Small Stream Ecosystem Variability in the Sierra Nevada of California

Carolyn T. Hunsaker, Sean M. Eagan

Abstract

The quality of aquatic and riparian ecosystems is a function of their condition and the integrity of adjacent uplands in their watersheds. While small streams make up a large proportion of the overall stream network, our knowledge of how they function is still limited. The Kings River Experimental Watershed (KREW) was initiated in 2000 to quantify the variability in characteristics of small stream ecosystems and their associated watersheds in the Sierra Nevada of California. The primary management questions to be answered are the effects of prescribed fire and mechanical thinning on the riparian and stream physical, chemical, and biological conditions.

Two mixed conifer sites are being developed. Data will be gathered for at least a 3-year reference period. After fire and harvest treatments are applied, data will be gathered for at least seven years. Each site has a control watershed that receives no treatments, a watershed that is burned, a watershed that is harvested, and a watershed that is both burned and harvested. We are interested in assessing the integrated condition of the streams and their associated riparian and watershed areas (i.e., physical, chemical, and biological characteristics). The watersheds range in size from 49 to 228 ha (120 to 562 acres); a size that can be consistently treated.

Keywords: stream ecosystem, watershed experiment, prescribed fire, mechanical thinning, sustainable forests

Hunsaker is a Research Ecologist and Eagan is a Hydrologist, both with the U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Sierra Nevada Research Center, Fresno, CA 93710. E-mail: chunsaker@fs.fed.us.

Introduction

Sixty percent of California's water originates from small streams in the Sierra Nevada, yet very little information is known about how these streams are affected at the source. This water is considered some of the highest quality water in the state. The quality of aquatic and riparian (near-stream) ecosystems associated with streams is directly related to the condition of adjacent uplands within their watersheds. The degradation of forest streams and their associated watersheds is often the result of nonpoint sources such as past timber harvesting, roads, fire suppression, and catastrophic wildfires. Restoration of the Sierra Nevada's forest watersheds to historic or desired conditions requires active management such as reintroduction of frequent, cool fires and removal of accumulated fuel loads.

The Kings River Experimental Watershed (KREW) is a long-term watershed research study being designed and implemented on the Sierra National Forest to provide much needed information for forest management plans regarding water quantity and quality. This experimental watershed research is designed to: (1) quantify the variability in characteristics of headwater stream ecosystems and their associated watersheds, and (2) evaluate the effect of fire and fuel-reduction treatments on the riparian and stream physical, chemical, and biological conditions. This is an integrated ecosystem project at the watershed scale and is part of a larger adaptive management study that began in 1994 as a collaborative effort between the Sierra National Forest, Southern California Edison, and the Pacific Southwest Research Station of the Forest Service to evaluate the effects of approaches for creating an uneven-aged forest similar to that present before European settlement, circa 1850. The experiment will implement mechanical thinning, prescribed fire, and thinning with fire combination treatments on headwater areas.

"Aquatic/riparian systems are the most altered and impaired habitats of the Sierra" (University of California, Davis 1996). However, what is considered appropriate management for such ecosystems is currently a point of debate and quantitative information is needed (USDA Forest Service 2001). While watershed research and stream monitoring have been ongoing, much of the work addresses larger streams. Much of the information on effects from forest management activities likely is not applicable for Sierran forests because it comes from wetter forests and severe treatments (e.g., clearcuts and wildfire). Also, few integrated ecosystem studies exist; these are essential for understanding stream/watershed ecosystem processes and functions for adaptive management, thus critical information is lacking (Naiman and Bilby 1998).

Methods

The KREW recognizes that measurements of physical, chemical, and biological variables are necessary to accomplish a holistic watershed study and has carefully tried to include those attributes critical to detect change in both patterns and processes in atmospheric inputs, watershed uplands and riparian areas, and stream channels. Human actions jeopardize the biological integrity of water resources by altering one or more of five principal factors: physical habitat, seasonal flow of water, the food base of the system, interactions within the stream biota, and chemical contamination (Karr 1998). We are taking measurements for each of these factors.

