Addendum to

Caspar Creek Experimental Watersheds

Experiment Three Study Plan:

The influence of forest stand density reduction on

watershed processes in the South Fork

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[1]Contact information on original updated 14 December 2017

Introduction

Since their establishment in 1962, the Caspar Creek Experimental Watersheds have provided foresters, land managers, researchers, and citizens with information that has influenced forest management in northwestern California. The primary goal in establishing Caspar Creek was to understand how harvesting timber could affect streamflow and suspended sediment concentrations (SSC). The first experiment (1962-1985) was a classic paired-watershed study undertaken before the implementation of the modern California Forest Practice Rules (FPRs): roads were constructed in the South Fork and 60-70% of the stand volume was selectively cut and tractor yarded, while the North Fork served as a control (Rice et al., 1979). The second experiment (1985-present) was designed to address cumulative watershed effects using the modern FPRs by investigating how clearcutting sub-watersheds in the North Fork influenced downstream streamflow and SSC (Ziemer, 1998; Lewis et al., 2001). Streamflow and SSC measurements began in 2000 at a network of sub-watersheds in the South Fork in anticipation of a third experiment that would investigate the impact of harvesting under updated California FPRs.

The U.S. Forest Service established numerous paired watershed experiments across the United States in the mid-1900s with the goal of understanding how forest practices affect streamflow and sediment production. These paired watershed studies, located in a wide range of ecosystems, found similar water yield results regardless of topography or vegetation type: removing >20% of basal area from a stand resulted in increased streamflow (Hibbert, 1967; Stednick, 1996). The effects of vegetation removal were found to decrease as regrowth occurred. Increases in water yield were caused by decreases in evapotranspiration and interception loss that occur when removing vegetation from a watershed.

In contrast to water yield results, there is still not agreement on the magnitude, persistence, and mechanisms responsible for peak flow changes, despite decades of data from paired watershed studies (Grant et al., 2003). Similarly, while there is general consensus that sediment generation has decreased in experimental watersheds with improved forest practices, the degree that remaining effects from timber operations should be reduced continues to be debated (Loehle et al., 2014). While paired watershed studies have answered key questions on cause and effect, the question of equifinality (the idea that a given end state can be achieved by many potential means) still remains. The third experiment will broaden our process-based understanding of forest hydrology by investigating how contemporary forest management, including harvests, affect water movement and storage, peak flows, and sediment production in the South Fork Caspar Creek.

Third Experiment Objectives

Results from the first two Caspar Creek studies have contributed to the body of knowledge for a wide range of watershed topics, including cumulative effects, changes in peak flows with timber harvest, logging-related sediment production, appropriate buffer strip design, logging-related impacts on anadromous fish and benthic macro-invertebrate communities, management of headwater channels, impacts of timber harvesting on subsurface flow, nutrient cycling impacts associated with clearcutting, changes in fog drip and interception loss with harvest, and design of water quality monitoring programs (Cafferata and Reid, 2013). The third experiment at Caspar Creek is designed to expand upon the findings of the first two experiments by investigating hydrological, geomorphic, and ecological processes in coast redwood forests at the tree, plot, hillslope, sub-basin, and catchment scales. This study will look at the effect of stand density reduction (i.e., reducing the quantity of trees) on watershed processes and characteristics on sites that have been historically managed for timber. The overarching objective of the third experiment is to ***quantify the influence of forest stand density reduction on watershed processes while utilizing the current California Forest Practice Rules***. Specific goals of the study are to:

1. Determine the consequences of superimposing current logging practices, including new road building, on previously tractor logged watershed in the South Fork by quantifying the effect of different levels of stand density reduction on daily, seasonal, and annual streamflow and sediment yields (Watershed Resilience and Recovery Study);
2. Investigate the role of stand density reduction in partitioning precipitation and fog inputs into evapotranspiration, soil moisture, groundwater, and stream discharge (Plant-Soil-Water Dynamics Study);
3. Improve our mechanistic understanding of how timber harvesting influences both the delivery of water from hillslopes to streams and residual tree water use (Water Worlds Study);

4. Determine the effects of contemporary forest practices on macroinvertebrate assemblages and stream nutrients in the third experiment (Bioassessment Study);
5. Calibrate the Distributed-Hydrology-Soil-Vegetation Model (DHSVM) for the Caspar Creek experimental watersheds in order to simulate the effects of different silvicultural and road building practices on streamflow and sediments (DHSVM Study);
6. Identify the sources of stream channel sediments and determine if the level of stand density reduction influences sediment sources in the channel (Sediment Fingerprinting Study);
7. Apply novel descriptors of hydrological (fine suspended sediments and streamflow) events to suspended data collected from the second and third experiments (Fine Sediments Study);
8. Determine the erosional consequences of legacy road rehabilitation (Road Rehabilitation Study);
9. Develop an updated landslide features map within the Caspar Creek drainage (Landslide Mapping Study);
10. Quantify concentrations and loads of nutrients (N, P, and C) and ions from the South Fork Caspar Creek, the effect of different intensities of timber harvest on these constituents, and the degree of biochemical processing within the main stem of the South Fork (Nutrient Cycling and Transport Study); and
11. Determine the seasonal moisture dynamics in the unsaturated zone and the impact of trees on this moisture storage (Unsaturated Zone Moisture Dynamics Study).

<u>Site Description</u>

The Caspar Creek Experimental Watersheds (39°21′N, 123°44′W) are located in the Jackson Demonstration State Forest (JDSF) in northwestern California (Figure 1), approximately 7 km from the Pacific Ocean (Henry, 1998). Established as a joint study with the U.S. Forest Service and the California Department of Forestry and Fire Protection (CAL FIRE) in 1961, research has focused on water and sediment production in a watershed located in the northern part of the California Coast Ranges. The Caspar Creek watershed has a drainage area of 2,167 ha, with the study area encompassing 473 ha and 424 ha of the North and South Forks, respectively.

