Received: 29 September 2020 | Revised: 16 March 2021 | Accepted: 20 March 2021

DOI: 10.1002/hyp.14142

WILEY

The Kings River Experimental Watersheds: Infrastructure and data

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Funding information
California Department of Forestry and Fire Protection; Joint Fire Science Program; Sierra Resource Conservation District; USDA Forest Service

Abstract

The Kings River Experimental Watersheds (KREW) were established in 2002 to expand our knowledge of catchment physical, chemical, and biological processes in Sierra Nevada headwater forests, and to better understand the impacts of prescribed burning and forest thinning on these processes. Two elevation strata (high and low) were selected for the KREW sites, with four independent catchments and one nested catchment within each stratum. Both high and low elevation study areas were instrumented for continuous measurements of meteorology, streamflow, and turbidity. Atmospheric and stream chemistry, suspended sediment concentration, and bedload sediment delivery were measured on a regular schedule. Soil chemical and physical properties and vegetation were systematically sampled before and after the initial thinning and prescribed burning treatments, which were implemented between 2012 and 2016. Post-treatment data collection continues today as we explore opportunities for the second round of possible treatments. The critical research infrastructure and long-term baseline data collection has been instrumental in building partnerships with downstream managers, end users, non-governmental organizations, academic researchers, and national research programmes. Contributions to date include fundamental understanding of magnitude and variability of nutrient deposition; carbon, nutrient, and major ion dynamics in headwater streams; aquatic algae and macroinvertebrate populations; vegetation composition and structure; and streamflow responses to precipitation in the two elevation strata. Data from the experimental watersheds also support calibration and validation of diverse hydrologic models used for water resources planning.

KEYWORDS
forest hydrology, meteorology, paired catchment, prescribed fire, sediment, Sierra Nevada, watershed

1 | DATASET NAME

Kings River Experimental Watersheds Data.

2 | STUDY CONTEXT AND DATA

Streamflow, meteorology, sediment, and water chemistry data were collected from 10 catchments as part of the Kings River Experimental Watersheds (KREW) project starting in 2002. The main purposes of the project have been to (1) assess the variability of catchment responses across an elevational gradient spanning high elevation, snow-dominated (Bull) and low elevation, mixed rain and snow (Providence) winter precipitation regimes and (2) assess the impacts of low-intensity mechanical thinning and understory prescribed burning on the catchment responses. These data are available to other researchers and the public through the USDA Forest Service research data archives (Hunsaker & Padgett, 2019; Hunsaker & Safeeq, 2017,

2018) and will be periodically updated as new data become available. In addition, data relating soil physical and chemical properties, sediment delivery, and vegetation conditions are in the final review stages and will be made available through the Forest Service research data archive (https://www.fs.usda.gov/rds/archive/).

3 | STUDY SITES

The 10 KREW catchments (Figure 1) are located on USDA Forest Service land managed by the Sierra National Forest except for portions of the P301 and D102 catchments, which are owned by the Southern California Edison Corporation. The five higher-elevation (2050–2480 m), snow-dominated sites are referred to as the Bull catchments and consist of four primary independent catchments (B201, B203, B204, and T003) and a 474 ha catchment (B200) that integrates streamflow from three of the four primary catchments (B201, B203, and B204) and 116 ha of otherwise ungaged area. The contributing area to the four primary gaging stations ranges from 53 to 228 ha. The T003 catchment is located within the Teakettle Experimental Forest (https://www.fs.fed.us/psw/ef/teakettle/) and, along with adjacent paired catchments, was intermittently gaged between 1938 and 2002 (Kattelmann, 1989). The lower elevation (1500–2120 m) rain and snow mixed winter precipitation sites are referred to as the Providence catchments and also consist of four primary independent catchments (P301, P303, P304, and D102; 49–132 ha), and one 461 ha catchment (P300) that integrates streamflow from three of the primary catchments (P301, P303, and P304) and 181 ha of ungaged area. The integrating locations were established to evaluate cumulative watershed effects. Four meteorological stations (Upper and Lower Bull and Upper and Lower Providence) collect data on atmospheric and radiation conditions across the elevation range of the KREW, and snow water equivalent is measured at the two Upper meteorological stations (Figure 1).

