precision and accuracy of the measurements: i) the precision and accuracy of the measuring tools and instruments, ii) the abilities of the individuals using the tools, and iii) the care and attention with which the measurements are made under the variable conditions of day-to-day operations. Common problems encountered in long-term monitoring programs have been with data quality, consistency and comparability, and availability and accessibility (Shampine 1993). A quality assurance and quality control effort can effectively address these problems.

The NPS (1992) defines six procedures that are routinely applied:

- Use of consistent collection and analytical methods over time unless scientific and/or technological advances allow for improvements, so long as later data are still comparable with earlier data
- Use of equivalent monitoring equipment among different sites
- Use of consistent formats in field and laboratory data reporting and structure of files
- Use of procedures that maximize the capacity to integrate data sets with a minimum of manual data re-entry (GIS technologies)
- Maximum use of automated data handling techniques that ensure quick access to recently acquired data and ease of access to all data
- Use of existing and proven data collection protocols

The justifications for change in any specific steps employed in gathering data are driven principally by changes in precision and accuracy objectives (National Park Service 1992) and by scientific and technological advances. New methods are not to be employed merely for convenience or on the suspicion that they may improve data precision and accuracy. Instead, new methods are to be adopted when it has been determined that there is a need and/or opportunity for data with better precision and accuracy. At that point, change should be brought about by smooth transition between the old and new procedures in a manner that provides for continuity and comparability (National Park Service 1992).

A primary criterion in ensuring high data quality is consistent use of proven procedures, a process best ensured by hiring and retaining qualified and committed personnel (National Park Service 1992). Seasoned, committed personnel can detect situations that appear to deviate from the norm through familiarity with the indicators they are observing and an understanding of analytical procedures. Moreover, their observations or suspicions are often the keys in detecting the need for better procedures, or perhaps even in taking a new conceptual approach in data acquisition or research. Because seasoned personnel may not always be available, this protocol has detailed SOPs that explicitly describe the steps involved in collecting, processing, and analyzing the data so that anyone with a basic set of field skills can perform the field work without introducing large error or bias.

Our monitoring objectives focus on calculated measures, such as mean daily discharge, that are derived from field data. Therefore we must have confidence in the accuracy of the field data, and when there are periodic lapses in data quality, we must be able to document the departures and identify causation. The purpose of our quality assurance activities is to reduce measurement errors to agreed-upon limits and to produce results of acceptable and known quality. We drew upon information in the USGS Workbook on Surface Water Quality Assurance Plans (Schertz et al. 1998) to develop quality assurance measures relevant to the collection, processing, analysis, computer storage, and publication processes (see SOP 10).

Because this protocol relies on data harvested from sources other than our own direct collection, we will use established data providers whose data also meet SIEN standards. During our data analyses we will examine the mean daily discharge values for any obvious errors and communicate with the operators about any concerns. SIEN will acquire only finalized and approved data that have gone through each operator's quality control procedures. Data qualifiers are normally reported with results to inform readers of important restrictions or limitations to the data. Using reliable sources and carrying forward such qualifiers to the reporting audience allows us to avoid situations where the reporting audience could potentially misconstrue the levels of precision and inference conveyed by reported data. If project staff or report readers identify questionable results or become aware of changes to source data after a report is made, an assessment by project staff will determine whether it is necessary to re-do any or all of the analysis and reporting.



## 6. Data Analysis and Reporting

We will produce two types of reports for the hydrologic data collected or acquired through this protocol: i) a hydrologic status report produced on a biennial basis and ii) a comprehensive status and trend report produced every four years. Reports and the associated data are shared publicly through the NPS Integrated Resource Management Applications (IRMA) website (<https://irma.nps.gov/Portal>) and the SIEN website (<http://science.nature.nps.gov/im/units/sien/monitor/rivers.cfm>).

This section outlines the data summarization and analysis tasks specific to the hydrologic data collected at streamgages by SIEN and other organizations. Detailed procedures are included in SOP 8. Our intent is to rely on procedures from hydrologic literature and the USGS rather than to pursue new data analysis methods. We refer to the original documents for detailed analysis instructions rather than duplicate them in our SOPs. We particularly rely upon Andrews (2012) and Starcevich and Kane (Appendix C). The Andrews (2012) report was the product of a SIEN partnership with USGS Hydrologist Edmund Andrews where Dr. Andrews inventoried relevant hydrologic records (streamgages and snow courses) and performed trend analyses on all long-term records. The Starcevich and Kane report is a power analysis for detecting trends in streamflow in SIEN parks.

### 6.1. Data Summarization

Data summaries rely on mean daily discharge values for each station. Mean daily discharge values are available from our cooperators and are downloaded in this format from online sources (refer to SOP 1 for links). SIEN will calculate mean daily discharge for SIEN-supported sites as part of the analysis. In SIEN reports, summary information includes a hydrograph for each station, showing the mean daily discharge for the two water years being summarized as well as the median daily discharge over the period of record (Figure 17).

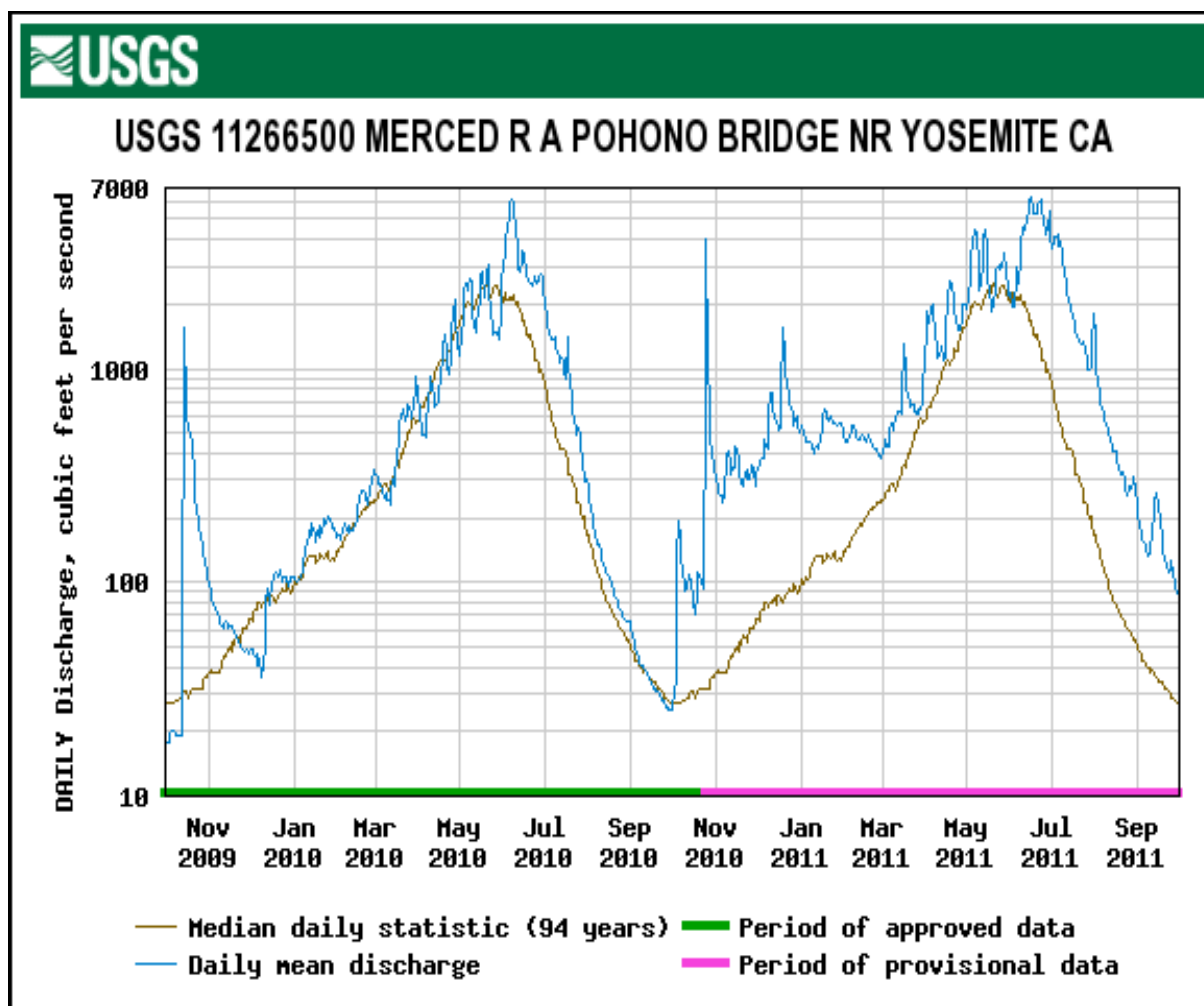


**Figure 17.** An example of a USGS hydrograph that will be included in the hydrologic status report. SIEN will only use approved data.

The mean daily discharge data are used to calculate additional summary parameters for each station (see SOP 8). These parameters are calculated for the two most recent water years and for the period of record and displayed in a format similar to Table 10. Extreme events, such as the maximum peak flow are reported with the date on which they occurred within each water year and throughout the period of record.

**Table 10.** An example of the summary statistics table in the hydrologic status reports. Included are values for current years and the full period of record. Some of the data below are fabricated for illustrative purposes. NA equals not applicable.

| Summary Statistics                                                                        | Water Year 2009 | Water Year 2010 | Period of Record<br>(Water Years 1917-2010) |
|-------------------------------------------------------------------------------------------|-----------------|-----------------|---------------------------------------------|
| Annual total discharge (cfs)                                                              | 247,079         | 266,961         | 179,566.1                                   |
| Annual mean discharge (cfs)                                                               | 677             | 731             | 627                                         |
| Highest annual mean (cfs)                                                                 | NA              | NA              | 1,466 in 1983                               |
| Lowest annual mean (cfs)                                                                  | NA              | NA              | 127 in 1977                                 |
| Highest daily mean (cfs)                                                                  | 4,380 on May 2  | 6,230 on June 7 | 21,000 on Jan 2, 1997                       |
| Lowest daily mean (cfs)                                                                   | 18 on Oct 1     | 18 on Oct 1     | 5.4 on Oct 26, 1977                         |
| Maximum peak flow (cfs)                                                                   | 6,900 on June 4 | 7,010 on June 7 | 24,600 on Jan 3, 1997                       |
| Annual seven-day minimum (cfs)                                                            | 19 on Sept 27   | 19 on Oct 1     | 5.6 on Oct 20, 1977                         |
| Annual seven-day maximum (cfs)                                                            | 1,200 on June 3 | 1,575 on June 2 | 14,100 on June 1, 1997                      |
| Number of Days to Snowmelt Onset                                                          | 161             | 155             | 166                                         |
| April, May, June, July discharge as a percent of the total annual discharge (AMJJ/Annual) | 65 percent      | 62 percent      | 71 percent                                  |
| Number of Days from Oct 1 to the Runoff Center of Mass                                    | 125             | 137             | 145                                         |

The following statistics are also calculated for each station and presented in separate tables:

- The 3, 7, 10 and 14-day winter and summer low flows and the dates on which they occurred.
- The 3, 7, 10, and 14-day high flows and the date on which they occurred.
- The number of days from October 1 to the 7-day winter and summer low flows.

Summary analyses also include calculation of low flow durations and flood frequencies, which use the full record of flows at a station to show the frequency at which a given discharge is observed. Flow duration and flood frequency figures will be included in the comprehensive status and trend reports. These analyses will occur every four years and we will examine and draw attention to how the curves may have changed since the previous analysis. Figure 18 shows the flood frequency plot for the Merced River at Pohono Bridge station which has a 96-year record. The peak discharge for each year is plotted with a symbol representing the season in which the peak flow occurred. This type of flood frequency plot is particularly valuable because it shows the reader what time of year the highest floods occurred. In this case, the highest floods occurred during the November to March (winter) season and were orders of magnitude larger than those floods that occurred during the

remainder of the year. By showing when these floods occurred, it is possible to infer that they were the result of large rainstorms because they did not occur during the snowmelt period. This information is particularly valuable for flood planning, but can also be used to determine whether large winter storms are becoming more common.

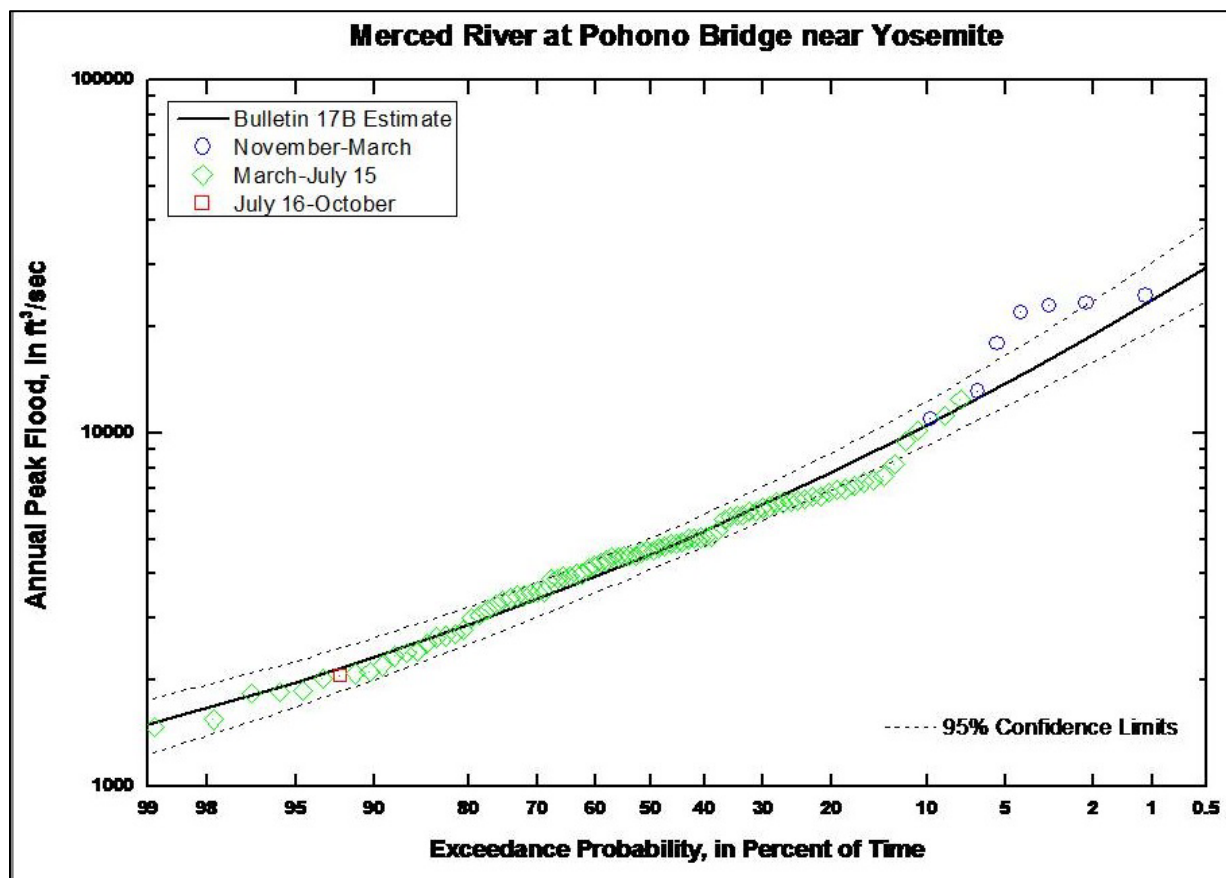


**Figure 18.** Flood frequency curve for the Merced River at Pohono Bridge streamgage.

## 6.2. Trend Analysis

The SIEN Physical Scientist will perform trend analyses on the yearly hydrologic parameters that are calculated as part of the comprehensive analyses. Andrews (2012) confirms the published findings of other broad regional studies that show lack of widespread significant trends in mean annual discharge (Pagano and Garen 2005, Luce and Holden 2009). However, stationarity in mean annual flow does not indicate stationarity in other descriptors of streamflow timing (Luce and Holden 2009). For this reason, we will examine trends in a variety of hydrologic statistics that are more descriptive of streamflow timing.

The first step in trend analysis is to plot the data that will be analyzed and visually examine them for apparent trends. While trends observed in the visual assessment step may not be statistically significant, they can provide an overview of how a parameter has changed over time. For example, if the smoothed trend lines hint that a trend has been up for 10 years and then down for 10 years, a

typical monotonic trend test might conclude “no trend” (Manly 2001). This conclusion might be less helpful to a resource manager than a conclusion that might result from looking at a simple plot of values vs. time.

There are several parametric, non-parametric, and mixed methods for hydrologic trend analysis. In preparation for this protocol, Starcevich and Kane (Appendix C) performed trend analyses for multiple statistics from two SIEN rivers and found that a parametric test may be significant at the 0.10 level when the nonparametric test is not significant and vice versa. For this reason and to add weight to any significant results, we will use more than one test when performing our trend analysis.

We will first conduct trend analyses with parametric tests if assumptions of normality are met as parametric tests typically provide higher power (Starcevich and Kane, Appendix C). We will use linear regression as described in Andrews (2012) and Starcevich and Kane (Appendix C) for single station trend analyses. Linear regression is considered a fundamental tool in the analysis of water-resources data (Helsel and Hirsch 2002) and can be a powerful method for detecting trend if the assumptions of the models are met (Starcevich and Kane, Appendix C). Linear regression is the process of fitting a straight line to a data set that consists of an explanatory (independent, predictor, or  $X$ ) variable and a response (dependent, predicted, or  $Y$ ) variable. We will use a linear mixed model, as described in the trend and power analysis, to examine trends for multiple stations and as a secondary parametric analysis for single stations (Starcevich and Kane Appendix C). A mixed model allows some effects to be considered fixed and some to be considered random. Fixed effects contribute to the mean of the outcome and random effects contribute to the variance. Random effects are used to estimate variation of linear trends among subjects (e.g., streams) and over time.

If assumptions for parametric trend tests are not met, nonparametric tests will provide a more powerful and robust approach (Starcevich and Kane, Appendix C). We will use the Kendall tau-b test as our primary nonparametric test for single stations per Andrews (2012) and Starcevich and Kane (Appendix C). The Kendall tau-b uses the ordinal nature of the year covariate and the ranks of outcomes of interest to find trends in the data. The Kendall tau-b is a rank test that uses the qualities of the ranks in the presence of no trend to assess trend as opposed to distributional assumptions. This method has been used by the US EPA (Kelly and Jett 2006) and by state natural resource agencies (Sargeant et al. 2011) to detect hydrologic trends. The Regional Kendall Test (Helsel and Frans 2006) is a nonparametric approach that can be used to assess the trends across multiple stations (e.g., park and network groupings). We will use this method when the assumptions for the mixed linear model are not met and as a secondary test for the linear mixed model when assumptions are met. In SOP 8, we discuss additional methods that the data analyst might consider particularly when interested in comparing SIEN data to other studies that have used different methods.

Finally, our data analysis will involve exploration of covariates as appropriate. We will use a step-wise linear regression of log transformed values of stream discharge (i.e., total annual) in a regression with the annual precipitation volume, or the percent of precipitation arriving in a given season within a watershed (i.e., AMJJ precipitation as a percent of the total annual precipitation). Other potential covariates may include, but are not limited to, snow water content at snow courses within each watershed and water temperature (from those streamgages where temperature is recorded

continuously). Precipitation and snow water content for nearby climate and snow course monitoring stations may be obtained from CDEC (<http://cdec.water.ca.gov/>).

### 6.3. Additional Hydrologic Analysis

Several of the streamgages selected for this protocol occur along an elevational gradient within watersheds (Table 11). These stations were installed along the elevational gradient and were selected by SIEN in part because the magnitude of observed and predicted hydrologic changes varies with elevation. Our exploratory data analysis will involve calculating the ratio of the contributing area to the mean annual, mean monthly or seasonal mean discharge at each gage. We will examine the variability of this ratio between years and between stations.

**Table 11.** SIEN watersheds containing streamgages located along an elevational gradient. Both watersheds are in YOSE.

| Watershed | Station name                                   | Elevation | Contributing Area    |
|-----------|------------------------------------------------|-----------|----------------------|
|           | Merced River at Happy Isles                    | 4,017 ft  | 181 mi <sup>2</sup>  |
|           | Merced River at Pohono Bridge                  | 3,862 ft  | 321 mi <sup>2</sup>  |
|           | Lyell Fork of the Tuolumne below Maclure Creek | 9,615 ft  | 6.0 mi <sup>2</sup>  |
|           | Tuolumne River at Tioga Road Bridge            | 8,583 ft  | 70.6 mi <sup>2</sup> |
|           | Tuolumne River above Hetch Hetchy              | 3,830 ft  | 301 mi <sup>2</sup>  |

### 6.4. Reporting

Hydrologic data will be analyzed and reported biennially in hydrologic status reports, as well as every four years in comprehensive status and trend reports (Table 12). Short two page resource briefs and summaries of the longer reports are published following the completion of each report. All reports will be published through the National Park Service's Natural Resources Report (NRR) series or Natural Resources Data Series (NRDS) and follow the respective review processes required for each series. The format for these reports and more detailed descriptions of the suggested content are included in SOP 9. Prior to publication, reports will be sent to those organizations whose data are included in the reports so they may have an opportunity to comment.

#### 6.4.1. Hydrologic Status Reports

Hydrologic status reports are prepared on a two-year basis. Park staff have agreed that this is an acceptable schedule and we feel it is more manageable than yearly reporting. Reports will be distributed to NPS WRD, network and park resource management staff, Resource Chiefs, Steering Committee members, and cooperators whose data is included in the report. Reports will also be made available to interested park staff and the public via the SIEN I&M web pages. Resource briefs will summarize the two-year hydrologic status report or may be produced more frequently to draw attention to any exceptional events.

These reports will include hydrographs and summary statistics tables for each water year and station. The reports will draw attention to any failures to comply with minimum flow permit requirements

and any extraordinary events such as multiple large winter storms or a particularly early or late snowmelt onset. SIEN produces annual climate reports, and we will include any climate information that may be relevant to streamflow results. Although these reports are produced on a biennial timeframe, the SIEN Physical Scientist will review the SCE records each spring and will report any failures to comply with minimum flow requirements to park management.

**Table 12.** Reporting schedule for river monitoring during the first six years. Schedule repeats with a trend report every four years and status report every two years.

| Report Type                                         | FY 2018                | FY 2019            | FY 2020                | FY 2021 | FY 2022                | FY2023             |
|-----------------------------------------------------|------------------------|--------------------|------------------------|---------|------------------------|--------------------|
| Hydrologic status report                            | For WYs<br>2016 & 2017 | —                  | For WYs<br>2018 & 2019 | —       | For WYs<br>2020 & 2021 | —                  |
| Comprehensive hydrologic<br>status and trend report | —                      | Through<br>WY 2017 | —                      | —       | —                      | Through<br>WY 2021 |

#### **6.4.2. Comprehensive Status and Trend Reports**

For trend analyses, it is common to wait until stream discharge records exceed 30 years so that decadal oscillations in precipitation (averages about 11 years) can be included in the analyses of flow. Our first trend report will be completed in FY 2019 and every four years thereafter. Although records of 30 years or more are preferred, stations with records of 15 years or more will be included in trend analyses. For the first trend report, three stations will not have long enough records to be included in the analyses, four will have records of at least 15 years, and six will have records longer than 30 years. The Marble Fork at Potwisha, will not be included in trend analyses because the precision of the calculated annual values is difficult to quantify (refer to Section 2.2.1). The station will be included in the hydrologic status reports, because it provides an accurate representation of the runoff timing in the Marble Fork Kaweah watershed in comparison to the Middle Fork Kaweah.

Flood and low-flow frequency analyses are included in comprehensive reports. However, when there is a long record, as with most of our stations, these distributions will change little with each year of additional data so these analyses will be included in every other report (every 8 years). The results from our trend analyses may identify areas of significant change that could be further examined through a more intensive modeling project. Modeling is a useful tool for understanding forcing mechanisms and identifying causality of trends. The report authors may also elect to include more detailed analyses as appropriate.



