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Effects of forest stand density reduction on nutrient transport at the Caspar Creek Watershed

Progress report on Grant #124

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1 Introduction

1.1 Caspar Creek Experimental Watershed

The Caspar Creek Experimental Watershed, located in the Jackson Demonstration State Forest, has been continuously studied since its establishment in 1962 as a collaboration between the California Department of Forestry and Fire Protection (CAL FIRE) and the U.S. Forest Service Pacific Southwest Research Station (PSW). The Caspar Creek Experimental Watershed has conducted thus far, two long-term research experiments. The primary goal of the first two experiments (1962-85, 1985-present) was to understand the effect of timber harvest on streamflow and suspended sediment concentrations in coastal-forested watersheds. The first experiment was set up as a classic paired watershed study. Cumulative effects (e.g. sediment, discharge) of removing 60-70% of the timber stand volume were studied in South Fork Caspar Creek and compared to the North Fork Caspar Creek watershed, which served as control. In the second experiment (1985-present) modern California Forest Practice Rules (FPRs) were tested in different sub-watersheds of the North Fork Caspar Creek and effects were compared among the different sub-watersheds.

In 2016, the PSW's postdoctoral Research Hydrologist Dr. Salli Dymond designed a third experiment with the goal to expand upon the findings of the first two experiments to investigate the effect that different reductions in stand density (e.g. reduction in the quantity of trees) might have on the interconnected hydrological, geomorphic, and ecological processes in coastal redwood forests (Dymond 2016). To improve this understanding several research projects were set up that study these processes at the tree, plot, hillslope, sub-catchment and catchment scale. Table 1 shows the proposed stand reductions in the sub-watersheds of South Fork Caspar Creek. Most of the research is focused on four sub-watersheds, which will be harvested beginning in June 2018. The WIL watershed will serve as a control (0% vegetation removal), the TRE watershed will demonstrate a light harvest (35% reduction in stand density), the UQL watershed is a moderate harvest (55% reduction) and the ZIE watershed represents a high harvest (75% reduction).

1.2 Background

The current report is a summary of our findings related to pre-harvest geochemical sampling of the Caspar Creek watershed. Additional funding for the nutrient study is being provided by CAL FIRE, and the State Board of Forestry and Fire Protection's Effectiveness Monitoring Committee (EMC), and will cover the post-harvest sampling and analysis of the proposed research. Post-harvest data and findings will be addressed in the second half of this report, when treatments are completed.

Table 1. South Fork Caspar Creek sub-watershed names and planned treatments.

Sub-watershed name	Sub-watershed ID	Treatment (% Leaf area reduction)
South Fork Caspar Creek	**SFC***	TBD
Quetelet	QUE	TBD
Richards	RIC	0
Yocom	YOC	47
Williams	**WIL***	0
Ogilvie	OGI	45
Treat	**TRE***	35
Porter	POR	25
Uqlidisi	**UQL***	55
Sequoyah	SEQ	65
Ziemer	**ZIE***	75

* Sub-watershed outlets intensively monitored for streamwater chemistry analysis.

Since summer 2016, monthly baseflow samples and more frequent winter stormwater samples have been collected at the outlet of the four sub-watersheds and the outlet of South Fork Caspar Creek to understand baseline conditions in flow and nutrient export from these watersheds. The baseline samples will be used to characterize the flow regime and biogeochemistry of Caspar Creek at near-pristine conditions and to evaluate whether all sub-watersheds behave hydrologically and biogeochemically in a similar manner. This catchment comparison ensures that observed differences in the flow regime and nutrient export from the sub-watersheds subject to stand reductions are due to the treatment and not the watershed characteristics themselves.

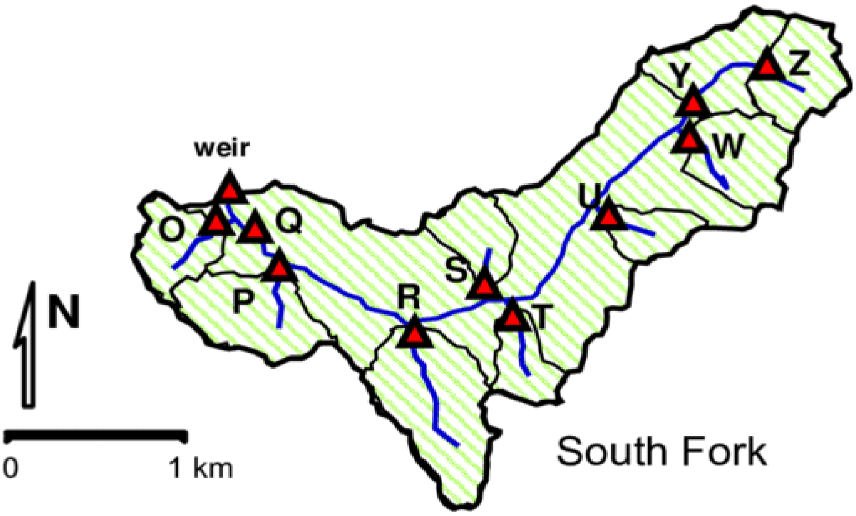


Figure 1. Study sites are located in a subset of gauged sub-watersheds in the South Fork Caspar Creek watershed.

2 Research objectives

The goal of this research proposal 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-watersheds) of South Fork Caspar Creek watershed in response to different stand density reductions. The hypothesis of the project is that stand density reduction will increase export of total N, total P, NO_3^-, and particulate/dissolved organic C from the treated watersheds immediately following the forest harvest, with greater impacts observed with greater stand density reduction. The hypothesis is 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. The proposed research attempted to address this hypothesis 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 export between harvested and reference watersheds.

2.1 Changes to project timeline and objectives

Harvest treatments according to original project timeline were expected to take place during the spring and summer of 2017, and analysis of postharvest geochemistry to take place during fall 2017 and winter 2018 (and continue as funding allows). The harvesting logistics have been a cooperation between CAL FIRE and the US Forest Service staff, as well as contracted loggers. The logging at Caspar Creek has taken longer than anticipated due to contracting and permitting matters in addition to shifting of schedules due to the weather-dependent nature of forest harvesting activities. To avoid erosion, the ground had to be sufficiently dry in order for logging to take place which coincided in 2017 and 2018 with the start of the fire season in California. Priorities of agency staff have consequently been directed toward the many wildfires that have occurred in the area during spring/summer of 2017 and 2018. Fire response has taken precedence over some of the planned harvesting in Caspar Creek (Liz Keppler, USFS pers. Communication). Timber market prices, limitations on available loggers, and a yearly mandatory survey for spotted owls in this area have all impacted the initial project timeline.

As such, the delay in harvest has impacted the proposed research. Sampling of post-harvest streamwater chemistry in the paired watersheds was not conducted. Instead, the delay in harvest provided us with an additional year of pre-harvest sampling. The ability to compare pre and post-harvest nutrient export is dependent upon the pre-disturbance system being well characterized. The additional accumulation of baseline water chemistry samples has provided us with a better understanding of the pre-harvest conditions, and even more certainty in the normal ranges of ion and nutrient concentrations and fluxes that are characteristic of the South Fork of Caspar Creek.

In summer 2017 matrix harvest of trees started in the SouthFork Caspar Creek watershed in the area surrounding the subwatersheds of interest in this study. The matrix harvest consisted mainly of a thinning of the trees. This harvest is a routine management practice, designed to reduce tree density to maintain forest health. The matrix harvest was not intended or expected to affect the stream water chemistry in any of the subwatersheds to any significant degree, as it was conducted around the entire South Fork study area. Documentation of the location based timeline of the matrix harvest, as well as the ongoing harvest treatments are kept by CAL FIRE staff. Currently this documentation is in the process of being digitized and will eventually be available as GPS data.

3 Methods and Materials

3.1 Study Site and Experimental Design

3.1.1 Study Site

The Caspar Creek experimental watershed is located in coastal northern California in the Jackson Demonstration State Forest, at approximately 39° 21' N, 123° 44' W. The watershed is located approximately 7 km from the Pacific Coast and approximately 14 km southeast of Fort Bragg, CA (Henry 1998). The Caspar Creek watershed has a total drainage area of 2,167 ha, of which 897 ha are included in the experimental watershed study area (Henry 1998). The study area contains two main drainage basins, the North Fork and the South Fork of Caspar Creek, with basin areas of 473 ha and 424 ha respectively (Dymond, 2016). The North Fork drainage basin is divided into thirteen sub-watersheds ranging in individual drainage areas from 10 ha to 384 ha. Within the South Fork of Caspar Creek, there are 10 sub-watersheds, which range in drainage area from 13 ha to 394 ha (Table 2). The South and North Forks drain into the main branch of Caspar Creek, which, from their confluence point, flows northeast and empties into the Pacific Ocean.

Table 2. Physical characteristics of South Fork sub-watersheds.

Sub-watershed ID	% Reduction	Area (ha)	Average slope (%)	Elevation range (m)	Dominant soil subgroups
SFC*	TBD	424	60	46-329	Ultic hapludalf
QUE	TBD	394.3	50	48-329	Mollic/Ultic hapludalf
RIC	0	48.8	42	73-198	Mollic/Ultic hapludalf
YOC	47	52.9	48	146-329	Typic haplohumult
WIL*	0	26.5	51	146-323	Typic haplohumult
OGI	25	18.3	26	58-174	Mollic/Ultic hapludalf
TRE*	35	14.1	47	98-244	Mollic/Ultic hapludalf
POR	45	31.7	34	61-186	Ultic hapludalf
UQL*	55	12.5	49	122-323	Typic haplohumult
SEQ	65	16.8	38	79-207	Ultic hapludalf
ZIE*	75	25.3	43	213-329	Typic haplohumult

*Sub-watershed outlets intensively monitored for streamwater chemistry analysis.

The Caspar Creek watershed lies within the Jackson Demonstration State forest (JSDF) in Mendocino County. JSDF is the largest (19,689 ha) of eight demonstration forests in the state, and is managed and operated by CAL FIRE. The main land use in JSDF is the growth and harvest of timber, revenue from which goes to fund a variety of the Department's Resource Management programs, while providing research and demonstration opportunities in natural resource management, which include wildlife habitat and watershed protection and restoration. The forest stands in the South Fork of Caspar Creek were approximately 95 years old when they were last harvested during the First Experiment at Caspar Creek. Harvest began with the eastern portion of the South Fork in 1971, and the final northwestern portion was completed in 1973. During this experiment, all ten sub-watersheds in the South Fork were harvested, with stand volume reduction ranging from 60-70%. Results from the First Experiment have been reported by Rice et al. (1979) and Ziemer (1998).

Forest vegetation in Caspar Creek is dominated by coast redwood (*Sequoia sempervirens* (D. Don) Endl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), with some associated grand fir (*Abies grandis* (Doug. ex D. Don) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and minor amounts of hardwoods, including tanoak (*Lithocarpus densiflorus* (Fook. and Arn. Rohn) and red alder (*Alnus rubus* Bong.). The understory vegetation is comprised of evergreen huckleberry (*Vaccinum ovatum* Pursh), Pacific rhododendron (*Rhododendron macrophyllum* D. Don), and sword fern (*Polystichum munitum* (Kaulf.) Presl.) (Henry 1998).

The northwest Pacific Coast of California has a Mediterranean climate regime, characterized by mild, moist winters of low-intensity rainfall. Summers are typically cool and dry, with coastal fog frequently observed, which can have a significant contribution to the total annual precipitation in some coastal redwood forest ecosystems in the form of fog drip (Burgess and Dawson 2004). This has not, however, been shown to be the case for the Caspar Creek watershed (Keppeler 2007). Normal daily temperatures typically range from 5 to 14°C in the winter and 10 to 25°C during the summer (Dahlgren 1998). Between 1990-1995, minimum average temperature was 6.7°C in December and maximum average temperature was 15.6°C during July (Henry 1998). From 2001-2016, mean annual precipitation was approximately 1190 mm, about 90% of which occurs between the months of October through April.