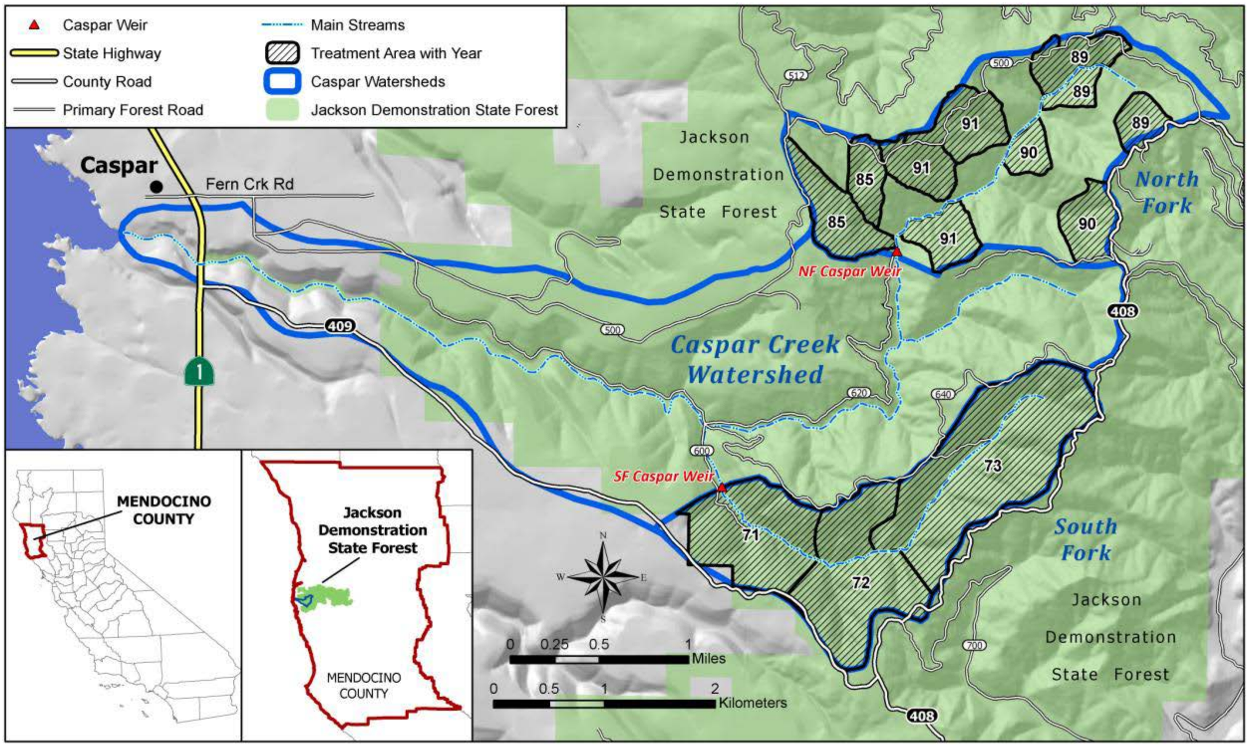

Figure 1. The Caspar Creek Experimental Watersheds are located on the north coast of California. Numbers indicate the year in which timber harvest began during the first (1971-1973) and second (1985-1991) phases. From Cafferata and Reid (2013).

The climate at Caspar Creek is Mediterranean, with cool, dry summers characterized by coastal fog and mild, moist winters. Mean annual precipitation from 1990 – 1995 was 1190 mm, with 90% of the rainfall occurring from October to April. Snowfall is rare in the Caspar Creek watershed. The mean annual temperature from 1990 – 1995 was 4.7°C in December and 15.6°C in July. The landscape is dominated by coast redwood (*Sequoia sempervirens* (D. Don) Endl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Doug. ex D. Don) Lindl.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), with smaller amounts of tanoak (*Lithocarpus densiflorus* (Fook. and Arn.) Rohn) and red alder (*Alnus rubus* Bong.). Elevations in the region range from 37 to 320 m and slopes can reach an excess of 50%. Soils in the basin are predominately well-drained clay-loam ultisols and alfisols (Henry, 1998).

Experimental Design

The ultimate goal of this experiment is to better understand how current forest management practices affect watersheds in the coast redwood region. To meet this objective, stand density was incrementally reduced in each of the gauged sub-watersheds. The broad range of stand density reductions used in experiment three will result in both multi- and even-aged forest stands. With this framework in mind, the third experiment was designed using a range of harvesting intensities to discern potential thresholds in which vegetation removal begins to affect watershed processes. This study will result in a mechanistic understanding of the connection between canopy reduction and watershed processes that can be used to develop sound management practices in similar Coast Range watersheds in the future.

Study Watersheds

Second growth trees in the South Fork of Caspar Creek were harvested from 1971-1973 as part of the original Caspar Creek paired watershed study. Results and findings from the first experiment are summarized by Rice et al. (1979) and Ziemer (1998). In 2000, ten sub-watersheds within the South Fork were instrumented in preparation for a third experiment; a total of eleven gaging stations are being used to monitor streamflow and sediment (Table 1, Table 2, Figure 2).

Table 1. Experimental sub-watersheds located in the South Fork of Caspar Creek as well as harvesting information from the first Caspar Creek experiment.

Watershed Name	Watershed ID	Area (ha)	Streamflow Record Begins	Year of Harvest	% Volume Logged
South Fork	SFC	424	11/1962	1971-1973	65%
Ogilvie	OGI	18	10/2000	1971	60%
Porter	POR	32	10/2000	1971	60%
Quetelet	QUE	394	10/2000	1971-1973	65%
Richards	RIC	49	10/2000	1972	70%
Sequoyah	SEQ	17	10/2000	1972	70%
Treat	TRE	14	10/2000	1972	70%
Uqlidisi	UQL	13	10/2000	1973	65%
Williams	WIL	26	10/2000	1973	65%
Yocum	YOC	53	10/2000	1973	65%
Ziemer	ZIE	25	10/2000	1973	65%

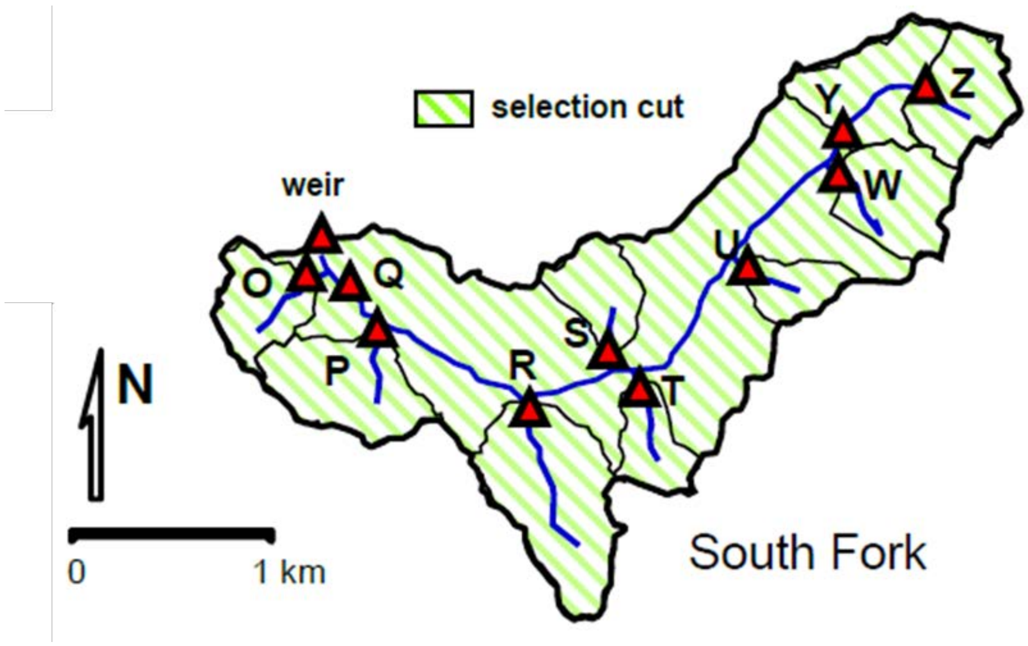

Figure 2. Gaging stations in the South Fork of Caspar Creek. Stations are identified by initial. Adapted from Cafferata and Reid (2013).