## 7. Personnel Requirements and Training

### 7.1. Roles and Responsibilities of SIEN staff

The SIEN Physical Scientist, as the Protocol Lead, will oversee protocol implementation, which includes providing technical assistance for SIEN-supported sites, communicating with station operators to acquire data each year, managing and analyzing associated data, assisting with agreements, and preparing reports and other products (Table 13). The SIEN Data Manager will be available for consult on data management and facilitate the data management life cycle. The SIEN Program Manager will assign budgets, supervise the Protocol Lead, manage associated agreements, and review associated products. Other park or network staff may periodically assist with field work.

**Table 13.** Assigned staff, specific responsibilities, and time estimates for River Hydrology Monitoring Protocol.

| Assigned staff and time requirement      | Responsibilities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SIEN Physical Scientist<br>8 pay periods | <ul style="list-style-type: none"> <li>• Project oversight and administration</li> <li>• Protocol updates and revisions</li> <li>• Install and download water temperature loggers</li> <li>• Provide technical support for SIEN-supported gages, includes periodic site visits</li> <li>• Ensure compliance with safety procedures for SIEN staff conducting field work</li> <li>• Communicate with and solicit data from non-SIEN station operators</li> <li>• Manage continuous stage data and including rating curves for SIEN-supported sites in YOSE</li> <li>• Maintain and archive project records</li> <li>• Perform data summaries and analyses</li> <li>• Complete reports, metadata, and other products</li> <li>• Assist with agreements</li> <li>• Every 4 yrs: Additional 2 PP for comprehensive status and trends report</li> </ul> |
| SIEN Data Manager<br>2 pay periods       | <ul style="list-style-type: none"> <li>• Consultant on data management activities</li> <li>• Facilitate review and posting of data, metadata, reports, and other products to national databases and clearinghouses</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| SIEN Program Manager<br>2 pay periods    | <ul style="list-style-type: none"> <li>• Project Lead oversight</li> <li>• Ensure Physical Scientist has received safety training, understands principles, and implements safety procedures</li> <li>• Budget and agreement administration</li> <li>• Consultant on all phases of protocol review and implementation</li> <li>• Review reports and other products</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

### 7.2. Annual Schedule of SIEN Responsibilities

Table 14 provides approximate timeframes for completing office and field work associated with this protocol. Certain tasks have specific timing, such as performing high flow measurements or acquiring data from the USGS in April after it has been finalized. Other tasks, such as ordering

equipment or performing data analysis, can be performed more opportunistically and during periods when it is most convenient for the SIEN Physical Scientist.

**Table 14.** Routine field and office tasks and approximate timeframe for completion (check-mark equals yes).

| Action                                                                                                                                          | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sept | Oct | Nov | Dec |
|-------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------|-----|------|-----|-----|-----|
| Prepare and submit research permits and MRA's (parks).                                                                                          | –   | ✓   | ✓   | –   | –   | –   | –    | –   | –    | –   | –   | –   |
| NPS responsible for DEPO site visits (once every 4 to 6 weeks).<br>USGS responsible Feb-Jun.                                                    | ✓   | –   | –   | –   | –   | –   | ✓    | ✓   | ✓    | ✓   | ✓   | ✓   |
| Review and perform QA/QC on summer field data. Update rating curves.                                                                            | ✓   | ✓   | –   | –   | –   | –   | –    | –   | –    | –   | ✓   | ✓   |
| Obtain data and update station descriptions from other station operators, format and upload to database                                         | –   | –   | ✓   | ✓   | ✓   | –   | –    | –   | –    | –   | –   | –   |
| Perform high flow measurements (parks and USGS)                                                                                                 | –   | –   | –   |     | ✓   | ✓   | –    | –   | –    | –   | –   | –   |
| Perform data analysis and compile status and trend reports (could occur any time after all data has been acquired and uploaded to the database) | ✓   | ✓   | –   | –   | –   | –   | –    | –   | –    | ✓   | ✓   | ✓   |
| Site visits for SIEN-supported sites in Yosemite (YOSE)                                                                                         | –   | –   | –   | –   | –   | –   | ✓    | ✓   | ✓    | ✓   | –   | –   |
| Download water temperature loggers                                                                                                              | –   | –   | –   | –   | –   | –   | –    | –   | ✓    | –   | –   | –   |
| Repair or order equipment – send current meters for calibration                                                                                 | –   | –   | –   | –   | –   | –   | –    | –   | –    | –   | ✓   | ✓   |

### 7.3. Roles and Responsibilities of Park Staff

A key component to the success of this protocol is involvement and support from park staff. Staff from YOSE and SEKI have and will continue to contribute to this project through participation in the water work group. YOSE and DEPO oversee operation of the three SIEN-supported sites, with assistance from SIEN (Table 15). YOSE's responsibilities include overseeing permits and compliance, site improvements for long-term operation, station maintenance, and field visits. DEPO's responsibilities include overseeing permits and compliance staff, operational communications with USGS, and field visits from mid-June through mid-February per the inter-agency agreement between NPS (DEPO and SIEN) and USGS. Parks also provide significant resource support by providing office and laboratory facilities.

**Table 15.** Park staff responsibilities and time estimates toward operation of SIEN-supported sites.

| <b>Staff Title and Time Estimate</b>                      | <b>Responsibilities</b>                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| YOSE Hydrologist<br>1 pay period                          | <ul style="list-style-type: none"> <li>• Participate in water work group</li> <li>• Oversees SIEN-supported sites in YOSE, includes supervision of hydrologic technicians</li> <li>• Provide technical support as needed, such as compliance, stabilization, and survey of sites</li> </ul>                                                                                                                                                                     |
| YOSE Field Lead<br>1 pay period                           | <ul style="list-style-type: none"> <li>• Oversees field operations of SIEN-supported sites in YOSE</li> <li>• Communicates status of sites, field visits, and data to SIEN Physical Scientist and YOSE Hydrologist.</li> </ul>                                                                                                                                                                                                                                  |
| YOSE Technicians<br>4 pay periods (total between 2 techs) | <ul style="list-style-type: none"> <li>• Oversees field operations of SIEN-supported sites in YOSE</li> <li>• Communicates status of sites, field visits, and data to SIEN Physical Scientist and YOSE Hydrologist.</li> </ul>                                                                                                                                                                                                                                  |
| DEPO Superintendent<br>0.5 pay periods                    | <ul style="list-style-type: none"> <li>• Agreement technical representative on USGS agreement</li> </ul>                                                                                                                                                                                                                                                                                                                                                        |
| DEPO Ecologist<br>2 pay periods                           | <ul style="list-style-type: none"> <li>• Participate in water work group</li> <li>• Coordinate and participate in DEPO streamgage visits, including management of field data sheets and AquaCalc files.</li> <li>• Train and supervise staff &amp; volunteers supporting data collection at the DEPO streamgage from mid-June through mid-February</li> <li>• Coordinate with the USGS when they conduct site visits, including wilderness tracking.</li> </ul> |
| DEPO staff & volunteers<br>2 pay periods                  | <ul style="list-style-type: none"> <li>• Support data collection at DEPO streamgage</li> <li>• Agreement administrative support</li> </ul>                                                                                                                                                                                                                                                                                                                      |

#### 7.4. Qualifications and Training

The SIEN Physical Scientist is responsible for overseeing implementation of the river protocol. We anticipate that the individual in this position will have met the basic requirements for a GS-11 Physical Scientist, which include a basic familiarity with field techniques, surface water data, data management, and data analysis. Training will include: i) field methods as outlined in Chapter 3, ii) rating curve development and use of the Aquarius software for data management and iii) data analysis methods for status and trend reports. Additionally, any SIEN staff who may assist with station visits will need to be familiar with all SIEN safety principles and procedures, including use of communication devices and the ability to safely navigate to backcountry stations (all SIEN stations are located adjacent to trails).

It is the responsibility of YOSE and DEPO to ensure that field staff, including volunteers and interns, are properly trained in field safety, emergency communications, winter backcountry travel, and river sampling, as applicable to their respective sites. SOPs 2 and 5 provide training requirements and river sampling safety procedures, but park staff are ultimately responsible for adopting the protocols or developing their own. Winter DEPO staff and volunteers, and any participating SIEN staff, will require specific training on safely conducting winter streamgage visits.



## 8. Budget and Implementation Schedule

The long-term annual budget for the River Monitoring Protocol is \$53,062 and includes SIEN staff salaries, contribution to USGS inter-agency agreement for DEPO station, equipment, and travel (Table 16). Every fourth year, the annual budget will increase by \$6,440 due to an additional two pay periods of Physical Scientist time spent on the comprehensive status and trend report. The long-term annual operations cost for river monitoring, excluding SIEN core staff salaries, is \$10,900. The budget includes equipment funds, start-up and long-term, that can be utilized to help support the parks with equipment needs. Equipment costs are higher in the first two years to account for start-up costs. Travel costs may be used for periodic site visits by the Physical Scientist, trainings, or to bring in outside technical expertise (e.g., NPS-WRD). Long-term travel costs are relatively low because trips to YOSE are often combined with other network responsibilities and may include inexpensive accommodations (i.e. camping and backcountry per diem). We will use one of the five NPS service-wide, concurrent-user licenses, which are administered by the WRD, for the Aquarius Software (Aquatic Informatics Inc. 2013); thus, we will not purchase this software. Costs that are absorbed at the program level include computers, vehicles, meeting-related travel, office supplies, and administrative support. Significant portions of the project resources are applied toward data management, primarily time from the Physical Scientist and Data Manager. As a consequence, approximately 52% of the total long-term monitoring budget is dedicated to data management, analysis, and reporting.

**Table 16.** Annual SIEN budget for river monitoring, including start-up costs for the first four years. Subtotals are provided for personnel and operations costs.

| Startup Costs (1st four years) |          |          |          |          |                          | Data Management |          |
|--------------------------------|----------|----------|----------|----------|--------------------------|-----------------|----------|
| Program Item                   | 2017     | 2018     | 2019     | 2020     | Long-term Annual Costs** | Time (%)        | Cost     |
| Personnel*                     | \$43,772 | \$43,772 | \$50,212 | \$42,162 | \$42,162                 | 80              | \$20,608 |
| Phys. Scientist (GS-11)        | \$27,370 | \$27,370 | \$33,810 | \$25,760 | \$25,760                 | 100             | \$7,080  |
| Data Manager (GS-11)           | \$ 7,080 | \$ 7,080 | \$ 7,080 | \$ 7,080 | \$ 7,080                 | —               | —        |
| Prog. Manager (GS-13)          | \$ 9,322 | \$ 9,322 | \$ 9,322 | \$ 9,322 | \$ 9,322                 | —               | —        |

\* Salary costs are based on 2012 wages and time estimates in Table 13. We do not include cost of living salary increases because they are unpredictable from year to year. We have accounted for and have strategies in place to accommodate personnel cost changes (e.g., from COLAs, step increases, staff turnover) at the program level where we have more flexibility.

\*\* Every 4th year, salary and total project cost will increase by \$6,440 due to the additional 2 pay periods of Physical Scientist time spent on the status and trends report. The long-term annual costs listed do not include the additional pay period.

**Table 16 (continued).** Annual SIEN budget for river monitoring, including start-up costs for the first four years. Subtotals are provided for personnel and operations costs.

| Startup Costs (1st four years) |          |          |          |          |                          | Data Management |          |
|--------------------------------|----------|----------|----------|----------|--------------------------|-----------------|----------|
| Program Item                   | 2017     | 2018     | 2019     | 2020     | Long-term Annual Costs** | Time (%)        | Cost     |
| Operations                     | \$11,820 | \$13,400 | \$10,900 | \$10,900 | \$10,900                 | —               | —        |
| Travel                         | \$400    | \$400    | \$400    | \$400    | \$400                    | —               | —        |
| Equipment                      | \$3,420  | \$5,000  | \$2,500  | \$2,500  | \$2,500                  | —               | —        |
| USGS DEPO agreement            | \$8,000  | \$8,000  | \$8,000  | \$8,000  | \$8,000                  | —               | —        |
| Total                          | \$55,592 | \$57,172 | \$61,112 | \$53,062 | \$53,062                 | —               | \$27,688 |

\* Salary costs are based on 2012 wages and time estimates in Table 13. We do not include cost of living salary increases because they are unpredictable from year to year. We have accounted for and have strategies in place to accommodate personnel cost changes (e.g., from COLAs, step increases, staff turnover) at the program level where we have more flexibility.

\*\* Every 4th year, salary and total project cost will increase by \$6,440 due to the additional 2 pay periods of Physical Scientist time spent on the status and trends report. The long-term annual costs listed do not include the additional pay period.

SIEN has been working with the parks over the last several years on maintaining the SIEN-supported sites and starting the transition to being compliant with this protocol. Full protocol implementation is scheduled to start in FY2017. The focus in FY2017 will be on fully implementing SIEN protocols at the three SIEN-supported sites and transitioning management of the YOSE data and rating curves to the SIEN Physical Scientist. FY2018 is the first year of reporting, and the focus will be acquiring and managing data from all sites and producing the first hydrologic status report. The first hydrologic status and trends report will be in FY2019.

NPS-WRD and SIEN identified improvements that will need to be made to the SIEN-supported stations. The timeline for these improvements are within the first two years of protocol implementation (2017 and 2018). In 2017, the first year of implementation, we will focus on transitioning the SIEN-supported gages. A good portion of this time will include addressing improvements identified by WRD and SIEN. An additional week of time was added to the Physical Scientists work load for the first two years of implementation (2017 and 2018) so ample time is allocated to address these recommendations. The recommendations are listed in SOP 3 (Table 3.2) and described in detail in the NPS-WRD technical assistance visit trip report (Appendix F).

### 8.1. Equipment Budget

SIEN is able to provide some financial support to the parks for equipment purchases and maintenance. Much of the necessary equipment is already owned by the parks and SIEN, because we are incorporating existing stations. The equipment already owned and in operation is listed in Table 17. Note that this table does not include the equipment owned by USGS and provided under the DEPO inter-agency agreement.

**Table 17.** Equipment already owned and in operation. Prices are included if available.

| <b>Equipment – already owned</b>                                     | <b>Owner</b>     | <b>Cost</b>     |
|----------------------------------------------------------------------|------------------|-----------------|
| Field mini-laptop                                                    | YOSE             | \$1,600         |
| Loggernet software for downloading data from Campbell gages          | YOSE             | \$600           |
| Handheld electronic water temperature meter                          | YOSE, DEPO       | \$500           |
| AquaCalc, plus AA meter and pygmy meter                              | USGS, SIEN       | \$3,700         |
| Flowtracker                                                          | YOSE             | \$7,000         |
| Personal Flotation Devices (\$100/ea)                                | YOSE, DEPO, SIEN | \$300           |
| Tag line tape                                                        | YOSE, DEPO       | \$200           |
| HOB0 Temp loggers & shuttle for DEPO, SEKI and YOSE                  | SIEN             | \$700           |
| Waders                                                               | YOSE, DEPO, SIEN | \$200           |
| Campbell logger, pressure transducer, and temperature sensor (1 set) | YOSE             | \$2,300         |
| Acoustic Doppler current profiler (ADCP)                             | YOSE             | 18,000          |
| MATLAB Software                                                      | YOSE             | —               |
| Survey equipment                                                     | YOSE             | —               |
| <b>Total cost of equipment already in operation</b>                  |                  | <b>\$34,850</b> |

We have identified additional equipment needed at the SIEN-supported stations (Table 18). A rhodamine sensor is listed as an item to purchase, but we are also considering renting one from USGS as we anticipate infrequent use. We have a long-term equipment budget of \$2,500/year to help support parks with replacement and maintenance of equipment. The strategy is to spend less than \$2,500 every year in order to save for larger purchases (e.g.; dataloggers) when needed. Ultimately, we have flexibility, because the equipment budget is managed at the SIEN program-level.

**Table 18.** Start-up equipment to be purchased.

| <b>Equipment</b>                                                      | <b>Cost</b>    |
|-----------------------------------------------------------------------|----------------|
| FlowTracker wading rod adapter (YOSE has FlowTracker and wading rods) | \$300          |
| Rhodamine sensor and logger (cost share with YOSE; total ~\$10,000)   | \$5,000        |
| Upfront repair and maintenance of existing equipment                  | \$3,000        |
| NIST thermometers (2)                                                 | \$120          |
| <b>Total Start-up Costs</b>                                           | <b>\$8,420</b> |

## **8.2. DEPO Streamgage**

DEPO has an interagency agreement with USGS to operate and report data from the DEPO streamgage. DEPO and SIEN will renew this agreement with USGS annually, equally sharing the agreement cost of \$15,200 per year (50% = \$7,600 per party). To reduce the annual agreement cost from the typical amount of ~\$22,000 per year, DEPO assumed responsibility for conducting field work from mid-June to mid-February each year. During this period, DEPO will perform discharge and water level measurements and communicate information about how ice may be affecting the gage to the USGS Hydrologist. SIEN will provide technical assistance and may periodically assist with field work. DEPO staff may also assist with high flow measurements during peak snowmelt runoff. The USGS is responsible for establishing and maintaining the site where they own the streamgage equipment. They will perform discharge and water level measurements from mid-February to mid-June, train DEPO and SIEN staff, ensure that DEPO and SIEN field visits meet USGS requirements, manage the data, rating curve, and station description, and post data to NWIS.

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## Appendix A. Important Data Sets, Monitoring Programs and Partnerships

During Phase I in the Vital Signs Program development (Mutch et al. 2004), the SIEN Physical Scientist Andi Heard, compiled “Evaluating Existing Water Resources Information in the Sierra Nevada Network for the Vital Signs Water Quality Monitoring Plan” (Heard and Stednick 2012). This document is an excellent compilation of historic data sets and monitoring programs. In this appendix, we have drawn from information in the above compilation, highlighted programs relevant to this protocol, and described other programs that began after 2005.

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

Bioassessment is an evaluation of the biological condition of a waterbody that uses biological surveys and other direct measurements of resident biota (macroinvertebrates, algae, diatoms) in surface waters. Data collected from bioassessments can be used to determine whether the biological health of the waterbody would meet expected conditions, if pollution and other water quality stressors were not causing an effect. Reference conditions define the biological assemblages expected under minimal human influence and are fundamental to a bioassessment program. Reference site surveys are necessary because they set objective and defensible benchmarks for attainment of ecological condition objectives, account for natural variation in expected biological assemblages in different physical settings across the state, and identify high quality watersheds to prioritize protection efforts. Reference program data can also be used to help define physical habitat expectations and help separate physical habitat impairment from water quality impairment.

To account for the large amounts of natural variation in the biology in California streams, reference sites are chosen from throughout the state. A subset of these sites must be sampled repeatedly over time to account for inter-annual variation at reference sites and support the ongoing development and refinement of biological and physical condition indicator scoring tools (MMIs, O/E models, tiering of condition expectations). A number of sites were surveyed in the greater Kaweah Watershed (in SEQU) as reference sites for the SWAMP program in summer 2011. Program website: [http://www.waterboards.ca.gov/water\\_issues/programs/swamp/](http://www.waterboards.ca.gov/water_issues/programs/swamp/).

***Long-term Research and Monitoring in the Tokopah Watershed:*** Over 25 years of monitoring has been conducted at several waterbodies in the Tokopah watershed, located in the upper Marble Fork of the Kaweah River Watershed in Sequoia National Park. The Emerald Lake watershed is one of the most highly studied sub-alpine watersheds in the world. University of California, Santa Barbara leads the majority of the research including maintaining the gaging station at Emerald Lake (Sickman et al.

2003). However, multiple agencies and universities have contributed significant research and monitoring efforts, including U.S. Geological Survey, National Park Service, UC Riverside, and others. A number of studies have focused on water chemistry including acid deposition (Tonnessen 1991) and nutrient dynamics (Sickman et al. 2003). Many of the studies have also examined climate, water balance, and watershed hydrology (Williams et al. 1993).

***The Hydrologic Benchmark Network:*** A long-term monitoring program of the USGS, designed to study status and trends in surface water flow and water chemistry in minimally affected basins and as a benchmark against which to compare changes in flow and chemistry in developed watersheds. The SIEN has two HBN stations, the Merced River at Happy Isles in YOSE (1967-present) and the Marble Fork of the Kaweah above Tokopah Falls in SEKI (2003-present). The USGS provides support to the parks to collect 14 samples per year at these stations. Samples are collected more frequently during the peak snowmelt runoff period. The samples are analyzed at the USGS laboratory in Colorado and results are posted to the USGS NWIS website. The SIEN stations were visited by the USGS in 2011 to characterize the physical, chemical, and biological integrity of the sites. Samples of algae, benthic invertebrates and fish were taken along with physical measurements of habitat, to establish a baseline condition and contribute to regional characterization tools such as indices of biological integrity (IBIs). In SEKI, the USGS was not able to visit the actual HBN site, and conducted their sampling downstream of Tokopah Falls near the Lodgepole Campground.

***The Yosemite Hydroclimate Network:*** In the early 1990s, researchers from numerous agencies and universities installed a network of sensors throughout YOSE to monitor hydrologic and climate dynamics. The network includes streamgages, groundwater wells, meteorological stations and others. While some of the hydroclimate researchers have ongoing research, many have completed their research, leaving established sites and data sets that can be built upon. USGS researcher, Dave Clow, established streamgages in both the Merced and Tuolumne watersheds with a focus on water quality (Clow et al. 1996, 2011).

***University of California Santa Barbara, Sierra Nevada Aquatic Research Laboratory (Dave Herbst) - An early warning network for assessing the impacts of climate change on stream ecosystems of the Sierra Nevada:*** This project measures: i) aquatic invertebrates, including insects, mollusks, crustaceans, arachnids, and annelids, and ii) site data (channel geomorphology including substrate composition, depth, width, current velocity, slope, riparian cover, water chemistry, sedimentation, sinuosity, shading, algae density, particulate organic matter, large wood debris, discharge, temperature, barometric pressure, etc.). There are multiple sites in SEKI, YOSE, and the USDA Forest Service lands between the parks.

***The Sierra Nevada Research Institute (SNRI) at UC Merced (Roger Bales and Bob Rice) - Water balance & carbon cycling across the snow line in forested landscapes:*** The Mountain Hydrology Research Group at SNRI is performing extensive water balance studies at:

- Sequoia Field Station in Wolverton (SEKI) – The Marble Fork of the Kaweah Watershed
- Yosemite Field Station in Wawona – Merced Watershed (YOSE)

**Visitor Experience and Resource Protection Program (VERP):** Yosemite National Park monitors a suite of indicators, including water quality and hydrology, to assess visitor use impacts along the Merced and Tuolumne Wild and Scenic River corridors. The program examines bacteria, nutrients, and petroleum hydrocarbons in or downstream of heavy use areas (Clow et al. 2011, Yosemite National Park 2011).

**California Department of Water Resources snow courses, snow pillows, and water level data:** Data are available from sites operated by the California Department of Water Resources, as well as other agencies through the California Data Exchange Center (CDEC) <http://cdec.water.ca.gov/>.

**Kings River Experimental Watershed (KREW):** The national forests around KICA are involved in this integrated watershed study, which is part of the larger Kings River Project that is developing forest management techniques for sustainable forest ecosystems in the Sierra Nevada (Hunsaker 2007). Eight sub-watersheds have been chosen and fully instrumented to monitor ecosystem changes in this watershed-level, integrated ecosystem project for headwater streams in the Sierra Nevada.

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## Appendix B. Recommendations for Expanded Surface Water Monitoring

Below are recommendations that would improve coverage of major watersheds, increase types of data collected, facilitate data retrieval and accessibility, enhance our understanding of observed patterns in discharge, and engage citizens in surface water monitoring. While none of these are monumental undertakings, they are currently beyond SIEN's capacity to implement.