The experimental watershed is planned as a 15-year study and has two sites, the Providence Creek Site and the Bull Creek Site, located in mixed-conifer forest between 1,500 (5,000 ft) and 2,134 m (7,000 ft) elevation on granitic-based soils. As such, these sites are very typical of the central Sierra Nevada and forested headwaters that provide a substantial amount of source water to the San Joaquin River basin of California. The Providence Site typically experiences rain and snow events while the higher elevation Bull Site is a snow-dominated location. Each site consists of four watersheds, one for each of the three management treatments and one control. Core field measurements on each watershed comprise the following components: stream discharge, water chemistry, sediment loading, stream invertebrates, soil characterization, meteorology, vegetation, and fuel loading. Instrumentation began in 2000, baseline data collection (3 years minimum) began in 2002, the first treatments should occur in the fall of 2005, and post-treatment data collection is planned to continue for 5-7 years. A site consists of four adjacent headwater watersheds; the Providence Site is made up of P301, P303, P304 and D102 (Figure 1). A grid with 150-m (492-ft) spacing has been placed within each watershed; for the small size of P304 the grid was densified in the north-south directions with a 75-m (246-ft) spacing. Sampling for physical soil characteristics, upland vegetation, and fuel loads are all located using this grid. All measurements are made in the same manner at both sites, but the Providence Site has evolved to have more types of measurements (i.e., sediment ponds in the streams, sediment fences to quantify upland erosion, vacuum lysimeter collectors for shallow soil water, and riparian microclimate).

Stream discharge is measured using two fiberglass Parshall-Montana flumes in each stream, a large and a small, because the streams have approximately a 500-fold difference between lowest and highest flow for a 20-year time span. We can measure precisely flows from 0.75 l/s (0.03 cfs) to 900 l/s (32 cfs) and with less precision flows from 0.3 l/s (0.01 cfs) to 1,400l/s (49 cfs). These flumes are good at passing debris and do not require large upstream ponds to accurately measure flow. Stage is measured with the Isco 730 bubbler; Sequoia Scientific Aquarods provide backup data for stage measurements.

Measuring the seasonal variation in air temperature, solar radiation, and precipitation is considered basic to all hydrologic and natural resource studies (Hanson et al. 2001). Each site has a high elevation and a low elevation meteorological station with a 6 m (20 ft) tower, a precipitation gage, and a telemetry antenna. The high elevation stations also have a snow pillow to measure snow water equivalence. Each tower has instruments to measure relative humidity, temperature, wind speed, wind direction, wind run, solar radiation, and snow depth.

Universal physical laws govern streams, yet every stream exists in a unique way within its watershed. Differences in watershed size, climate, location, geology, and past management activities are only a few of the factors that create the range of fluvial forms we see. Each stream must balance erosion, transport and deposition in the context of these factors. To understand the effects of a given management practice, a baseline of existing physical conditions must be established for the stream channel. With this foundation of technically correct and comparable data, it is possible to track changes in the character of the stream (Harrelson et al. 1994). A 100-m (328-ft) reach, often just upstream of the flumes, is being