Table 2. Landscape features of the sub-watersheds in the South Fork of Caspar Creek.

Watershed Name	Station ID	Area (ha)	Elevation Range (m)	Average Slope (%)	Dominant Soil Subgroup(s)
South Fork Caspar	SFC	424	46 - 329	59.6	Ultic hapludalf
Ogilvie	OGI	18	58 - 174	26.3	Mollic/Ultic hapludalf
Porter	POR	32	61 - 186	34.2	Ultic hapludalf
Quetelet	QUE	394	48 - 329	49.8	Mollic/Ultic hapludalf
Richards	RIC	49	73 - 198	41.6	Mollic/Ultic hapludalf
Sequoyah	SEQ	17	79 - 207	37.9	Ultic hapludalf
Treat	TRE	14	98 - 244	46.5	Mollic/Ultic hapludalf
Uqlidisi	UQL	13	122 - 323	48.5	Typic haplohumult
Williams	WIL	26	146 - 323	50.5	Typic haplohumult
Yocum	YOC	53	146 - 329	47.5	Typic haplohumult
Ziemer	ZIE	25	213 - 329	43.0	Typic haplohumult

Stand Density Reduction

Light is a fundamental driver of various ecosystem processes, from photosynthesis to evaporation to decomposition. Light plays a large role in the regeneration of coast redwood stands, with increased self-thinning of stump sprouts and decreased leaf-area-index (LAI) occurring in stands with poor light regimes (O'Hara and Berrill, 2010). Forest managers routinely alter the light environment in forests by removing trees via timber harvest, which promotes regeneration of desirable species (Oliver and Larson, 1990). Changes in forest stand density are characterized based on the attributes of interest. For instance, the economic value of a stand is often quantified in terms of merchantable stem volume, or board feet. Forest managers routinely use basal area (the surface area of stems at a height of 1.37 m (4.5 ft) above ground per unit area) to quantify a stand's density because of its ease of measurement. Leaf area index (e.g., the ratio of total leaf area to ground area covered), on the other hand, has the potential to better explain ecological processes because the amount of leaf area in a stand reflects the availability of sunlight to drive photosynthesis and transpiration.

Despite the connection between leaf area and ecosystem processes, forest managers routinely develop silvicultural prescriptions based upon basal area. This is in large part due to the complexity associated with measuring or determining leaf area. Current leaf area calculations for coast redwood include sapwood area measurements, which must be collected via destructive sampling or increment cores. Kevin O'Hara, UC Berkeley, is working on developing an equation for calculating coast redwood leaf area from easily obtained measurements such as diameter at 1.37 m and tree height. To form a more physical basis for this experiment, treatments were established on the basis of basal area and other forest density attributes. This will also allow us to explore the ecological (i.e., leaf area) as well as practical (i.e., basal area) effects of stand density reduction on watershed processes.

Treatment Plan

In order to achieve the desired experimental stand density reductions, the type of harvest applied to each sub-watershed will vary. Stand density reduction rates of less than 35% will be similar to selection harvests used for uneven-aged management, per the FPR. The higher density reductions will result in stands with fewer residual trees and more regeneration by utilizing the FPR for the variable retention method. All logging operations will be in accordance with the current California Forest Practice Rules and the specific prescriptions to implement the timber harvesting plan (THP) for the third experiment will be developed by CAL FIRE-JDSF foresters. The planned harvest practices will require some new road construction along ridgetops to accommodate cable-yarding equipment. In contrast to the first experiment, tractor-yarding systems will be limited to areas with gentler slopes. Road layout and design will be determined by CAL FIRE with input from PSW to ensure that road construction will not impact control watersheds. Designated segments of the mid-slope road (Road 605) traversing ZIE through UQL will be performed in advance of or in conjunction with harvest activities. No decommissioning will be done in the control sub-watersheds. Road decommissioning began in 2011. Harvesting began in spring 2017 and is anticipated to finish by fall 2018. Harvest of the six gauged sub-watersheds is scheduled for 2018.

Assigning Watershed Treatments

Two no treatment sub-watersheds will be established as long-term reference watersheds for monitoring of streamflow and sediment. No additional road-building will occur in these reference watersheds (WIL and RIC, Table 3). Six additional sub-watersheds will be harvested using a range of percent leaf area removal. The highest harvest rate will remove 75% of the current leaf area from the stand, while the lowest harvest rate will remove 25% of the current stand leaf area. Four additional harvest removal rates were established within this gradient (Table 3). The treatment sub-watersheds were verified by a field reconnaissance crew (with members from CAL FIRE, PSW, UC Berkeley) in July 2015.The higher harvest endpoints were designed to push the systems beyond typical uneven-aged management, which will allow for identifying thresholds at which hydrologic and ecological function of the watersheds may be compromised. This variability in stand density reduction can serve as a resource for exploring economic and environmental consequences of such management regimes. The matrix area between the sub-watersheds will be harvested at a moderate intensity (rate to be determined by CAL FIRE), producing downstream effects that will combine with the effects of the treatments in the sub-watersheds. Streamflow and sediment yield/turbidity levels associated with harvesting from both the matrix area and sub-watersheds will be documented at stations located on the main stem of South Fork Caspar Creek (Figure 2).

Table 3. Planned harvest rates for the sub-watersheds in South Fork Caspar Creek. These treatments are based on basal area; additional calculations will be required to determine removal rates based on leaf area. Stocking for the controls will be determined during the post-treatment inventory in the harvest units and is indicated in the table as TBD1. Actual reduction targets for the matrix areas (between sub-watersheds) vary, and the actual pre- and post-treatment stocking rates for the South Fork Caspar and Quetelet watersheds, which include matrix area and control sub-watersheds, will be determined post-harvest and is indicated by TBD2.