- 1) ***Expanded streamflow monitoring in Yosemite (YOSE):*** A streamgage was established on the Merced River above High Sierra Camp (elevation 7,240 ft) in 2001 by USGS researcher Dave Clow. Dave Clow's research wound down around 2012, and Yosemite subsequently committed to maintaining the gage, despite uncertainty in long-term funding. The station has not been operated with adequate quality control (for SIEN objectives) and the rating curve has not been developed, although some wading measurements have been made and 15-minute stage has been recorded over the full period of record. The station has several major challenges, most importantly, there is not an easy way to measure discharge at higher flows. If this station were added as a site, SIEN would need to investigate and consider using indirect method(s) to capture the high flows. This station is of high importance to YOSE and the Merced Irrigation District, would contribute to the nested watershed approach, and would provide additional data about the hydrology above the rain/snow transition line.
- 2) ***Expanded streamflow monitoring in Sequoia and Kings Canyon (SEKI):*** A streamgage was operated by Southern California Edison (SCE) at the Marble Fork Kaweah at Potwisha for 50 years. The streamgage was removed in 2002 based on concerns by SEKI and SCE that visitors were using the infrastructure for recreational purposes, which resulted in safety issues. Additionally, the cross-section is a poor location for a gage because it is frequently used by park visitors who construct small dams with rocks, which influence the streamflow control and rating curve. SCE has been providing a calculated value based upon discharge measurements at the power house downstream, below the Marble Fork and Middle Fork confluence. Although this calculated value will suffice to provide the park with assurance that minimum flows are being met, there is some uncertainty about the precision of these values. Error in the calculated value would likely confound our ability to detect trends with a high level of confidence. Therefore, if possible, it would be beneficial to re-install a streamgage near the former location, preferably upstream of the SCE diversion, in order to build upon the historic record for trend analyses. The SIEN does not have adequate resources to do so at this time, but would assist with data collection and station operation if the station were re-established.
- 3) ***Addition of conductivity to SIEN-supported gages:*** Conductivity can be a useful parameter to monitor the effects of atmospheric deposition of pollutants, which is a primary resource threat and management concern in SIEN parks. Several academic researchers have collected conductivity using sensors that are linked to the streamgage logger. Unfortunately, they have reported that SIEN surface waters are too dilute during much of the year for the sensors to operate properly. In dilute waters, conductivity sensors often have reduced precision and need to

be checked or re-calibrated frequently. Water quality monitoring equipment is continually improving and there may eventually be sensors available that work well in dilute waters.

- 4) ***Expanded water level monitoring throughout SIEN:*** Streamgages provide both water level and discharge, but are time-consuming and costly to operate due to the necessary site visits. Water level monitoring stations do not provide discharge, but are fairly easy to install and can act as sentinels of change across SIEN, providing information about streamflow timing, including snowmelt and thunderstorms. An expanded network of stage monitoring on tributaries to the major rivers we are already monitoring would also expand our understanding of contributions to these rivers. For example, the Illiloutte has a large percentage of its drainage area in the rain/snow transition zone. For planning purposes and to better understand climate change effects near the rain/snow transition, it would be helpful to monitor the upper Merced, Tenaya Creek and Illilouette Creek and their contributions to the lower Merced. In SEKI, water level monitoring on the major tributaries to the Kern would expand our knowledge of dynamics in this southernmost SIEN watershed, where the only gage is located below most major tributaries and outside the park. To undertake installation and continued downloading of a network of water level loggers, SIEN would need to partner with other park programs, because several of the desired locations are remote and SIEN does not have adequate staff time.

## **Appendix C. Power Analysis of Trends in Streamflow Parameters for the Sierra Nevada Network**

Submitted to the Sierra Nevada Network

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Authors:

Leigh Ann Harrod Starcevich  
PO Box 1032  
Corvallis, OR 97339  
(541) 738 6198

Stephanie L. Kane  
PO Box 444290  
Moscow, ID 83844-4290  
(208) 885 5849

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## **Introduction**

The Sierra Nevada Network (SIEN) of the National Park Service (NPS) has identified several important resources for monitoring in the vital signs program. SIEN rivers and streams comprise one of the systems selected for long-term monitoring. Rivers and streams are examined by collecting discharge information from streamgages. Outcomes of interest include summaries of maximum flow discharge, minimum flow discharge, and days to an event for a range of time periods and events. In this report, streamgage outcomes from long-term data sets from the Kern and Merced Rivers are used to assess the power to detect trends in those rivers. Status, trend, and variance component estimates from the long-term data are used to conduct a power analysis.

## **Trend Analysis**

The historic data from the Kern and Merced Rivers are first examined. Then tests of trend are discussed and applied to the long-term data sets. The estimates of status, trend, and variance are used to inform a power analysis for trend detection.

## **Historic Data**

The available pilot data consist of daily discharge data measured in ft<sup>3</sup>/s collected from streamgages in the Kern and Merced Rivers in SIEN, California (USGS National Water Information System 2011). The Kern River has been monitored since 1913 and the Merced River has been monitored since 1916. The Kern River gage is operated by the electric company Southern California Edison (SCE), with the records reviewed and made public by the USGS while the Merced River gage is operated by the USGS. The contributing surface area for the Kern River gage is 846 mi<sup>2</sup> and 181 mi<sup>2</sup> for the Merced. For each river, the following 18 dependent variables were calculated on an annual basis over the entire period of record (Andrews 2012):

- mean annual discharge,
- 3, 7, 10, and 14-day high flow;
- number of days from October 1 to three-day high flow;
- number of days from October 1 to fourteen-day high flow;
- 3, 7, and 14-day winter low flow;
- 3, 7, and 14-day summer low flow;
- number days from October 1 to winter seven-day low flow;
- number of days from October 1 to summer seven-day low flow;
- number of days from October 1 to the center of mass;
- percent of annual flow from April to July; and
- number of days from January 1 to the onset of snowmelt

These data are provided in a command that may be used in the R programming language (R Development Core Team 2011) for analysis. The power to detect trend in these metrics with

parametric and nonparametric approaches is examined in this report. Plots indicate that some of the metrics have substantial year-to-year variation which can differ between rivers (Figures C.1-C.14).