Elevation in the South Fork of Caspar Creek ranges from 46 to 329 m, with average sub-watershed slopes ranging from about 26 to 50%. In certain areas within the watershed, slopes can reach an excess of 65% (Dymond 2016). The geomorphology of this coastal system consists of uplifted marine terraces, which have been significantly incised by stream processes (Henry 1998). The soils in the Caspar Creek watershed are predominantly Alfisols and Ultisols, which have been derived from residuum of Franciscan sandstone and Cretaceous Age shale (Henry 1998). Soils in the watershed have been found to consistently exhibit thick argillic horizons, which are suspected to influence hydrologic processes occurring in response to storm events, specifically subsurface lateral flow (Dahlgren 1998). Dominant soil subgroups are identified in Table 2.

3.1.2 Experimental Watersheds – Third Experiment

The study area for the Third Experiment is located in the South Fork of Caspar Creek. The entire South Fork watershed is divided into ten sub-watersheds, each of which has a direct outlet to the main stem of the South Fork (Figure 1). In 2000, each of the sub-watershed outlets was instrumented with a gaging station to monitor streamflow in preparation for the Third Experiment. Since the spring of 2016, all of the ten sub-watersheds have been sampled for water chemistry baseline analysis. Since initial streamwater sampling began, four of these ten sub-watersheds (TRE, UQL, WIL, and ZIE) have been more intensively sampled, and will be the primary focus of the streamwater chemistry study over the course of the Third Experiment.

3.1.3 Treatments

Two of the ten South Fork sub-watersheds have been designated as long-term reference watersheds (WIL and RIC) and will not receive a harvest treatment. Seven other sub-watersheds have been assigned harvest treatments ranging from 25% to 75% reduction in leaf area (Table 1). Forest managers typically prescribe stand harvest intensity based on basal area (the surface area of stems at a height of 4.5 feet above ground per unit ground area), as opposed to overstory density (leaf area), partially due to the difficulty of obtaining leaf area measurements. However, leaf-area-index (LAI) plays a large role when examining regrowth processes in coast redwood ecosystems due to stump resprouting (O'Hara and Berril 2010). Therefore, for the purpose of examining forest response to stand reduction, harvest reductions percentages will be calculated by leaf area index (the ratio of leaf area per unit of ground area) in the Third Experiment. Harvesting of the matrix area (i.e. remaining area surrounding the sub-watersheds in South Fork Caspar Creek) began in the summer of 2017, and harvest treatments of the seven sub-watersheds began in June of 2018. Harvest treatments and corresponding sub-watersheds are summarized in Table 1.

3.1.4 Paired Watershed Study Design

Paired watersheds have been widely used in hydrological and biogeochemical research to study long-term trends in forested systems (Hornbeck 1973, King 2008, Dahlgren 1994). This is partly due to the time it takes for forest stands to return to pre-treatment conditions, as well as difficulties in attributing effects to treatments as opposed to other time-dependent variables. The paired watershed design has been employed in both long-term experiments previously conducted at Caspar Creek (First and Second Experiments). The Third Experiment will also employ a paired watershed design, aiming to compare treatment effects between sub-watersheds in the South Fork. In order to employ the effective use of the paired watershed design, the ten South Fork sub-watersheds have been assessed in terms of their physical, hydrologic, and streamwater chemical characteristics. The four sub-watersheds that will provide the majority of the water chemistry data (TRE, UQL, WIL and ZIE) are being closely monitored in order to validate this study design. Qualitative assessments of drainage area, watershed slope, topography, soil characteristics, and riparian zone characteristics will form the basis for sub-watershed compatibility. Climate and precipitation parameters have been assumed to be identical among South Fork sub-watersheds.

3.2 Data Collection and Analysis

3.2.1 Soils

Soil data for the initial soil assessment of South Fork watershed was obtained from the USDA-NRCS Web Soil Survey using the South Fork watershed boundary file provided by the Caspar Creek Experimental Watersheds project staff. Field soil sampling is planned to be conducted by the Sediment Fingerprinting Study lead by Jeff Hatten (Oregon State University).

3.2.2 Hydrology and Water Chemistry

The outlet of the South Fork main stem is equipped with a compound weir with a 120° v-notch for weir stages up to 2 feet, and a 20-foot rectangular weir for stages above 2 feet. Turbidity is recorded at the South Fork weir using an FTS DTS-12 temperature/turbidity sensor. All subcatchment outlets are equipped with Montana flumes, and turbidity is recorded using Campbell Scientific OBS-3 turbidity sensors. Stage is measured at all flume and weir locations with Campbell Scientific pressure transducers. Stage and turbidity are recorded on a 10-minute interval. Stage is converted to discharge from a developed, site-specific stage-discharge relationship. Streamwater samples are collected by ISCO 6712 automated samplers, as well as by PSW Caspar Creek staff, who manually collect grab samples during storm events. All samples are collected mid-stream where sufficient mixing is assumed to occur. Following streamwater sample collection, samples are shipped from Caspar Creek to UC Davis for laboratory analysis. The samples are shipped in insulated packaging and upon arrival, are stored below 4°C until analysis. Sub-samples are vacuum filtered through a 0.2-micron pore diameter membrane filter prior to analysis of pH, electric conductivity (EC) and dissolved nutrients. pH and EC are each measured potentiometrically using a combination electrode. Anion concentrations (Cl^- and SO_4^-) and cation concentrations (K^+ and Na^+) are determined by ion chromatography using a Dionex ICS-2000 Ion Chromatograph. Orthophosphate, or "dissolved reactive phosphorous" (DRP), which includes PO_4-P plus any other compounds that might give PO_4-P during reaction conditions or react as PO_4-P, are determined using the 1 Phosphomolybdate blue/ascorbic acid method. Mg and Ca cation concentrations are determined using atomic absorption spectroscopy, with a Perkin Elmer AAnalyst 800 Spectrometer. Total dissolved nitrogen (TDN), dissolved organic nitrogen (DON), nitrate plus nitrite nitrogen (NO_3+NO_2-N) and ammonium (NH_4-N) are measured using spectrophotometric determination.

Since January 2018, analysis of dissolved cations, including calcium, magnesium, potassium, and sodium have been conducted using two different methods of analysis to verify concentrations, and determine the accuracy of each method. Ion chromatography has been compared with atomic absorption and emission spectroscopy. Calcium and magnesium have been shown to be most accurate via atomic absorption, while sodium and potassium are most accurate via atomic emission techniques.

All nutrient loads (e.g., NO_3^-) were calculated by first multiplying the analyte concentration with the measured water volume for each individual sample. The water volume associated with each sample was determined using the midpoint approach (the temporal midpoint between each sample was determined, and the water volume for that time period was determined by multiplying discharge by time-step, and summing over the time duration for each sample). The nutrient load for each sample is assumed to be representative over this time duration.

Nutrient loads have been calculated for storm events during the 2017 hydrologic year (HY2017). The hydrologic year for the Caspar Creek watershed begins August 1st 2016 and ends July 31st 2017, as opposed to the USGS designated water year (Oct. 1st-Sept. 30th). Annual nutrient fluxes have been calculated for both HY2017 and the 2018 hydrologic year (HY2018), which begins August 1st 2017 and will end July 31st 2018. Storm events for 2016-2017, and year-to-date 2017-2018 were identified from the discharge hydrograph where discharge and corresponding precipitation reached a relative minimum. Currently, our analysis has not defined a specific discharge threshold to define a storm event based on present hydrologic data. However, Caspar Creek Experimental Watershed Staff have typically used an index value of a stage greater-than or equal-to 2 feet at the South Fork weir to constitute a storm event.

3.2.3 Statistical Analyses

In order to validate the paired watershed design, King et al. (2008) has identified four criteria for paired watershed validation, each of which will be considered in this study. These criteria include (1) similar physical characteristics between paired watersheds including drainage area, slope and soil characteristics (Downes et al. 2002), (2) moderate correlations between response variables (i.e., 0.6 or greater) between paired watersheds (Loftis et al. 2001), (3) lack of temporal trend differences between treatment and reference watersheds prior to treatments (Stewart-Oaten and Murdoch 1986), and (4) demonstration of minimal effect sizes needed to observe a significant change between reference and treatment watersheds (Clausen and Spooner 1993).

Four statistical data analysis approaches will be used to validate these four criteria in this study. First, similarity in physical characteristics between watersheds will be compared by calculating the total or mean of each response variable (drainage area, slope and soil characteristics). Secondly, simple linear regression analysis will be employed for a subset of water chemistry and hydrologic (stream discharge) variables to determine the degree of correlation present between watersheds. Third, temporal trends between watersheds will be analyzed using the Daniels Test for Trend (Conover 1999). Lastly, minimum percent change required to detect significant differences in hydrology and water chemistry will be determined using Analysis of Covariance (ANCOVA) for data acquired before and after treatments are applied.

4 Results and Discussion

4.1 Sub-watershed comparison

Thus far, qualitative assessment between the South Fork sub-watersheds suggests that the sub-watersheds are moderately well correlated in terms of slope and soil characteristics. Table 3 shows the percent difference in watershed slopes between each treatment sub-watershed and each control (0% harvest) sub-watershed. Two sub-watersheds (OGI and POR) exceed a 25% difference in mean slope as compared to the WIL sub-watershed. One sub-watershed (OGI) exceeds a 25% difference in mean slope as compared with the other control watershed (RIC). All other comparisons of mean sub-watershed slope indicate a high degree of similarity, with percent differences less than 25%.

Table 3. Percent differences in slope between treatment sub-watersheds compared with reference watersheds.

Sub-watershed ID	Reduction %	Average slope (%)	% difference to WIL	% difference to RIC
SFC*	TBD	60	18.0	43.3
QUE	TBD	50	1.4	19.7
RIC	0	42	17.6	0.0
WIL*	0	51	0.0	21.4
OGI	25	26	47.9	36.8
TRE*	35	47	7.9	11.8
POR	45	34	32.3	17.8
UQL*	55	49	4.0	16.6
SEQ	65	38	25.0	8.9
ZIE*	75	43	14.9	3.4

* Sub-watershed outlets intensively monitored for streamwater chemistry analysis.

Soil characteristics are similar between all sub-watersheds, at the subgroup level, and are listed in Table 2. Soil data from the NRCS Web Soil Survey indicate that there are nine major soil units mapped in the South Fork watershed area. Of these nine soil units, the Dehaven-Hotel complex, the Irmulco-Tramway complex, and the Vandamme loam cover about 35.6%, 31.3% and 19.1% respectively. Figure 2 shows the soil map units and their distribution within the South Fork watershed, which is largely uniform and slope dependent.

Vegetation and aerial extent of the riparian zones in each sub-watershed have yet to be evaluated quantitatively, but a combination of GIS based analysis, and/or collaboration with other Third

Experiment research teams is anticipated. The California Department of Fish and Wildlife (DFW) Bioassessment Study has set up sampling sites within the South Fork to implement the State Water Board's Surface Water Ambient Monitoring Program (SWAMP). The SWAMP bioassessment protocol includes evaluation of riparian vegetation and habitat, macroinvertebrates, and water chemistry in late spring/early summer. Field sampling has occurred in 2016, 2017, and 2018, and will continue for two more years. Sampling sites are immediately above and below POR, RIC, and SEQ, as well as within the three tributaries. Results from 2016 macroinvertebrate data indicate that all sites were remarkably similar, with consistently high biological metric scores (J. Harrington, DFW, personal communication).

