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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

WILEY

Fifty-eight years and counting of watershed science at the Caspar Creek Experimental Watersheds in northern California

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Abstract

The Caspar Creek Experimental Watersheds are the site of a long-term paired watershed study in the northern Coast Ranges of California. The watersheds are predominately forested with coast redwood and Douglas-fir. Old-growth forest was logged between 1860 and 1904. Two harvesting experiments have been completed since then and a third experiment is currently underway. Caspar Creek data are split into three phases corresponding to three experiments: Phase 1 (1962–1985) reports on a selection harvest (1971–1973) and initial recovery in the South Fork watershed; Phase 2 (1985–2017) includes clearcut harvesting of ~50% of the North Fork watershed (1985–1992) and recovery; and Phase 3 (2017 onward) corresponds to a second selection harvest in the South Fork watershed with a range of subwatershed harvest intensities (2017–2019) and recovery. All three experiments included harvest-related road-building and relied primarily on measurements of streamflow and sediment delivery from both treated and reference watersheds. Major findings include modest increases in post-harvest peak flows and cumulative flow volumes, post-harvest low flows that initially increased and then decreased 12 to 15 years after harvesting, and the consequences of different yarding techniques and road design on sediment yields. Some of the data for Phase 1 and Phase 2 are available in a USDA Forest Service online archive. The archived data include precipitation, streamflow, suspended sediment concentrations, turbidity, accumulated weir pond sediment volumes, bedload transport rates, water stable isotope data, and geospatial data. Archiving activities are ongoing. Phase 3 data are currently being collected and will be archived after a post-harvest monitoring period.

KEYWORDS

Caspar Creek, experimental watersheds, geomorphology, hydrology, paired watersheds, timber harvest

1 | DATASET NAME

Caspar Creek Experimental Watersheds data.

2 | CASPAR CREEK DESCRIPTION

The Caspar Creek Experimental Watersheds are located in the Jackson Demonstration State Forest near Fort Bragg, CA (39.361°N, 123.736°W) and consist of the North Fork (NFC, 479 ha) and South Fork (SFC, 417 ha) watersheds. Monitoring of precipitation, discharge, accumulated weir pond sediment volumes, and suspended sediment began in 1962. The watersheds are forested by coast redwood (*Sequoia sempervirens* [D Don.] Endl.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), with lesser amounts of grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.), tanoak (*Notholithocarpus densiflorus* [Hook & Arn.]), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and red alder [*Alnus rubra* Bong.]. Mean January air temperature is 9 °C and mean July air temperature is 14 °C. Mean annual precipitation is 1170 mm and most of this occurs between October and April (Cafferata & Reid, 2013). Snow is insignificant. The local rock type is the Coastal Belt of the Franciscan Complex (Evitt & Pierce, 1975), which is primarily composed of sandstone, siltstone, mudstone, and conglomerates at Caspar Creek (Cafferata & Spittler, 1998). Hydrologic years at Caspar Creek span 1 August of the preceding year to 31 July of the hydrologic year of record.

3 | CONTRIBUTION TO UNDERSTANDING HYDROLOGICAL PROCESSES

Data collected during the Phase 1 and 2 experiments have informed our understanding of the consequences of timber harvest and influenced forestry best management practices (BMPs) in California (Cafferata & Reid, 2013) and elsewhere. Along with many other observations regarding timber harvest effects, the Phase 1 and 2 experiments documented the following: (1) modest increases in post-harvest peak flows (Lewis et al., 2001; Ziemer, 1998) and cumulative flow volume (Keppeler, 1998; Keppeler & Ziemer, 1990), (2) initially increased post-harvest low flows followed by decreased low flows 12 to 15 years after harvesting (Coble et al., 2020; Keppeler, 1998; Keppeler & Ziemer, 1990; Reid, 2012), and (3) consequences of different yarding techniques and road design on sediment yields (Lewis, 1998; Lewis et al., 2001). An extensive summary of Caspar Creek scientific achievements and results for Phases 1 and 2 are available in Cafferata and Reid (2013). During the period of operation, Caspar Creek has also served as a platform for other experiments related to methods development, organisms, carbon and nutrient cycling, and more. As of September 2020, 80 journal articles, 76 proceedings, 11 book chapters, and 31 theses or dissertations have been published based on Caspar Creek data (please see www.fs.fed.us/psw/topics/water/caspar/caspubs.shtml for a complete bibliography). The Phase 3 timber harvest experiment, which is currently underway, will assess how contemporary California forestry BMPs influence hillslope water movement and storage, peak flows, low flows, landslide frequency and size, and fluvial sediment transport.