Watershed Name	Station ID	Area (ha)	Pre-treatment Basal Area (m^2 ha^{-1})	Reduction Rate (%)	FPR Method
South Fork Caspar	SFC	424	TBD2	TBD2	Selection
Ogilvie	OGI	18	65.5	45%**	Selection
Porter	POR	32	61.3	25%**	
Quetelet	QUE	394	TBD2	TBD2	Selection
Richards	RIC	49	TBD1	0%	Control
Sequoyah	SEQ	17	87.3	65%	Variable Retention
Treat	TRE	14	85.3	35%	Selection
Uqlidisi	UQL	13	66.3	55%	
Williams	WIL	26	TBD1	0%	Control
Yocum	YOC	53	156.6	0%/75%	No Cut*
Ziemer	ZIE	25	74.5	75%	Variable Retention

*The Yocum watershed encompasses Ziemer, but no additional harvesting will occur downstream of the ZIE gauge.

** Revised August 2016 to better fit constraints and experiment goals.

Statistical Analysis

Paired watershed studies are unique compared to other environmental investigations in that replicates are often not used due to budget or space limitations. In the case where replicates do exist, as in sub-watershed studies, the watersheds are inherently variable due to differences in geology, soils, cover types, etc. In addition to these constraints, the gauged sub-watersheds in the South Fork Caspar Creek are particularly heterogeneous due to legacy effects of past logging practices. Because of the large variability between the gauged sub-watersheds in the South Fork, a regression-based experimental design was chosen for the third experiment.

In a regression-based design, the independent variable (i.e., percent reduction in leaf area) is a continuous variable. The type of regression (e.g., linear, non-linear, multiple, or logistic) will depend upon the response variables of individual research hypotheses. The range of treatments (0% to 75% reduction in canopy leaf area) should capture the full range of responses from the different response variables. The type of statistical analysis used will depend on the individual research questions developed for the study.

Research Projects

Currently there are eleven research projects ongoing as part of the third experiment. These studies are briefly described below. Individual research plans have been developed for each study to describe the objectives, methods, anticipated findings, and personnel requirements of each in more detail (see Appendix A). All research plans associated with the third experiment must be approved by PSW and CAL FIRE before they can proceed.

Project 1: Watershed Resilience and Recovery Study

Project PI: Joe Wagenbrenner (PSW)

Project Collaborators: CAL FIRE, PSW, Salli Dymond (University of Minnesota-Duluth)

Funding Sources: CAL FIRE ($1.9M through 31 December 2019)

A myriad of studies have investigated the role of vegetation removal on streamflow and sediment yield (e.g., Hibbert, 1967; Stednick, 1996; Karwan et al. 2007; Keppeler and Lewis, 2007). However few studies have linked watershed processes to the intensity of stand density reduction, especially in previously logged stands. Determining the relationship between stand density reduction and streamflow and sediment yield across a range of intensities will allow managers to evaluate thresholds at which reducing stand density may begin to affect watershed processes. The goal of the watershed resilience and recovery study is to quantify the effect of different levels of canopy removal on streamflow and sediment yield in the South Fork Caspar Creek. Specifically, this project will address the following research questions:

1) How does stand density reduction influence annual streamflow (i.e., water yield), peak flows, low flows, turbidity levels, and sediment yield?
2) What are the response and recovery of streamflow and sediment yield following stand density reduction?
3) Is there a threshold at which stand density reduction begins to influence streamflow and sediment yield?

Streamflow and turbidity have been measured continuously at the South Fork tributary gauging stations since 2001. Streamflow and turbidity are recorded on 10-minute intervals using Montana flumes equipped with electronic data loggers, pressure transducers, and continuously recording turbidimeters. These data are not currently recorded during the summer months when flows are too low to be gauged accurately. Suspended sediment samples are collected at pre-determined turbidity thresholds using ISCO pumping samplers triggered with turbidity threshold sampling (TTS, Lewis and Eads, 2009). Water samples are measured for suspended sediment concentration using gravimetric methods. These data will continue to be collected by PSW throughout the length of the third experiment in order to track the response and recovery of each sub-watershed following stand density reduction and new road construction.

Project 2: Plant-Soil-Water Dynamics Study

Project PI: Salli Dymond (University of Minnesota-Duluth)

Project Collaborators: PSW, CAL FIRE, Kevin Bladon (Oregon State University)

Funding Sources: PSW ($70, 000)

Forest hydrologists understand the role that vegetation plays in mediating streamflow. Thus, harvesting a watershed will temporarily increase streamflow. We hypothesize that this response in streamflow is due to decreased evapotranspiration and interception loss, which produces an increase in subsurface flow (Reid and Lewis, 2009). However, relatively few studies have looked at how forest management influences hydrological processes in a watershed. The objective of this project is to broaden our understanding of the role of vegetation in partitioning precipitation and fog into evapotranspiration, soil moisture, groundwater, and stream discharge by comparing sites that have undergone different timber harvest intensities (e.g., low, moderate, high) to sites left intact. This research will address the following questions:

1) What are the annual, seasonal, and diurnal variations and patterns of precipitation, fog, evapotranspiration, soil moisture, groundwater, and stream discharge in coast redwood forests?
2) How do soil moisture, stream discharge, groundwater, and evapotranspiration respond to precipitation events in these systems?

3) How do different levels of timber harvest change the patterns, magnitudes, and variations of soil moisture, stream discharge, groundwater, and transpiration compared to pre-harvest conditions?

We will install transects of water measurements in four different sub-watersheds along a gradient of stand density reduction treatments (Table 4), which will allow us to assess the relationship between harvest intensity and different hydrologic components in the sub-watershed. Each sub-watershed will contain one transect and each transect will be on a similar-facing slope. Three transects were installed in 2015 and a fourth was installed in spring 2016. At five points along each transect, evapotranspiration, soil moisture, groundwater, photosynthetically active radiation (PAR) will be measured. Fog inputs, throughfall, temperature and relative humidity are measured at a subset of locations along each transect. Equipment was installed by PSW researchers with additional aid provided by CAL FIRE staff. Monitoring of equipment will continue by PSW researchers for at least three years following the completion of harvesting.

Table 4. Subset of watersheds that are included in the soil-plant-water dynamics study.