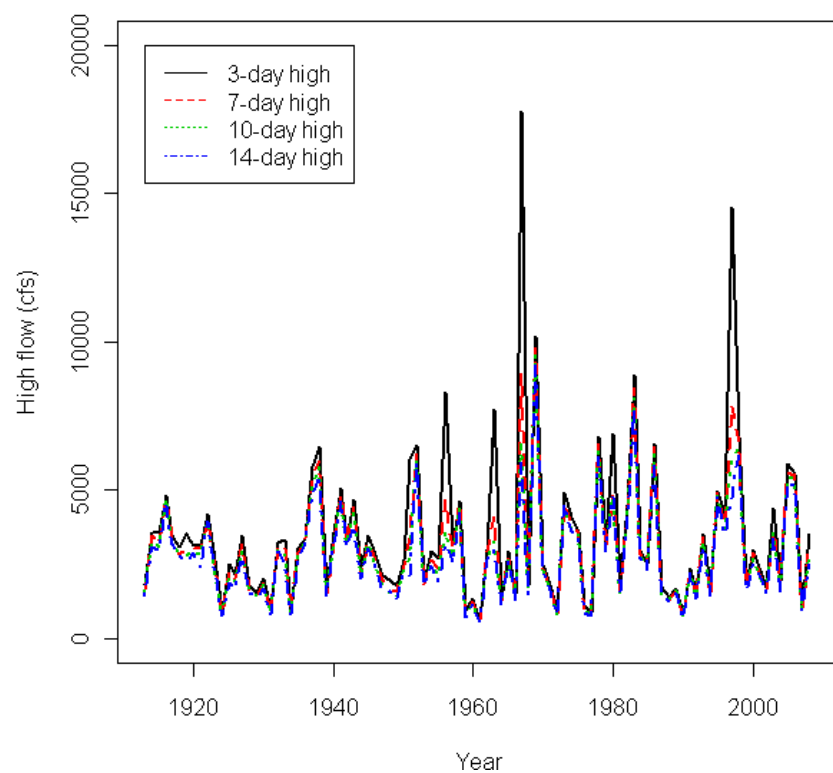


**Figure C.1.** Kern high flows.

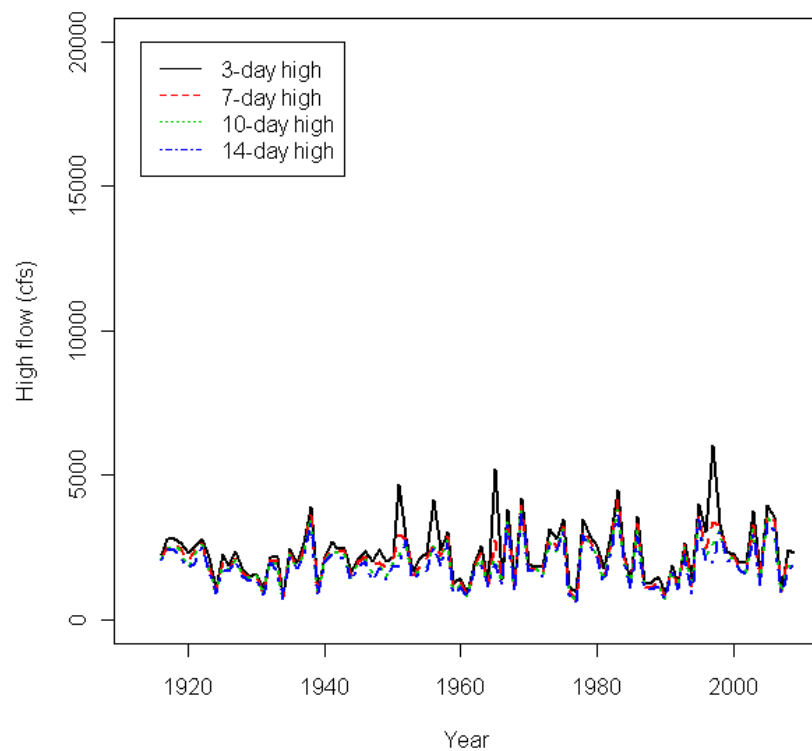


**Figure C.2.** Merced high flows.

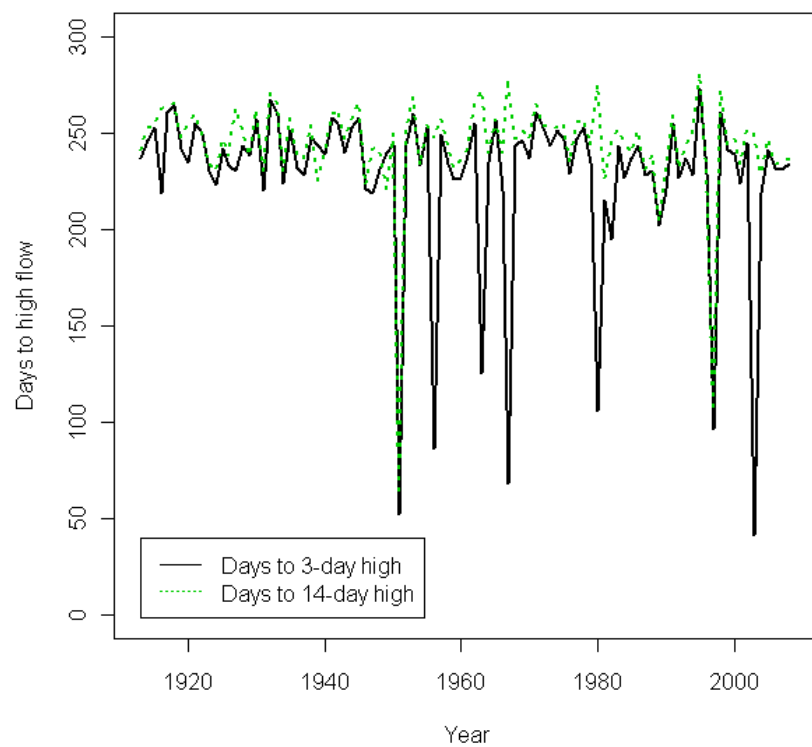


**Figure C.3.** Number of days from October 1 to 3 and 14-day high flows at the Kern River.

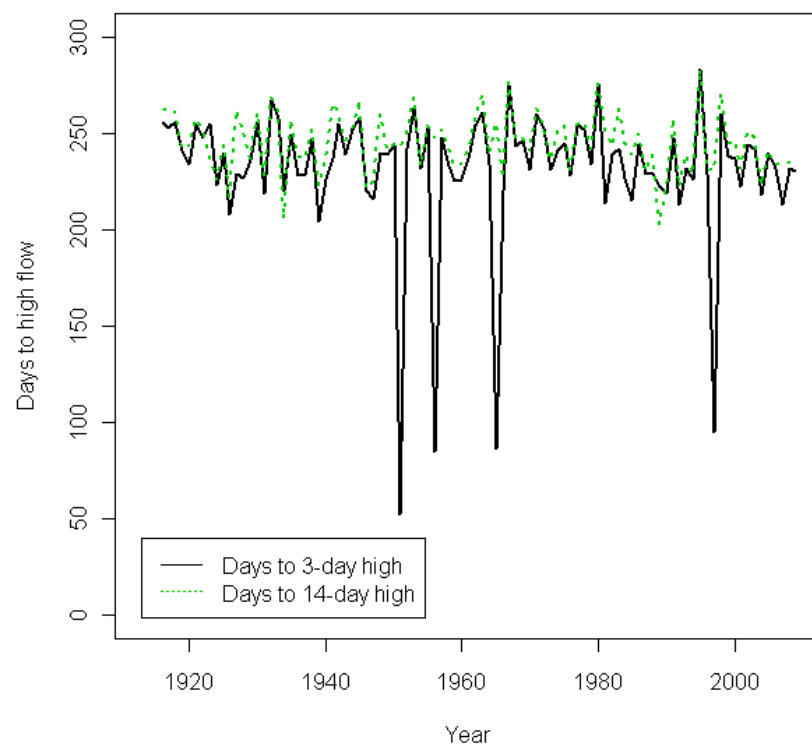


**Figure C.4.** Number of days from October 1 to 3 and 14-day high flows at the Merced River.

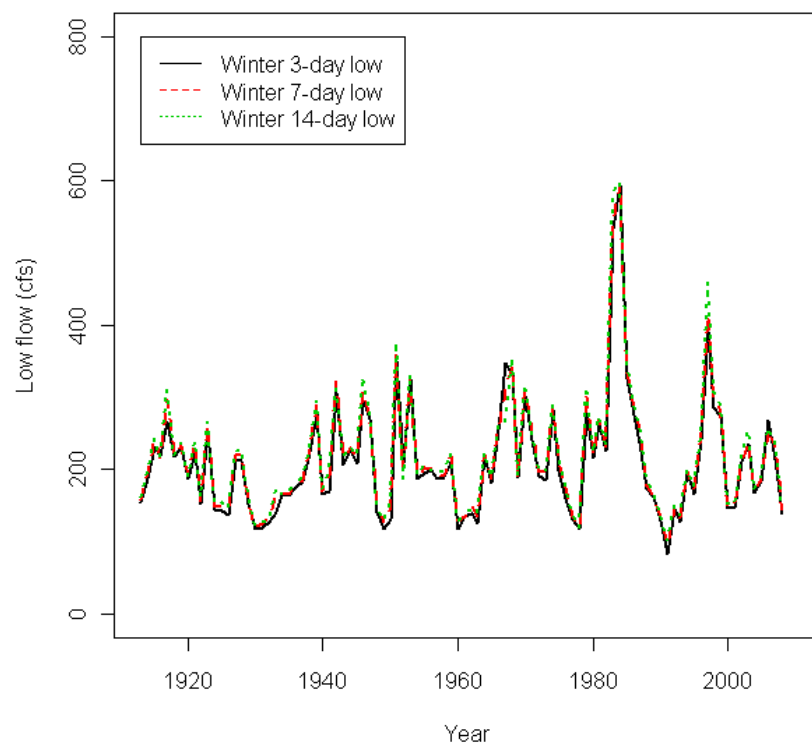


**Figure C.5.** Kern winter low flows.

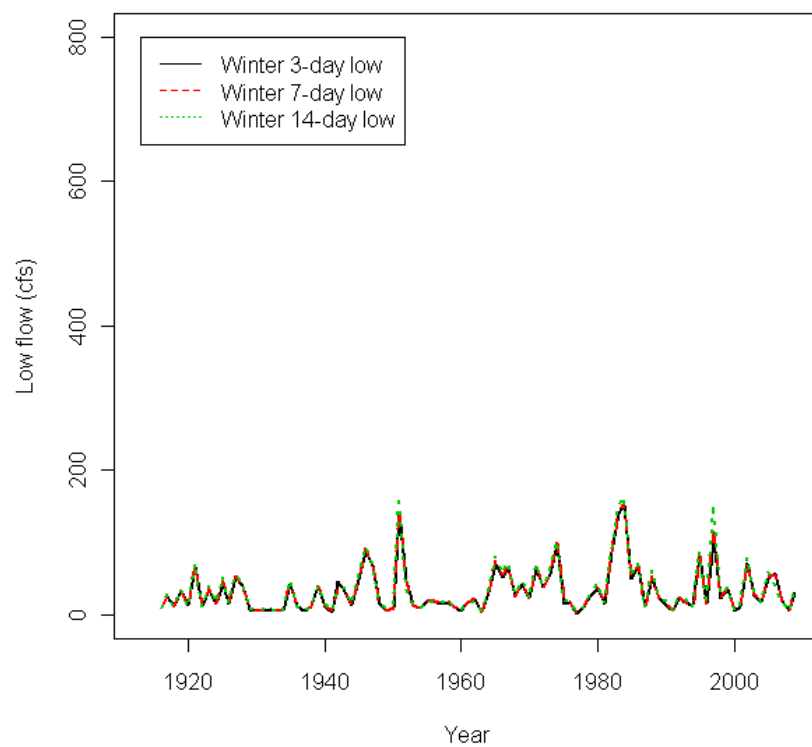


**Figure C.6.** Merced winter low flows.

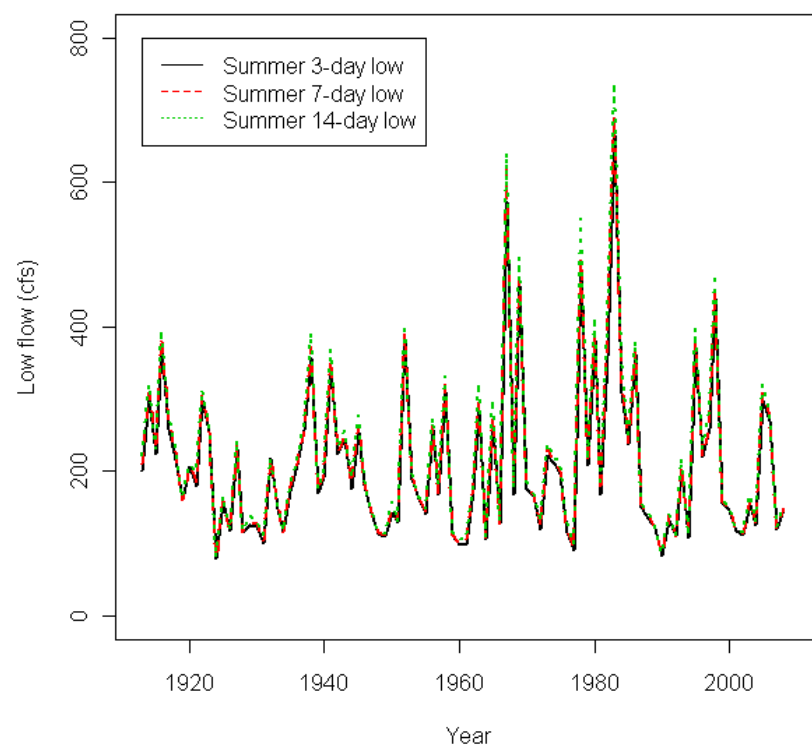


**Figure C.7.** Kern summer low flows.

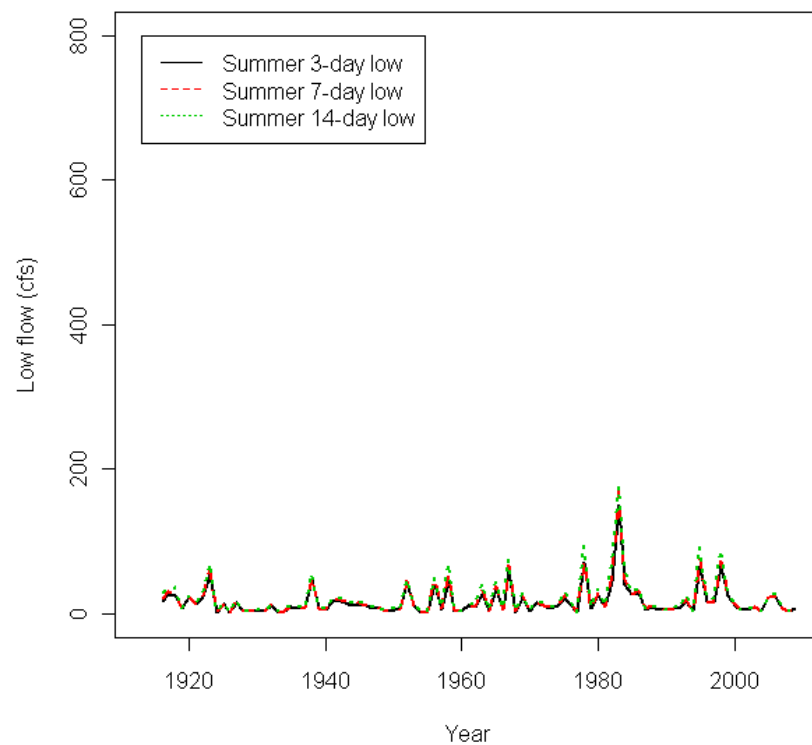


**Figure C.8.** Merced summer low flows.

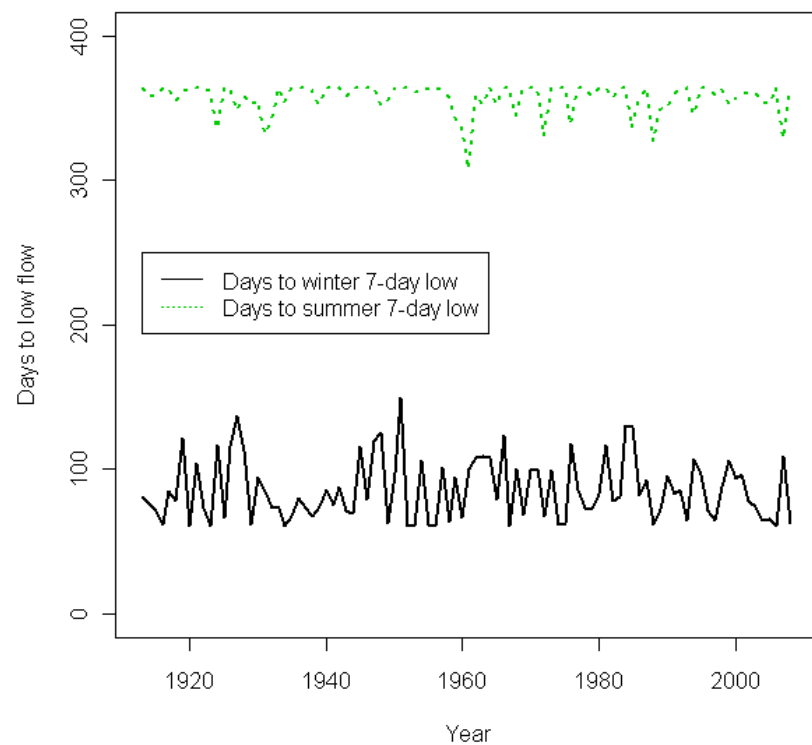


**Figure C.9.** Kern days to seasonal low flows.

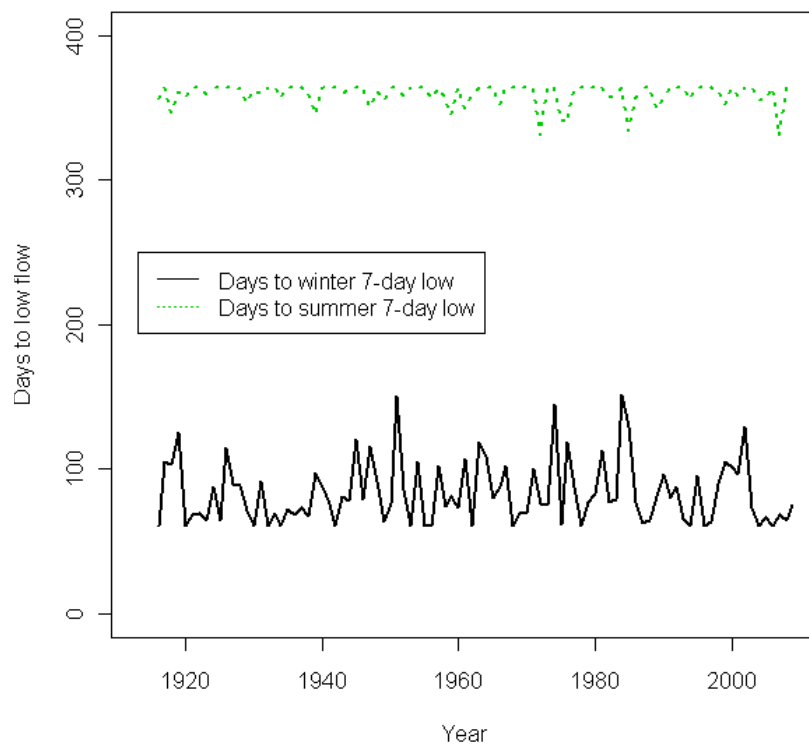


**Figure C.10.** Merced days to seasonal low flows.

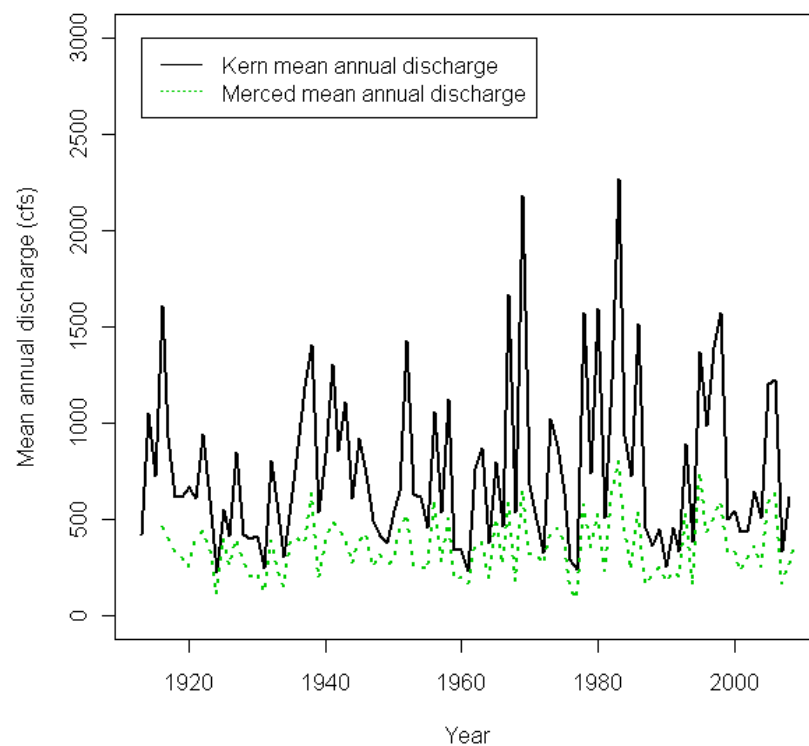


**Figure C.11.** Mean annual flow, Kern and Merced Rivers.

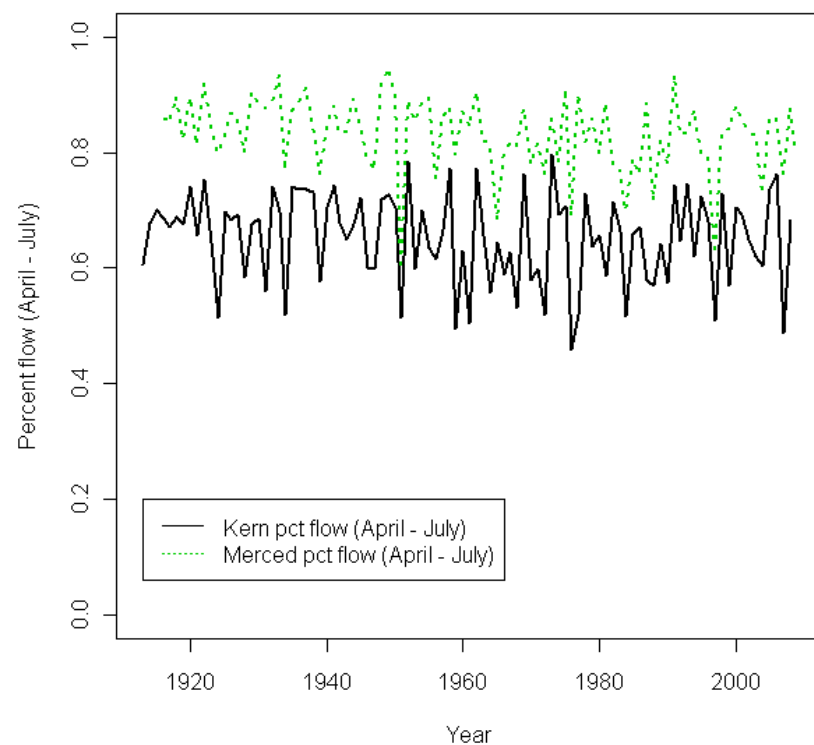


**Figure C.12.** Percent of annual flow from April to July, Kern and Merced Rivers.

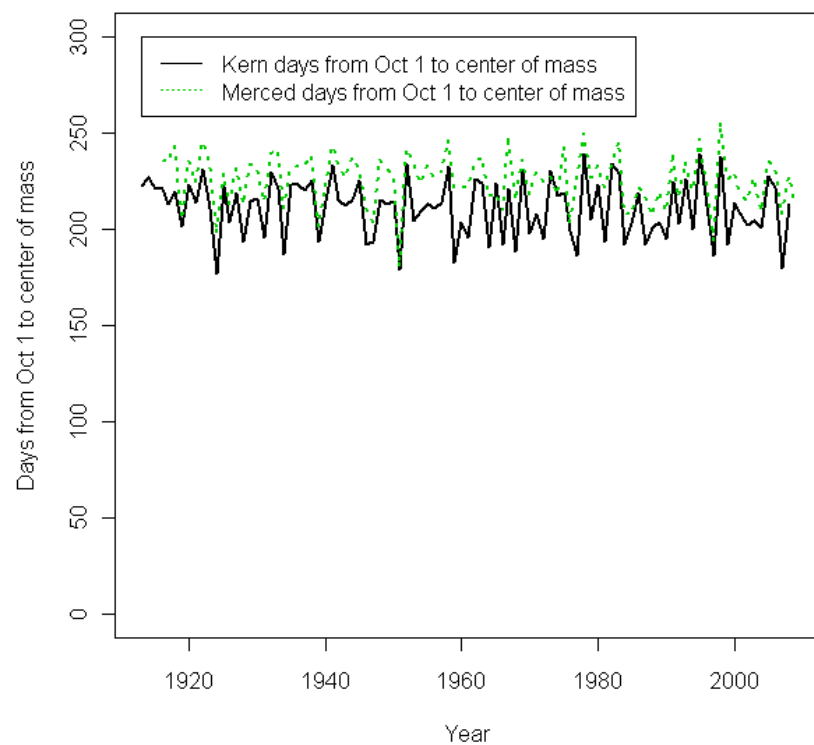


**Figure C.13.** Days from October 1 to center of mass, Kern and Merced Rivers.

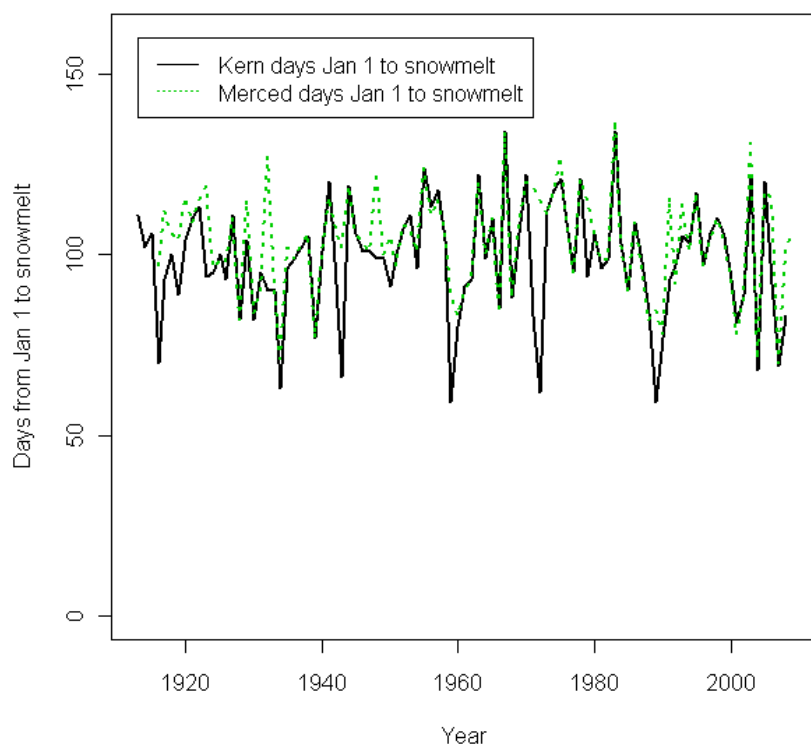


**Figure C.14.** Days January 1 to onset of snowmelt, Kern and Merced Rivers.

### Trend Methods

Two trend tests are examined in this power analysis: the t-test derived from a linear mixed model for trend (VanLeeuwen et al. 1996, Piepho and Ogutu 2002) and the Kendall tau-b test (Higgins 2004). Mixed models include fixed effects, which contribute to the mean of the outcome of interest, and random effects, which contribute to the variance form. Linear trend is assessed with a fixed slope effect over time using a t-test, a parametric test requiring assumptions of normality for variance components, independence of residual errors, and equal residual variance within groups based on random effects.

The Kendall tau-b test is a nonparametric test that uses the ordinal nature of the year covariate and the ranks of the outcomes of interest to find increasing or decreasing patterns in the data. Because the data are ranked, qualities of the ranks in the presence of no trend are used to assess trend rather than distributional assumptions. The Kendall tau-b test of correlation has been used by the US EPA (Kelly and Jett 2006) and by state natural resource agencies (Illinois Department of Energy and Natural Resources 1994, Sargeant et al. 2011) to detect trends in water discharge parameters.

### Parametric trend model

The historic data are analyzed in two different ways. First, an analysis of trend across rivers provides an estimate of the year-to-year variation. Then, trend is estimated within each river to obtain estimates of status, trend, and residual variation within each river. A heteroscedastic model providing all estimates of interest (within-river estimates of status, trend, and residual error as well as year-to-year variation across rivers) was examined but resulted in essentially zero estimates of

residual error for the Merced River data. The use of estimates from both across-river and within-river trend models provided a more conservative basis for power approximations. When data from the two rivers are used in the same model, the site effect (intercept term for the Kern or Merced River) is treated as a fixed effect because inference is not made to a larger population of rivers.

The mixed linear model proposed for stream discharge monitoring outcomes is:

$$y_{ij} = \alpha_i + w_j\beta + b_j + e_{ij},$$

where  $i=1,\dots,m_a$ ;  $j=1,\dots,m_b$ ; and

$m_a$  = the number of sites in the sample;

$m_b$  = the number of consecutive years in the sample;

$y_{ij}$  = the outcome of interest at river  $i$  and year  $j$ ;

$\alpha_i$  = fixed intercept of  $i^{\text{th}}$  river;

$w_j$  = constant representing the  $j^{\text{th}}$  year (covariate)

$\beta$  = fixed intercept and slope of the linear time trend;

$b_j$  = random effect of the  $j^{\text{th}}$  year, independent and identically distributed as  $N(0, \sigma_b^2)$ ; and

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

When trend is assessed for a single river, the year random effect is inestimable and the linear mixed model reduces to the following ordinary least squares regression model:

$$y_j = \mu + w_j\beta + e_j.$$

All dependent variables were logarithmically transformed to correct non-constant variance through time with the exception of the variable measuring percent flow between April and July which was analyzed after applying the arcsine square-root transformation. Three possible predictors were considered in the trend models: snow course, the number of days from October 1 to the center of mass, and the number of days from January 1 to snowmelt onset. Note that trends for these predictors are also modeled as outcomes of interest. Also note that snow course information was available for measurements collected in 1930 and later. Snow course was a significant predictor for many outcomes of interest and was helpful in explaining year-to-year variation, so the loss of 14 to 17 years of historic data is considered acceptable in the interest of obtaining accurate variance components for the power analysis.

Information criteria (AIC, BIC) were compared for each possible set of predictors and the smallest information criterion was used to identify the final model for each dependent variable. In addition, separate slopes for each river were considered but in no case did the final model include separate slopes (i.e. the model with the lowest BIC/AIC contained only a slope term across rivers, indicating that the slopes were not statistically different for the two rivers). In the models examining days to summer and winter seven-day lows and the number of days from January 1 to the onset of

snowmelt, the final model did not include a fixed river effect, indicating similar status for the two rivers.

### **Nonparametric Trend Model**

In addition to fitting parametric mixed models, the Kendall's tau-b test (Higgins 2004) was used to examine linear effects of time. The Kendall tau-b is a nonparametric test to measure correlations between two variables providing an indicator of the degree of concordance or discordance where:

$$r_{\tau} = \frac{2(\sum_{i=1}^{n-1} V_i)}{\binom{n}{2}} - 1$$

and  $V_i$  is the number of pairs that are concordant (Higgins 2004). Large-sample properties of the test statistic are then used to evaluate the test. Like all correlation coefficients, the tau-b statistic ranges from -1 to 1. In this test, the correlation between years and the ranks of the outcome of interest is assessed. If the outcome of interest is increasing linearly over time, the ranks of the outcomes would be similar to 1, 2, 3,...,  $n$  (with a ranking of 1 given to the smallest value of the outcome). The correlation between these ranks and the year variable (1913, 1914, 1915,..., 2008) would be near 1 (positively correlated). If the outcomes were decreasing over time, the ranks would be similar to  $n$ ,  $n-1$ , ..., 1 and the correlation of these ranks would be near -1 (negatively correlated). A significant result for a two-sided test would be a test statistic near -1 or 1, indicating consistent change in one direction.

The enhanced version of the Kendall tau-b test provides estimates of trend based on the Sen (1968) slope. Note that two variables can have very high linear correlation but very different trends. Correlation quantifies the degree but not the magnitude of the linear relationship. The enhanced version of the Kendall tau-b test is chosen as the nonparametric trend approach because it provides a trend test that accounts for ties, and estimates of trend based on the Sen (1968) slope can be obtained with this technique in R software. Note that two variables can have very high linear correlation but very different trends. Correlation quantifies the degree but not the magnitude of the linear relationship, so the additional function of nonparametric trend slope estimation is useful when both trend estimation and trend testing are of interest.

When the assumptions of the linear mixed model are met, the test of trend from the linear mixed model will tend to be more powerful than the trend test from nonparametric approaches. When the assumptions of the linear mixed model are not met, the nonparametric approach will provide the more powerful and robust trend test. If one test indicates a significant trend, it is prudent to be sure that multiple tests of trend indicate the same result before implementing an expensive management action.

### Explanation of the Linear Mixed Model

An effect describes the amount by which a treatment changes the value of a measurement on a sampled unit (Kuehl 1994). A linear mixed model incorporates both fixed effects and random effects. Fixed effects are population-level effects that do not change under repeated sampling (Pinheiro and Bates 2004). Random effects are effects associated with sampling units and may vary for repeated sampling. This variability is modeled by defining the effect as a random variable with a known distribution. The linear mixed model used in the trend analysis for both rivers is given by:

$$y_{ij} = \alpha_i + w_j\beta + b_j + e_{ij},$$

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

$m_a$  = the number of rivers in the sample;

$m_b$  = the number of consecutive years in the sample;

$y_{ij}$  = outcome of interest (possibly transformed),

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

$\alpha_i$  = fixed intercept for river  $i$ ;

$\beta$  = fixed slope for the linear time trend for the linear mixed model;

$b_j$  = random effect of the  $j^{\text{th}}$  year, iid  $N(0, \sigma_b^2)$ , where  $\sigma_b^2$  is the year-to-year variation; and

$e_{ij}$  = unexplained error, iid as  $N(0, \sigma_e^2)$ , where  $\sigma_e^2$  is the unexplained residual variation.

The expected values of the random effects are 0, so these effects do not affect the mean structure of the outcome of interest. Because these effects are assumed to be random variables that represent a larger population, the variance of the random effect impacts the variance of the outcome of interest. However, the definition of sources of variation can be informative and reduces the unexplained variation, which negatively impacts the power to detect trend.

For comparison, the simple linear regression model has the form of a straight line with residual error for each observation and is given by the following notation:

$$y_{ij} = \alpha'_i + \beta'_1 w_j + e'_{ij},$$

$\alpha'_i$  = fixed intercept for river  $i$ ;

$\beta'_1$  = fixed slope of the linear time trend for the simple linear regression model; and

$e'_{ij}$  = unexplained error, iid as  $N(0, \sigma^2)$ , where  $\sigma^2$  is the unexplained residual variation

Note that the regression parameters are augmented by prime notation to distinguish these values from the regression parameters in the linear mixed model. The mean structure is defined by the fixed effects only for both the simple linear regression model ( $\alpha'_i$  and  $\beta'_1$ ) and the linear mixed

model ( $\alpha_i$  and  $\beta_i$ ). These parameters are not assumed to come from some larger population of effects and therefore do not affect the variance structure of the outcome of interest. For the linear mixed model, the error term is broken into a linear combination of random effects and a residual error term. The random effects correspond to components of variance for levels of factors that influence the variance structure but not the mean structure.

Previous work in trend modeling using the linear mixed model approach (Urquhart et al. 1993; Piepho and Ogutu 2002) has incorporated variance components for year-to-year variation ( $\sigma_b^2$ ), site-to-site variation ( $\sigma_a^2$ ), and variation in site-level slopes ( $\sigma_t^2$ ). Site-to-site variation has less impact on the power to detect trend than the other components of variation. Highly-variable site-level slopes and high year-to-year variation can negatively impact the power to detect trend. Large variation in these components can be orders of magnitude smaller than the site-to-site variation and still have more impact on the power to detect trend.

Let a "group" be defined by levels of factors for which random effects are modeled (e.g. *Year*, *Transect*, or *Year-by-Transect* groups). Two primary assumptions are required for the linear mixed model (Pinheiro and Bates 2004):

- 1) Independent and identically-distributed errors within groups with mean 0 and a common group-level variance, which is independent of the random effects
- 2) Normally-distributed random effects with mean 0 and covariance matrix  $\Psi$ , where both the random effects and the covariance matrix are independent of groups.

Assumption (1) is assessed with normal quantile-quantile plots and box plots of estimated residual errors from the linear mixed model fit. Checking assumption (2) requires normal quantile-quantile plots and paired plots of the estimated random effects within groups and comparisons of fits with more general variance structures with analysis of variance. Pinheiro and Bates (2004) provide an excellent discussion of residual diagnostics for S and S-PLUS programming languages.

The Piepho and Ogutu (2002) model may be fit in R as follows:

```
fit<-lmer(Y ~ WYear +(1|Year), data=dataset).
```

The correspondence of the R code to the terms in the linear mixed model is provided in Table C.1.

**Table C.1.** Correspondence of the R code to the linear mixed model terms.

| R code   | Linear mixed model notation | Description                                                                                                                   |
|----------|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Y        | $y_{ij}$                    | Outcome of interest                                                                                                           |
| lmer     | –                           | R function that specifies a linear mixed model will be used with REML as the default method for variance component estimation |
| WYear    | $w_j$                       | Generates the regression coefficient corresponding to the linear trend in Y.                                                  |
| (1 Year) | $b_j$                       | Random year intercept effect                                                                                                  |
| Data set | -                           | The data set containing all of the variables listed                                                                           |
| –        | $e_{ij}$                    | The residual error is automatically estimated                                                                                 |

Because the  $t$ -distribution is assumed for the regression coefficient estimates, appropriate degrees of freedom must be obtained for hypothesis testing of trend and confidence interval construction for trend estimates. When all sites are not visited every year, the data are considered unbalanced. Satterthwaite degrees of freedom are recommended for unbalanced data sets (Spilke et al. 2005). However, due to disagreement by R programming language developers regarding a one-size-fits-all approach to estimating degrees of freedom (see <https://stat.ethz.ch/pipermail/r-help/2006-May/094765.html> for more on this discussion), the degrees of freedom are not provided in *lmer* output. Spilke et al. (2005) recommend the Kenward and Roger (1997) degrees of freedom approximation to Satterthwaite's (1946) degrees of freedom. These may be obtained from the *doBy* R package.

### Trend Test Results

The results of the parametric and nonparametric trend tests are discussed and compared. Two-sided trend tests are assessed at a Type I error level of 0.10. Considering that a large number of tests were examined in this trend analysis, a more conservative approach to trend testing may consider testing at a Type I error level that accounts for the multiple comparisons. For a total of 54 trend tests (18 tests across river type and 18 tests for both rivers), a Bonferroni correction (Kuehl 1994) on the Type I error rate would result in a comparison-level Type I error rate for each trend test of  $0.10/54 = 0.0019$ . Note that all of the  $p$ -values exceed this comparison-level error rate, so no significant trends would be detected at the 0.0019 level. This conservative approach retains a Type I error rate of 0.10 for all tests combined.

### Mixed Model

When both sites are included in the trend model, significant trends are observed for ten-day high flows ( $p = 0.0819$ ) and fourteen-day high flows ( $p = 0.0538$ ). Statistically-significant linear trends for winter three-day low flows ( $p = 0.0894$ ), winter seven-day low flows ( $p = 0.0960$ ), and winter fourteen-day low flows ( $p = 0.0813$ ) are also detected. The hypothesis of different slopes was rejected for every dependent variable tested, indicating that the trend for each river was not statistically different. However, the fixed effect for the river was statistically significant in every

model except that for the number of days to three-day high flow (Table C.2). This indicates similar trends over time despite significantly different status estimates for most outcomes.

Model selection with information criteria resulted in models containing all three potential predictors in the trend models for overall high metrics and most winter low metrics. The number of days from October 1 to the center of mass was the only predictor in the trend models for the number of days to the three-day high, the number of days to the fourteen-day high, and the number of days to the winter low. Snow course was the only predictor in the models of summer lows and the number of days to the summer low flow.

### **OLS Model**

Plots of the metrics over time indicated that the residual variation may differ between rivers. Therefore, the trend analyses were conducted separately for the two rivers with ordinary least squares regression since the random time effect is inestimable for a single river. Model selection employed AIC and BIC to identify suitable covariates for each trend model. Model predictors were similar between the models for each river. Snow course and the number of days from January 1 to the snowmelt onset were selected by model criteria to predict overall high metrics, most summer low metrics, and mean annual discharge. The number of days from October 1 to the center of mass was selected as a predictor in the trend models for the days to the three-day high for the Merced River, the days to the fourteen-day high for both rivers, and percent of variable flow from April to July for both rivers. All three predictors were retained in the models for winter lows for both rivers. The models for the number of days to the winter seven-day low and the number of days from January 1 to the onset of snowmelt included only a single predictor (the number of days from October 1 to the center of mass), and the models for the number of days to the summer seven-day low retained none of the three predictors in the trend model.

Significant trends were detected in the following Merced River metrics (Table C.3): three-day high ( $p = 0.0992$ ), seven-day high ( $p = 0.0982$ ), fourteen-day high ( $p = 0.0888$ ), winter three-day low ( $p = 0.0533$ ), winter seven-day low ( $p = 0.0504$ ), winter fourteen-day low ( $p = 0.0456$ ), summer three-day low ( $p = 0.0366$ ), summer seven-day low ( $p = 0.0491$ ), summer fourteen-day low ( $p = 0.0828$ ), and percent of flow between April and July ( $p = 0.0151$ ). Days to the three-day high ( $p = 0.0930$ ) was the only significant trend detected in the Kern River data.