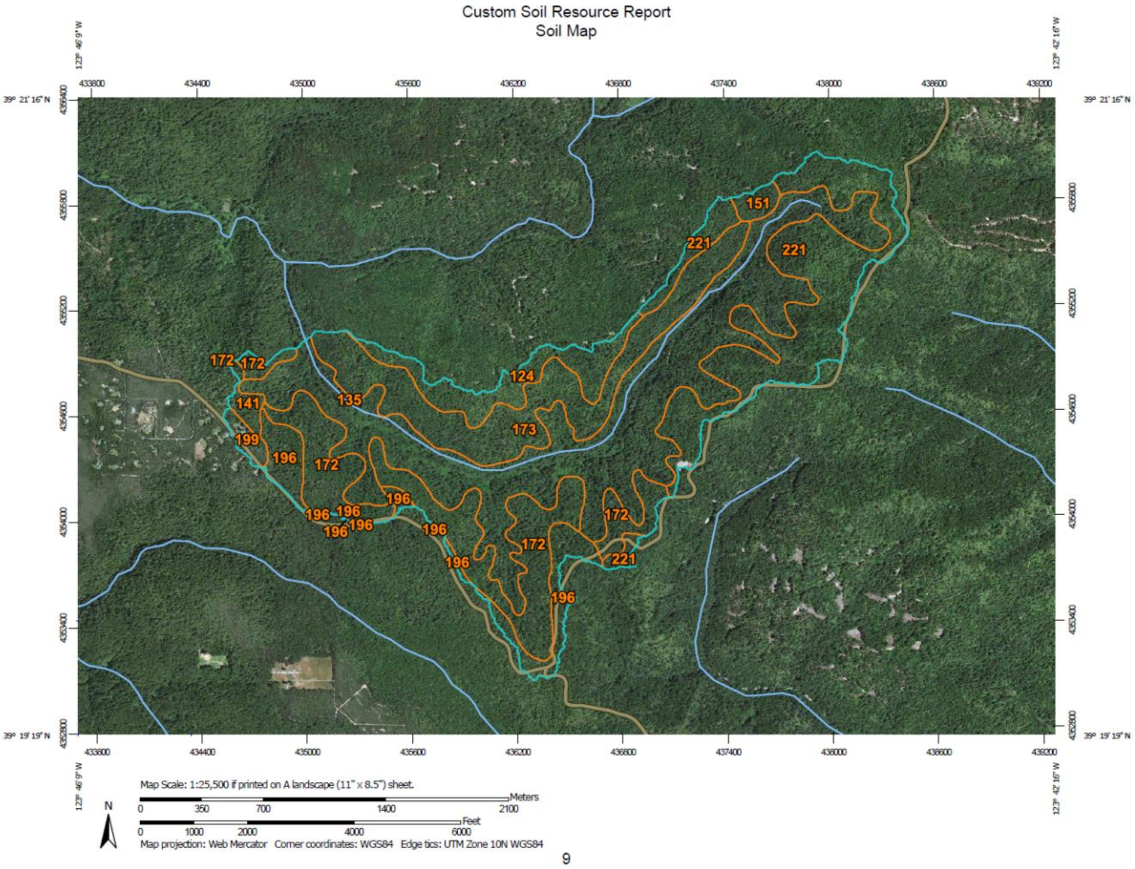


Figure 2. Soil map units within South Fork Caspar Creek watershed. Dominant map units include 135: Dehaven-Hotel complex, 172/173: Irmulco-Tramway complex, and 221: Vandamme loam.

4.2 Hydrology

Stream discharge, precipitation and antecedent moisture conditions have been analyzed for the entire monitoring period (May 2016-May 2018) and selected periods of interest including the summer baseflow period (May-September), the fall wetting-up period, and the winter rainy season based on discharge measurements taken at the WIL, TRE, UQL, and ZIE sub-watershed outlets. Discharge for the 2017 Hydrologic Year (HY2017) and associated chemical streamwater sampling events are displayed in Figures 3-6. Discharge and sampling events for HY2018 are displayed in Figures 7-10.

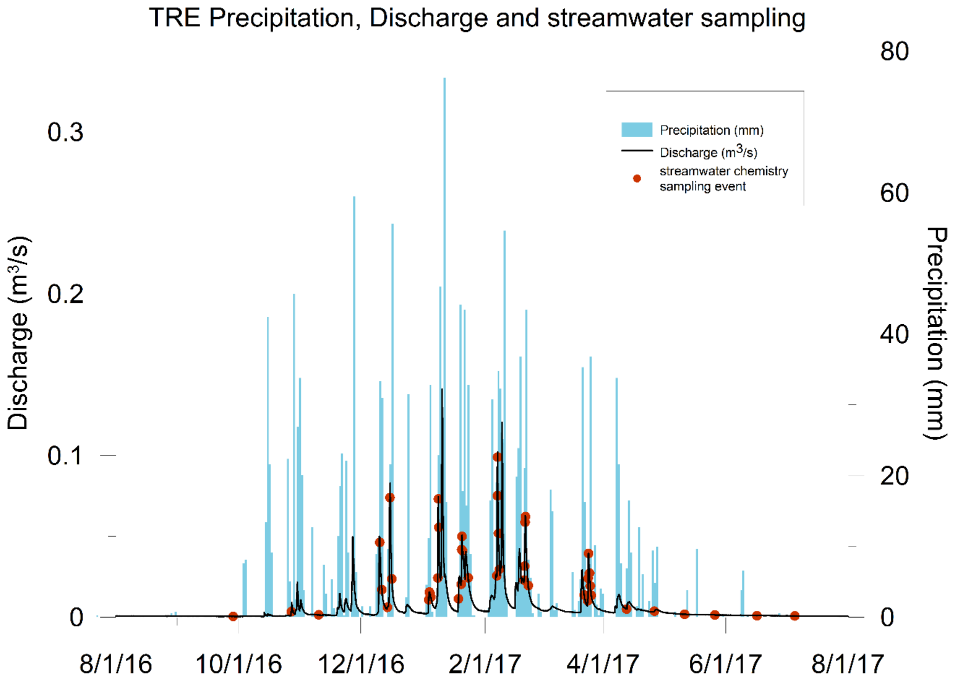


Figure 3. HY2017 TRE precipitation, discharge and sampling events.

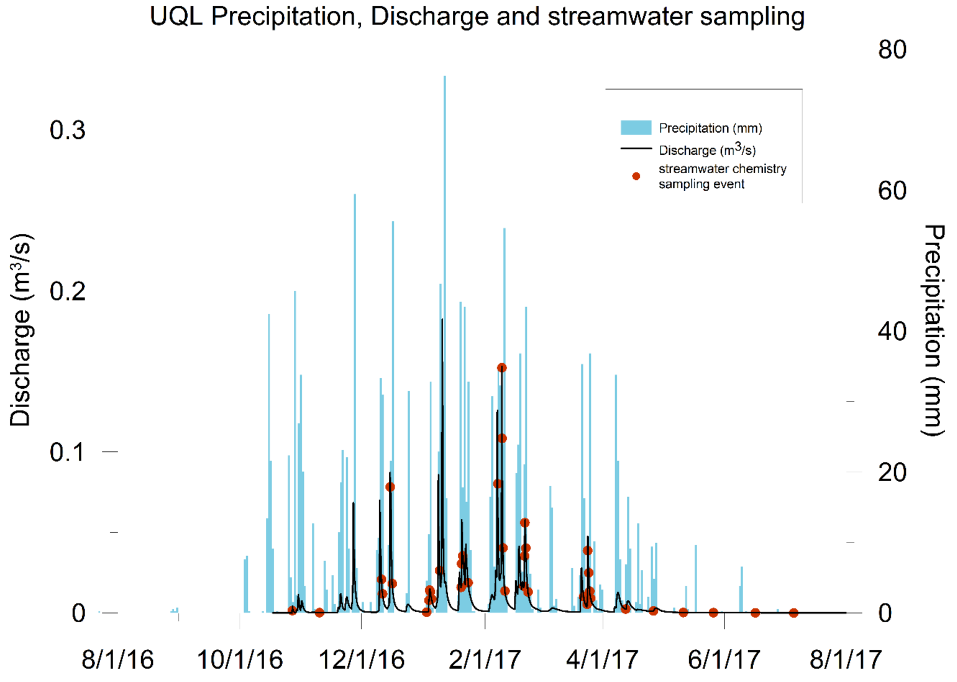


Figure 4. HY2017 UQL precipitation, discharge and sampling events.

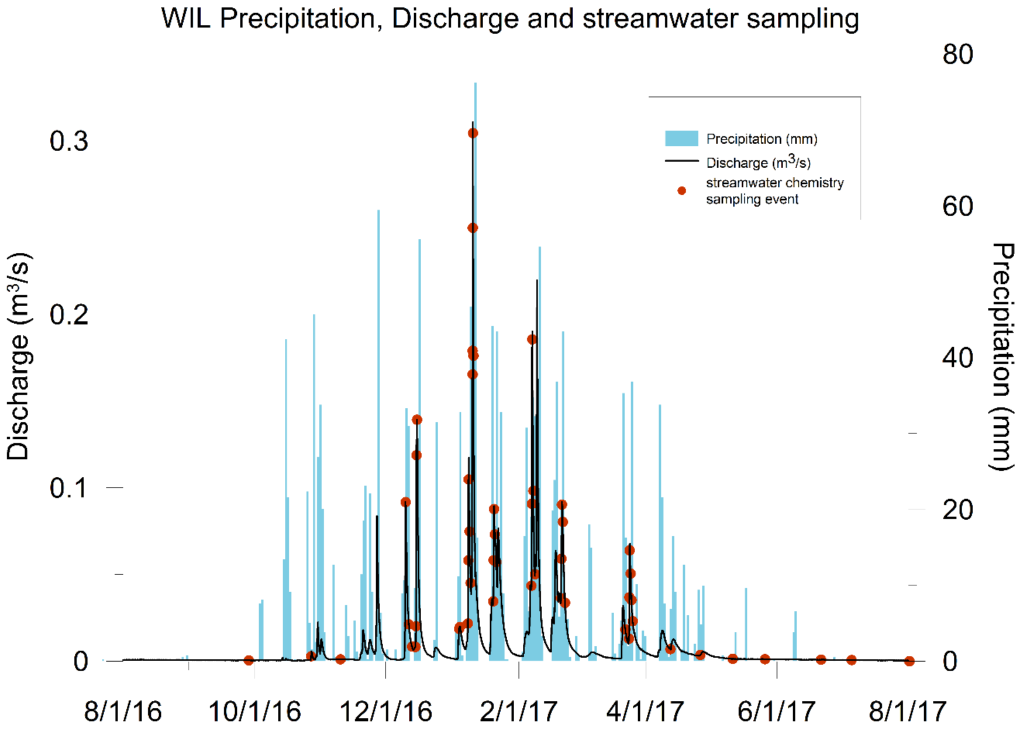


Figure 5. HY2017 WIL precipitation, discharge and sampling events.

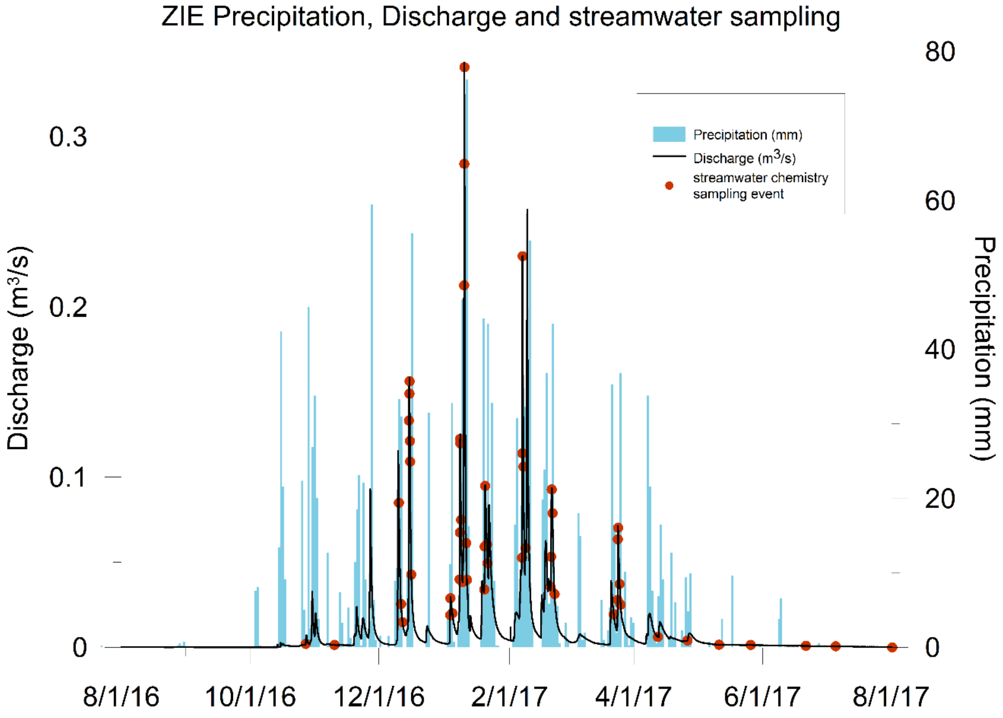


Figure 6. HY2017 ZIE precipitation, discharge and sampling events.