WS Name	WS ID	Harvest Intensity	Reduction Rate (%)	Installation Year	Anticipated Harvest Year
Williams	WIL	None	0%	2015	n/a
Treat	TRE	Low	35%	2015	2018
Uqlidisi	UQL	Moderate	55%	2016	2018
Ziemer	ZIE	High	75%	2015	2018

Project 3: Water Worlds Study

Project PI: Salli Dymond (University of Minnesota-Duluth)

Project Collaborators: PSW, Jeff McDonnell (University of Saskatchewan), Kevin Bladon (Oregon State University), Jim McNamara (Boise State University)

Funding Sources: Unknown amounts from University of Saskatchewan and Boise State University, CAL FIRE ($18,800), additional funds to be determined

It was traditionally believed that water movement along a hillslope followed the theory of translatory flow, or that precipitation entering the soil displaces the water that is currently present by displacing the older water further into the soil profile and eventually to the stream (Pearce et al., 1986). New research, however, has suggested the existence of "two water worlds," whereby soil water does not mix with precipitation (Brooks et al, 2010). It is unknown whether or not forest management activities may disturb subsurface flow processes enough to enhance or eliminate mixing of subsurface water pools. The primary objectives of this project are to improve mechanistic understanding of how timber harvesting influences (a) the delivery of water from hillslopes to streams, and (b) residual tree water use. Specifically, the research will address the following questions:

1) How does timber harvesting affect hydrologic connectivity across the upslope-riparian-stream continuum, thereby influencing the hydrologic response of a catchment to storm events?
2) How does the residence time of water in a catchment change following forest harvesting?
3) How does the ratio of event (new) to pre-event (old) water change following timber harvesting?
4) Do residual trees change their source of water for transpiration following timber harvesting?

A dual isotope (δ^2H, $\delta^{18}O$) approach will be used to compare water samples from soil, groundwater, streamflow, and trees before and after harvesting across a gradient of harvest intensities (i.e., low, moderate, high). This approach allows an investigation of the influence of timber harvesting on the 'two water worlds': (a) the tightly bound water used by trees, and (b) the mobile water related to infiltration, groundwater recharge, hillslope runoff, and streamflow. Water samples will be collected 4-6 times per year at the same locations as the soil-plant-water dynamics study sites by PSW researchers. All samples will be analyzed for δ^2H and $\delta^{18}O$; liquid water samples will be analyzed at either the McDonnell Stable Isotopes lab at the University of Saskatchewan or the Dymond lab at the University of Minnesota-Duluth; soil water samples will be analyzed at the McDonnell lab; tree water samples will undergo vacuum extraction and analysis at the McNamara lab at Boise State University. Data will be collected for at least one year post-harvest.

Project 4: Bioassessment Study

Project PI: Jim Harrington and Pete Ode (CDFW)

Project Collaborators: Salli Dymond (University of Minnesota-Duluth), CAL FIRE, PSW

Funding Sources: CAL FIRE ($155,327)

California is in the process of adopting ecological performance measures (EPMs) to evaluate resource management practices and support effective regulatory policies. Bioassessment protocols—one potential type of EPM associated with chemical, physical, and biological water quality monitoring—have been developed by the California Department of Fish and Wildlife (CDFW) and are overseen by the State Water Board's Surface Water Ambient Monitoring Program (SWAMP). Over the past decade, SWAMP has invested a considerable portion of its annual budget to develop standard bioassessment tools for measuring the health of streams based on the composition of invertebrate and algal communities that reside in them. SWAMP's bioassessment protocols are derived from a widely accepted nationwide US EPA program, and have been used as the standard method for evaluating stream health throughout California since 2000 (Ode et al., 2011). The objectives of this study are to:

1) Establish sampling sites within the South Fork Caspar Creek.

2) Sample the sites annually using SWAMP bioassessment procedures.

3) Summarize results for assessing the biotic response to the stand density reduction treatments.

This project will use the CDFW SWAMP protocol, which is a well-tested, standardized method for direct site assessment of channel, hydrologic, and geomorphic conditions, stream and riparian habitat type, water chemistry, and benthic macroinvertebrate and algal community composition. The sites will be assessed using the full SWAMP protocol and additional measures relevant to forestry such as riparian canopy cover, vegetation and species stand type will be included. All sample locations will be permanently monumented to help field crews locate the exact stream site for future monitoring events. Field sampling will be conducted by trained personnel from CAL FIRE and PSW. A strict QA/QC program will be used to train, calibrate, and audit the crew following SWAMP procedures. Biological and chemical samples will be processed by Aquatic Bioassessment Laboratory (ABL) staff using standard taxonomic procedures or an independent laboratory.

Sampling sites will be established at the base of three sub-watersheds in the South Fork Caspar Creek watershed near gauging stations POR, RIC, and SEQ (Figure 2). Sampling will take place on the mainstem downstream of the confluence, on the mainstem upstream of the confluence, and in the sub-watershed tributary upstream of the confluence. The 9 sites were sampled using SWAMP procedures in spring of 2016 and 2017 before timber harvest and will be sampled at the same time each year from 2018 through 2020. A report of findings will be completed before the 2021 sampling period to determine current conditions and whether additional sampling should occur.

Project 5: Distributed-Hydrology-Soil-Vegetation Model (DHSVM) Study

Project PI: Chris Surfleet (California Polytechnic State University-San Luis Obispo)

Project Collaborators: CAL FIRE, PSW

Funding Sources: CAL FIRE ($96,257)

The third Caspar Creek experiment will investigate how varying levels of forest stand density reduction influence watershed processes while utilizing current California Forest Practice Rules. These results can be compared with the first and second experiments to look at how the impacts of management have changed in conjunction with updated FPRs. However, because the third experiment is limited by a small number of treatment areas (sub-watersheds), only the combined effect of the updated FPRs can be tested as part of the experiment. Calibrating a hydrologic model for use at Caspar Creek will allow a multitude of questions about how timber harvesting and road construction influence streamflow and sediment at this site. Specific research questions for this study include:

1) Calibrate a hydrologic model for use at the Caspar Creek watersheds.
2) Determine, via modeling, how specific FPR requirements (e.g., riparian buffer width) influence water and sediment yield.

The Distributed Hydrology Soil Vegetation Model (DHSVM) will be used for the hydrologic modeling. DHSVM is a complex model, yet has an advantage over other models because it incorporates road networks and forest practices into sediment and streamflow predictions (Wigmosta et al., 1994). Calibrating and validating the model will be possible due to the long-term records available at Caspar Creek. Following calibration, streamflow and sedimentation at Caspar Creek will be simulated while changing model parameters, such as vegetation type and road standards (which will simulate logging and road best management practices, respectively).