The climate of KREW is Mediterranean with warm dry summers and cool wet winters (Köppen-Geiger Csb). Mean annual precipitation was 1407 and 1332 mm at the Upper Bull and Upper Providence meteorological stations for water years 2004–2017, with approximately 85% and 61% falling as snow, respectively. Mean daily minimum/maximum January temperatures were −5.5/−2.4°C at Upper Bull and 0.2/7.5°C at Upper Providence, while mean daily minimum/maximum July temperatures were 13.0/21.6°C and 15.2/24.9°C, respectively. The soils across the catchments have coarse sandy loam or loamy sand textures. The Bull catchments are dominated by the Cagwin soil series derived from a quartzite metasedimentary roof pendant, while the soils of Providence are characterized as Shaver or Gerle-Cagwin series underlain by granodiorite (Bateman, 1992; Johnson et al., 2011; USDA, 2020). Vegetation is mixed conifer typical of

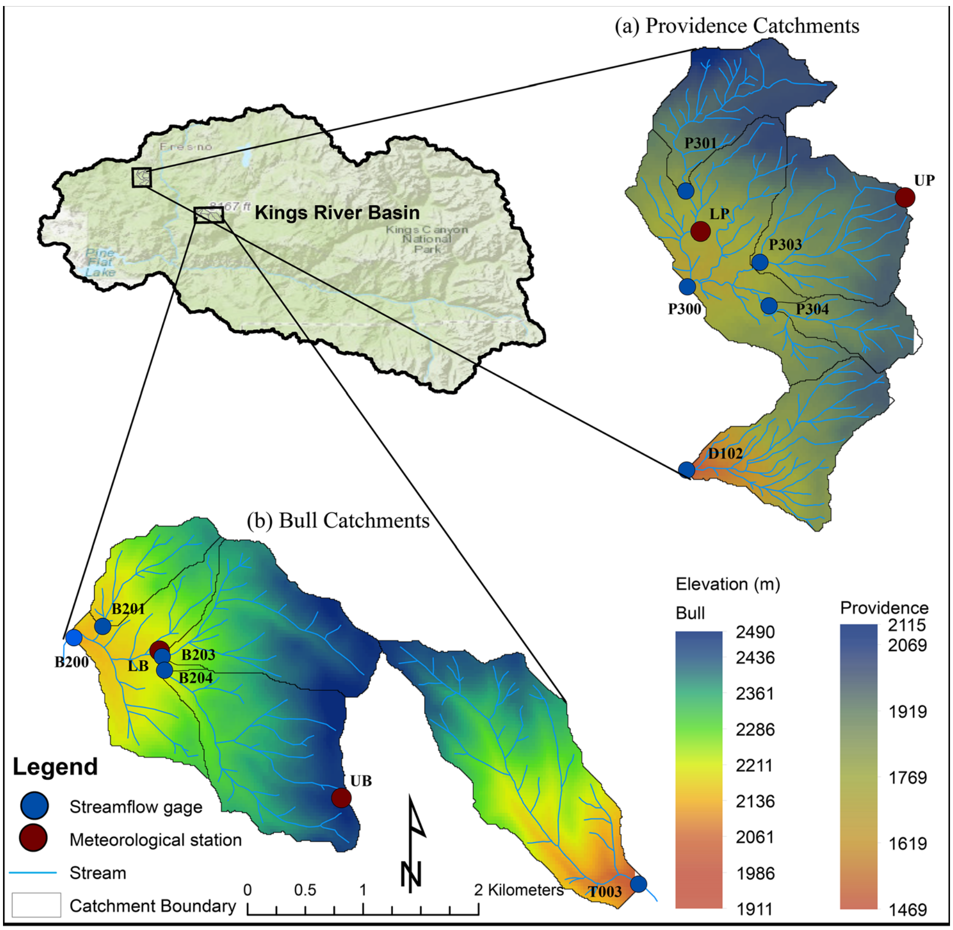

FIGURE 1 Map of the Kings River Experimental Watersheds study locations: (a) Providence and (b) Bull. Catchment streamflow stations are identified by their abbreviations (e.g., P301) and meteorological stations are identified by LP, UP, LB, and UB for the Lower and Upper Providence and Bull sites

this elevation range in the southern Sierra, and consists primarily of ponderosa, sugar, and Jeffrey pines (*Pinus ponderosa*, *Pinus lambertiana*, and *Pinus jeffreyi*, respectively), incense cedar (*Libocedrus decurrens*) and white and red firs (*Abies concolor* and *Abies magnifica*, respectively).