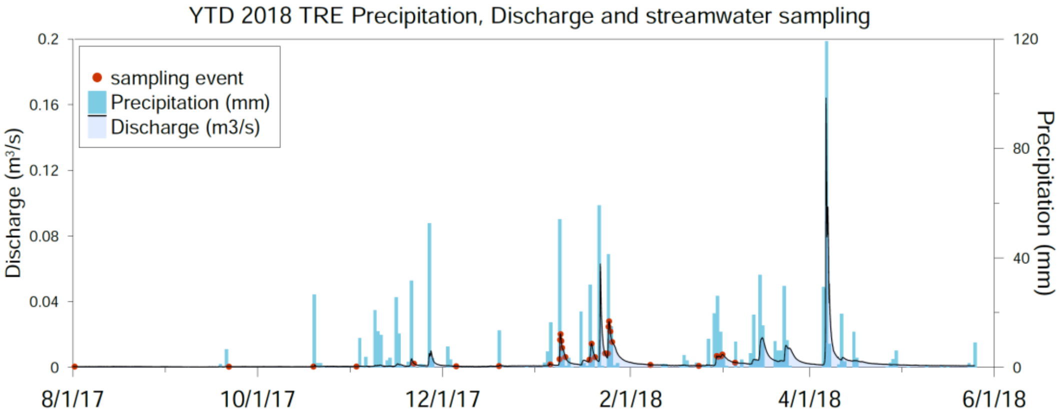


Figure 7. Year-to-date HY2018 TRE precipitation, discharge and sampling events.

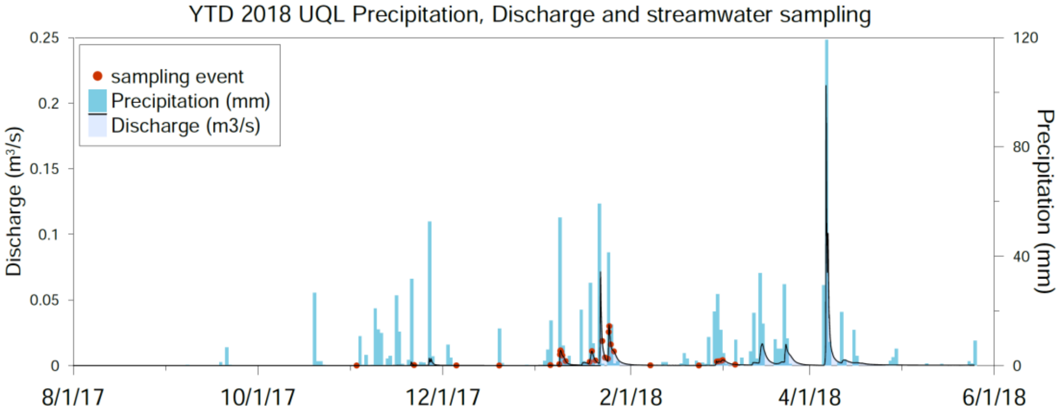


Figure 8. Year-to-date HY2018 UQL precipitation, discharge and sampling events.

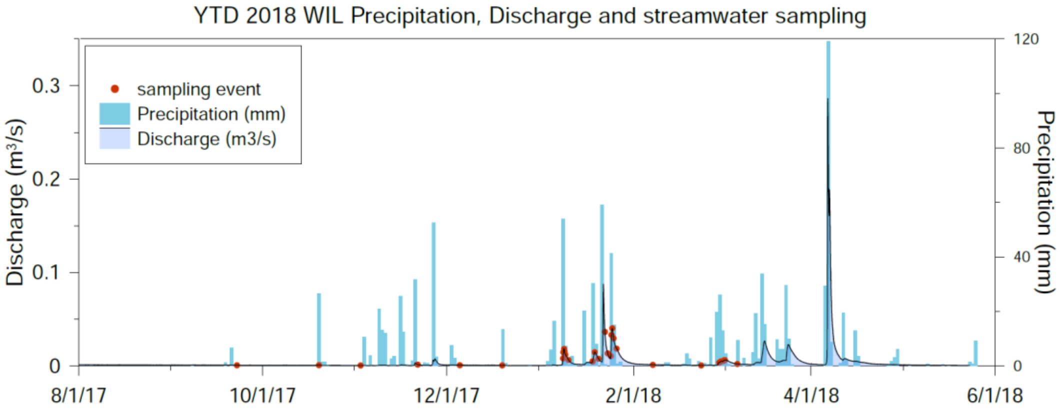


Figure 9. Year-to-date HY2018 WIL precipitation, discharge and sampling events.

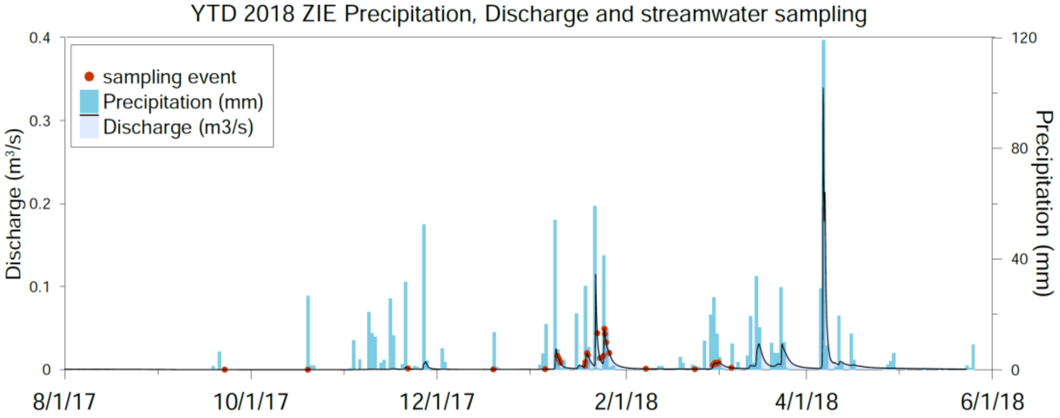


Figure 10. Year-to-date HY2018 ZIE precipitation, discharge and sampling events.

Rainfall-runoff ratios were calculated for each sub-watershed for eleven storm events that occurred during HY2017 between November and March. Thus far in our analysis of HY2018, seven storm events have been identified for rainfall-runoff evaluation (Tables 4 and 5). Runoff ratios represent the total amount of runoff volume generated for each individual storm event, normalized by sub-watershed area. The amount of runoff (in mm) is divided by the precipitation accumulated over the same time-period, which gives a ratio of cumulative event runoff: cumulative event precipitation.

During the fall wetting-up period runoff ratios in all watersheds were lower than at the height of the winter rainy season, indicating that a greater fraction of the observed event precipitation was used to wet-up the watershed. The antecedent precipitation in early October 2016 was 103.1 mm, reaching 295.4 mm by mid-November. The 2016 fall wetting-up period (early October through mid-October) was identified based on sub-watershed hydrographs and cumulative precipitation totals were calculated for these periods. The 2017 fall-wetting up period (early October-end of December) was much longer in duration than it took for each watershed to saturate during the previous year. The antecedent precipitation period is the amount of time it takes for enough precipitation to accumulate to fully saturate the soil profile. The first hydrologic response for the water year is typically not observed until antecedent moisture conditions are met. Tables 4 and 5 display Rainfall-runoff coefficients for both years. The relative changes observed amongst runoff ratios of each sub-watershed indicate similarity and predictability in watershed behavior. It is clear that HY2017 and HY2018 were very different in terms of the timing, magnitude, and frequency of precipitation events and storm events. However, the observed Rainfall-runoff values are consistent with one another on a relative basis, which indicates that even during variable precipitation/climatic conditions, these four watersheds behave predictably, and should be able to serve as an adequate basis for comparison among treatment levels.

Table 4. HY2017 Runoff-rainfall ratios and antecedent moisture conditions for sub-watersheds TRE, UQL, WIL, and ZIE.

2016-2017 Storm Events	Dates	TRE	UQL	WIL	ZIE	Event Average
Antecedent Precipitation	(10/2/16-11/17/16)	0.17	0.06	0.08	0.12	**0.11**
Wetting Period	(10/2/16-11/23/16)	0.1	0	0.04	0.03	**0.04**
1	(10/23/16-11/17/16)	0.21	0.09	0.1	0.16	**0.14**
2	(11/17/16-12/5/16)	0.49	0.47	0.34	0.43	**0.43**
3	(12/5/16-12/20/16)	0.68	0.67	0.59	0.69	**0.66**
4	(12/20/16-1/16/17)	0.73	0.67	0.62	0.68	**0.68**
5	(1/16/17-1/31/17)	0.81	0.71	0.7	0.76	**0.75**
6	(1/31/17-2/14/17)	0.82	0.76	0.73	0.8	**0.78**
7	(2/14/17-3/17/17)	1	0.85	0.8	0.85	**0.88**
8	(3/17/17-4/5/17)	0.77	0.57	0.56	0.58	**0.62**
9	(4/5/17-4/23/17)	0.56	0.38	0.38	0.41	**0.43**
Annual Average	**N/A**	**0.59**	**0.47**	**0.45**	**0.50**	

Table 5. HY2018 Year-to-date Runoff-rainfall ratios and antecedent moisture conditions for sub-watersheds TRE, UQL, WIL, and ZIE.

YTD 2017-2018 Storm Events	Dates	TRE	UQL	WIL	ZIE	Event Average
Antecedent Precipitation	10/2/17-1/1/18	0.20	0.03	0.08	0.06	**0.09**
1	1/1/18-1/13/18	0.28	0.14	0.12	0.16	**0.18**
2	1/13/18-1/20/18	0.31	0.21	0.16	0.21	**0.22**
3	1/20/18-1/23/18	0.48	0.48	0.36	0.44	**0.44**
4	1/23/18-2/4/18	0.96	0.70	0.64	0.71	**0.75**
5	3/11/18-3/19/18	0.47	0.35	0.29	0.36	**0.37**
6	3/19/18-4/1/18	0.72	0.49	0.52	0.60	**0.58**
7	4/4/18-4/10/18	0.62	0.64	0.60	0.66	**0.63**
Annual Average	**N/A**	**0.51**	**0.38**	**0.35**	**0.40**	

Table 6. Sub-watershed slope, area, and annual antecedent precipitation for HY2017 and HY2018.

Average watershed slope (%)	**47**	**49**	**51**	**43**
Watershed Area (m^2)	141,000	125,000	265,000	253,000
Treatment (% Reduction)	35	55	0	75
HY2017 Antecedent Precipitation (cm)	**28.78**	**28.78**	**28.78**	**28.78**
HY2018 Antecedent Precipitation (cm)	**25.35**	**25.35**	**25.35**	**25.35**

Figures 4 and 5 show annual averages in Runoff-rainfall coefficients for each sub-watershed, which are generally higher for HY2017 than for HY2018. This is likely due to the fact that the entire water year (particularly the spring which generally has the highest runoff ratio values) has not yet been evaluated for HY2018, which would tend to skew the ratio values down. Additionally, there have been fewer storm events subsequent to the antecedent moisture period during 2018, which would also result in lower overall Runoff-rainfall ratios for 2018 compared to 2017. Nevertheless, TRE, ZIE, UQL, and WIL have a clear relationship during both years of monitoring, from highest runoff ratio to lowest runoff ratios, respectively. Table 6 indicates that antecedent moisture conditions required to wet up the South Fork watersheds was 28.78 cm in HY2017, and 25.35 cm in HY2018. This indicates that the four representative sub-watersheds should be expected to respond similarly, and that they each require, approximately 27 cm (10.5 inches) of antecedent precipitation to initiate a significant hydrologic response.