**Table C.2.** Transformations, fixed effects estimates, two-sided trend test results, and variance components estimates by logged outcome for the mixed model trend analysis across rivers.

|                     | $\hat{\beta}_o$       | $\hat{\beta}_o$         | $\hat{\beta}_1$    |                           |                              |                              |             | $\hat{\sigma}_b^2$  | $\hat{\sigma}_e^2$ |
|---------------------|-----------------------|-------------------------|--------------------|---------------------------|------------------------------|------------------------------|-------------|---------------------|--------------------|
| Dependent Variable  | Est. Intercept (Kern) | Est. Intercept (Merced) | Est. trend (SE)    | Trend test p-value        | Days to Oct 1 center of mass | Days Jan 1 to snowmelt onset | Snow-course | (year-to-year var.) | (residual var.)    |
| Three day high      | 5.4223                | 6.1681                  | 0.00177 (0.00154)  | 0.2542                    | -                            | 0.0145                       | 0.0199      | 0.0581              | 0.0843             |
| Seven day high      | 3.4737                | 4.2655                  | 0.00226 (0.00143)  | 0.1204                    | 0.0109                       | 0.0100                       | 0.0141      | 0.0613              | 0.0482             |
| Ten day high        | 3.0967                | 3.9137                  | 0.00241 (0.00136)  | <b>0.0819<sup>B</sup></b> | 0.0128                       | 0.0091                       | 0.0138      | 0.0565              | 0.0416             |
| Fourteen day high   | 2.9665                | 3.8149                  | 0.002515 (0.01278) | <b>0.0538<sup>B</sup></b> | 0.0130                       | 0.0089                       | 0.0149      | 0.0470              | 0.0421             |
| Days to 3 day high  | 4.0864                | 4.1445                  | -0.00083 (0.00085) | 0.3315                    | 0.0061                       | -                            | -           | 0.0404              | 0.032              |
| Days to 14 day high | 4.6054                | 4.6509                  | -0.00018 (0.00032) | 0.5651                    | 0.0040                       | -                            | -           | 0.0000              | 0.0134             |
| Winter 3 day low    | 8.7053                | 11.1297                 | 0.00447 (0.0026)   | <b>0.0894<sup>B</sup></b> | -0.0313                      | -                            | 0.0358      | 0.1759              | 0.2109             |
| Winter 7 day low    | 8.8176                | 11.1633                 | 0.0039 (0.0023)    | <b>0.0960<sup>B</sup></b> | -0.0376                      | 0.0143                       | 0.0333      | 0.1186              | 0.2124             |
| Winter 14 day low   | 8.9584                | 11.262                  | 0.00408 (0.0023)   | <b>0.0813<sup>B</sup></b> | -0.0382                      | 0.0146                       | 0.0328      | 0.1129              | 0.2159             |
| Summer 3 day low    | 0.8811                | 4.4822                  | 0.00374 (0.00227)  | 0.1034                    | -                            | -                            | 0.0393      | 0.1353              | 0.1629             |
| Summer 7 day low    | 0.9654                | 4.5120                  | 0.003528 (0.00233) | 0.1337                    | -                            | -                            | 0.0397      | 0.1485              | 0.1598             |
| Summer 14 day low   | 1.1293                | 4.5557                  | 0.003478 (0.00237) | 0.1469                    | -                            | -                            | 0.0395      | 0.1623              | 0.1508             |

<sup>A</sup> Arcsine square-root transformation<sup>B</sup> Tests significant at the 0.10 level (also in bold)

**Table C.2 (continued).** Transformations, fixed effects estimates, two-sided trend test results (tests significant at the 0.10 level in bold), and variance components estimates by logged outcome for the mixed model trend analysis across rivers.

| Dependent Variable                   | $\hat{\beta}_o$<br>Est. Intercept (Kern) | $\hat{\beta}_o$<br>Est. Intercept (Merced) | $\hat{\beta}_1$<br>Est. trend (SE) | Trend test p-value | Days to Oct 1 center of mass | Days Jan 1 to snowmelt onset | Snow-course | $\hat{\sigma}_b^2$<br>(year-to-year var.) | $\hat{\sigma}_e^2$<br>(residual var.) |
|--------------------------------------|------------------------------------------|--------------------------------------------|------------------------------------|--------------------|------------------------------|------------------------------|-------------|-------------------------------------------|---------------------------------------|
| Days to winter 7 day low             | 5.2604                                   | 5.2604                                     | -0.00007<br>(0.00074)              | 0.9247             | -0.0039                      | -                            | -           | 0.0288                                    | 0.0235                                |
| Days to summer 7 day low             | 5.8855                                   | 5.8855                                     | -0.00009<br>(0.00008)              | 0.3014             | -                            | -                            | -           | 0.0003                                    | 0.0004                                |
| Mean annual discharge                | 3.9708                                   | 5.2168                                     | 0.001323<br>(0.001208)             | 0.2776             | -                            | 0.0089                       | 0.0245      | 0.0411                                    | 0.0411                                |
| April-July percent flow <sup>A</sup> | 0.05644                                  | -0.0832                                    | -0.00027<br>(0.000183)             | 0.1419             | 0.0049                       | -                            | -           | 0.0018                                    | 0.0012                                |
| Days Oct 1 to center of mass         | 5.2646                                   | 5.203                                      | -0.00032<br>(0.000201)             | 0.1200             | n/a                          | 0.001632                     | -           | 0.0026                                    | 0.0009                                |
| Days Jan 1 to snowmelt               | 3.6242                                   | 3.6242                                     | 0.000035<br>(0.000455)             | 0.9381             | 0.004482                     | n/a                          | -           | 0.0118                                    | 0.0071                                |

<sup>A</sup> Arcsine square-root transformation<sup>B</sup> Tests significant at the 0.10 level (also in bold)

**Table C.3.** Transformations, fixed effects estimates, two-sided trend test results, and variance components estimates by logged outcome for the ordinary least squares trend analysis by river.

| Dependent Variable                     | $\hat{\beta}_0$<br>Est. Intercept | $\hat{\beta}_1$<br>Est. trend (SE) | Trend test<br>p-value<br>(two-sided) | Days to Oct<br>1 center of<br>mass | Days Jan 1<br>to snowmelt<br>onset | Snow course | $\hat{\sigma}_e^2$<br>(residual<br>variation) |
|----------------------------------------|-----------------------------------|------------------------------------|--------------------------------------|------------------------------------|------------------------------------|-------------|-----------------------------------------------|
| Three day high, Kern                   | 5.9410                            | 0.001409<br>(0.001938)             | 0.4697                               | -                                  | 0.01365                            | 0.04354     | 0.1538                                        |
| Three day high, Merced                 | 5.7318                            | 0.002254<br>(0.001350)             | <b>0.0992<sup>B</sup></b>            | -                                  | 0.01256                            | 0.01572     | 0.0777                                        |
| Seven day high, Kern                   | 6.0387                            | 0.001363<br>(0.001553)             | 0.3831                               | -                                  | 0.01132                            | 0.04611     | 0.0988                                        |
| Seven day high, Merced                 | 5.6535                            | 0.001909<br>(0.001140)             | <b>0.0982<sup>B</sup></b>            | -                                  | 0.01197                            | 0.01713     | 0.05542                                       |
| Ten day high, Kern                     | 6.0527                            | 0.001627<br>(0.001447)             | 0.2646                               | -                                  | 0.01035                            | 0.04728     | 0.08570                                       |
| Ten day high, Merced                   | 5.6047                            | 0.001721<br>(0.001079)             | 0.1151                               | -                                  | 0.01185                            | 0.01752     | 0.04968                                       |
| Fourteen day high, Kern                | 5.9991                            | 0.001702<br>(0.00137)              | 0.2181                               | -                                  | 0.01023                            | 0.04809     | 0.07682                                       |
| Fourteen day high, Merced              | 5.5451                            | 0.001818<br>(0.001055)             | <b>0.0888<sup>B</sup></b>            | -                                  | 0.01167                            | 0.01800     | 0.04744                                       |
| Days to 3 day high, Kern               | 5.4879                            | -0.00197<br>(0.001162)             | <b>0.0930<sup>B</sup></b>            | -                                  | -                                  | -           | 0.09958                                       |
| Days to 3 day high, Merced             | 3.3708                            | 0.000067<br>(0.000803)             | 0.9335                               | 0.009087                           | -                                  | -           | 0.04401                                       |
| Days to 14 day high, Kern <sup>1</sup> | 4.4723                            | -0.00021<br>(0.00059)              | 0.7178                               | 0.004860                           | -                                  | -           | 0.02522                                       |
| Days to 14 day high, Merced            | 4.8486                            | -0.00015<br>(0.000187)             | 0.4319                               | 0.002921                           | -                                  | -           | 0.002399                                      |
| Winter 3 day low, Kern                 | 8.4091                            | 0.000871<br>(0.001475)             | 0.5568                               | -0.02111                           | 0.01018                            | 0.02067     | 0.08754                                       |

<sup>A</sup> Arcsine square-root transformation<sup>B</sup> Tests significant at the 0.10 level (also in bold)

**Table C.3 (continued).** Transformations, fixed effects estimates, two-sided trend test results, and variance components estimates by logged outcome for the ordinary least squares trend analysis by river.

| Dependent Variable               | $\hat{\beta}_0$<br>Est. Intercept | $\hat{\beta}_1$<br>Est. trend (SE) | Trend test<br>p-value<br>(two-sided) | Days to Oct<br>1 center of<br>mass | Days Jan 1<br>to snowmelt<br>onset | Snow course | $\hat{\sigma}_e^2$<br>(residual<br>variation) |
|----------------------------------|-----------------------------------|------------------------------------|--------------------------------------|------------------------------------|------------------------------------|-------------|-----------------------------------------------|
| Winter 3 day low, Merced         | 11.2834                           | 0.006957<br>(0.003543)             | <b>0.0533</b>                        | -0.05505                           | 0.02555                            | 0.03607     | 0.5227                                        |
| Winter 7 day low, Kern           | 8.3493                            | 0.000689<br>(0.001434)             | 0.6324                               | -0.02036                           | 0.009790                           | 0.01954     | 0.08272                                       |
| Winter 7 day low, Merced         | 11.3008                           | 0.006876<br>(0.003458)             | <b>0.0504<sup>B</sup></b>            | -0.05512                           | 0.02580                            | 0.03649     | 0.4980                                        |
| Winter 14 day low, Kern          | 8.4402                            | 0.00084<br>(0.001439)              | 0.5610                               | -0.02076                           | 0.009785                           | 0.01965     | 0.08332                                       |
| Winter 14 day low, Merced        | 11.5750                           | 0.006961<br>(0.003424)             | <b>0.0456<sup>B</sup></b>            | -0.05651                           | 0.02673                            | 0.03592     | 0.4882                                        |
| Summer 3 day low, Kern           | 3.9845                            | 0.000647<br>(0.001193)             | 0.5895                               | -                                  | 0.007563                           | 0.03394     | 0.05827                                       |
| Summer 3 day low, Merced         | -1.1160                           | 0.007110<br>(0.003341)             | <b>0.0366<sup>B</sup></b>            | 0.001701                           | 0.01584                            | 0.03292     | 0.4650                                        |
| Summer 7 day low, Kern           | 3.9779                            | 0.000618<br>(0.001221)             | 0.6140                               | -                                  | 0.007895                           | 0.03383     | 0.06172                                       |
| Summer 7 day low, Merced         | -0.7761                           | 0.006649<br>(0.003324)             | <b>0.0491<sup>B</sup></b>            | -                                  | 0.01708                            | 0.03376     | 0.4770                                        |
| Summer 14 day low, Kern          | 3.9605                            | 0.000719<br>(0.001254)             | 0.5682                               | -                                  | 0.008339                           | 0.03406     | 0.0644                                        |
| Summer 14 day low, Merced        | 0.8864                            | 0.006343<br>(0.003486)             | <b>0.0728<sup>B</sup></b>            | -                                  | -                                  | 0.04193     | 0.4759                                        |
| Days to winter 7 day low, Kern   | 5.7072                            | -0.00029<br>(0.000831)             | 0.7241                               | -0.00601                           | -                                  | -           | 0.05005                                       |
| Days to winter 7 day low, Merced | 5.7659                            | -0.00019<br>(0.000889)             | 0.8289                               | -0.00602                           | -                                  | -           | 0.05394                                       |

<sup>A</sup> Arcsine square-root transformation<sup>B</sup> Tests significant at the 0.10 level (also in bold)

**Table C.3 (continued).** Transformations, fixed effects estimates, two-sided trend test results, and variance components estimates by logged outcome for the ordinary least squares trend analysis by river.

|                                              | $\hat{\beta}_0$ | $\hat{\beta}_1$     |                                |                              |                              |             |                                         |
|----------------------------------------------|-----------------|---------------------|--------------------------------|------------------------------|------------------------------|-------------|-----------------------------------------|
| Dependent Variable                           | Est. Intercept  | Est. trend (SE)     | Trend test p-value (two-sided) | Days to Oct 1 center of mass | Days Jan 1 to snowmelt onset | Snow course | $\hat{\sigma}_e^2$ (residual variation) |
| Days to summer 7 day low, Kern               | 5.8827          | -0.00010 (0.000112) | 0.3721                         | -                            | -                            | -           | 0.000290                                |
| Days to summer 7 day low, Merced             | 5.8888          | -0.00009 (0.000081) | 0.2925                         | -                            | -                            | -           | 0.000449                                |
| Mean annual discharge, Kern                  | 5.1312          | 0.001184 (0.001297) | 0.3644                         | -                            | 0.007100                     | 0.04348     | 0.06882                                 |
| Mean annual discharge, Merced                | 4.1263          | 0.001562 (0.001230) | 0.2079                         | -                            | 0.007673                     | 0.02315     | 0.06450                                 |
| April-July percent flow, Kern <sup>A</sup>   | -0.05972        | -0.00008 (0.000151) | 0.6174                         | 0.004767                     | -                            | -           | 0.001643                                |
| April-July percent flow, Merced <sup>A</sup> | 0.3338          | -0.00065 (0.000245) | <b>0.0092<sup>B</sup></b>      | 0.003783                     | -                            | -           | 0.004106                                |
| Days Oct 1 to center of mass, Kern           | 5.2779          | -0.00024 (0.000229) | 0.2953                         | n/a                          | -                            | 0.005855    | 0.002144                                |
| Days Oct 1 to center of mass, Merced         | 5.1727          | -0.00019 (0.000195) | 0.3257                         | n/a                          | 0.002453                     | -           | 0.002616                                |
| Days Jan 1 to snowmelt, Kern                 | 3.4313          | 0.000265 (0.000572) | 0.6448                         | 0.005368                     | n/a                          | -           | 0.02373                                 |
| Days Jan 1 to snowmelt, Merced               | 3.2931          | -0.00002 (0.000452) | 0.9635                         | 0.005932                     | n/a                          | -           | 0.01391                                 |

<sup>A</sup> Arcsine square-root transformation

<sup>B</sup> Tests significant at the 0.10 level (also in bold)

### Nonparametric Tests of Trend

Kendall's tau-b is also used to test for trends in rivers independently (Table C.4). Note that tau-b statistic represents a rank correlation coefficient rather than an estimate of trend. In the Kern River, a statistically-significant temporal trend was detected in the number of days to the three-day high ( $p = 0.0269$ ) and in the number of days to the fourteen-day high ( $p = 0.0681$ ). In the Merced River, significant trends were observed in the number of days to the three-day high ( $p = 0.0799$ ), the number of days to the fourteen-day high ( $p = 0.0728$ ), the winter three-day low ( $p = 0.0321$ ), winter seven-day low ( $p = 0.0319$ ), winter fourteen-day low ( $p = 0.0294$ ), percent of variable flow from April to July ( $p = 0.0070$ ) and number of days October 1 to the center of mass ( $p = 0.0735$ )

**Table C.4.** Kendall's tau-b statistic, by river (site). Untransformed data.

| Dependent Variable           | Kern<br>$r_\tau$ | Kern<br>p-value | Merced<br>$r_\tau$ | Merced<br>p-value |
|------------------------------|------------------|-----------------|--------------------|-------------------|
| Three day high               | 0.00132          | 0.9848          | 0.03503            | 0.6172            |
| Seven day high               | 0.00833          | 0.9043          | 0.03570            | 0.6104            |
| Ten day high                 | 0.00877          | 0.8992          | 0.02013            | 0.7738            |
| Fourteen day high            | 0.01053          | 0.8792          | 0.00389            | 0.9557            |
| Days to 3 day high           | -0.15457         | <b>0.0269</b>   | -0.12349           | <b>0.0799</b>     |
| Days to 14 day high          | -0.12744         | <b>0.0681</b>   | -0.12662           | <b>0.0728</b>     |
| Winter 3 day low             | 0.06604          | 0.3407          | 0.15027            | <b>0.0321</b>     |
| Winter 7 day low             | 0.06275          | 0.3653          | 0.15041            | <b>0.0319</b>     |
| Winter 14 day low            | 0.07151          | 0.3021          | 0.15263            | <b>0.0294</b>     |
| Summer 3 day low             | -0.04432         | 0.5226          | 0.04581            | 0.5136            |
| Summer 7 day low             | -0.04848         | 0.4842          | 0.03938            | 0.5742            |
| Summer 14 day low            | -0.04518         | 0.5144          | 0.03227            | 0.6451            |
| Days to winter 7 day low     | 0.01439          | 0.8369          | 0.01937            | 0.7857            |
| Days to summer 7 day low     | -0.07590         | 0.3090          | -0.01587           | 0.8369            |
| Mean annual discharge        | 0.00482          | 0.9445          | 0.03561            | 0.6092            |
| April-July percent flow      | -0.0890          | 0.1988          | -0.1887            | <b>0.0070</b>     |
| Days Oct 1 to center of mass | -0.0983          | 0.1562          | -0.1254            | <b>0.0735</b>     |
| Days Jan 1 to snowmelt       | -0.0023          | 0.9672          | -0.0268            | 0.7046            |

### Comparing the Results

Least squares estimates are highly sensitive to heteroscedasticity (when subpopulations have unequal variance) and outliers. Logarithmic transformation can correct for unequal variance but not the presence of outliers. The power for non-parametric tests can greatly exceed the power of parametric tests when the assumptions of the parametric test are not met (Lettenmaier 1976). The p-values of two sets of tests (Table C.5) indicate that the parametric test may be significant at the 0.10 level when the nonparametric test is not significant, and vice-versa.

While residual diagnostics did not indicate dramatically-different outliers, more detailed trend analysis might consider specific points as outliers and examine their influence by assessing trend

without those points. When data transformation cannot correct the problem, trend testing with a nonparametric test is a robust and conservative approach. Before implementing a management action to mitigate the impacts of a potential trend, resource managers often require evidence from multiple tests. However, if results between trend tests conflict it may be an indication that one test has low power for trend detection. For the 18 outcomes across and within river type, testing at the Bonferroni-correction Type I error level of 0.0019 would provide conservative trend test results and a study-wide Type I error level of 0.10.

**Table C.5.** Comparison of p-values for trend tests by river.

| Dependent variable       | River  | Reduced OLS Models | Kendall's Tau |
|--------------------------|--------|--------------------|---------------|
| Three-day high           | Kern   | 0.4697             | 0.9848        |
| Three-day high           | Merced | <b>0.0992</b>      | 0.6172        |
| Seven-day high           | Kern   | 0.3831             | 0.9043        |
| Seven-day high           | Merced | <b>0.0982</b>      | 0.6104        |
| Ten-day high             | Kern   | 0.2646             | 0.8992        |
| Ten-day high             | Merced | 0.1151             | 0.7738        |
| Fourteen-day high        | Kern   | 0.2181             | 0.8792        |
| Fourteen-day high        | Merced | <b>0.0888</b>      | 0.9557        |
| Days to 3 day high       | Kern   | <b>0.0930</b>      | <b>0.0269</b> |
| Days to 3 day high       | Merced | 0.9335             | <b>0.0799</b> |
| Days to 14 day high      | Kern   | 0.7178             | <b>0.0681</b> |
| Days to 14 day high      | Merced | 0.4319             | <b>0.0728</b> |
| Winter three-day low     | Kern   | 0.5568             | 0.3407        |
| Winter three-day low     | Merced | <b>0.0533</b>      | <b>0.0321</b> |
| Winter seven-day low     | Kern   | 0.6324             | 0.3653        |
| Winter seven-day low     | Merced | <b>0.0504</b>      | <b>0.0319</b> |
| Winter 14 day low        | Kern   | 0.5610             | 0.3021        |
| Winter 14 day low        | Merced | <b>0.0456</b>      | <b>0.0294</b> |
| Summer three-day low     | Kern   | 0.5895             | 0.5226        |
| Summer three-day low     | Merced | <b>0.0366</b>      | 0.5136        |
| Summer seven-day low     | Kern   | 0.6140             | 0.4842        |
| Summer seven-day low     | Merced | <b>0.0491</b>      | 0.5742        |
| Summer 14 day low        | Kern   | 0.5682             | 0.5144        |
| Summer 14 day low        | Merced | <b>0.0728</b>      | 0.6451        |
| Days to winter 7 day low | Kern   | 0.7241             | 0.8369        |
| Days to winter 7 day low | Merced | 0.8289             | 0.7857        |
| Days to summer 7 day low | Kern   | 0.3721             | 0.3090        |
| Days to summer 7 day low | Merced | 0.2925             | 0.8369        |
| Mean annual discharge    | Kern   | 0.2079             | 0.9445        |
| Mean annual discharge    | Merced | 0.3644             | 0.6092        |

**Table C.5 (continued).** Comparison of p-values for trend tests by river.

| Dependent variable           | River  | Reduced OLS Models | Kendall's Tau |
|------------------------------|--------|--------------------|---------------|
| April-July percent flow      | Kern   | 0.5096             | 0.1988        |
| April-July percent flow      | Merced | <b>0.0151</b>      | <b>0.0070</b> |
| Days Oct 1 to center of mass | Kern   | 0.2049             | 0.1562        |
| Days Oct 1 to center of mass | Merced | 0.2695             | <b>0.0735</b> |
| Days Jan 1 to snowmelt       | Kern   | 0.8638             | 0.9672        |
| Days Jan 1 to snowmelt       | Merced | 0.4953             | 0.7049        |

### Power Analysis

The power of the parametric and nonparametric trend tests is examined with a Monte Carlo power simulation. The most recent estimates of status and estimates of residual error from the individual river analyses are used with the year-to-year variation estimates from the across-river analyses to simulate the populations of interest under known levels of trend. Note that variance components are taken from different trend analyses so that total variance may be overestimated. This approach is considered conservative but useful given the large impact of the year-to-year variation on the power to detect trend (Urquhart and Kincaid 1999). The simulated data are combined with the historic data for a complete data record for trend detection. Note that the trend is imposed only in the simulated data. The two-sided parametric and nonparametric trend tests are conducted and compared against a Type I error level of 0.10. A total of 1000 iterations are used to assess the power of each test as the proportion of times the test results in a correct rejection of the null hypothesis.

The results of the power analysis are provided in Figures C.15 through C.22. Note that the trend is assessed for the historic data as well as the simulated data. As expected, a trend of 4% annually is detected with higher power than an annual trend of 1%. Overall, the power to detect trends in flow metrics of 4% per year exceeds 80% within the 10 to 20 years of monitoring. Achieving 80% power to detect a 1% annual trend may take up to 40 years but most outcomes achieve 80% power within 20 to 30 years of monitoring. No outcome consistently performed with higher or lower power than the rest. Power for the Kendall tau-b test of trend is generally higher than that of the linear mixed model when the residual variation is relatively large for an outcome.

Power for the two tests is very similar with generally slightly higher power for the linear mixed model (LMM). This result is not surprising since the data are generated to meet the assumptions of least squares. One exception is found in the power plots for the number of days to the three-day high in the Merced River (Figure 17d). For this outcome, the power to detect a 1% annual trend is much higher for the first 10 years of the monitoring program then it drops before increasing monotonically again. This pattern is due to a significant negative trend detected in the pilot data by the Kendall tau-b test (Table C.4) that is not detected by the linear mixed model (Table C.3). After additional years of data are observed, the power increases monotonically over time. Note that this is an artifact of the data; when the power to detect trend in this outcome is assessed without the historic data, the power increases monotonically for all monitoring periods. Because a significant negative trend was

observed in the number of days to the three-day high in the Kern River and the percent flow between April and July in the Merced River, this simulation was conducted assuming a negative trend.