4 | MEASUREMENTS

4.1 | Streamflow

Streamflow has been measured at the SFC and NFC weirs using compound v-notch weirs (Figure 1). Originally, chart recording devices (Stevens A-35, Portland, OR and Belfort 5-FW-1, Baltimore, MD) were used for analog stage measurements. In 1985, pressure transducers and digital data loggers replaced analog chart recorders. Campbell Scientific CS450 and CS451 pressure transducers (Logan, UT) are currently used to measure stage (accuracy of ±2 mm). The original stage data have been discretized to a 10-min interval and current stage measurements continue at this interval. Streamflow has also been measured at a semi-engineered cross-section (ARF) on the North Fork mainstem, a natural cross-section (QUE) on the South Fork mainstem, and tributaries for both watersheds with Montana flumes and pressure transducers housed in stilling wells (Figure 1). Rating equations are used to determine discharge from stage at each station

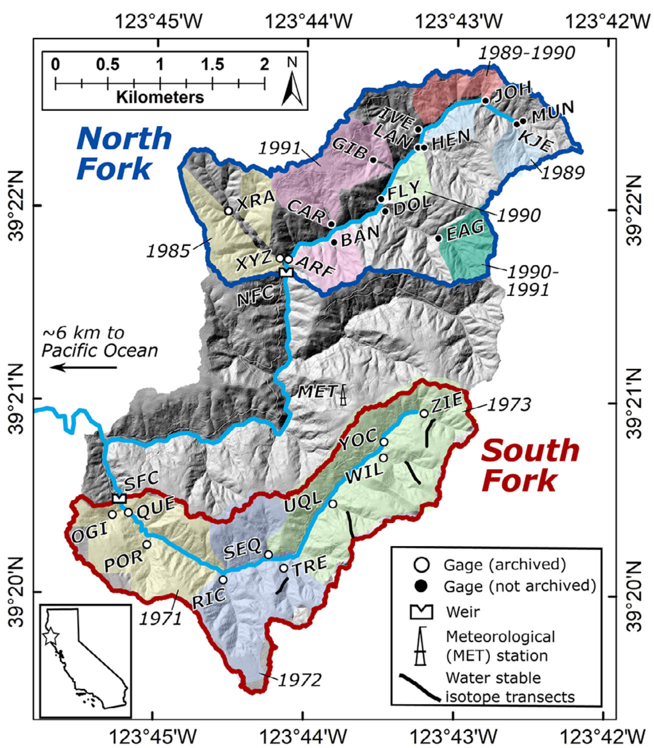

FIGURE 1 Shaded relief map of the Caspar Creek Experimental Watersheds showing the South Fork and North Fork watersheds. Colormap indicates the year the harvesting unit was felled in Phase 1 or Phase 2 experiments. All gaging stations are shown. Data from gages not yet archived will be included in a future data publication. The inset map of California shows the location of Caspar Creek marked with a star

except ARF and QUE. Rating equations were originally used to calculate discharge at the ARF site but were found to vary through the study (Richardson et al., 2020), so they were abandoned. ARF discharge can be estimated by subtracting discharge measured at the XYZ station from discharge measured at the NFC station for years when XYZ discharge data exist (Richardson et al., 2020). A similar approach is used to estimate discharge at QUE because of a non-stationary rating equation.