To evaluate the hydrologic compatibility of the sub-watersheds receiving timber reduction treatments (TRE, UQL and ZIE) to the control watershed (WIL), a simple linear regression of the watersheds' discharges was conducted. All treatment watersheds show a high degree of correlation with the control watershed WIL over the course of the 2017 Hydrologic year (Figures 11-13), as well as the Year-to-date 2018 Hydrologic year (Figures 14-16). Similarity in discharge magnitude, and high coefficients of determination for both years of baseflow study, are indicative of a strong basis for comparison for each treatment sub-watershed (TRE, UQL, and ZIE) to the reference (WIL) during baseflow conditions.

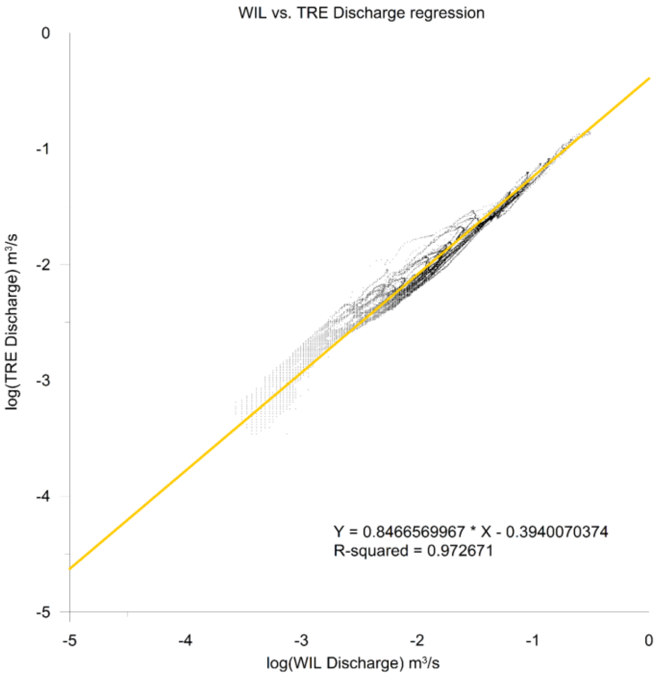


Figure 11. HY2017 WIL vs. TRE discharge regression.

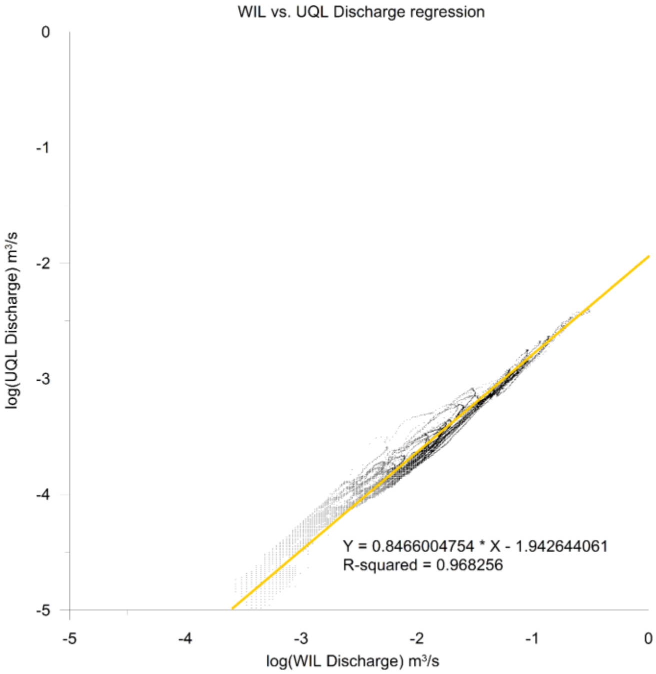


Figure 12. HY2017 WIL vs. UQL discharge regression.

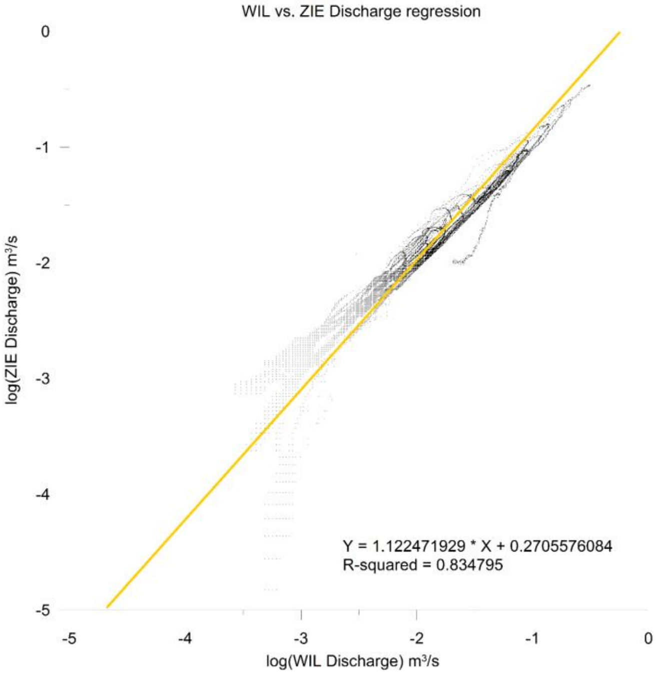


Figure 13. HY2017 WIL vs. ZIE discharge regression.

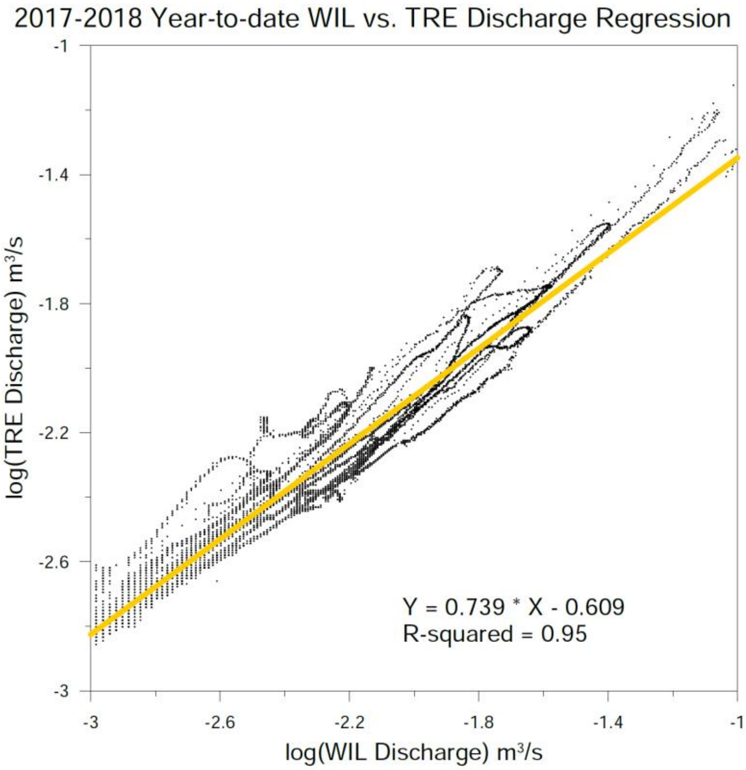


Figure 14. HY2018 TRE vs. WIL discharge regression.

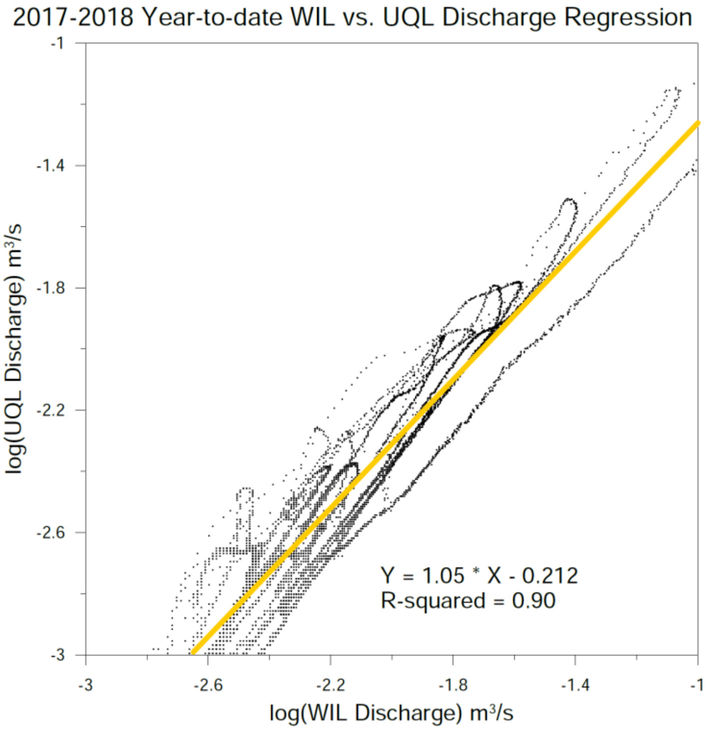


Figure 15. HY2018 UQL vs. WIL discharge regression.