Project 6: Sediment Fingerprinting Study

Project PIs: Jeff Hatten (Oregon State University)

Project Collaborators: Catalina Segura and Kevin Bladon (OSU), Salli Dymond (University of Minnesota-Duluth), Bob Danehy (Catchment Aquatic Ecology)

Funding Sources: CAL FIRE ($63,729)

Timber harvesting inherently affects the hydrologic regime of associated streams and rivers through decreased evapotranspiration and interception. The resultant change in frequency and/or magnitude of high flows (e.g., peak flows, storm flow volumes) affects the transport of suspended sediment in the watershed (Lewis et al., 2001). An increase in suspended sediment within the channel could have cascading effects on riparian functions. Identifying the source of sediment within a watershed will help managers identify whether or not sediment in the channel is coming from active timber operations, post-harvest erosion, or in-channel sediment resulting from an increase in scouring due to higher flows. This will help managers identify places to target improved management and BMPs. The specific goals of this study are to:

1) Determine the source of sediments in the sub-watersheds of South Fork Caspar Creek using geochemical fingerprinting techniques.
2) Investigate how different levels of stand density reduction influence the source of sediment in this stream system.

Sediment source fingerprinting techniques require that likely sources of sediment be known, and that the chemical characteristics can be measured and used to distinguish the sources (Stout and Belmont, 2011; Belmont, 2013). Source material samples will be collected from hillslopes, stream banks, and ephemeral channel soil, as well as sediment from the streambed and bars. Source materials will be identified, sampled, and their chemical characteristics determined. Soils will be collected from soil pits throughout the experimental area prior to timber harvesting. This was done in December 2016 prior to harvesting for all of the sub-watersheds. Fine sediment stored within the streambed will be collected using a freeze-core method approximately annually in order to examine the scouring/infilling cycle in relation to storms and time since harvest. Suspended sediment trapped in the filters used for processing water samples in the Arcata sediment lab will also be analyzed. Relatively large samples are needed for most of the source analyses, so a network of in situ time-integrating sediment samplers (Phillips Samplers) were also installed just downstream of the ZIE, WIL, UQL, and TRE stream gauges. Sediment from these samplers will be collected annually.

Project 7: Fine Sediment Study

Project PI: Ivan Arismendi (Oregon State University)

Project Collaborators: Salli Dymond (University of Minnesota-Duluth), Bob Danehy (Catchment Aquatic Ecology)

Funding Sources: NCASI ($50,000), CAL FIRE ($4,999)

A large body of evidence has shown that historical forest management practices substantially increased fine sediment delivery to streams. As a result, current forest management is designed to mitigate and minimize negative effects on riparian ecosystems. Sediment delivery to streams under contemporary forest practices are therefore very different than what was documented in past studies of historical management practices (Loehle et al, 2014). Little is known about the consistency of fine sediment transport among neighboring watersheds, leaving questions about how contemporary sediment transport in streams varies spatially and temporally. Watersheds with high natural variability of in-stream sediment transport under baseline conditions add to the difficulty in identifying the contribution of contemporary forest management practices to sediment rates. Moreover, simple descriptors of central tendency (e.g., mean and median) are inadequate to provide insights about the frequency, duration, or timing of extreme hydrological events that lead to changes in sediment transport. The detection of potential shifts in extreme hydrological events may be especially relevant to understand stressful conditions to salmonids.

The goal of this study is to apply novel descriptors of hydrological (fine suspended sediment and streamflow) events to suspended sediment data collected from the second and third experiments at the Caspar Creek Experimental Watersheds. The specific research objectives are to:

1) Evaluate and apply previously developed descriptors of fine suspended sediment regimes to the long-term datasets available from Caspar Creek (Diehl et al., 2010; Arismendi et al. 2013; Arismendi et al. 2015).
2) Contrast changes in hydrological events within sub-watersheds and between the South Fork and North Fork of Caspar Creek.
3) Evaluate the utility of these descriptors for analyzing streamflow datasets from Caspar Creek.

Specifically, we will evaluate and contrast forest management practices from the second experiment (1985-present) conducted in the North Fork with the third experiment in the South Fork by using two novel statistical techniques: the magnitude-magnitude plot and the magnitude-duration plot. We will also use post-harvest data from the South Fork Caspar Creek experiment to determine the effect of different harvest treatment intensities relative to background streamflow and sediment conditions. Streamflow and SSC data will be collected by PSW researchers and analyses for this study will be conducted by the PI.

Project 8: Erosional Consequences of Legacy Road Rehabilitation Study

Project PI: Liz Keppeler (PSW)

Project Collaborators: PSW, CAL FIRE

Funding Sources: PSW and CAL FIRE

The effects of legacy roads and skid trails on erosion and sediment production remain of critical concern to managers and regulators. Two previous watershed-scale experiments at the Caspar Creek Experimental Watersheds have contributed greatly to our understanding of watershed processes affecting sediment transport and water quality and have led to improved Forest Practice Rules in California and elsewhere. However, the trade-offs between short-term sediment "costs" of road rehabilitation and long-term benefits are not well-documented. The objective of this project is to assess the effects of the rehabilitation treatments in isolation from logging effects and compare them to the combined effects of rehabilitation preformed in conjunction with timber harvest. The specific questions to be addressed are:

1) What are the erosional consequences of road rehabilitation treatments done in the absence of timber harvest in comparison to coincident harvest and rehabilitation?

2) What is the duration of road rehabilitation effects on downstream water quality (SSC and turbidity) with and without additional timber harvest?

Rehabilitation work along 4 km of a mid-slope road (Road 605) constructed in the 1970s will consist of removing abandoned stream crossings and improvement of road drainage to dissipate surface runoff before it contributes to saturation and destabilization of hillslopes. Road rehabilitation work began in 2011 and will continue with harvest operations (Table 5). Measurements include establishment and annual monitoring of longitudinal profiles and multiple cross-sections at stream crossings and hillslope transects before and after treatment. In addition, these direct measurements of on-site disturbances and subsequent erosion will be compared to sediment loads measured at the downstream gauging stations. Annual survey measurements will be completed for a minimum of two years post-harvest and at less frequent intervals subsequently based on magnitude of response and peak flows.

Table 5. Timeline for the road rehabilitation treatments.

Watershed	Treatment	Date
YOC	Rehabilitation treatment only (no harvest)	2011
ZIE	Rehabilitation with delayed harvest	2011
WIL	none	NA
UQL	Rehabilitation treatment with harvest	2018

Project 9: Landslide Mapping Study

Project PI: Dave Longstreth (CGS)

Project Collaborators: CAL FIRE, PSW

Funding Sources: CGS

Equipped with modern georeferenced mapping techniques, CGS will map landslide geomorphology within the 424 ha (1048 acre) South Fork Caspar Creek experimental watershed, and the 473 ha (1169 acre) North Fork watershed. The field based landslide mapping will utilize the 2004 georeferenced LiDAR, iPad, GPS, and multiple sets of historic aerial photographs. Previous landslide data accuracy and detail will be revised as needed. The georeferenced landslide information will provide updated landslide information that can be used by CAL FIRE JDSF staff in THP preparation and by researchers conducting the third experiment in the South Fork Caspar Creek watershed.