Because the power analysis for each river for a given outcome assumes the same estimate of year-to-year variation, the power for the river exhibiting less residual variation is generally higher. An exception occurs when the simulated trend is similar to that of the observed trend from the historic data. In these cases, the trend is consistent over the entire monitoring period so the power to detect this trend is higher than if no trend was observed for the first 93 to 96 years despite increased unexplained variation. This pattern is demonstrated by the winter three-, seven- and fourteen-day lows for the Merced River (Figures C.18 and C.19).

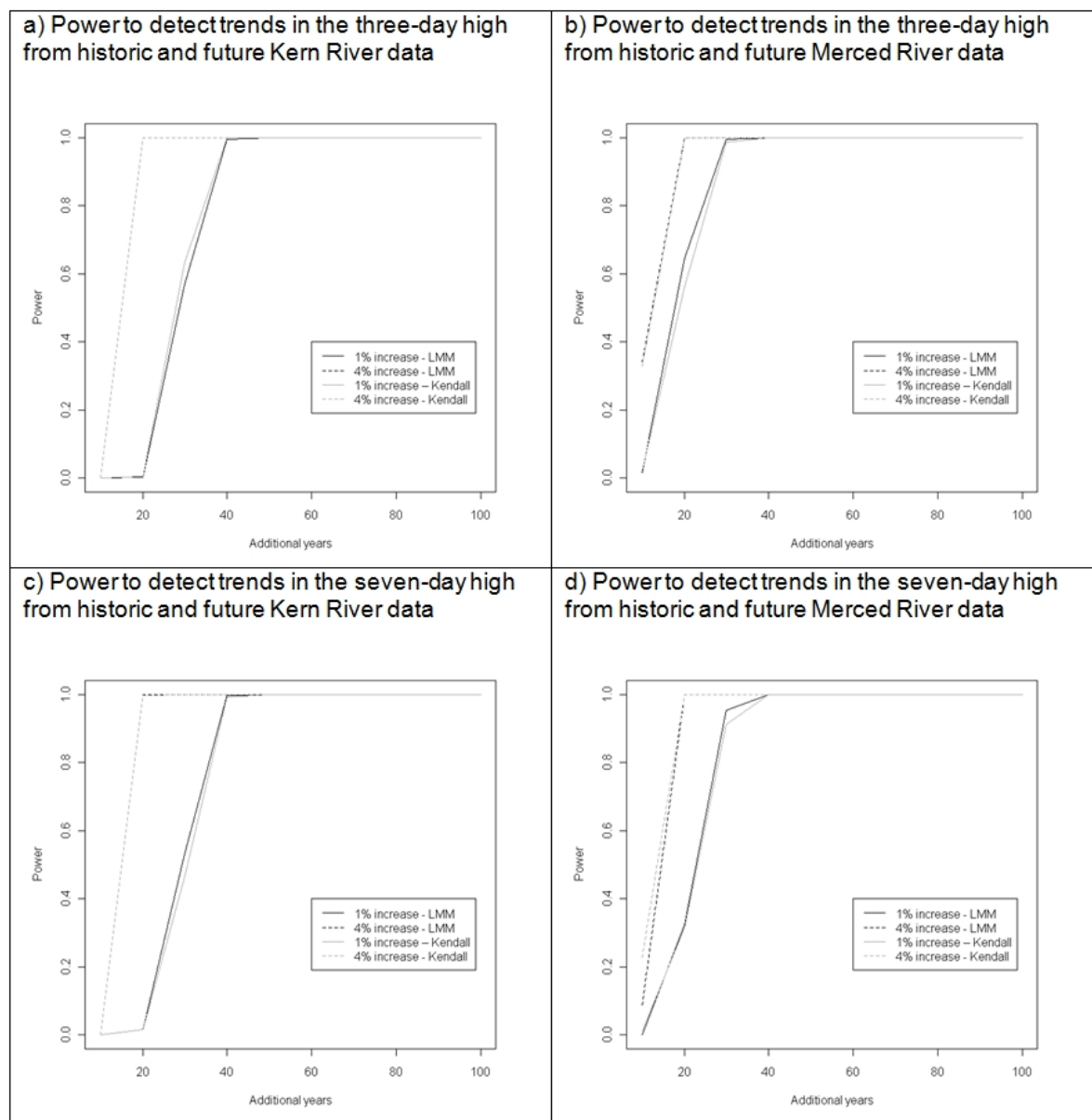


**Figure C.15.** Power to detect trends in the three- and seven-day highs in the Kern and Merced Rivers for two levels of change and two trend tests.

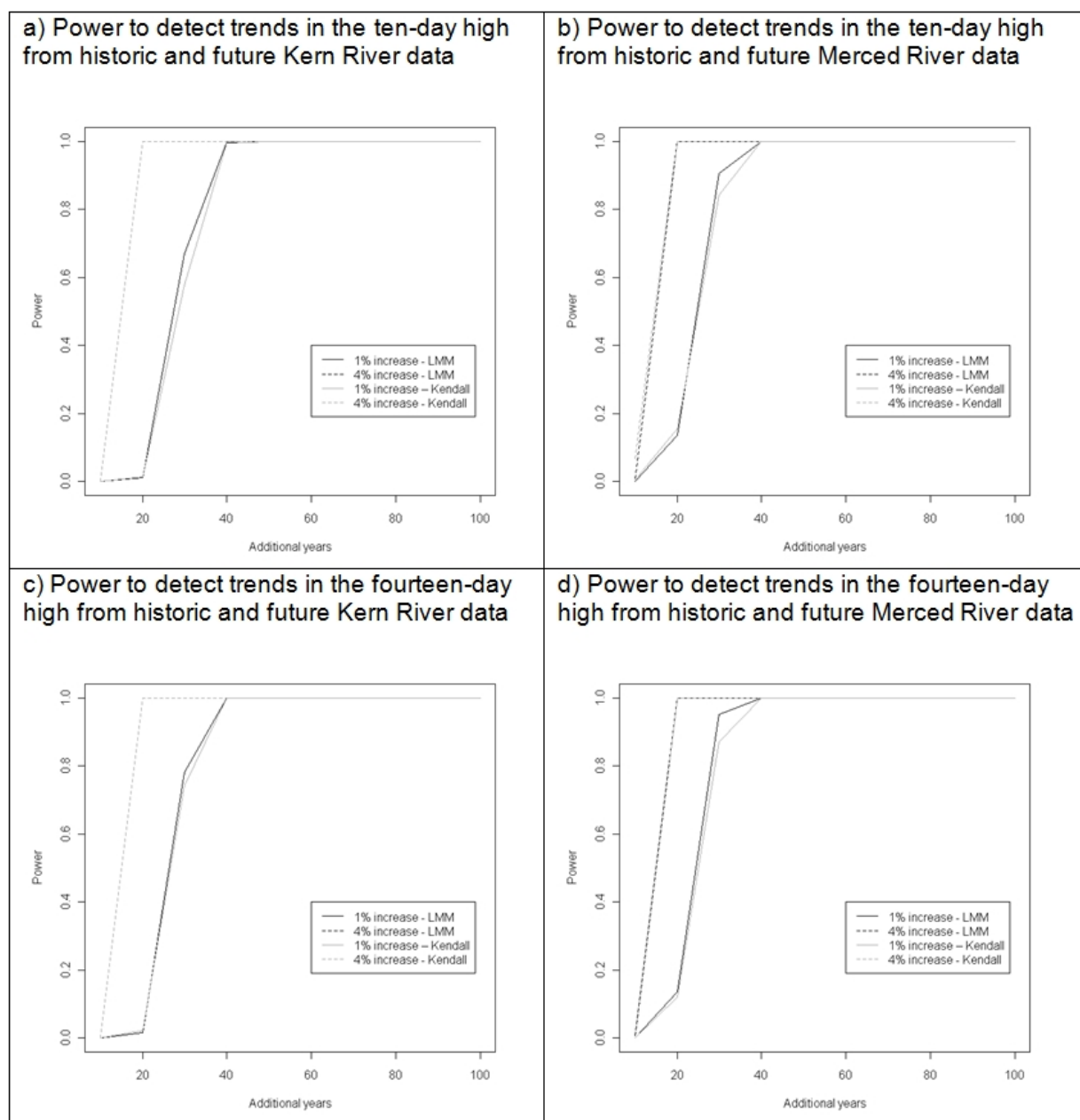


**Figure C.16.** Power to detect trends in the ten- and fourteen-day highs in the Kern and Merced Rivers for two levels of change and two trend tests.

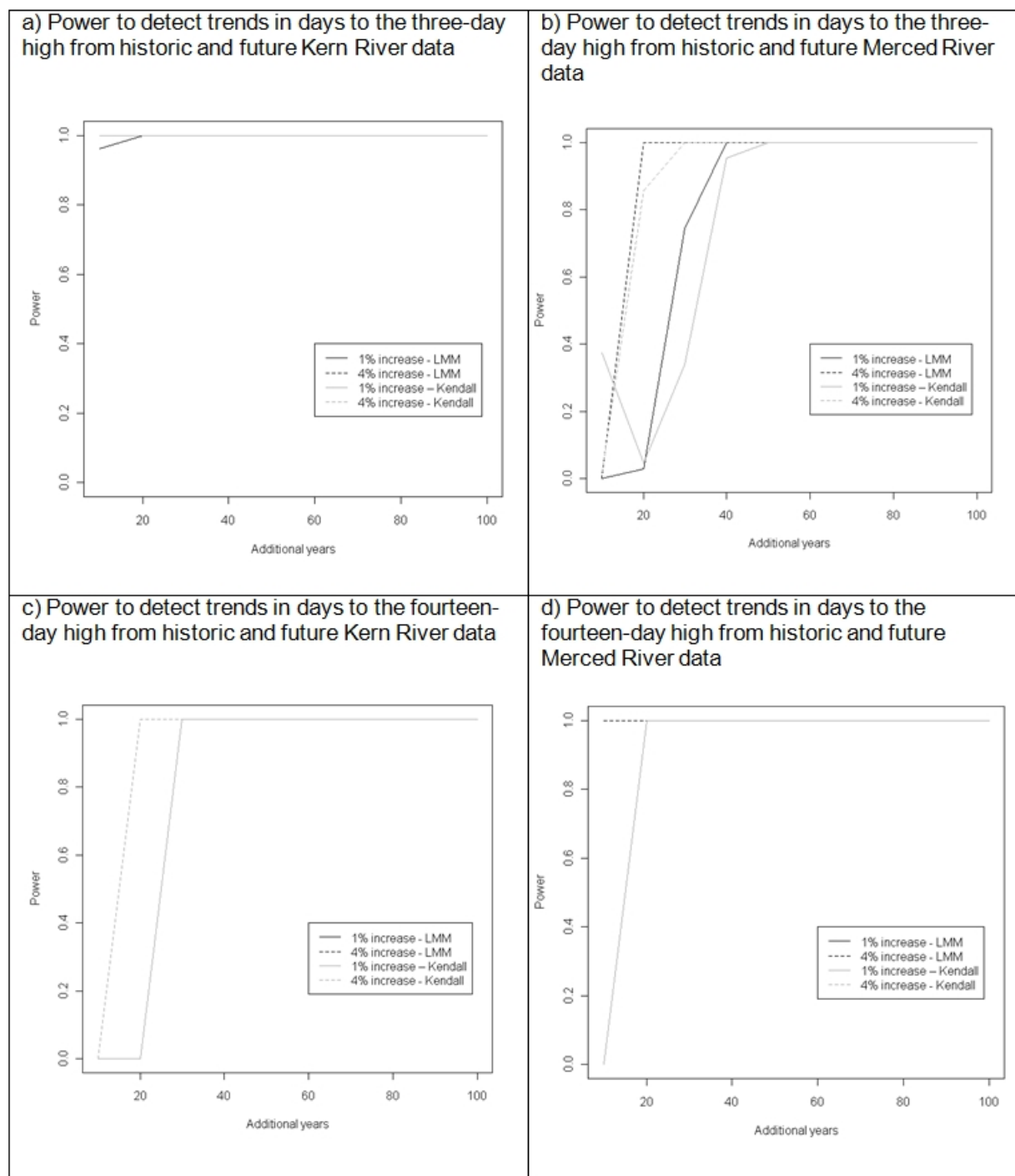


**Figure C.17.** Power to detect trends in the number of days to the three-day high and the number of days to the fourteen-day high in the Kern and Merced Rivers for two levels of change and two trend tests.

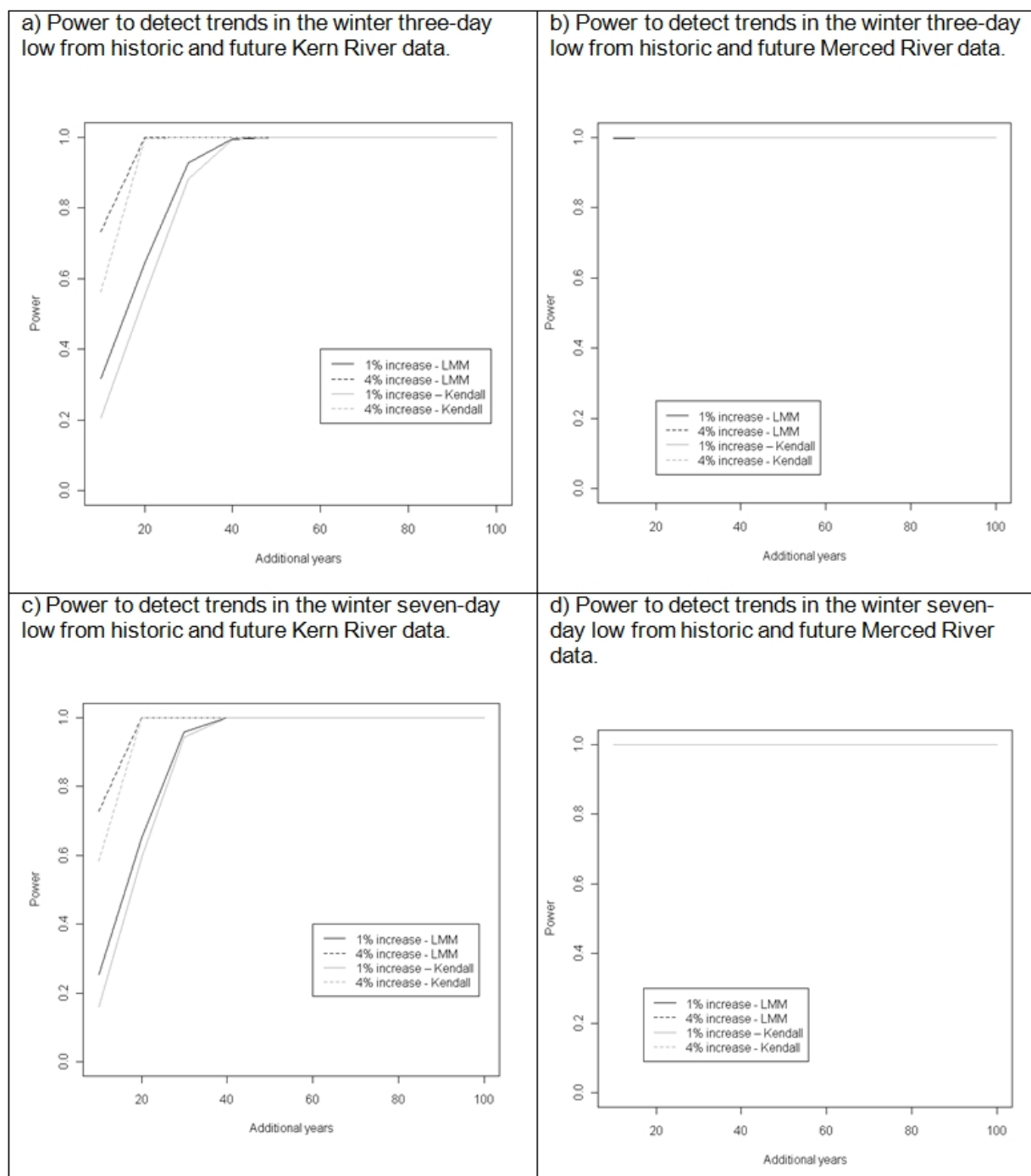


**Figure C.18.** Power to detect trends in the winter three- and seven-day lows in the Kern and Merced Rivers for two levels of change and two trend tests.

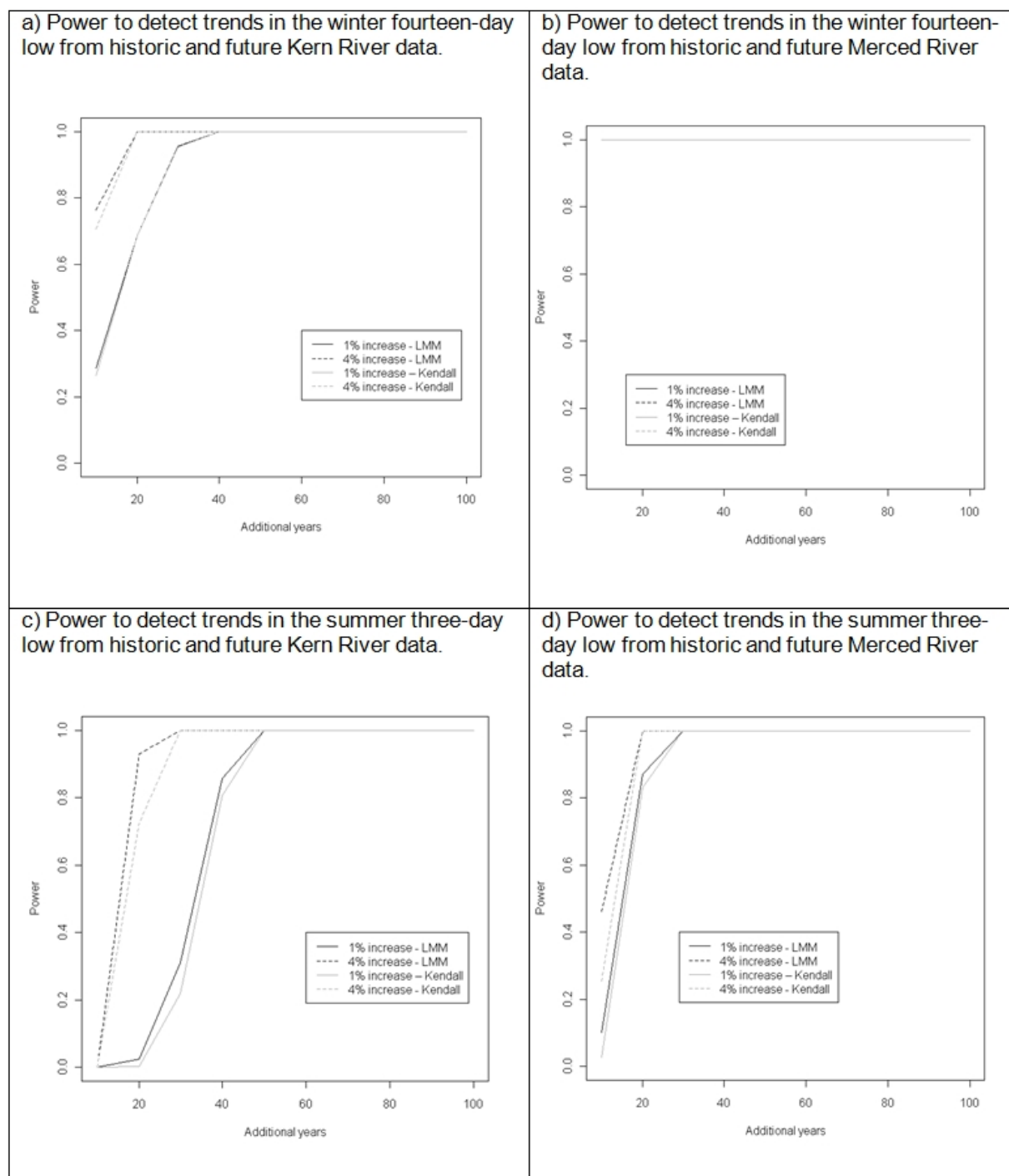


**Figure C.19.** Power to detect trends in the winter fourteen-day low and summer three-day lows in the Kern and Merced Rivers for two levels of change and two trend tests.

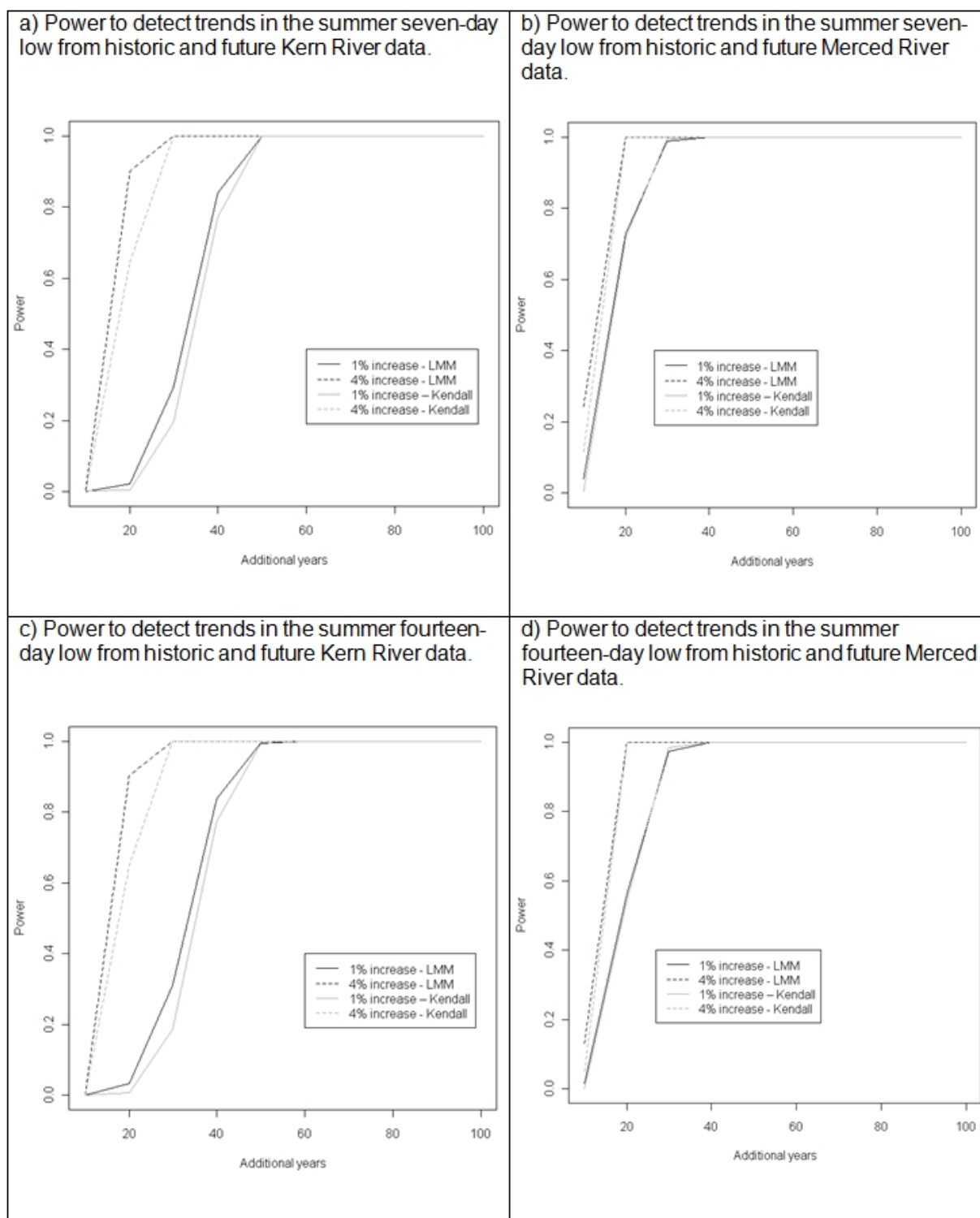


**Figure C.20.** Power to detect trends in the summer seven- and fourteen-day lows in the Kern and Merced Rivers for two levels of change and two trend tests.