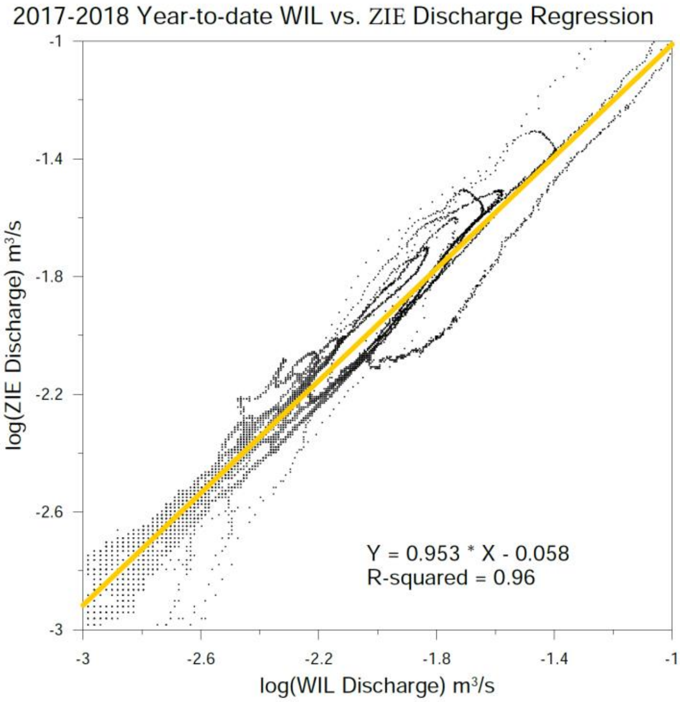
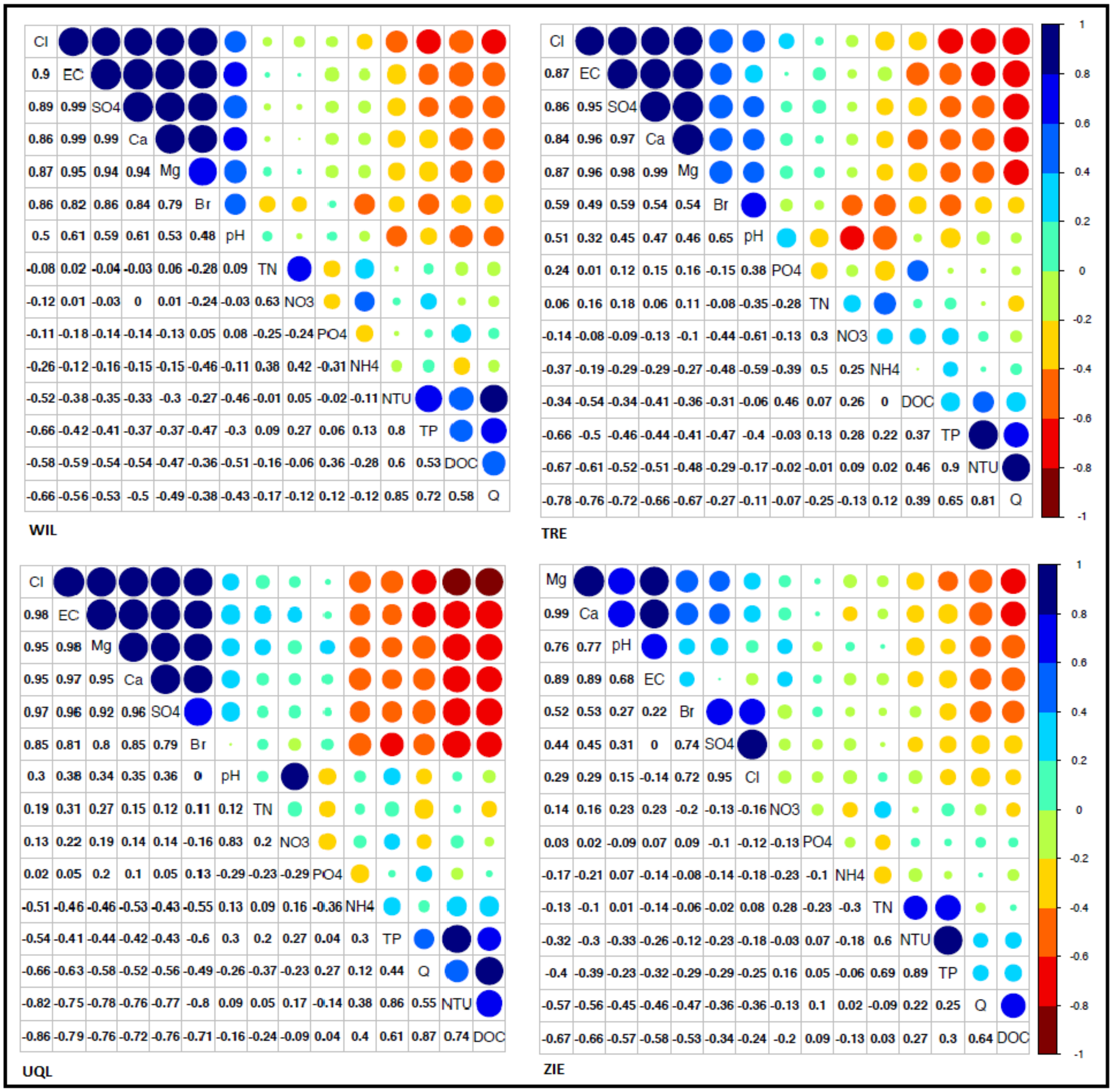


Figure 16. HY2018 ZIE vs. WIL discharge regression.

4.3 Water Chemistry

Water chemistry components of each sub-watershed have been evaluated by correlation matrices between all biogochemical variables analyzed in this study. These variables include stream discharge (Q), Turbidity (NTU), Electrical Conductivity (EC), pH, Total Phosphorous (TP), Total Nitrogen (TN), dissolved organic carbon (DOC), major cations (Ca, Mg, and NH4-N), and major anions (Cl, SO4, Br, PO4, and NO3-N). Correlation matrices of all variables are summarized for the sub-watersheds TRE, UQL, ZIE, and WIL in Figure 10, for the 2017 water year.

High degrees of positive correlation (coefficients >0.6) are observed in all watersheds between Mg, Ca, Cl, Br, and EC. Turbidity and discharge are also generally strongly correlated with dissolved organic carbon and total phosphorous in most of the examined sub-watersheds. Negative correlation trends between Mg/Ca and DOC/TP/NTU/Q are also observable. The high degree of negative or positive correlation between biogeochemical variables is a good indication that the selected sub-watersheds behave hydrologically and biogeochemically in a similar manner. This ensures that these watersheds can be used to assess changes in the water balance and nutrient export as a result of the different timber harvest treatments. Streamwater chemistry will continue to be monitored throughout the winter of 2018/2019, and will be statistically evaluated as chemical sample analysis continues.



Cl														
0.9	EC													
0.89	0.99	SO4												
0.86	0.99	0.99	Ca											
0.87	0.95	0.94	0.94	Mg										
0.86	0.82	0.86	0.84	0.79	Br									
0.5	0.61	0.59	0.61	0.53	0.48	pH								
-0.08	0.02	-0.04	-0.03	0.06	-0.28	0.09	TN							
-0.12	0.01	-0.03	0	0.01	-0.24	-0.03	0.63	NO3						
-0.11	-0.18	-0.14	-0.14	-0.13	0.05	0.08	-0.25	-0.24	PO4					
-0.26	-0.12	-0.16	-0.15	-0.15	-0.46	-0.11	0.38	0.42	-0.31	NH4				
-0.52	-0.38	-0.35	-0.33	-0.3	-0.27	-0.46	-0.01	0.05	-0.02	-0.11	NTU			
-0.66	-0.42	-0.41	-0.37	-0.37	-0.47	-0.3	0.09	0.27	0.06	0.13	0.8	TP		
-0.58	-0.59	-0.54	-0.54	-0.47	-0.36	-0.51	-0.16	-0.06	0.36	-0.28	0.6	0.53	DOC	
-0.66	-0.56	-0.53	-0.5	-0.49	-0.38	-0.43	-0.17	-0.12	0.12	-0.12	0.85	0.72	0.58	Q

WIL

Cl														
0.87	EC													
0.86	0.95	SO4												
0.84	0.96	0.97	Ca											
0.87	0.96	0.98	0.99	Mg										
0.59	0.49	0.59	0.54	0.54	Br									
0.51	0.32	0.45	0.47	0.46	0.65	pH								
0.24	0.01	0.12	0.15	0.16	-0.15	0.38	PO4							
0.06	0.16	0.18	0.06	0.11	-0.08	-0.35	-0.28	TN						
-0.14	-0.08	-0.09	-0.13	-0.1	-0.44	-0.61	-0.13	0.3	NO3					
-0.37	-0.19	-0.29	-0.29	-0.27	-0.48	-0.59	-0.39	0.5	0.25	NH4				
-0.34	-0.54	-0.34	-0.41	-0.36	-0.31	-0.06	0.46	0.07	0.26	0	DOC			
-0.66	-0.5	-0.46	-0.44	-0.41	-0.47	-0.4	-0.03	0.13	0.28	0.22	0.37	TP		
-0.67	-0.61	-0.52	-0.51	-0.48	-0.29	-0.17	-0.02	-0.01	0.09	0.02	0.46	0.9	NTU	
-0.78	-0.76	-0.72	-0.66	-0.67	-0.27	-0.11	-0.07	-0.25	-0.13	0.12	0.39	0.65	0.81	Q

TRE

Cl														
0.98	EC													
0.95	0.98	Mg												
0.95	0.97	0.95	Ca											
0.97	0.96	0.92	0.96	SO4										
0.85	0.81	0.8	0.85	0.79	Br									
0.3	0.38	0.34	0.35	0.36	0	pH								
0.19	0.31	0.27	0.15	0.12	0.11	0.12	TN							
0.13	0.22	0.19	0.14	0.14	-0.16	0.83	0.2	NO3						
0.02	0.05	0.2	0.1	0.05	0.13	-0.29	-0.23	-0.29	PO4					
-0.51	-0.46	-0.46	-0.53	-0.43	-0.55	0.13	0.09	0.16	-0.36	NH4				
-0.54	-0.41	-0.44	-0.42	-0.43	-0.6	0.3	0.2	0.27	0.04	0.3	TP			
-0.66	-0.63	-0.58	-0.52	-0.56	-0.49	-0.26	-0.37	-0.23	0.27	0.12	0.44	Q		
-0.82	-0.75	-0.78	-0.76	-0.77	-0.8	0.09	0.05	0.17	-0.14	0.38	0.86	0.55	NTU	
-0.86	-0.79	-0.76	-0.72	-0.76	-0.71	-0.16	-0.24	-0.09	0.04	0.4	0.61	0.87	0.74	DOC

UQL

Mg														
0.99	Ca													
0.76	0.77	pH												
0.89	0.89	0.68	EC											
0.52	0.53	0.27	0.22	Br										
0.44	0.45	0.31	0	0.74	SO4									
0.29	0.29	0.15	-0.14	0.72	0.95	Cl								
0.14	0.16	0.23	0.23	-0.2	-0.13	-0.16	NO3							
0.03	0.02	-0.09	0.07	0.09	-0.1	-0.12	-0.13	PO4						
-0.17	-0.21	0.07	-0.14	-0.08	-0.14	-0.18	-0.23	-0.1	NH4					
-0.13	-0.1	0.01	-0.14	-0.06	-0.02	0.08	0.28	-0.23	-0.3	TN				
-0.32	-0.3	-0.33	-0.26	-0.12	-0.23	-0.18	-0.03	0.07	-0.18	0.6	NTU			
-0.4	-0.39	-0.23	-0.32	-0.29	-0.29	-0.25	0.16	0.05	-0.06	0.69	0.89	TP		
-0.57	-0.56	-0.45	-0.46	-0.47	-0.36	-0.36	-0.13	0.1	0.02	-0.09	0.22	0.25	Q	
-0.67	-0.66	-0.57	-0.58	-0.53	-0.34	-0.24	-0.2	0.09	-0.13	0.03	0.27	0.3	0.64	DOC

ZIE

Figure 17. Pearson correlation coefficient matrices for sub-watersheds WIL, TRE, UQL, and ZIE of selected watershed and water chemistry parameters. The diagonal indicates what parameters are correlated and numbers in the lower half indicate the Pearson correlation coefficient, r.

Nutrient loads for 10 storm events between November 2016 and April 2017 have been calculated for each of the four sub-watersheds sampled for streamwater chemistry. Additionally, nutrient loads for the 2016 fall wetting period (mid-Oct. to Nov. 2016), and the total nutrient flux over the antecedent moisture period (mid-October through end of November 2016) have been calculated. HY2017 nutrient loads for each sampled sub-watershed are summarized in Tables 7-10. Annual Year-to-date nutrient flux calculations for HY2018 can be found in Tables 11-14. Nutrient load calculations are indicative of general trends in watershed nutrient fluxes in response to storm events and during baseline conditions. These trends are particularly informative about the initial conditions in each watershed during the calibration (pre-treatment) period, and allow for more informed evaluation of observed nutrient fluxes in the post-treatment phase**.**

Table 7. HY2017 TRE Event-based flux of selected nutrients (in kg/ha/event).

NUTRIENT FLUX (kg/ha/event)

Rainfall Runoff Events	Start Date	End Date	TN	NH4-N	NO3-N	TP	PO4	DOC	Cl	SO4	Br	Mg new	Ca new	Na	K
A	10/2/2016	11/17/2016	0.2	0.0	0.0	0.0	0.0	4.8	16.0	5.9	0.3	5.8	4.7	19.0	0.9
W	10/2/2016	10/23/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	10/23/2016	11/17/2016	0.2	0.0	0.0	0.0	0.0	4.8	16.0	5.9	0.3	5.8	4.7	19.0	0.9
2	11/17/2016	12/5/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	12/5/2016	12/20/2016	0.4	0.1	0.0	0.1	0.0	4.6	25.8	7.1	0.4	7.0	6.4	27.6	2.3
4	12/20/2016	1/16/2017	0.3	0.1	0.0	0.1	0.0	6.6	24.0	6.9	0.4	5.1	3.3	24.6	1.5
5	1/16/2017	1/31/2017	0.2	0.0	0.0	0.0	0.0	5.3	21.2	5.5	0.3	4.3	2.7	22.4	1.5
6	1/31/2017	2/14/2017	0.3	0.2	0.0	0.1	0.0	4.7	23.6	6.6	0.4	5.9	3.4	27.1	1.7
7	2/14/2017	3/17/2017	0.4	0.2	0.0	0.0	0.0	3.5	23.8	6.4	0.3	4.9	3.1	26.6	1.5
8	3/17/2017	4/5/2017	0.5	0.1	0.0	0.1	0.0	2.1	15.3	4.8	0.2	3.8	2.2	19.6	1.1
9	4/5/2017	4/23/2017	0.2	0.0	0.0	0.0	0.0	0.9	9.8	3.3	0.2	1.9	1.4	11.1	0.6
Annual total	10/2/2016	4/23/2017	2.6	0.6	0.2	0.5	0.1	32.5	159.5	46.5	2.3	38.7	27.2	177.9	11.1

Table 8. HY2017 UQL Event-based flux of selected nutrients (in kg/ha/event).