The georeferenced landslide information will provide:

1) A dynamic geologic and landslide features map based on ArcGIS that will be able to be updated and added to over time, so as to accurately capture existing landslide features and locations as they are recorded.
2) A comparison of previous landslide mapping efforts versus georeferenced mapping (GPS, ArcGIS, LiDAR) techniques conducted during this mapping exercise.
3) An updated detailed geographic context for erosion and/or landslide causal relationships that may be observed during the new South Fork Caspar Creek experiment.

Critical Questions:

- Can georeferenced-based landslide mapping provide a more accurate and detailed representation of landslide and erosion geomorphological features compared to more conventional mapping techniques (areal photographic interpretation)?
- Can a dynamic map contain updated geologic information of the Caspar Creek watershed over time?
- Based on observations conducted during the South Fork experiment, is a dynamic and georeferenced landslide map useful and more accurate in determining causal relationships between landsliding and erosion versus logging operations?
- Would this sort of information be useful in better understanding the effectiveness of the California Forest Practice Rules in reducing anthropogenic-related erosion and sediment production?

Project 10: Nutrient Cycling and Transport Study

Project PI: Helen Dahlke (UC Davis)

Project Collaborators: Randy Dahlgren (UC Davis), CAL FIRE, PSW

Funding Sources: CAL FIRE ($100,000), Board of Forestry and Fire Protection ($92,251), Save the Redwoods League ($24,939)

The goal of this research is to examine changes in the mass balance of major nutrients (C, N, P) and base cations/anions across the main functional watershed units (e.g. whole watershed vs. sub-watershed vs. instream) within the South Fork watershed of Caspar Creek in response to the stand density reductions. We hypothesize that stand density reduction will increase export of total N, total P, NO3–, and particulate/dissolved organic C from the treated watersheds immediately following the forest harvest, with greater impacts observed with greater stand density reduction. We hypothesize that the increased hydrologic connectivity associated with macropore flow and fast subsurface stormflow above the clay-rich, argillic soil horizon promote rapid flow pathways for storm flow and nutrient transport from hillslopes to streams. We hypothesize that the increased NO3–-export from the disturbed hillslopes will be offset by increased riparian zone and instream autotrophic and biogeochemical activity (e.g., denitrification and benthic assimilation), in particular, along stream segments that receive more light as a result of the upland forest thinning. The proposed research attempts to address these hypotheses through the following specific objectives:

1) Determine the changes in stream water and soil water solute concentrations and nutrient fluxes during storm flow and baseflow conditions prior- and post-harvest in the South Fork Caspar Creek watershed.
2) Compare nutrient cycling within harvested and reference watersheds.
3) Identify hydrological or biogeochemical mechanisms that explain the observed patterns along the hydrologic continuum: watershed-hillslope-riparian zone-instream/hyporheic.

Project 11: Unsaturated Zone Moisture Dynamics Study

Project PI: Jesse Halm (UC Berkeley)

Project Collaborators: Daniella Rempe (University of Texas, Austin), David Dralle (UC Berkeley), William Dietrich (UC Berkeley), CAL FIRE, PSW

Funding Sources: UC Berkeley

In Mediterranean climates, trees rely on occult precipitation (including fog) and stored subsurface water to sustain transpiration in the dry summer growing season. In many upland landscapes, mobile near surface soils are typically thin (< 1 m) and are underlain by a variably thick weathered saprolite and rock zone that can extend tens of meters below the ground surface (Rempe and Dietrich 2014, Riebe et al. 2017). Recent research at the Angelo Coast Range Reserve (40 km NNE of Caspar Creek), part of the Eel River Critical Zone Observatory, has revealed that up to ~1/4 of the annual water budget is stored and released as rock moisture, i.e., seasonally dynamic water stored in the unsaturated zone below the soil within saprolite and weathered rock. This rock moisture has an average seasonal change of ~280 mm across the landscape (Rempe and Dietrich in revision, Salve et al. 2012) and is almost entirely depleted by growing season tree transpiration rather than drainage to groundwater and stream runoff. Dry season rock moisture storage deficits are replenished annually by initial wet season rains, typically from the top down following a progressive wetting front. Replenished rock moisture exhibits field-capacity-like behavior, where additional wet season rains trigger drainage under gravity to groundwater without resulting in extra unsaturated zone storage (Rempe and Dietrich in revision). These findings demonstrate that rock moisture is expected to be an important regulator of plant available water and runoff in many upland landscapes. However, its magnitude and dynamics are generally unknown because the rock moisture zone is largely unmapped due to its relative inaccessibility. Where deep boreholes that extend below the soil are available, rock moisture dynamics can be quantified via repeat down-well neutron probe surveys.

The 2018 harvest treatment within the gauged sub-watersheds of South Fork Caspar Creek offers a unique opportunity to separate biotic (i.e. trees) and abiotic (e.g. drainage) controls on rock moisture dynamics. We hypothesize that, relative to forested areas, cleared areas will show shallower changes in water content, and within the weathered bedrock region, the magnitude of water content changes will be smaller. We also hypothesize that the lack of deep rock moisture dynamics will lead to a more rapid runoff response to winter rainfall relative to pre-treatment conditions. To evaluate these hypotheses, we will drill ~ 6 deep boreholes to 10 m depth at the ZIE (Ziemer) catchment of the South Fork, where nominally 75% of the stem basal area will be harvested and we will use those boreholes to monitor rock moisture using downhole nuclear gauges. These holes will be located nearby existing monitoring infrastructure (see Project 2) to link rock moisture dynamics with soil moisture, sapflow, and groundwater levels. Most holes will be situated within areas with negligible tree stem basal area.

Identifying the role of deep moisture dynamics on runoff generation: To investigate how the weathered bedrock beneath the soil influences runoff generation, an existing set of deep piezometers at the M1 swale of the North Fork (Brown 1995), located in a ~135 year old mixed coast redwood-Douglas-fir forest, will be retained as a control. Our specific hypotheses for these wells is that the trees within the M1 swale will use rock moisture throughout the unsaturated zone in the summer, that rock moisture constitutes a significant fraction of dry season water flux out of the swale, and that depleted rock moisture must be replenished prior to significant catchment runoff in the wet season. To test these hypotheses, we will measure water content profiles over time in existing piezometers, and where necessary, new monitoring wells.