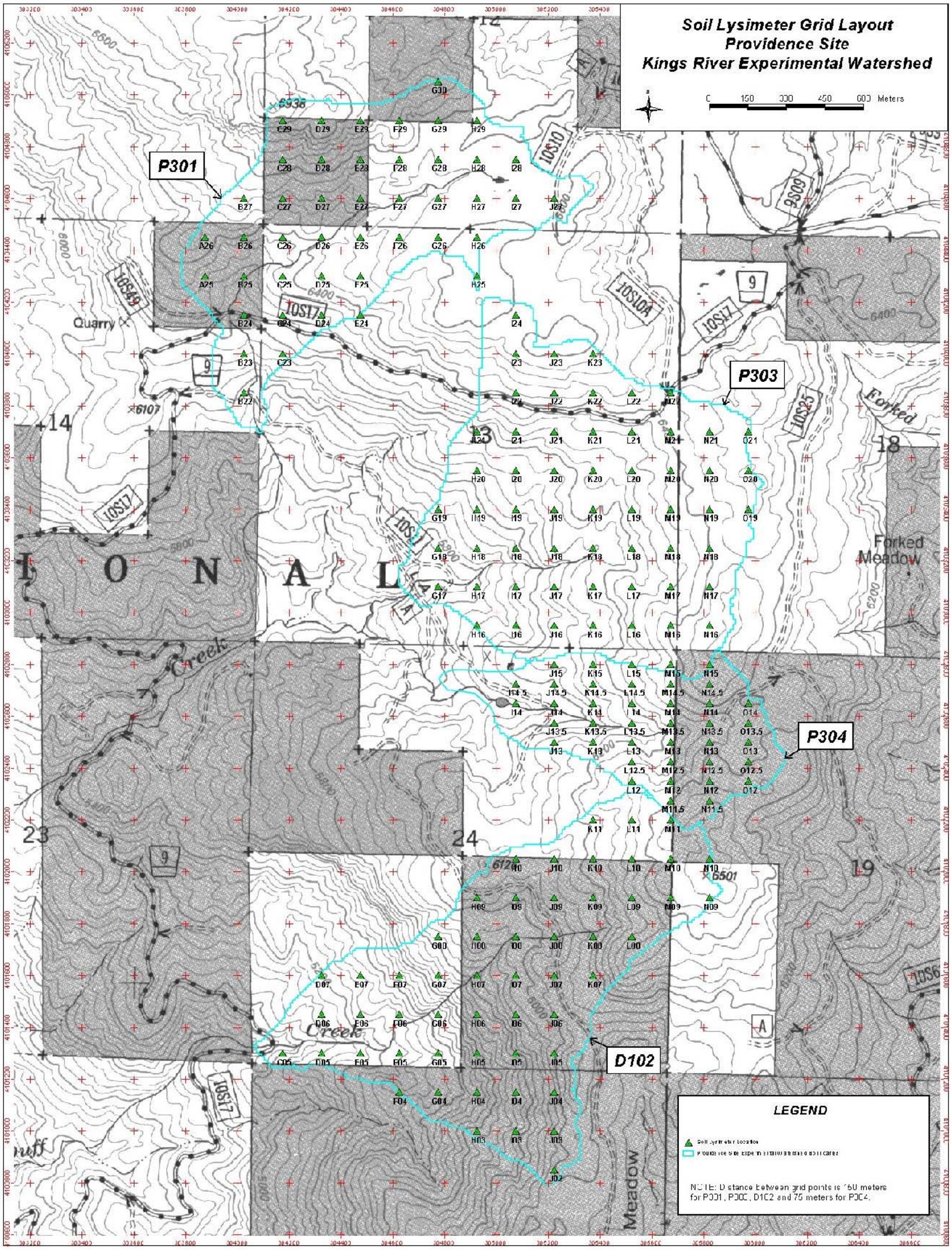

Figure 1. The Providence Site has four adjacent headwater watersheds (P301, P303, P304, and D102). The sampling grid is displayed against the landscape's topography and is used to locate resin lysimeters, vegetation, fuel loading, and physical soil characteristic measurements.

used as a representative reach for stream invertebrate and geomorphology measurements. These measurements are taken annually. Permanent cross sections are planned.

Natural deposition areas that existed directly downstream of the flumes were transformed into sediment ponds with 12 to 40 m^3 (423 to 1,412 ft^3) of storage space. We will be estimating the annual load for each sediment basin, the relative percentage of organic versus inorganic material in that load, and the class size distribution within the inorganic fraction. Upland sediment fences will provide information on the proportion of sediment coming from different upland sources such as roads and other erosional areas. Some existing headcuts are also being characterized and monitored.

Soil physical properties profoundly influence the growth and distribution of vegetation through their effects on soil moisture regimes, aeration, temperature profiles, soil chemistry, and even the accumulation of organic matter. These properties also influence erosion potential and the chemical composition of water that reaches streams. In general, the dominant soil type by watershed accounts for 50% or more of the area: Shaver and Gerle-Cagwin soils dominate the Providence Site, and Cagwin soil dominates the Bull Site. Soil sampling begins in 2003 and will be colocated with vegetation and fuels loading measurements.

Within a watershed the chemical composition of stream water serves as an integrator or expression of the condition of the watershed both in the uplands and in the stream. Our goal is to measure water chemistry in several parts of the hydrologic cycle—incoming precipitation, in shallow soil, and in the stream. Currently KREW is measuring several anions and cations; however, after one water year we will evaluate the need to continue this entire set of measurements. In general, water chemistry measurements are taken every two weeks although during or after a storm event samples may be more frequent. Stream water samples are either collected as a grab sample by a person or by an Isco 6712 automated sampler that draws water from the stream and stores up to 24 un-refrigerated samples before retrieval.