The initial KREW experiment had a 10-year pre-treatment calibration period (2002–2012). Two of the primary catchments were left untreated as experimental controls and an assigned treatment was applied to each of the six remaining primary catchments. The treatments were: untreated control or reference (T003 and P304); mechanical, commercial thinning in summer/fall 2012 (B201 and D102); mechanical, commercial thinning in summer/fall 2012 followed by understory prescribed burning in fall 2013 (B204) or fall 2016 (P301); and prescribed burning in fall 2013 (B203) or fall 2016 (P303). The T003 catchment has not had timber management, whereas all the other catchments had some timber harvest in the twentieth century prior to establishment of the KREW. The thinning and understory prescribed fire treatments had relatively low impact, and the specific treatment effects were complicated by comparable changes to the forest stands stemming from a beetle-enhanced, drought-induced tree mortality that subsequently occurred in 2014–2016 (Lydersen et al., 2019). Lydersen et al. (2019) provide a thorough explanation of the treatment methods and treatment and mortality-induced changes in basal area, stand density, and canopy cover. The post-treatment measurement period will continue at the 10 gaging stations and four meteorological stations at least through March 2022. Opportunities for a subsequent experiment are being explored.

4 | METHODS

Seven of the streamflow gaging stations (B201, B203, B204, P301, P303, P304, and D102) have dual Montana Parshall flumes, with a smaller one (throat widths from 8 to 15 cm) installed just upstream of a larger one (throat widths from 30 to 122 cm) to capture the full range of flows experienced through a typical year. One gaging station (B200) has a natural rating section where depth and velocity measurements have been taken using an acoustic doppler velocimeter (Sontek, San Diego, CA, USA) across a range of flows. The P300 gaging station has a 90°, sharp-crested, v-notch weir. T003 has a compound weir made up of a 90° sharp-crested v-notch weir and a sharp-crested 0.61 by 1.83 m Cipolletti weir that activates at a stage of 91 cm in the v-notch weir. A broad-crested rectangular weir tops the sharp-crested weirs at T003, but the stream discharge has not been high enough to activate the rectangular weir (≥5.5 $m^3\ s^{-1}$) during the intermittent periods of record. Stage is measured at 15-min intervals using a bubbler (model 730, Teledyne Isco Inc., Lincoln, NE, USA; precision 0.003 m), a capacitance probe (AquaRod, GeoScientific, Vancouver, BC, Canada; precision 0.001 m), and/or an unvented pressure transducer (Levelogger Edge M5, Solinst, Georgetown, ON, Canada or Telog WLS-31, Trimble Water, Irvine, CA, USA; precision 0.03 m) corrected for local barometric pressure using a barologger (Solinst, Georgetown, ON, Canada; precision 0.05 kPa). Discharge is calculated from standard rating equations for the flumes and weirs and from an empirical stage-discharge rating equation developed for the natural cross section at B200. The precision of the stage as well as the inherent uncertainty in the rating equations, which varies but is typically about 5% for these methods (Grant, 1989), contribute to the uncertainty in the discharge calculations.

Each of the seven flume sites has a sediment detention pond downstream of the large flume (Eagan et al., 2007). Sediment also accumulates in the T003 weir pond. Sediment deposited in the ponds in the eight primary catchments is measured annually. Turbidity has been measured since water year 2004 at each of the 10 streamflow gaging stations using a DTS-12 turbidity sensor (Forest Technology System Ltd., Blaine, WA, USA; uncertainty ±2% for readings <399 NTU, else ±4%). Pumped samplers (Teledyne ISCO, Lincoln NE, USA) are installed at the 10 streamflow gaging stations and have collected periodic water samples between 2006 and the present. The samplers are triggered by a combination of stage and time thresholds, and the thresholds are periodically adjusted to account for seasonal variation. Manual samples are also obtained during approximately bi-weekly site visits. Samples are processed for suspended sediment concentration ($mg\ L^{-1}$) using vacuum filtration with 1 μm glass fibre filters (ASTM, 2019).