NUTRIENT FLUX (kg/ha/event)

Rainfall Runoff Events	Start Date	End Date	TN	NH4-N	NO3-N	TP	PO4	DOC	Cl	SO4	Br	Mg new	Ca new	Na	K
A	10/2/2016	11/17/2016	0.1	0.0	0.0	0.0	0.0	2.4	7.6	2.2	0.1	2.6	2.3	10.0	0.5
W	10/2/2016	10/23/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	10/23/2016	11/17/2016	0.1	0.0	0.0	0.0	0.0	2.4	7.6	2.2	0.1	2.6	2.3	10.0	0.5
2	11/17/2016	12/5/2016	0.1	0.0	0.0	0.0	0.0	1.6	5.0	1.2	0.0	1.4	0.7	5.8	0.4
3	12/5/2016	12/20/2016	0.5	0.0	0.0	0.1	0.0	5.8	24.3	6.1	0.3	5.5	4.2	25.6	1.9
4	12/20/2016	1/16/2017	0.2	0.1	0.0	0.1	0.0	7.4	23.0	6.4	0.0	4.5	2.0	24.9	1.5
5	1/16/2017	1/31/2017	0.1	0.0	0.0	0.0	0.0	4.7	16.7	4.6	0.2	3.2	1.5	18.1	1.1
6	1/31/2017	2/14/2017	0.3	0.1	0.0	0.1	0.0	7.1	18.7	5.7	0.3	5.5	2.8	22.9	1.6
7	2/14/2017	3/17/2017	0.4	0.2	0.0	0.0	0.0	4.0	16.4	4.8	0.2	3.5	2.5	19.3	1.1
8	3/17/2017	4/5/2017	0.4	0.1	0.0	0.0	0.0	1.9	10.4	3.2	0.1	2.5	1.6	13.4	0.8
9	4/5/2017	4/23/2017	0.2	0.0	0.0	0.0	0.0	0.7	7.6	2.5	0.2	1.5	1.3	8.8	0.5
Annual total	10/2/2016	4/23/2017	2.2	0.5	0.0	0.4	0.0	34.0	124.7	35.3	1.2	28.7	18.1	143.0	9.0

Table 9. HY2017 WIL Event-based flux of selected nutrients (in kg/ha/event).

NUTRIENT FLUX (kg/ha/event)

Rainfall Runoff Events	Start Date	End Date	TN	NH4-N	NO3-N	TP	PO4	DOC	Cl	SO4	Br	Mg new	Ca new	Na	K
A	10/2/2016	11/17/2016	0.1	0.0	0.0	0.0	0.0	2.6	7.7	3.3	0.2	2.9	3.6	9.1	0.5
W	10/2/2016	10/23/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	10/23/2016	11/17/2016	0.1	0.0	0.0	0.0	0.0	2.6	7.7	3.3	0.2	2.9	3.6	9.1	0.5
2	11/17/2016	12/5/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	12/5/2016	12/20/2016	0.4	0.0	0.0	0.1	0.0	4.6	20.1	5.8	0.3	4.9	7.2	21.9	1.5
4	12/20/2016	1/16/2017	0.5	0.0	0.0	0.1	0.0	6.5	20.3	5.6	0.4	4.0	4.2	21.6	1.2
5	1/16/2017	1/31/2017	0.6	0.0	0.0	0.0	0.0	3.5	16.5	4.4	0.3	3.0	3.2	17.1	0.8
6	1/31/2017	2/14/2017	0.3	0.1	0.0	0.1	0.0	4.1	21.2	6.0	0.4	4.6	4.8	23.9	1.6
7	2/14/2017	3/17/2017	0.3	0.2	0.0	0.0	0.0	2.7	16.8	4.8	0.2	3.2	3.2	18.6	0.9
8	3/17/2017	4/5/2017	0.6	0.1	0.0	0.0	0.0	1.4	10.2	3.5	0.2	2.3	2.6	13.4	0.6
9	4/5/2017	4/23/2017	0.1	0.0	0.0	0.0	0.0	0.6	7.2	2.5	0.2	1.7	1.8	7.9	0.3
Annual total	10/2/2016	4/23/2017	2.9	0.5	0.1	0.5	0.1	26.0	120.0	35.9	2.2	26.6	30.5	133.5	7.5

Table 10. HY2017 ZIE Event-based flux of selected nutrients (kg/ha/event).

HY2017 ZIE NUTRIENT FLUX (kg/ha/event)

Rainfall Runoff Events	Start Date	End Date	TN	NH4-N	NO3-N	TP	PO4	DOC	Cl	SO4	Br	Mg new	Ca new	Na	K
A	10/2/2016	11/17/2016	0.2	0.0	0.0	0.0	0.0	3.3	11.4	2.7	0.1	4.2	2.5	12.5	0.7
W	10/2/2016	10/23/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	10/23/2016	11/17/2016	0.2	0.0	0.0	0.0	0.0	3.3	11.4	2.7	0.1	4.2	2.5	12.5	0.7
2	11/17/2016	12/5/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	12/5/2016	12/20/2016	0.5	0.0	0.1	0.1	0.0	6.0	19.6	5.2	0.3	6.8	4.9	22.0	1.8
4	12/20/2016	1/16/2017	0.7	0.0	0.0	0.1	0.0	8.5	17.6	4.8	0.2	5.1	2.9	19.7	1.7
5	1/16/2017	1/31/2017	0.4	0.0	0.0	0.0	0.0	4.1	13.1	3.5	0.2	3.7	2.2	15.3	1.1
6	1/31/2017	2/14/2017	0.3	0.2	0.0	0.1	0.0	5.4	17.1	4.9	0.3	5.8	3.3	20.9	1.6
7	2/14/2017	3/17/2017	0.2	0.1	0.0	0.0	0.0	3.3	13.1	3.6	0.1	4.2	2.5	15.6	1.1
8	3/17/2017	4/5/2017	0.3	0.0	0.0	0.0	0.0	1.4	5.7	1.7	0.1	2.0	1.1	7.8	0.5
9	4/5/2017	4/23/2017	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Annual total	10/2/2016	4/23/2017	2.7	0.4	0.1	0.4	0.0	32.1	97.5	26.4	1.2	31.9	19.4	113.8	8.6

Table 11. HY2018 TRE Year-to-date-based flux of selected nutrients (kg/ha).

Location	Year Begin	Year end	TN	NH4-N	NO3-N	TP	PO4	DOC
TRE	10/2/2017	4/23/2018	0.33	0.03	0.02	0.10	0.01	4.17
UQL	10/2/2017	4/23/2018	0.19	0.04	0.01	0.04	0.00	3.46
WIL	10/2/2017	4/23/2018	0.20	0.05	0.01	0.07	0.01	3.42
ZIE	10/2/2017	4/23/2018	0.21	0.02	0.00	0.06	0.00	3.43

Total nutrient loads from the four watersheds were overall generally similar. Export of TN, NH4, NO3, PO4, and TP were negligible and ranged between 0.02 and 2.28 kg for the ten storm events between October 2016 and May 2017. In comparison, export of DOC, chloride and sulfate (SO4) were much higher. DOC export from the control sub-watershed WIL (27 kg/ha) was lowest among the four sub-watersheds and slightly higher (30-35 kg/ha) in the three sub-watersheds receiving the timber reduction treatments. Chloride export was highest in the TRE sub-watershed (147 kg/ha, 14.1 ha) and lowest in the ZIL sub-watershed (89 kg/ha, 25.3 ha). Further, sulfate showed a clear difference between the four sub-watersheds. Both WIL and ZIE showed low sulfate loads (7 kg/ha each) for the ten winter storms, while TRE and UQL showed SO4 loads that were at least 5-8 times higher (45 and 34 kg/ha respectively). During HY2018, chemical analysis has not been completed for ions. However, TN, NH4, NO3, TP and PO4 are generally negligible, while DOC is considerably greater, ranging from 3.42 to 4.17 kg/ha for the HY2018 year-to-date (October through April). Concentrations for major nutrients analyzed thus far for HY2018, have followed the expected projections based on HY2017, which indicates that the water chemistry in the South Fork behaves consistently, and predictably during baseflow conditions. Selected nutrient loads (kg/ha/event) along with stream discharge volumes (cubic meters) for HY2017 are displayed in Figures 18-26.

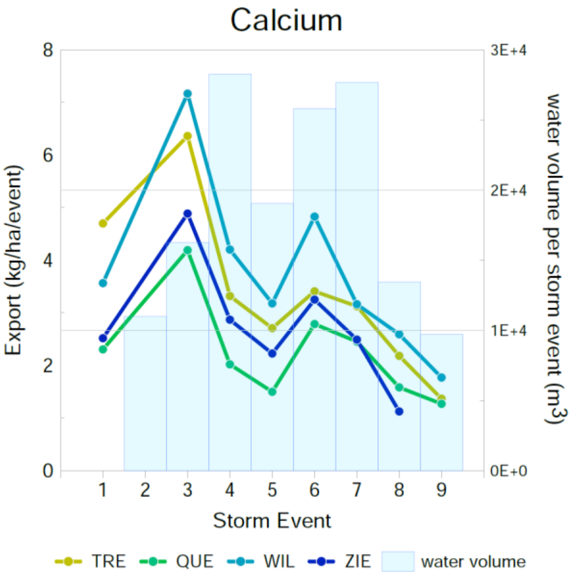


Figure 18. HY2017 Event-based calcium export vs. storm water volume.

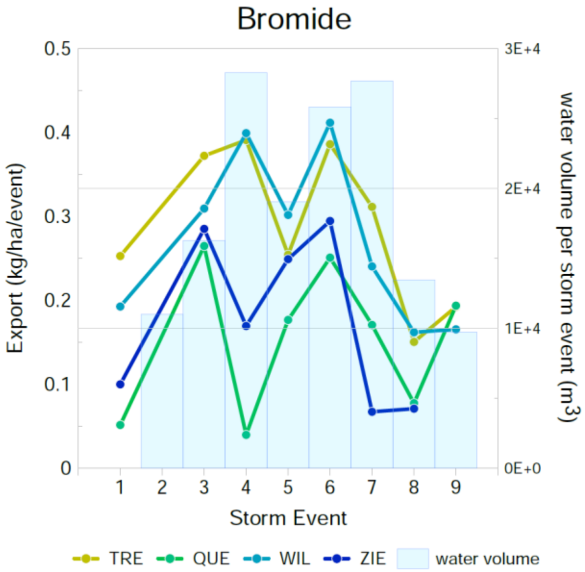


Figure 19. HY2017 Event-based bromide export vs. storm water volume.