We are using two types of lysimeters to characterize the nutrient fluxes and chemistry of shallow soil water. The soil resin lysimeters are placed on a uniform grid spaced at one depth, 13 cm (5 in), to measure the annual flux of nutrients through the forest litter and soil layers above them. These lysimeters provide information about soil nutrient flux. The Prenart vacuum lysimeter provides a continuous measurement of soil water chemistry at one location from depths of 13 cm (5 in) and 26 cm (10 in). The vacuum lysimeter data provides information on the variability of chemistry fluxes during the wet season.

Similar to soil water, we have two types of collection devices for atmospheric wet chemistry. The snowmelt collectors give an estimate of the variability in the precipitation chemistry during the wet season. The precipitation resin collectors give an annual measure of the total input from rain and snow during the period they are in the field. Soil lysimeters and precipitation collectors are placed in the field at the same time; they are built according to a design published by Susfolk and Johnson (2002).

The major objective of our vegetation research is to examine the treatment effects on the vegetation within the watersheds. A secondary objective is to determine effects on riparian vegetation in particular, and characterize the transition from riparian to upland vegetation. Riparian transects are placed perpendicular to the stream channel, starting at the bankfull edge, and extending 20 m (66 ft) into the upland. Upland transects are placed at a subset of the grid points extending 20 m at a randomly chosen azimuth. The number of riparian and upland transects varies depending on the length of the channel and size of the watershed, respectively. At each transect herbaceous vegetation will be sampled in 1x1 m quadrats, shrubby vegetation by line intercept, and trees by a 10x20 m belt transect. Riparian and upland transects follow an identical protocol.

Ground, surface, understory, and overstory fuels will be measured at the same subset of grid points as vegetation and soils. The protocol for these measurements has to be defined; however, methods for the fuel components will closely match those of the Sequoia National Park site of the Fire/Fire Surrogate study.

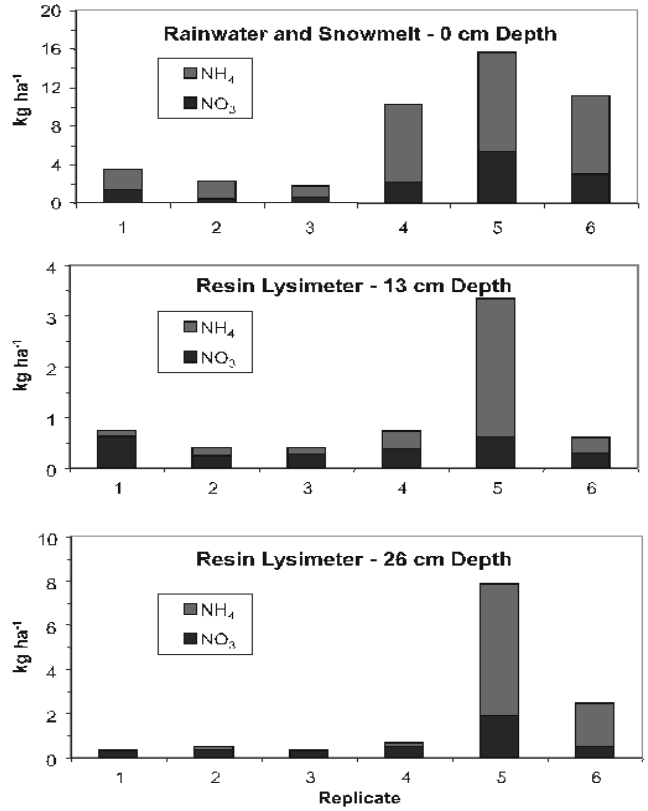

Figure 2. Ammonium and nitrate fluxes are measured with resin lysimeters; replicate 5 is high in both snowmelt and in both measured soil horizons. Preliminary sampling at Providence 303 revealed evidence that there are "hotspots" of high nitrogen availability within a fine spatial scale (meters).