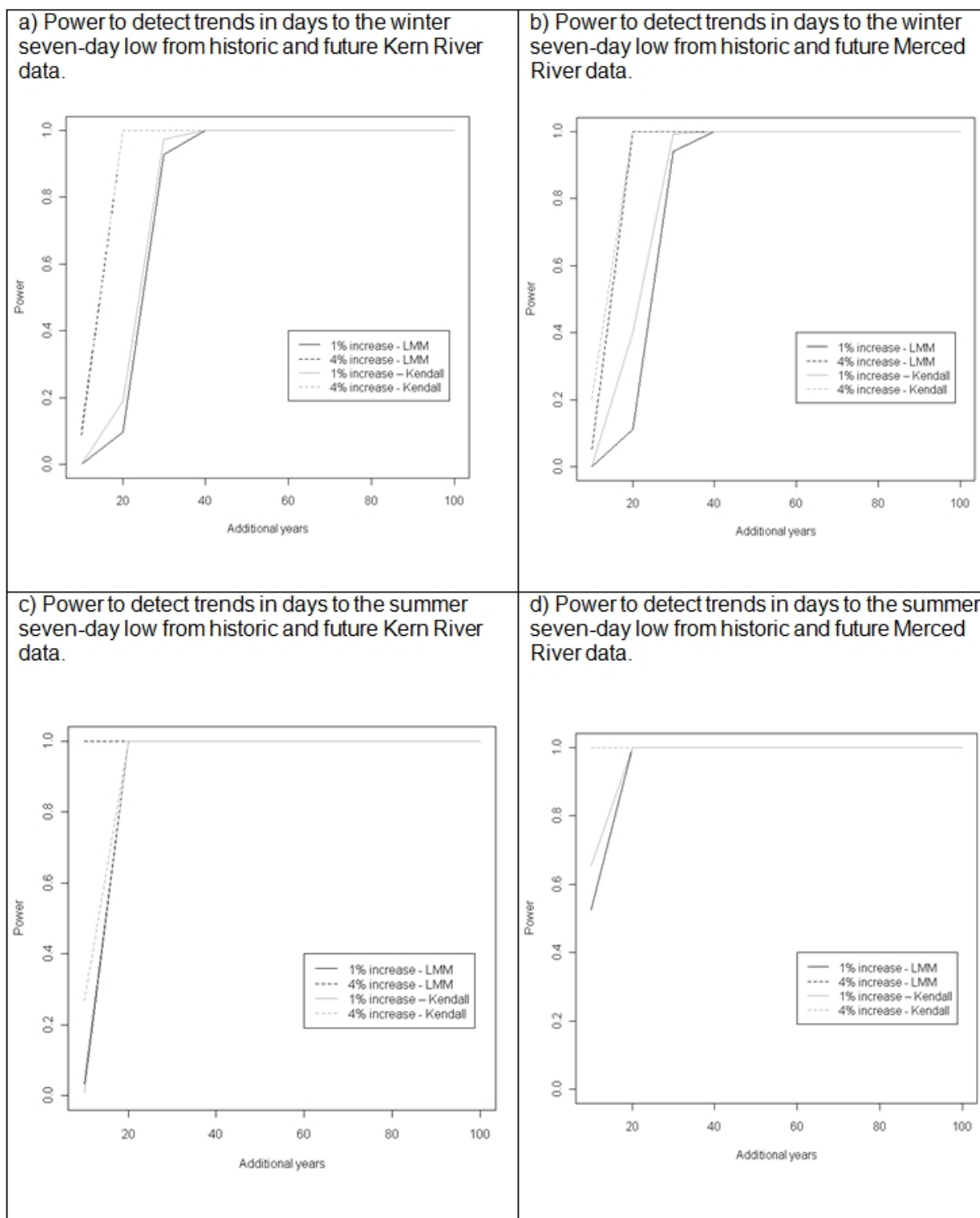


**Figure C.21.** Power to detect trends in the winter seven-day lows and in the summer seven-day lows in the Kern and Merced Rivers for two levels of change and two trend tests.

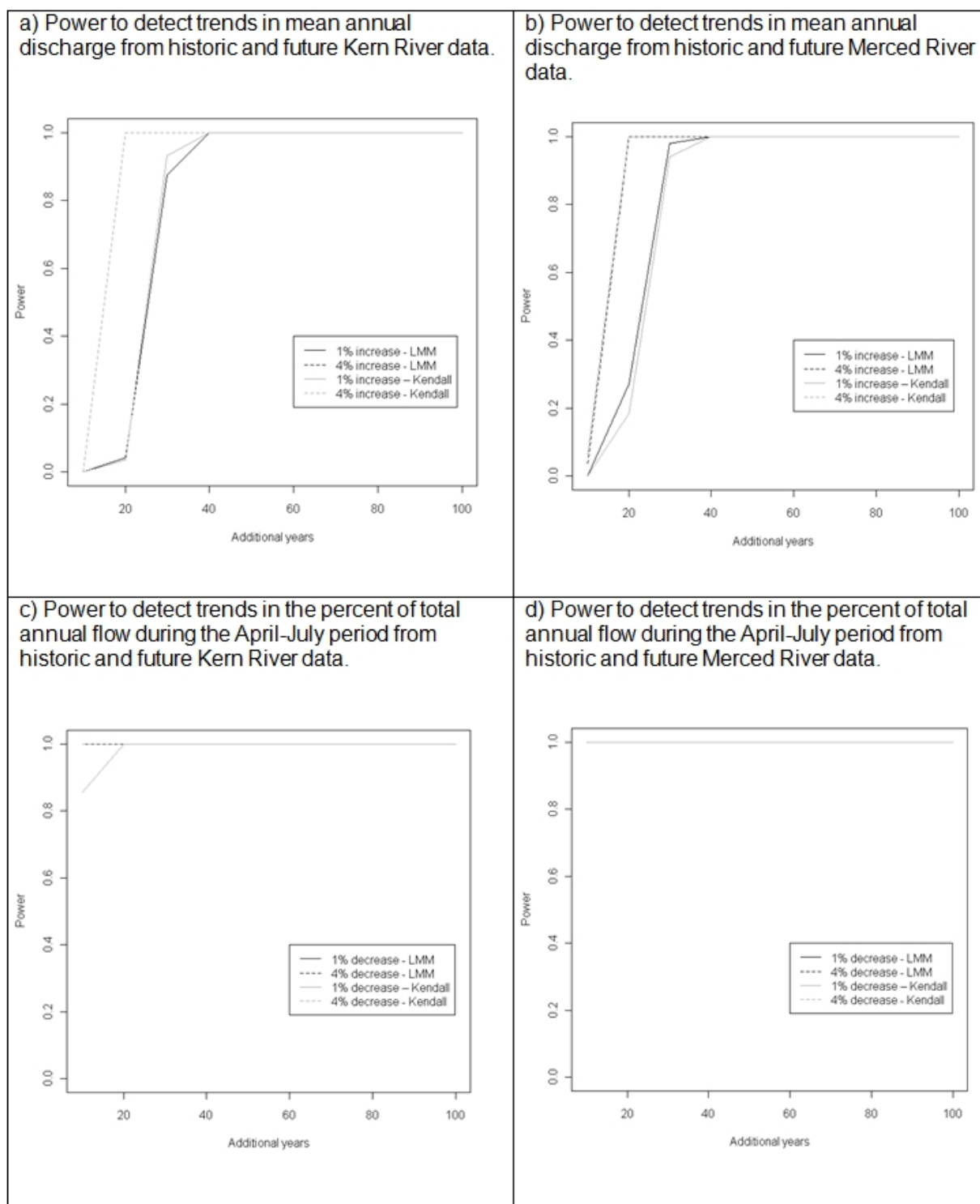


**Figure C.22.** Power to detect trends in the mean annual discharge and in the percent of total annual flow occurring between April-July period in the Kern and Merced Rivers for two levels of change and two trend tests.

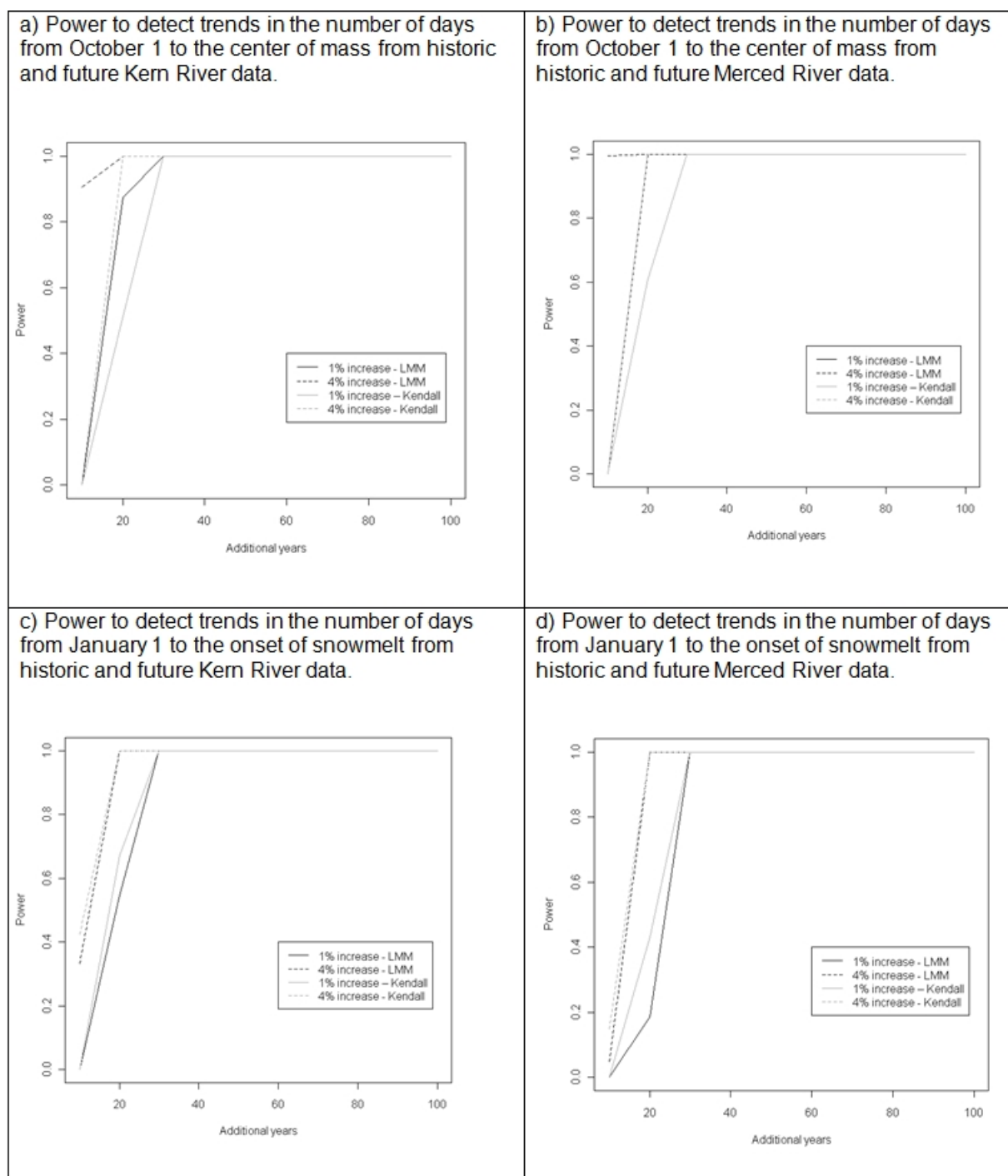


**Figure C.23.** Power to detect trends in the number of days from October 1 to the center of mass and in the number of days from January 1 to the onset of snowmelt in the Kern and Merced Rivers for two levels of change and two trend tests.

## Conclusions

Overall, trends in the eighteen metrics describing flow conditions in the Merced and Kern Rivers were detectable with at least 80% power. If an increasing annual trend of 1% occurred during the next 100 years, the power to detect this trend would exceed 80% within 20 to 40 years for most

outcomes. An annual trend of 4% would be detected with at least 80% power in less than 20 years for all of the outcomes examined. Only the outcome measuring percent of total flow occurring between April and July exhibited high power for both rivers.

The trend test from a linear mixed model (Piepho and Ogutu 2002) demonstrated slightly higher power than the Kendall tau-b test (Higgins 2004) for most outcomes. However, examination of the test size (the Type I error rate demonstrated by the test) for both tests indicated that test size may be lower than nominal for the t-test from the linear mixed model when the sample of years is relatively small (less than 40 to 50 years). For these monitoring time frames, the Kendall tau-b exhibited test size closer to nominal levels and may provide more reliable inference for these shorter monitoring periods.

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## Appendix D. Southern California Edison Infrastructure and Streamgauge Information

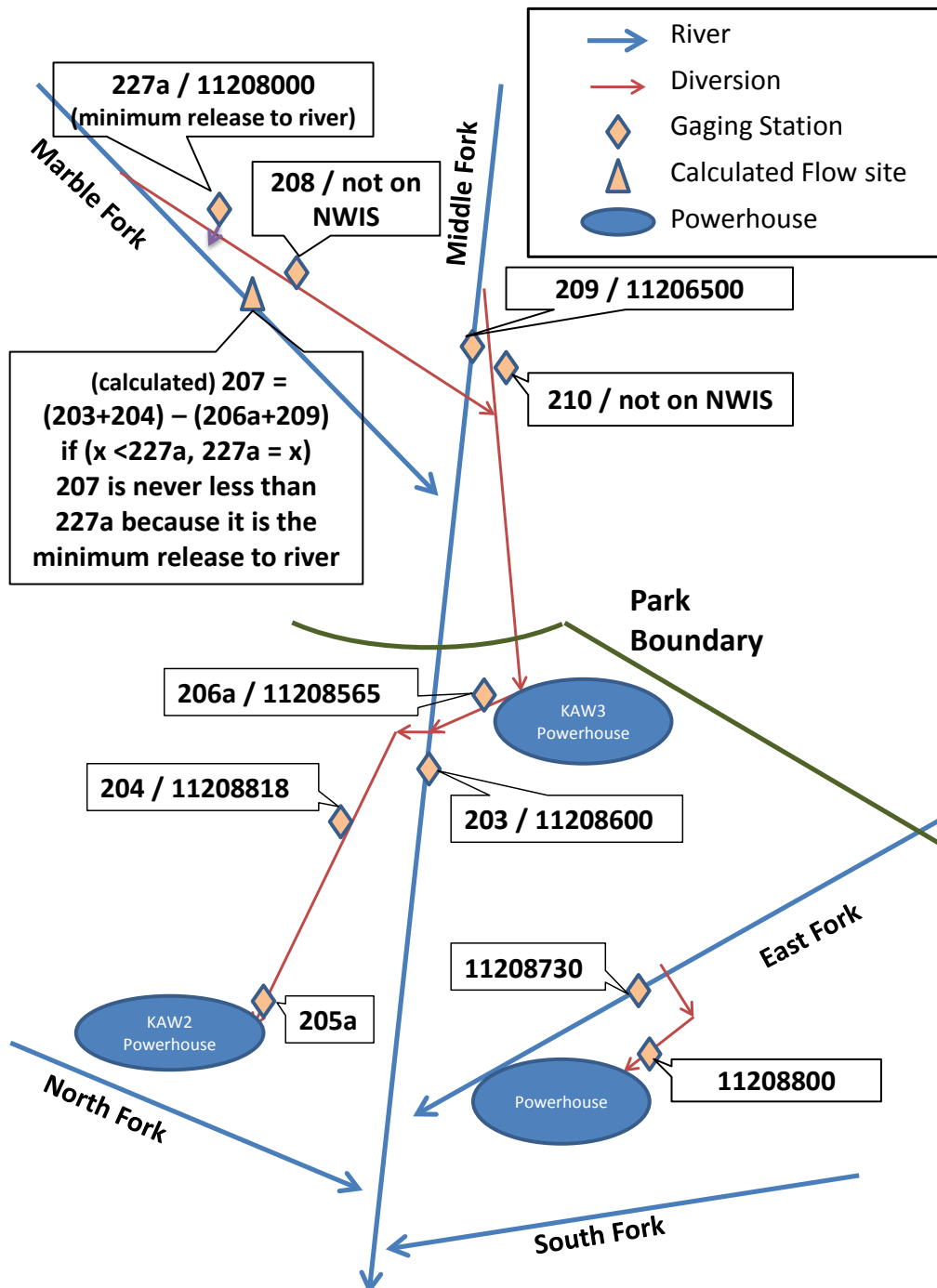


**Figure D.1.** The diversions and gaging stations operated by Southern California Edison (SCE) on the Middle, Marble, and East Forks of the Kaweah River. SCE uses an alternate numbering system from USGS. Gages are labeled: SCE # / USGS NWIS ID.



## Appendix E. Administrative Record

| Date          | Event                                                                                                                                                                                                                                         |
|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dec 2005      | First meeting of the water resources work group. General objectives for the water protocol(s) were discussed. Lakes and rivers divided into two protocols. Lakes protocol would be developed first and rivers second.                         |
| Feb 2008      | River protocol meeting with work group led by A. Heard to clarify objectives.                                                                                                                                                                 |
| June 2010     | SIEN term Physical Scientist hired to complete River protocol.                                                                                                                                                                                |
| July 2010     | Water work group meeting to prioritize protocol objectives. Water quantity and timing prioritized over water quality if budget does not allow both.                                                                                           |
| Sept/Oct 2010 | SIEN protocol prioritization meeting and 3-year review with SIEN Steering Committee and BOD reveal River protocol is not prioritized but should proceed with development and assume ~\$10,000 budget.                                         |
| Oct 2010      | Draft of SIEN surface water dynamics status and trends analysis complete (Andrews 2012). Andrews report results presented at YOSE Hydroclimate Workshop with SIEN cooperators. Discussion with cooperators about direction of River protocol. |
| Dec 2010      | Water work group meeting to prioritize watersheds and stations for monitoring.                                                                                                                                                                |
| Feb 2011      | Objectives and station selection rationale sent to water work group and steering committee for approval. SIEN Physical Scientist and Program Manager meet with SEKI Chief of Resources Management and Science.                                |
| Mar 2011      | SEKI Chief of Resources Management and Science submitted request for consideration of additional SEKI site prior to granting approval of site selection and objectives. Protocol development summary finalized                                |
| July 2011     | LAH Starceovich (U Idaho) begins work on power analysis                                                                                                                                                                                       |
| Sept 2011     | Steering Committee gives final approval to protocol objectives and sample design.                                                                                                                                                             |
| Oct 2011      | First draft of protocol to SIEN Program Manager and Data Manager for review.                                                                                                                                                                  |
| Jan 2012      | Final draft of river power analysis submitted to SIEN from U Idaho.                                                                                                                                                                           |
| Jan/Feb 2012  | Protocol circulated to water work group, MOJN Physical Scientist, and SIEN staff for internal peer review. Review comments received from all work group members.                                                                              |
| Mar 2012      | Final revisions. Formatting by UCBN technical editor.                                                                                                                                                                                         |
| Apr 2012      | Submission to PWR peer review process.                                                                                                                                                                                                        |
| Oct 2012      | Peer review comments returned to SIEN                                                                                                                                                                                                         |
| June 2013     | Peer-review response submitted                                                                                                                                                                                                                |
| Oct 2014      | Peer review comments returned to SIEN (round 2)                                                                                                                                                                                               |
| Feb 2017      | Peer-review response submitted (round 2)                                                                                                                                                                                                      |
| Mar 2017      | Protocol approved and submitted for publication                                                                                                                                                                                               |



## **Appendix F. National Park Service-Water Resources Division Technical Assistance Trip Report**



### **United States Department of the Interior**

NATIONAL PARK SERVICE

Water Resources Division

1201 Oak Ridge Drive, Suite 250

Fort Collins, CO 80525

**January 10, 2014**

IN REPLY REFER TO:

L54(2380)

SIEN/General

/ELECTRONIC COPY ONLY – NO HARD COPY TO FOLLOW/

### Memorandum

To: Alice Chung-MacCoubrey, Program Manager, Sierra Nevada Network

Through: William R. Hansen, Chief, Water Rights Branch (WRB)

From: Gwen Gerber, Hydrologist, Water Rights Branch (WRB)

Subject: Trip Report for assessing SIEN streamflow monitoring sites, August 20-23, 2013.

### **PURPOSE**

The purpose of the trip was to provide technical assistance to park and network staff regarding their stream gaging program associated with the Sierra Nevada Network (SIEN) River Hydrology Monitoring Protocol.

### **BACKGROUND**

SIEN is comprised of four units that are located within the Sierra Nevada mountain range: Devils Postpile National Monument (DEPO), Sequoia and Kings Canyon National Parks (jointly administered as SEKI), and Yosemite National Park (YOSE). Within these parks SIEN has selected 14 existing stream gaging stations to include in their monitoring program. Of these 14 gages, SIEN

provides operational or data management support for three gages (two at YOSE and one at DEPO)<sup>1</sup>. Monitoring objectives focus on timing and quantity of streamflow with specific measureable objectives requiring analysis of long-term trends.

As a part of WRD's review of the SIEN River Hydrology Monitoring Protocol, WRD recommended that a site visit of the three SIEN supported streamgages be performed. Due to time constraints, only the two gages in YOSE were evaluated. The SIEN operated gage at DEPO was not evaluated since operation and data management are overseen by the USGS.

The following was completed as a part of the site visit:

- 1) Review and critique of streamflow gaging sites to provide recommendations for improving data quality.
- 2) Review of discharge measurement field procedures to provide recommendations to improve accuracy of measurements and conformity with USGS standard procedures.
- 3) Review of stage-discharge data for each site to provide recommendations and assessment of the quality of the rating curves. Provide training on USGS procedures for developing and updating rating curves.
- 4) Review and assistance with data-workup and analysis via Aquarius software.

## **SITE VISIT REVIEW**

WRD staff visited the following stream gaging stations: 1) Lyell Fork of the Tuolumne River below Maclure Creek, and 2) Tuolumne River at Tioga Road Bridge. WRD staff also spent some time with SIEN/YOSE staff reviewing data in the Aquarius database. The following are recommendations on improving field, instrumentation, discharge measurement, and data processing methodologies. Figures are located at the end of the document.

### ***Lyell Fork of the Tuolumne River below Maclure Creek***

This Station was established in 2001 by Dave Clow of the USGS as a part of the Hydroclimate Monitoring Network in YOSE. The Station is located at almost 10,000 feet, just below the confluence of Maclure Creek and the Lyell Fork. The Station is approximately 9.5 miles from the Tuolumne Meadows Lodge via the John Muir/Pacific Crest Trail. This station is located in designated wilderness which presents challenges for equipment installation. The recommendations suggested below include equipment installation necessary to meet data quality requirements for monitoring objectives.

---

<sup>1</sup> The other 11 stream gages are operated by the USGS, Hetch Hetchy Water and Power, Kings River Water Association, Southern California Edison, and Sierra Hydrographics.

## Observations / Recommendations

### *Measuring Stage*

The existing stage datum is a fence post installed on the edge of the gage pool which is loose and angled approximately 10-15 degrees toward the right bank (Figure 1). Tapedown measurements are difficult to make and are made by laying an engineers ruler parallel to the angled fence post and measuring from the top of the post to the water surface. It is not known if previous stage readings (prior to 2012) were made this same way and there is no known history of any elevation surveys to determine the stability of the fence post.