Concentrations of several ions are measured in the grab samples, with detection limits ranging from 0.52 to 2.78 $\mu mol\ L^{-1}$ (Hunsaker & Padgett, 2019). Calcium, magnesium, potassium, sodium, sulphate, nitrate, and chloride are measured using ion chromatography (EPA, 1993a). Ammonium and ortho-phosphate are measured by automated colorimetric analysis (EPA, 1993b). Manual measurements of stream temperature, pH, and electroconductivity (precision 0.1°C, 0.01 pH, 0.1 $\mu S\ cm^{-1}$, respectively) are also made during the regular site visits using a hand-held sensor (Oakton Instruments, Vernon Hills, IL, USA; or Hach HQ30, Hach Company, Loveland, CO, USA).

Meteorological conditions are recorded every 15 min at four locations: Upper Bull, Lower Bull, Upper Providence, and Lower Providence (Figure 1). All four stations record precipitation using an Alter-shielded weighing bucket precipitation gage (Belfort 5-780 weighing rain gage, Baltimore, MD, USA and 260-952 Alter-style wind screen, Novalynx Corporation) (accuracy 0.25 mm) at 3 m above the ground surface through water year 2019. A Belfort AEPG weighing precipitation gage (Belfort, Baltimore, MD, USA) (resolution 0.025 mm) was added to the Lower Bull station in 2017. Mineral oil is used to reduce evaporation and food-grade antifreeze is used to reduce the freezing point in winter. Wind speed and direction are recorded at a height of 7 m above the ground using a cup anemometer and wind vane (Met One-TM 013A, Met One Instruments, Grants Pass, OR, USA; 2% measurement accuracy). Incoming solar radiation is recorded with a CM3 pyranometer (Kipp and Zonen B.V., Delft, The Netherlands; accuracy for daily sums 10%). Air temperature and relative humidity are measured with a Vaisala HMP45C (Vaisala Corporation, Helsinki, Finland; ±0.5°C and ±2% relative humidity) sensor housed in a radiation enclosure. Snow depth is recorded using an ultrasonic sensor (Judd Co., Logan, UT, USA; resolution 3 mm, accuracy ±1 cm). At the Upper Bull and Upper Providence stations, the mass of snow is measured using

2.4 by 3.0 m snow pillows (Mendenhall Manufacturing, McClellan, CA) each constructed from four adjacent rectangular steel bladders (1.2 by 1.5 m). The bladders are filled with the same non-toxic antifreeze used in the precipitation gage. Pillow plumbing is connected to a Sensotec pressure transducer (Honeywell, Columbus, OH, USA) which is used to convert the snowpack pressure to a snow water equivalent depth. Data are recorded with a solar-powered datalogger (CR10X from 2002 to 2017, CR1000 2017-present; Campbell Scientific, Logan, UT, USA), and 15-min and daily data totals or means are calculated as appropriate for the different variables. Sensors are inspected and manual measurements of precipitation accumulation, windspeed and direction, temperature and relative humidity, snow depth, and snow water equivalent are made during approximately monthly site visits. The Upper Providence meteorological station participates in the National Atmospheric Deposition Program National Trends Network (site CA28).

5 | CONTRIBUTION

KREW was designed as a forest ecosystem study at the headwater catchment scale and thus measured physical, chemical, and biological attributes. The physical catchment responses to precipitation, the tracing of chemicals from the atmosphere through the soils and into the streams, and the biological responses to the physical and chemical conditions establish baseline conditions and processes and help evaluate management effects. According to precipitation records from the PRISM rainfall model extracted at the P300 gage location (from 1980 to present), the period of record at KREW has spanned the two driest years (2014 and 2015 water years) and the third wettest (2017) on record (PRISM Climate Group, 2020). The 10 years of pre-treatment data allowed for a rigorous assessment of the natural variability in streamflow of headwater catchments in the southern Sierra Nevada (Safeeq & Hunsaker, 2016). The KREW sites have served as a platform for more than 40 papers on various environmental topics, including: the physical and chemical composition of soils (Johnson et al., 2011); the carbon content of the soils (Johnson et al., 2011; Stacy et al., 2015; Stacy et al., 2019); the vegetation conditions, including the riparian vegetation composition (Dolanc & Hunsaker, 2017) and the effects of tree thinning and a drought-enhanced beetle infestation that caused a widespread mortality event (2013–2017) (Lydersen et al., 2019); macroinvertebrate communities and their response to drought (Herbst et al., 2018; Herbst et al., 2019); streamwater chemistry (Hunsaker & Johnson, 2017); and streamflow generation (Hunsaker et al., 2012; Liu et al., 2013). The Southern Sierra Critical Zone Observatory established its first of four observatories in the P301 catchment in 2006, which led to a rich and diverse series of studies in the soil-vegetation-atmosphere continuum (Bales et al., 2018; Klos et al., 2018; O'Geen et al., 2018). Streamflow data have been used for hydrological modelling studies (Jepsen et al., 2016; Saksa et al., 2017; Son & Tague, 2019a, 2019b) and to assess the impacts of tree mortality and forest management (mechanical thinning and prescribed burning) on stream flow (Bart et al., 2020). Additional studies relating the sediment delivery, soil chemistry, and the effects of management treatments on various watershed conditions are underway. The observations will also be useful in assessing the potential impacts of climate change, using the elevations of the two sets of catchments as a proxy for future climates.