4.2 | Suspended sediment concentrations and turbidity

Stream samples for determining suspended sediment concentration (SSC) have been collected using three different methods. DH-48 and DH-75 depth-integrated hand samplers (Rickly Hydrological Company, Inc., Columbus, OH) have been used throughout the entire study period. From 1962 to 1975, fixed-stage samplers were used to collect stream samples on the rising limbs of the hydrographs at the NFC and SFC weirs. SSC from stream samples collected with fixed-stage samplers were known to be overestimated, and different researchers developed approaches to address the bias (Keppeler, 2012; Lewis, 1998; Richardson et al., 2020). Pumping samplers were deployed at both weirs in 1975. Initially, pumped samples were triggered by stage. Selection At List Time, an automated sampling protocol algorithm based on flow-proportional sampling (Thomas, 1989), was used from 1985 to 1995. Turbidity sensors were installed at all gaged sites in 1995. Beginning in 1995, samples were collected according to a turbidity threshold sampling protocol, which collects samples based on a combination of turbidity thresholds and timing (Lewis & Eads, 2009). SSC uncertainty depends on the accuracy of the sample volume and the dried sediment mass. Before 1988, dried sediment samples were weighed with a precision of 0.001 g. Water sample volumes were measured to the nearest 1 ml until 1991. From 1991 onward, water samples were weighed with a precision of 0.1 g and dried sediment samples were weighed with a precision of 0.0001 g. All SSC data (mg/L) were reported with 3-digit precision.

4.3 | Accumulated weir pond sediment volumes

Sediment and organic matter deposit in the ponds upstream of the two weirs. Accumulated weir pond sediment volumes have been surveyed and calculated each summer for NFC and SFC since 1962. Pond depositions were surveyed along established cross-sections spaced 2 to 4 m apart with either sag tapes, rod and level, or total station methods. Surveys of the pond bed topography are differenced from one year to the next to determine the accumulated volume. Every 5 to 10 years, the accumulated pond sediment is removed to maintain capacity for incoming sediment. Recently, the original survey data were reassessed using a standardized methodology to interpolate and delineate the pond surfaces. The reassessed pond surfaces were used to revise the accumulated pond sediment volumes for the entire study. Survey uncertainty is relatively low. The uncertainty of the accumulated weir pond sediment volume is dominated by our ability to interpolate the pond sediment surface between survey points and resolve the pond banks, and these vary through time. We expect that percent uncertainty decreases as the accumulated pond sediment volume increases. Richardson et al. (2020) assumed that one standard deviation of the pond sediment volume was 20% of the annual pond sediment volume.

4.4 | Bedload transport rates

Bedload transport rates were measured from 1988 to 1995 using four Birkbeck-style bedload pits (Reid et al., 1980) at the ARF gaging station (Figure 1). The pit openings were 0.1 m across the channel by 0.4 m parallel to the channel. The sample containers in the pits were 0.125 m^3 and the submerged mass of the containers was determined initially with pressure pillows and later by electronic load cells. During large storms, the bedload pits filled and needed to be evacuated (Lewis, 1991). The load cells that were used to measure the bedload sample weight for most of the study period had a median standard error of the estimate of 0.40 kg (Lewis, 1991). Bedload transport rates were measured during 13 storms and discretized to 10-min intervals.

4.5 | Meteorological data

A meteorological (MET) station has been operational since 2009 and is located in the SFC watershed (Figure 1). The MET station measures air temperature (accuracy of ±0.2 °C at 20 °C) and relative humidity (accuracy of ±1%) (Vaisala HMP45C, Vantaa, Finland), wind speed (accuracy of ±1.1%) and direction (accuracy of ±4°) (Met One 034B, Grants Pass, OR), solar radiation (accuracy of ±5%) (Apogee CS300, Logan, UT), photosynthetically active radiation (accuracy of ±5%) (Licor Quantum LI190SB, Lincoln, NE), and precipitation (accuracy of ±1%) (OTT Pluvio, Kempten, Germany). Data are recorded at 15-min intervals on a battery-powered datalogger (Campbell Scientific CR1000, Logan, UT).