Recommend installing a staff plate mounted on fiberboard flush against the rock on the right bank secured by rock bolts (examples shown in Figure 2). To address issues with visibility, the fence post can be removed once the staff plate has been installed. The fence post should be surveyed relative to the new staff plate prior to removal. Also, a USGS Style C staff gage which is only 2.5 inches wide can be installed rather than the standard USGS Style A staff gage (4 inches wide). The Style C staff plate can be ordered in 1, 1.5, and 2 foot lengths rather than the standard 3 1/3 foot sections. Surveys should be performed as recommended below to document the stability of the staff plate. Since this site is necessary for long-term monitoring it is crucial to have a way of measuring stage that is not subject to user interpretation and is stable for the long-term. Due to the channel substrate and the affect ice has on the channel, it is important that the staff plate be bolted directly to the rock.

If a small staff plate cannot be installed at this location due to wilderness issues, a rock bolt can be installed in the same location instead of the proposed staff plate. Tapedown measurements can be made from the bolt to the water surface by a weighted section of tape or engineers ruler. This is an alternative but is not the recommended method for measuring stage at this site for the following reasons: 1) seasonal staff changes regularly and tapedown methodology is subject to user interpretation, 2) error is greatly reduced when field personnel can read a number off of a staff plate rather than making tapedown measurements, 3) a small error in a stage reading corresponds to a large error in discharge; and 4) monitoring objectives require long-term data reliability.

The primary datalogger is a Campbell datalogger and vented pressure transducer installed horizontally along the channel bottom. A Solinst level logger is installed as a backup datalogger in a stilling well loosely secured with rebar to the right bank. Recommend installing both dataloggers in a stilling well secured to the rock adjacent to the new staff plate. Combining the dataloggers into one secure stilling well hidden behind the rocks near the staff plate will reduce the visibility while also allowing for easy access to the dataloggers. Set dataloggers to gage datum during each site visit so that the staff plate and datalogger read the same. This makes it easier with troubleshooting problems in the field and determining logger drift between site visits.

### *Surveys / Reference Marks*

No known reference marks have been installed at the gaging station. Recommend installing at least three benchmarks in the large granite boulders adjacent to the new staff plate. To address issues with visibility, small rock bolts can be installed rather than the typical NPS benchmarks (Figure 2). Rock bolts can easily be disguised in the granite rocks at the site and may even be difficult to find in

subsequent trips. Be sure to make a sketch and take photos following installation. Also, be sure to install rock bolts so that a survey rod can be placed and leveled on top. Due to the nature of the ground surface and the susceptibility of freeze-thaw affects, rock bolts offer the only acceptable stability that is required for long-term gaging stations. Stable reference marks are absolutely necessary at gaging stations since they provide the only way to determine elevation changes in gage datum, the channel, or the control (Kenney, 2010).

No known surveys have been performed at the gaging station. Recommend performing an Auto-Level survey after the staff plate and reference marks have been installed. Survey all three reference marks, the staff plate, the fence post, and the cross-section of the river at the control. WRD has provided blank survey forms. All final elevations should be calculated relative to gage datum. The cross section survey on the control will help in creating a rating curve for the site. Be sure to survey the entire channel x-section within the high flow channel. Also refer to USGS TWRI “Levels at Gaging Stations” (Kenney, 2010). Frequency of levels is dependent on stability of the staff gage and reference marks. If they are fixed to bedrock, it may only be necessary to run levels once every five years (following 3 sets of annual levels).

#### *Measuring Discharge:*

Discharge measurements by standard wading methods are difficult at this site due to the high gradient, very rough channel, and high turbulence. Discharge measurements at this site are usually made using the salt dilution method. At varying stages wading measurements can also be made. Eleven measurements between 8 and 31 cfs were made at the site since 2012. Discharge measurements prior to 2012 (since installation in 2001) were not available for review.

During the site visit, measurements were made using both the salt dilution method and wading methods. The first two discharge measurements (#7 and #8) were performed using the salt dilution method and the second two were performed using standard wading methods (#9 using a pygmy meter and #10 using a flowtracker).

For measurements #7 and #8, the salt slug was injected just downstream of the pedestrian bridge and measured downstream of the gaging station. Measurements were taken approximately one hour apart. Results from the measurements are shown in Table 1. Salt dilution measurements were within 17 percent of each other but stage had changed by -0.02 feet between the two measurements. Based on the time-concentration curves it appears that adequate mixing was achieved.

A good cross section for wading measurements was difficult to find due to the roughness of the channel. The best available cross section (at the discharge on 8/21/13) was located upstream of the gaging station (See Figure 3). Results of the measurements are shown in Table 1. Stage changed by -0.02 feet during the wading measurements but multiple stage readings were taken so that total weighted mean gage height (TWMGH) could be calculated. Wading measurements were within 1% of each other, although, due to the roughness of the cross-section they shouldn't be rated any better than fair (within 8%).

**Table 1.** Discharge Measurements from 8/21/2013 at the Lyell Fork gage.

| Measurement Number | Date      | Start Time | End Time | Q (cfs) | Stage (TWMGH in feet) | GH Change During Measurement | Cumulative GH Change (all meas) | Method               |
|--------------------|-----------|------------|----------|---------|-----------------------|------------------------------|---------------------------------|----------------------|
| 7                  | 8/21/2013 | 8:35       | 8:52     | 22.3    | 7.87                  | 0.00                         | 0.00                            | Salt Dilution        |
| 8                  | 8/21/2013 | 9:35       | 9:54     | 19.1    | 7.85                  | -0.01                        | -0.02                           | Salt Dilution        |
| 9                  | 8/21/2013 | 10:20      | 11:16    | 18.8    | 7.83                  | -0.01                        | -0.04                           | Wading - Pygmy       |
| 10                 | 8/21/2013 | 10:21      | 11:33    | 18.7    | 7.83                  | -0.02                        | -0.04                           | Wading - Flowtracker |

Unfortunately, it is difficult to directly compare salt dilution methods with the wading measurements taken on 8/21/2013 since stage changed by -0.04 feet between the first salt measurement and the last wading measurement. A preliminary stage/discharge rating was created as a part of this trip report (see rating discussion below) which allows for better comparisons of the measurements taken on 8/21/2013.

#### *Control / Rating Curve*

The section control on the gage pool is the boulders just downstream of the gage pool (Figure 4). This is likely the control at all flows since the drainage area is only  $\approx 6$  square miles. The control appears to be stable although no historical photos or descriptions of the control could be located. In addition, no stage/discharge measurements prior to 2012 (since installation in 2001) were available for review. It is important to document conditions of the control on each site visit and especially when taking discharge measurements (WRD field form provided). This will help explain any shifts to the rating curve. For example, if a tree lodged on the control measurements will plot to the left of the rating. Be sure to keep the control clear of debris and photo document during site visits.

A preliminary rating was drawn in Aquarius as a part of this trip report using only 11 measurements (between 8 and 31 cfs) taken since 2012. Without a survey of the control and a point of zero flow, the offsets and breakpoints could only be estimated. The rating shown in (Figure 5) was drawn within 8% of 8 of 11 measurements from 6 to 40 cfs. Measurement #2 (taken on 9/11/2012) plots 90% to the right from the rating and appears to be in error. Recommend reviewing the measurement file to determine the source of error. Measurements #1 and #4 plot 12-14% to the left of the rating which could be indicative of either stage or discharge measurement inaccuracies or simply because the rating is poorly defined. More rating points at all flows and a survey of the control are necessary to improve the rating. Measurements #8, #9, and #10 taken during the site visit plot within 2% of the preliminary rating which likely indicates a good comparison between the 2<sup>nd</sup> salt dilution measurement and both the pygmy and flowtracker wading measurements. The first salt dilution measurement plots 8% off the rating to the left and may indicate that the discharge measured is slightly high. It could also just as easily be a factor of the rating not being well defined.

*Discharge Measurement and Rating Curve Recommendations*

The following are recommendations to improve discharge measurement methods and the rating curve for the Lyell Fork gaging station.

- 1) Always get two back-to-back salt dilution measurements if time allows.
- 2) If time and conditions allow perform additional measurements during the field season to compare salt dilution measurements with wading measurements. Once the rating curve is better defined less frequent QA/QC measurements are necessary.
- 3) Create a field form for salt dilution methods that prompts the user to note start and end times and stage readings.
- 4) Use field radios to communicate start and end times during salt dilution measurements.
- 5) Bring the rating curve/table to the site when taking discharge measurements to compare new measurements to the rating. A reasonably obtainable goal for this site would be for measurements to plot within 8% of the rating (measurements rated “fair”). If the measurement does not plot within 8% of the rating, repeat the measurement to confirm the accuracy of the new rating point.
- 6) Manual staff plate readings should be taken before and after each discharge measurement to note water level changes during the measurement. If water levels are changing during the discharge measurement, multiple stage measurements should be taken so total weighted mean gage height can be calculated.
- 7) Use either the wading rod that came with the flowtracker or use the curved mounting bracket when making flowtracker measurements.
- 8) A field form for wading discharge measurements should be filled out during wading measurements. This will help eliminate errors as a result of data entry mistakes. Record each distance, depth and velocity along the cross-section (field form provided by WRD). This should be checked using the HMST spreadsheet (provided by WRD) against the flowtracker/aquacalc download file back at the office.
- 9) Always download flowtracker/aquacalc to review measurements in the office, upload raw files to Aquarius.
- 10) When the stream depth is greater than 1.5 ft, a 2-point measurement should be taken. See example from 8/21/13 measurement #10.

*Lyell Fork Summary of Recommendations:*

In summary, WRD recommends continuation of the Lyell Fork stream gaging station if 1) a staff plate and reference marks are installed and surveyed as recommended; 2) if a survey of the control is performed; and 3) if future discharge measurements are made with greater QA/QC. If these recommendations are not implemented, WRD suggests the gage be discontinued since staff time can't be justified to collect poor quality data. In making our recommendations we balanced wilderness, monitoring objectives, and data quality. We will continue to provide guidance and work with SIEN and YOSE during the compliance process to ensure the gage meets wilderness minimum tool requirements while still meeting the river monitoring objectives.

### ***Tuolumne River at Tioga Road Bridge***

This Station was established in 2001 by researchers as a part of the Hydroclimate Monitoring Network in YOSE. The Station is located at the Tioga Road Bridge on the Tuolumne River. Over 70 discharge measurements have been made at this location since 2001. This is a good location for a streamgage because good discharge measurements can be made at all stages.

#### Observations / Recommendations

##### *Measuring Stage*

The existing stage datum is a staff plate mounted to the Tioga Road Bridge (Figure 6 inset). The dataloggers are housed in a pipe mounted to the bridge adjacent to the staff plate. Datalogger data is transmitted hourly via GOES to CDEC. If the staff plate is difficult to read due to turbulence at the bridge during high flows, an alternate stage device such as a wire-weight gage should be installed. Recommend setting dataloggers to gage datum during each site visit so that the staff plate and datalogger both read the same. This will make it easier when troubleshooting problems in the field and determining logger drift between site visits.

##### *Surveys / Reference Marks*

The station was surveyed in 2007 to a Benchmark on the South side of Tioga Road. No known additional reference marks have been installed at the gaging station and no known additional surveys have been performed at the gaging station. Recommend installing at least two additional permanent reference marks and performing an Auto-Level survey after the reference marks have been installed. Survey the benchmark, reference marks, the staff plate, and the cross-section of the river at the control. WRD has provided blank survey forms. All final elevations should be calculated relative to gage datum (0.00 feet on the staff gage). The cross section survey on the control will help in creating a better rating curve for the site. Be sure to survey the entire channel x-section within the high flow channel. The frequency of levels is dependent on stability of staff gage and reference marks. In this case, since the staff gage is fixed to the bridge, it may only be necessary to run levels once every five years (following 3 sets of annual levels).

##### *Measuring Discharge*

This is a good site to measure discharge at all flows. Flows between 3 and 1,300 cfs have been measured at this site. Wading methods are performed at lower flows and an Acoustic Doppler Current Profiler (ADCP) is used at higher flows upstream of the bridge. Please apply applicable discharge measurement recommendations made for the Lyell Fork to this site. For this site, strive for wading measurements to plot within 5% of the rating (measurements rated “good”). Perform a second measurement if measurements plot greater than 5% from the rating. Higher flow measurements inherently have greater error, so strive for high flow measurements to plot within 8% of the rating (“fair”).

##### *Control / Rating Curve*

The low flow section control is a bedrock and gravel riffle just downstream of the bridge (Figures 6 and 7). In higher flows the channel control is the bridge and the bend in the river just downstream of the bridge. It is not known at what flow the section control is submerged. It is important to document

conditions of the control (section control versus channel control) for each site visit and especially when taking discharge measurements (WRD field form provided). There have been no known surveys of the cross-section at the control therefore the elevation of the gage height of zero flow and breakpoints are unknown.

A preliminary rating was drawn in Aquarius as a part of this trip report using 72 measurements (between 3 and 1,300 cfs) taken since 2002 (Figure 8). The rating was drawn within 5% of 54 of the measurements. A survey of the control is necessary to improve the rating. Measurements 3, 40, 50, 65 and 66 plot considerably from the rating and may be in error. Recommend reviewing measurement files to determine the source of error. The rating is not well defined below 25 cfs, between 60 and 120 cfs, and above 1,000 cfs. The low flow rating (< 10 cfs) may shift due to seasonal erosion/deposition of the gravel/cobble bar on the right bank of the section control. The rating appears to be stable through all other flows with no evident seasonal shifts. A break in the rating occurs somewhere between 3.2 and 3.7 feet ( $\approx$  60 and 120 cfs) and was drawn at 3.27 feet in the preliminary rating, but could be better defined by a survey of the control.

### **Data Processing**

WRD staff worked with SIEN and YOSE staff on 8/23/2013 with Aquarius software. Gaging station data had not been uploaded to Aquarius prior to the site visit. More helpful comments can be made regarding data processing after at least one full year of data has been uploaded into Aquarius. The following general data collection and processing comments apply to all SIEN operated gages:

- Set all dataloggers to “gage datum” so that 0.00 on the staff plate equals 0.00 on the datalogger.
- At each station, choose one datalogger to be the primary logger and one to be the backup. Data from both loggers should be loaded into Aquarius. Determine which logger data to use in the final record by evaluating each record individually. Do not average water levels between the loggers.
- Within a day or two of returning from the field, review flow measurements following field visits and upload raw field files from the AquaCalc or Flowtracker directly to Aquarius.
- Note discharge methods and quality for each measurement in Aquarius.
- Recommend attempting to locate stage/discharge measurements prior to 2012 for the Lyell Fork Gage to aide in rating curve development.
- When evaluating a data record, look for smooth curves, investigate and attempt to explain any jagged (noisy), spike (non-event related jumps), or flat (instrument malfunction) data. Downgrade data quality when appropriate in the analysis remarks section.
- Ice effected data will need to be corrected at both Tuolumne River sites and erroneous spikes in the data should be removed. Much of the winter data will likely be estimated.
- Since both the Lyell Fork and Tioga Road gages cannot be accessed during winter, it is important to perform site visits and discharge measurements as soon as possible in the Spring and as late as possible in the Fall.

Possible additional action items (SIEN/YOSE Technical Assistance Request #1596 for FY2014):

- Provide guidance regarding installation of staff plate, reference marks and surveying at the Lyell Fork gage; and surveying at the Tioga Road Bridge gage.
- Provide guidance, if needed, during the compliance process and in installation of gaging equipment in designated Wilderness Areas.
- Review and assist in data-workup and analysis via Aquarius software (concentration on rating curve developer and ice affected data).
- Rating curve and data workup: provide a follow up review on data analysis and workup once the first water year has been entered and analyzed.
- Review draft station descriptions for SIEN-supported sites.

If there are any questions regarding this trip report, please call Gwen at (970)-267-2144.

ec:

SIEN – Andi Heard

YOSE – Jim Roche

2380 – Bill Hansen, Gwen Gerber, Forrest Harvey

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**Figure 1.** Looking upstream at the gage pool and existing staff gage at the Lyell Fork Station. Inset: SIEN staff making a tapedown measurement.



**Figure 2.** Examples of staff plates installed flush against rock, Style C versus Style A, and examples of a NPS Benchmark versus rock bolt.



**Figure 3.** Looking upstream at the discharge measurement cross-section for measurements #9 and #10 upstream of the Lyell Fork gage.



**Figure 4.** Looking downstream at the control (red-dashed line) on the Lyell Fork gage pool.

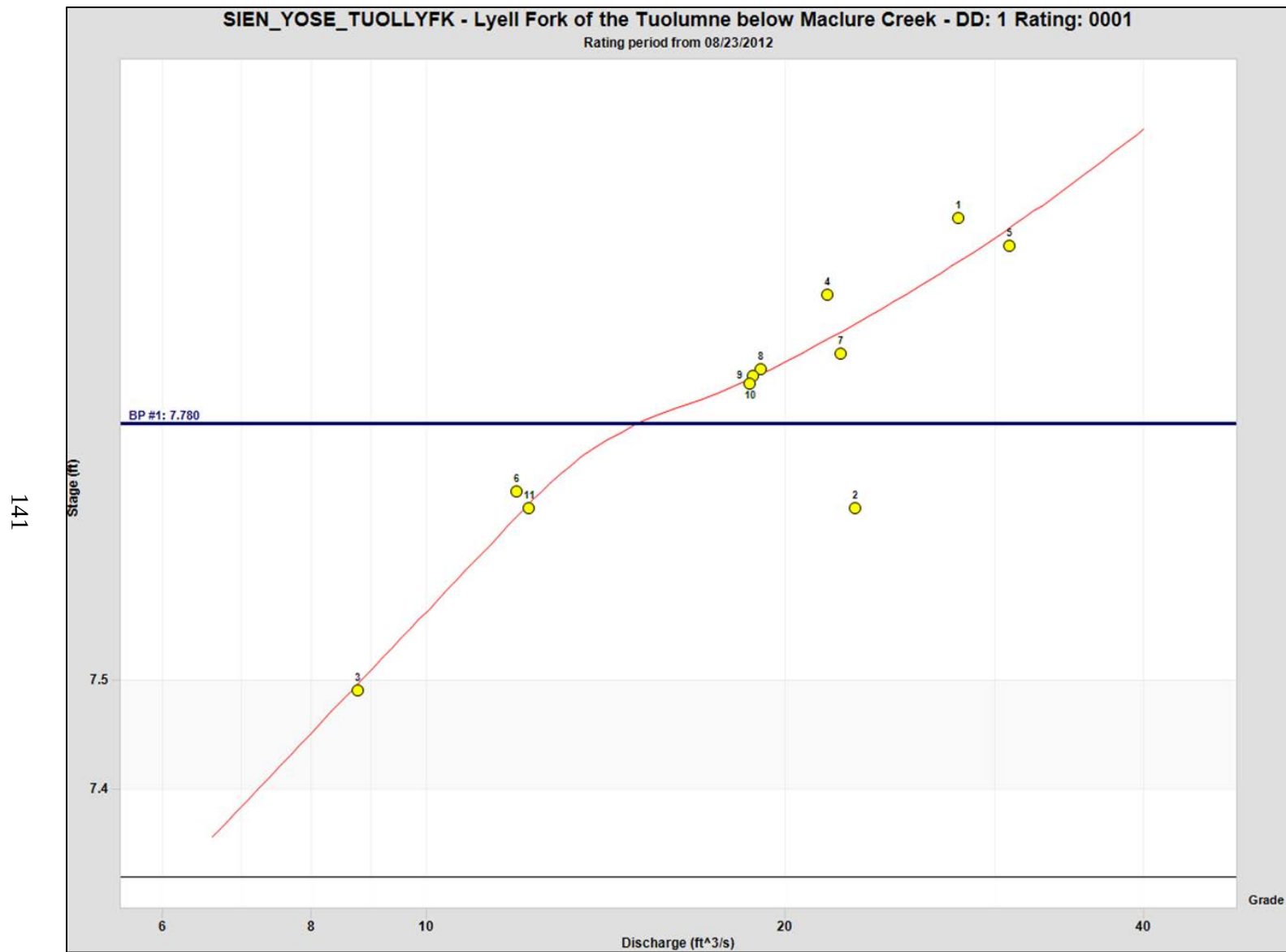


Figure 5. Preliminary rating for the Lyell Fork of the Tuolumne below Maclure Creek.



**Figure 6.** Looking upstream at the section control and gage pool at the Tioga Road gage. Inset: Looking downstream at staff gage.



**Figure 7.** Looking downstream at the controls on the Tioga Road gage pool.

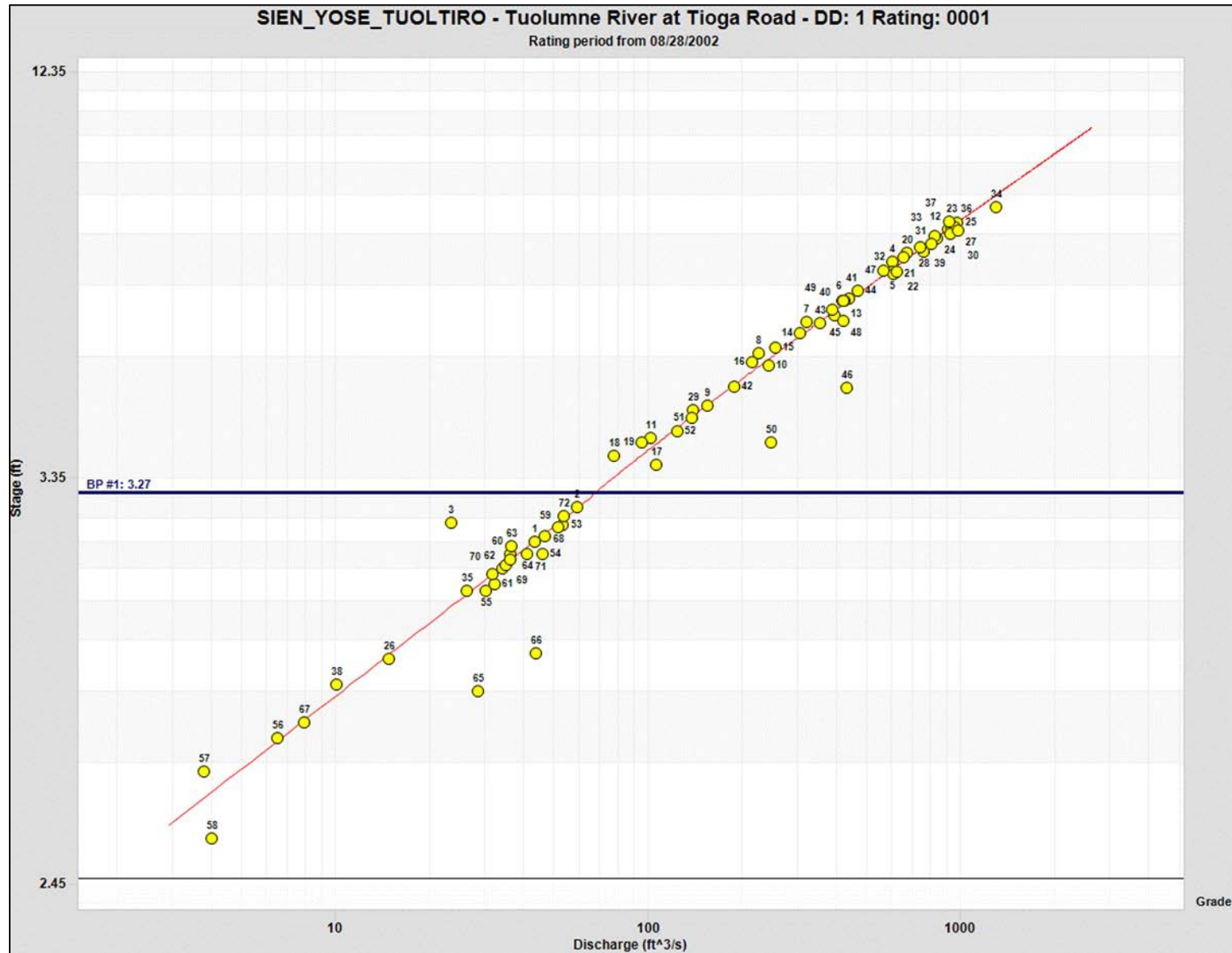


**Figure 8.** Preliminary rating for Tuolumne River at Tioga Road Bridge.



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**Natural Resource Stewardship and Science**  
1201 Oakridge Drive, Suite 150  
Fort Collins, CO 80525

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