In addition, these data will serve to calibrate and refine process-based ecohydrological models for, among other objectives, assessing the catchment-scale and cumulative effects of forest management activities. The data also will provide reference conditions for future studies related to regional meteorological, streamflow, and stream water chemistry dynamics. Further, when combined with data from organizations such as the Southern Sierra Critical Zone Observatory (www.hydroshare.org/group/145) or the Teakettle site of the National Environmental Observatory Network (www.neonscience.org/field-sites/tecr), these data will be used to assess the influence of regional, short-term (1–5 years) variability in weather patterns on streamflow and stream water chemistry and other effects. Data from the KREW will also be useful in larger-scale catchment and landscape assessments when combined with data from other sites such as those that are part of the Long Term Ecological Research Network, the Critical Zone Observatories, and other state and federally sponsored experimental catchments. Given the relatively low-intensity of the initial catchment-scale treatments, we are also planning a second set of experiments to make use of the KREW sites as a platform for continued process and catchment-scale discovery.

6 | FUNDING AND DATA OWNERSHIP STATEMENTS

Funding for the KREW project was provided by the USDA Forest Service, the USDI and USDA Forest Service Joint Fire Science Program, from California's State Water Resources Control Board, through Proposition 50 (Water Security Clean Drinking Water, Coastal, and Beach Protection Act of 2002), the California Department of Forestry and Fire Protection, and the Sierra Resource Conservation District. The related data are not subject to copyright in the United States and can be used without additional permissions or fees. Suggested citations for the data are provided in the metadata. Some instruments at two of the meteorological stations were provided by the Kings River Water Association through a grant from the California Department of Water Resources. Most KREW land is publicly held and managed by the Sierra National Forest, with the remaining ownership and management by the Southern California Edison Corporation.

ACKNOWLEDGEMENTS

We are grateful to the many people who have contributed their effort to the establishment of KREW and data collection since its inception. In particular, we thank Sean Egan, Jeff Anderson, Thomas Whitaker, Kevin Mazzocco, Amber Olsson, Matt Stuemky, and our other colleagues at the Sierra National Forest, Pacific Southwest Research Station, and University of California-Merced for their assistance. We are also grateful to our funding partners identified above in Funding and Data Ownership statements.

DATA AVAILABILITY STATEMENT

Data have been archived using strict review and description protocols in the USDA Forest Service Research Data archives, including streamflow (https://www.fs.usda.gov/rds/archive/catalog/RDS-2017-0037) (Hunsaker & Safeeq, 2017), stream water chemistry (https://www.fs.usda.gov/rds/archive/catalog/RDS-2017-0040) (Hunsaker & Padgett, 2019), and meteorological conditions (https://www.fs.usda.gov/rds/archive/catalog/RDS-2018-0028) (Hunsaker & Safeeq, 2018). These archives will be updated periodically. Additional archives for soil conditions, soil and precipitation chemistry, and vegetation are in preparation. Real-time, preliminary data from the Upper Bull and Upper Providence meteorological stations are available online through the California Department of Water Resources (https://cdec.water.ca.gov/dynamicapp/QueryF?s=kub and https://cdec.water.ca.gov/dynamicapp/QueryF?s=kup, respectively). Additional information about the sites is available at https://www.fs.fed.us/psw/topics/water/kingsriver/. Other data are available by reasonable email or written request to the corresponding author.

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How to cite this article: Wagenbrenner JW, Dralle DN, Safeeq M, Hunsaker CT. The Kings River Experimental Watersheds: Infrastructure and data. *Hydrological Processes*. 2021;35:e14142. https://doi.org/10.1002/hyp.14142