4.6 | Water stable isotopes

Samples were collected before, during, and after the Phase 3 timber harvest in the SFC watershed from precipitation, soil water (5–100 cm depths), shallow groundwater, streams, and trees to quantify water stable isotope composition (δ^2H and δ^{18}O). Samples were collected from transects in each of four catchments in the SFC watershed. Each transect included five sampling plots at the following topographic positions: riparian, toeslope, midslope, shoulder, and ridge top. Water stable isotopes of liquid water and soil water were quantified at the University of Saskatchewan using a Los Gatos Research liquid water Off-Axis Integrated Cavity Output Spectroscopy (Off-Axis ICOS) machine (ABB-Los Gatos Research, San Jose, CA) with an accuracy of ≤±1.0‰ for δ^2H and ±0.2‰ for δ^{18}O. The water stable isotopes of the vegetation samples were processed at Boise State University using a 2010 ThermoFisher Delta V Plus (ThermoFisher Scientific, Waltham, MA) continuous flow isotope ratio mass spectrometer with an accuracy of ≤±1.0‰ for δ^2H and ±0.1‰ for δ^{18}O. All sample values were related to the Vienna Standard Mean Ocean Water (in ‰). This data publication includes Phase 2 data collected from May 2016 to July 2017. A future data publication will include additional water stable isotope data collected after July 2017.

TABLE 1 Summary of archived Phase 1 and Phase 2 data products

Product	Station	Period	Description
Phase 1 (https://doi.org/10.2737/RDS-2020-0017-2)			
Streamflow	NFC, SFC	1962–1985	Stage measured at a compound v-notch weir; discharge calculated from a rating equation.
Suspended sediment concentration (SSC)	NFC, SFC	1962–1985	Suspended sediment concentration of stream samples collected by fixed-stage and depth-integrated hand sampling, and pumping samplers beginning in 1975.
Weir pond sediment volumes	NFC, SFC	1962–1985	Annually surveyed and differenced weir pond accumulated sediment volumes.
Spatial information			Timber harvest unit boundaries, instrumented station locations, watershed boundaries.
Phase 2 (https://doi.org/10.2737/RDS-2020-0018-2)			
Streamflow	NFC, SFC	1985–2017	Stage measured at a compound v-notch weir; discharge calculated from a rating equation.
Streamflow	ARF, QUE	1985[a]–2017	Stage measured for a semi-engineered cross-section[b] (ARF) and stage measured for a natural cross-section (QUE).
Streamflow	OGI, POR, RIC, SEQ, TRE, UQL, WIL, XRA, XYZ, YOC, ZIE	2000[a]–2017	Stage measured with a Montana-flume; discharge calculated from a rating equation.
Suspended sediment concentration (SSC)	ARF, NFC, SFC	1985–2017	Suspended sediment concentration of stream samples collected by depth-integrated and pumping samplers.
Suspended sediment concentration (SSC)	OGI, POR, QUE, RIC, SEQ, TRE, UQL, WIL, XRA, XYZ, YOC, ZIE	2000[a]–2017	Suspended sediment concentration of stream samples collected by depth-integrated and pumping samplers.
Turbidity	ARF, NFC, OGI, SFC, QUE, XYZ	1995[a]–2017	Turbidity measured at 10-min interval corresponding to stage measurements.
Weir pond sediment volumes	NFC, SFC	1985–2017	Annually surveyed and differenced weir pond accumulated sediment volumes.
Bedload transport rates	ARF	1988–1995	Bedload transport rates sampled with four Birkbeck-style bedload pits during thirteen storms.
Meteorological data	MET station	2009–2017	15-min measurements of air temperature, relative humidity, wind speed and direction, solar radiation, photosynthetically active radiation, heat index, dew point, and precipitation.
Water stable isotope	TRE, UQL, WIL, ZIE transects	2016–2017	Water stable isotope ratios (δ^2H and δ^{18}O) for precipitation, soil water (5–100 cm depths), shallow groundwater, streams, and trees data collected along four transects.
Spatial information			Timber harvest unit boundaries, station locations, watershed boundaries, water stable isotope transects, stream locations, 2017 LiDAR (point cloud, DEM, shaded relief map).