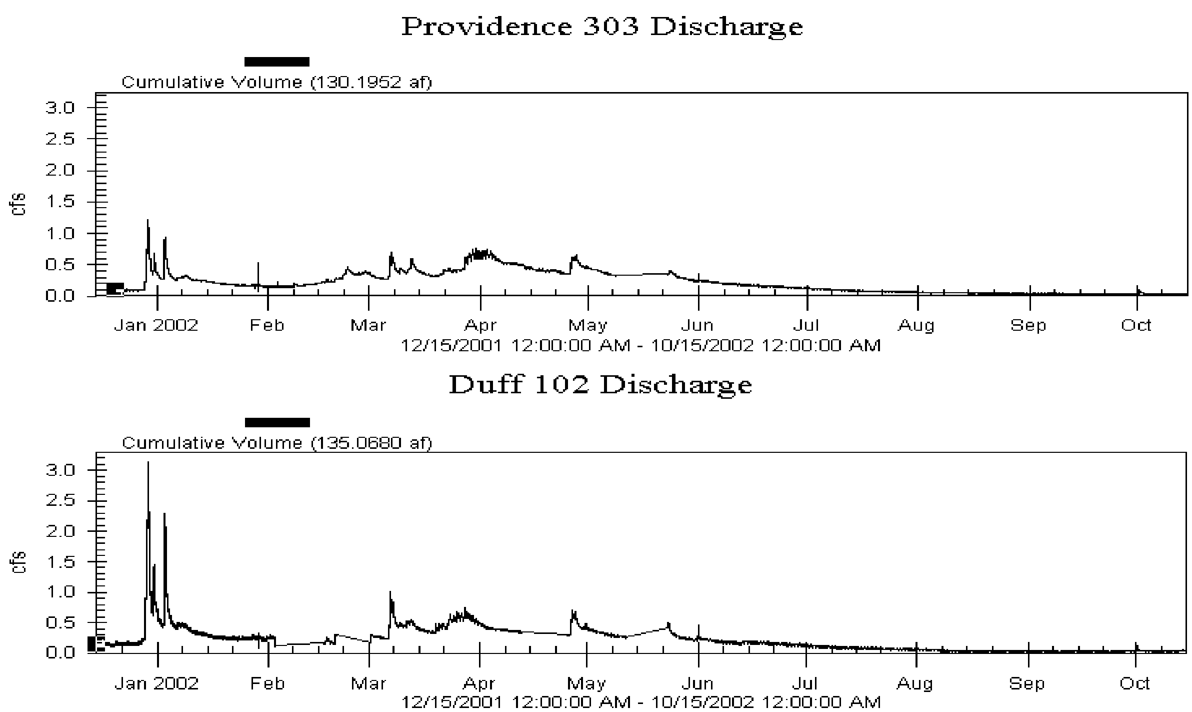

Figure 3. Stream discharge hydrographs for Providence 303 and Duff 102 streams. The base flow of these streams is between 0.05 and 0.1 cubic feet per second (cfs) and is controlled by groundwater sources. Duff has the lowest average elevation, and the January storms came mostly as rain that caused brief, large discharges.

Results and Conclusions

Preliminary sampling at Providence 303 revealed evidence that there are “hotspots” of high nitrogen availability within a fine spatial scale (Figure 2); replicate 5 is high for both incoming precipitation and both soil depths. The causes of this hotspot are not known at present, but the knowledge that such hotspots occur is important in guiding sampling plans and in assessing potential sources of nitrogen for the streams.

One of the challenges of a landscape-scale experiment is the similarity between study units, in this case, headwater watersheds. Stream discharge hydrographs for P303 and D102 during 2002 are shown in Figure 3. While the discharges differ for the two streams, the timing of peaks follows a similar pattern. For January, these hydrographs also illustrate the difference between discharge patterns when one stream receives snow (P303) and another receives rain (D102).

The intention of KREW is to be as holistic and integrated as possible with a focus on physical, chemical, and biological variables of headwater stream ecosystems and their associated watersheds. Much needed information for both basic and applied science questions will be developed for the southern Sierra Nevada and sustainable forestry in general. Attention has been given to developing a suite of measurements that will facilitate modeling in several disciplines: hydrology, meteorology and climate change, fire behavior and effects, soil erosion, and biogeochemistry. An exciting opportunity will be to calibrate and run models in the pretreatment phase and then verify their predictive capabilities after the management treatments.

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