Down-borehole neutron probe surveys will be performed roughly every two months at the forested M1 site and the manipulated ZIE site over two water years. By pairing the water content profiles over time with rainfall and runoff from preexisting precipitation collectors and stream gauges, the role of vegetation in mediating rock moisture dynamics and runoff response should become clear.

The results of this study will complement ongoing work that seeks to identify when and from where in the subsurface trees within the watershed obtain water (Dymond et al. 2017). Our activities will also further the larger scientific objectives of the third experiment, including water storage and runoff regulation in the Caspar Creek Watershed described in this plan and longstanding questions surrounding the effects of logging on watershed processes (Keppeler 1998, Keppeler and Brown 1998).

Other Studies

The third experiment at Caspar Creek presents a unique opportunity to investigate the relationship between stand density reduction and watershed/ecosystem processes. Additional project proposals will be reviewed by CAL FIRE and PSW on an ongoing basis (Appendix A). We aim for an intensive and comprehensive third experiment and an open, inclusive, and collaborative working group. A silviculture demonstration area has been established on the north side of the watershed that will explore variations in spatial distribution of harvest trees.

Project Timeline

Planning for this experiment began in 2000 in conjunction with the installation of 10 sub-watershed gauging stations Baseline channel profile surveys, erosion inventories, and geomorphic mapping occurred between 2001 and 2018. Pre-treatment surveys of legacy roads and site monitoring began in 2010 with initial treatments accomplished in 2011. Pre-harvest surveys and forest inventories occurred in 2015 and 2016. Project details were developed between 2015 and 2018. Harvesting in the matrix began in spring 2017, with harvest operations in the gauged sub-watersheds scheduled for 2018 (Table 6).

Partnership and Collaboration

The third experiment will provide excellent opportunities to collaborate with government agencies, non-governmental organizations (NGOs), and academic institutions (see Appendix B for a list of current collaborators/contributors to the experiment). Projects that add to the breadth of research collected at Caspar Creek that are able to fit into the current framework and provide their own funding of the third experiment will be welcome. Potential ancillary research ideas include (but are not limited to) carbon, soil fungi, biogeochemistry, aquatic and terrestrial habitat and wildlife species responses, non-commercial plant species responses, and growth and yield modeling.

QA/QC and Data Repository

The objective of quality assurance and control (QA/QC) for all Caspar Creek data is to reduce sources of error from the time of initial data collection, through data processing, and ending in the addition of data to the final data repository. Steps will be taken to (1) provide ongoing training to staff so that data collection and processing are performed in a standardized way, (2) ensure routine backup of all data to at least two locations, (3) perform audits to ensure the completeness of data, (4) provide metadata to document data entry and processing procedures, and (5) regularly calibrate and maintain equipment. Documents detailing QA/QC procedures will be developed in cooperation with the principle investigators. Collected data will be made public after undergoing QA/QC and results have been disseminated via academic publications.

Table 6. Timeline for management operations for the third experiment at Caspar Creek.

Objective	Responsible Agency	Est. Start Date	Est. End Date
Updated forest inventory	CAL FIRE	June 2015	June 2016
Assign treatment watersheds	PSW	July 2015	July 2015
Timber harvesting plan	CAL FIRE/PSW	July 2015	September 2016
Northern Spotted Owl survey	CAL FIRE	August 2015	August 2017
Marbled Murrelet survey	CAL FIRE	August 2015	August 2017
Botany survey	CAL FIRE	August 2015	August 2016
JDSF-RC* presentation	CAL FIRE/PSW	Nov. 9, 2015	Nov. 9, 2015
JAG** presentation	CAL FIRE/PSW	Nov. 16, 2015	Nov. 16, 2015
Timber sale bids	CAL FIRE	Winter 2016	January 2017
Road building	CAL FIRE	Spring 2017	Fall 2018
Road decommissioning	CAL FIRE	Summer 2011	Fall 2018
Timber Harvest	CAL FIRE	Spring 2017	Fall 2018

*Jackson Demonstration State Forest Research Committee
**Jackson Advisory Group

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APPENDIX A. Example of informational needs for potential research projects to be conducted as part of the third experiment at Caspar Creek. Official approval requires consent from PSW and CAL FIRE.

Project Title:	Name of the research project
Project PI:	List the principle investigator(s) as well as affiliation
Collaborators:	List any collaborators as well as their affiliations
Justification:	Briefly describe the justification for this research project (1-2 sentences)
Objectives:	Briefly describe the objectives of the research
Methods:	Give a brief overview of the methods used to achieve your objectives. A more detailed study plan will be required before project implementation.
Budget:	List the basic budget requirements for this project (does not need to be exact).
Timeline:	Detail the project timeline. Note the timeline for timber harvesting (Table 6).
Funding:	Please provide the funding agency for any financial support that you have secured or are planning to secure for this project.
Personnel:	List any additional personnel that will be assisting with this project (field/laboratory assistance, data analysis, etc.), as well as their affiliation.
Outcomes:	Indicate the anticipated outcomes of the project.

APPENDIX B. List of persons affiliated with discussions, planning, and research of the third experiment at Caspar Creek.

USDA FS-PSW: Leslie Reid (emerita), Liz Keppeler, Diane Sutherland, Jayme Seehafer, Brian Storms, Jim Baldwin, Matt Busse, Megan Arnold, Jack Lewis (retired), Tom Lisle (retired), Sue Hilton (retired)

CAL FIRE: Lynn Webb, Pete Cafferata, Pam Linstedt (retired), Drew Coe, Kirk O'Dwyer, Dennis Hall, Helge Eng, Brian Barrett (retired), Gwendolyn Ozard, Christopher Rowney (retired), Dave Loveless (retired), Gabriel Schultz

University of Minnesota, Duluth: Salli Dymond

UC Berkeley: Kevin O'Hara, Todd Dawson, Bill Dietrich, Jesse Halm

UC Davis: Helen Dahlke, Randy Dahlgren, Seanna McLaughlin

Oregon State University: Kevin Bladon, Jeff Hatten, Catalina Segura, Ivan Arismendi, Chris Still

University of Saskatchewan: Jeff McDonnell

California Polytechnic State University: Sarah Bisbing, Chris Surfleet

National Council for Air and Stream Improvement: Bob Danehy (currently Catchment Aquatic Hydrology)

CA Department of Fish and Wildlife: Jim Harrington, Pete Ode, Brad Valentine (retired)

CA Geological Survey: Dave Longstreth

Green Diamond Resource Company: Matt House

Colorado State University: Lee MacDonald

Campbell Global: Kevin Faucher (currently USFS)

Humboldt Redwood Company: Mike Miles, Nick Harrison (currently National Ecological Observatory Network--NEON)

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