Note: Uncertainties are discussed in the metadata that accompanies each dataset and qualitatively described with quality codes when possible.
[a]Some stations were operational for a subset of the listed period.
[b]See Richardson et al. (2020) for methods to calculate ARF discharge.

4.7 | Geospatial data

ESRI ArcGIS map products include watershed outlines and areas, stream locations, harvest boundaries, stable water isotope transects, and instrumented station locations. A 1-m digital elevation model, point cloud, and shaded relief map derived from LiDAR collected in 2017 prior to the Phase 3 timber harvest are also included.

5 | CASPAR CREEK DATA

5.1 | Data description

Caspar Creek data have long been publicly available in various forms, but recent efforts have made the data more consistent and accessible. For archiving purposes, the record was divided into three periods following the three experimental phases. Phase 1 is from 1 August 1962 to 31 July 1985. Phase 2 is from 1 August 1985 to 31 July 2017. Phase 3 begins on 1 August 2017. Publishing the data is an ongoing effort and data from Phase 1 (Richardson, Seehafer, Keppeler, Sutherland, & Wagenbrenner, 2021) and Phase 2 (Richardson, Seehafer, Keppeler, Sutherland, Wagenbrenner, Bladon, et al., 2021) are currently available through the USDA Forest Service online archive. Table 1 summarizes currently available data. Newly derived data, such as annual gravel yields, are also publicly available for Phase 1 and 2 (Richardson et al., 2020; Richardson & Wagenbrenner, 2020). All data have been reviewed for accuracy and adjusted when errors were encountered. Information detailing adjustments and data quality are described in the metadata that accompanies each dataset. Additional data from all three phases will be published after they are reviewed.

5.2 | Funding, ownership, and contributors

This project is funded by the USDA Forest Service Pacific Southwest Research Station and the California Department of Forestry and Fire Protection (CAL FIRE). Funding for the water stable isotopes was provided by the National Science Foundation (Grant # NSF-EAR-1807165). The Caspar Creek Experimental Watersheds are primarily located within the Jackson Demonstration State Forest, which is owned by the state of California and maintained by CAL FIRE. In addition, the SFC watershed includes approximately 6 ha of private property and approximately 5 ha that are located in the Russian Gulch State Park. Over the 58-year history of the Caspar Creek Experimental Watersheds, hundreds of scientists, students, and volunteers have contributed to the collection, processing, and analysis of data.

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DATA AVAILABILITY STATEMENT

Phase 1 data are included in the data publication "Caspar Creek Experimental Watersheds Phase 1 (1962–1985) data (2nd edition)" and accessible at https://doi.org/10.2737/RDS-2020-0017-2 (Richardson, Seehafer, Keppeler, Sutherland, & Wagenbrenner, 2021). Phase 2 data are included in the data publication "Caspar Creek Experimental Watersheds Phase 2 (1985–2017) data (2nd edition)" and accessible at https://doi.org/10.2737/RDS-2020-0018-2 (Richardson, Seehafer, Keppeler, Sutherland, Wagenbrenner, Bladon, et al., 2021). Table 1 summarizes data available in the Phase 1 and Phase 2 data publications. The annual bedload yields are accessible at https://doi.org/10.7910/DVN/ZKYNQC (Richardson & Wagenbrenner, 2020). Extensive metadata describing instrumentation, methods, and measurement uncertainty are included with each data publication. Each data publication includes an overview metadata document, a file index with a brief description of the metadata and data products, and specific metadata for each data product. Additional data from all three phases will be made available on the USDA Forest Service online archive. Phase 3 data are still being collected. We expect that the first Phase 3 data archive will be publicly available in 2022.

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