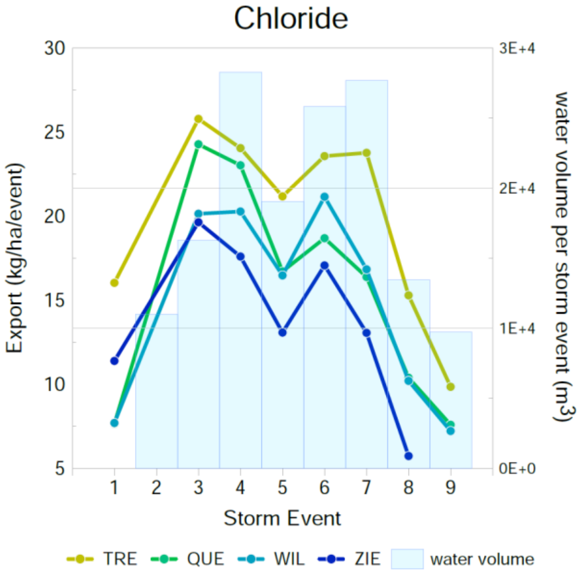


Figure 20. HY2017 Event-based chloride export vs. storm water volume.

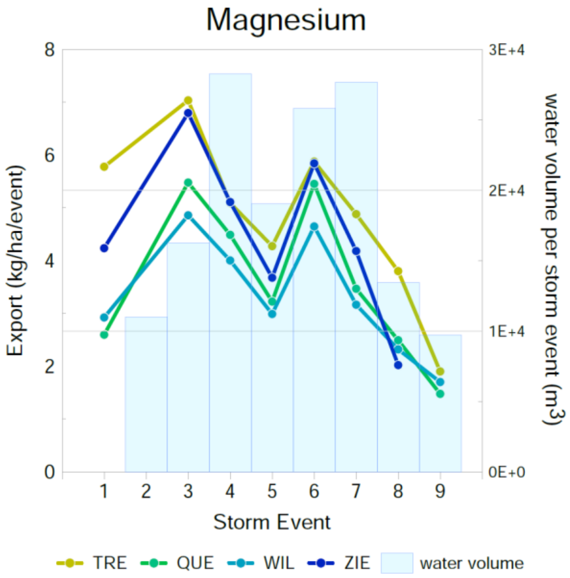


Figure 21. HY2017 Event-based magnesium export vs. storm water volume.

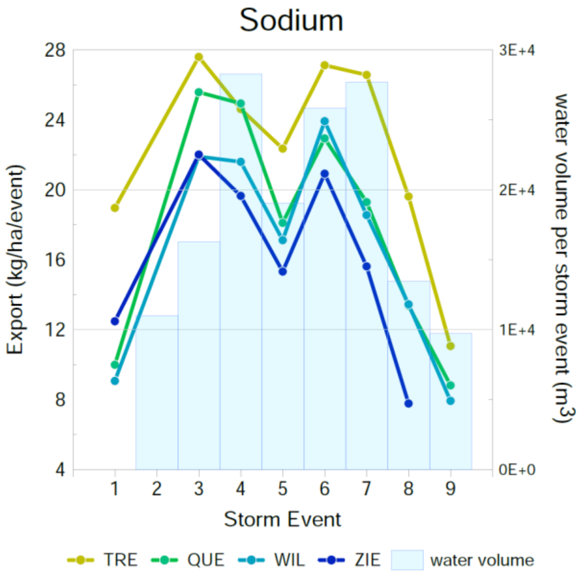


Figure 22. HY2017 Event-based sodium export vs. storm water volume.

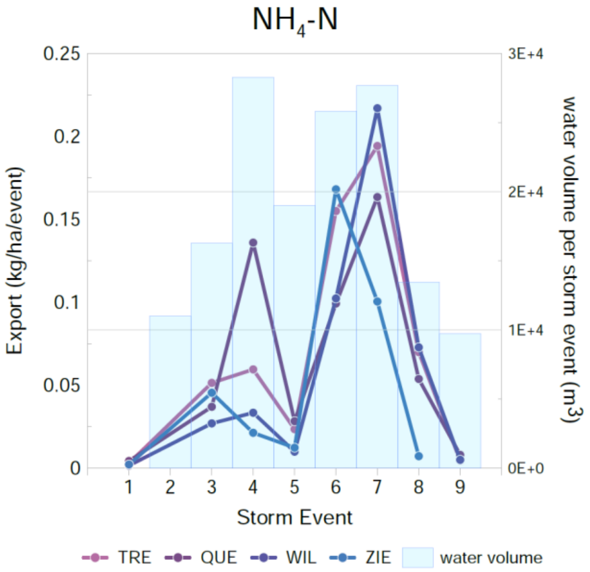


Figure 23. HY2017 Event-based ammonium export vs. storm water volume.

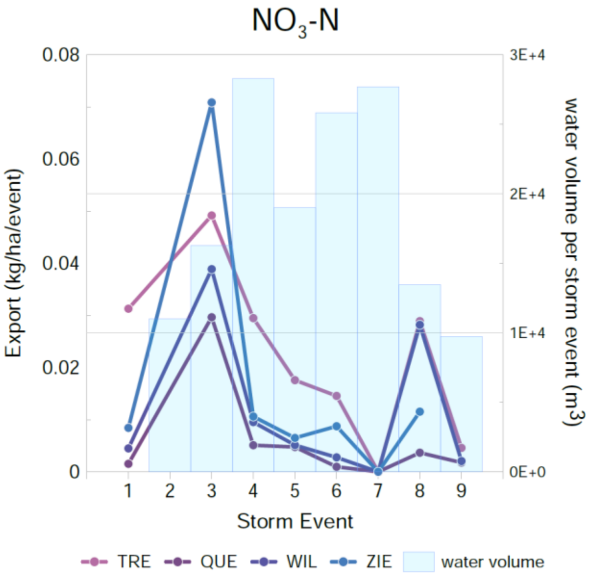


Figure 24. HY2017 Event-based nitrate export vs. storm water volume.

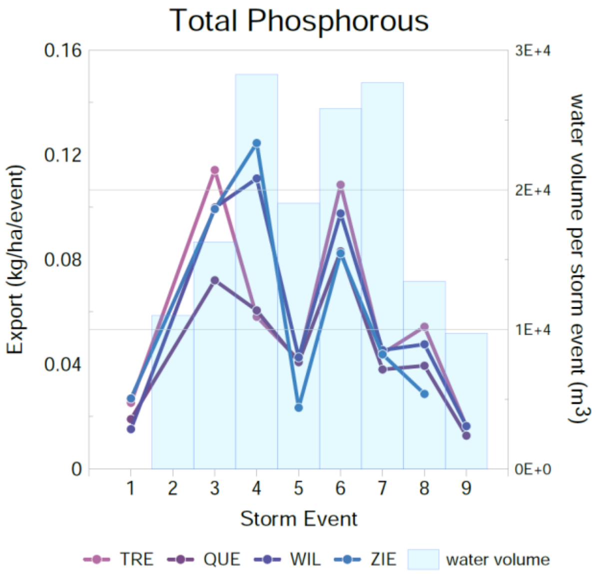


Figure 25. HY2017 Event-based total phosphorous export vs. storm water volume.

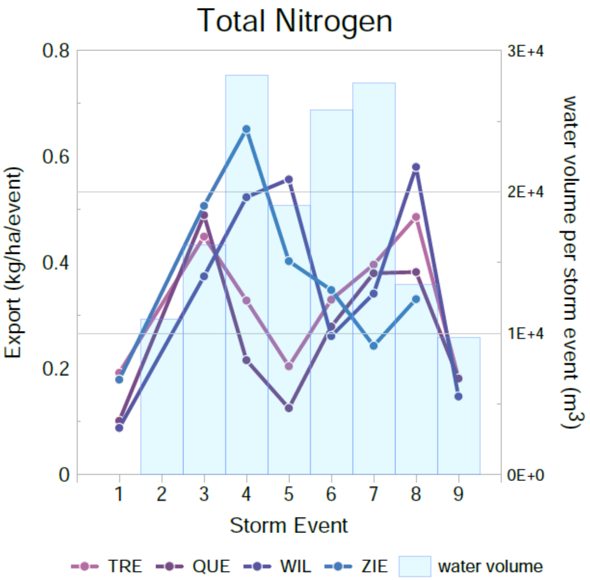


Figure 26. HY2017 Event-based total nitrogen export vs. storm water volume.

Figures 18-26 suggest that there is good correlation between storm event volumes and nutrient export for all major nutrients between each sub-watershed. Most ions (Ca, Mg, Na, K, Cl, Br) and nutrients (TP, DOC, and NH4) generally show positive correlations with water volume. These trends indicate similar hydrochemical responses among the four sub-watersheds in response to storm events of various magnitudes throughout the HY2017 year. Similar analysis for HY2018 is ongoing.

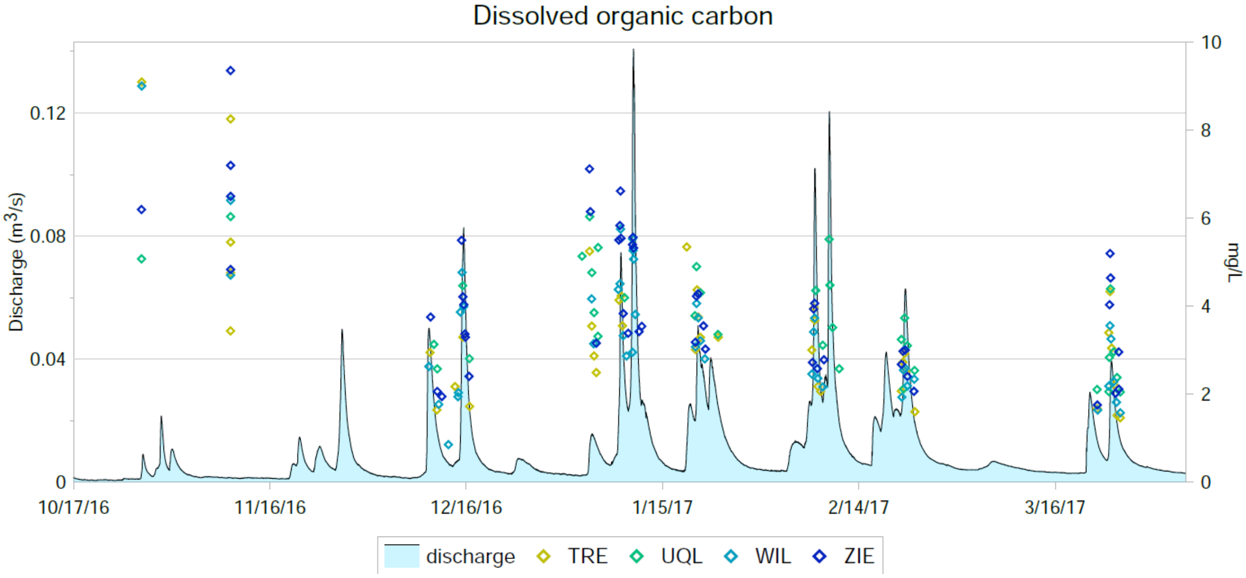


Figure 27. Dissolved organic carbon streamwater concentrations during each HY2017 sampling event.

Figure 27 shows the fall flushing events that export most of the labile nutrients (e.g. nitrate, ammonium, DOC, phosphorous, and major cations and anions) in the system. This figure is representative of the fall flushing trend that occurs in all sub-watersheds studied in South Fork Caspar Creek. The highest levels of nutrient concentrations can be seen during late October. In Figure 27, it appears that streamwater DOC concentrations show two peaks, straddling the first observed storm event at the end of October. In reality, these concentrations would likely have peaked between the two discrete sampling events (where sub-watershed concentrations are plotted in colored diamonds in Figure 27). However, we were not able to capture water chemistry samples at the peak of the October storm event, which explains the gap in chemical data at the discharge peak of this storm event. In reality, the concentrations at the peak of this initial flushing event could have easily exceeded 10 mg/L of DOC. After the initial flushing occurs, generally nutrient export levels are considerably lower for the remainder of the hydrologic year, as seen in Figure 27.

5 Summary and Conclusions

5.1 Continued hydrologic monitoring and chemical/statistical analysis

Hydrologic monitoring will continue throughout summer and fall of 2018 and will continue for the duration of the scheduled harvest treatments for the gaged sub-watersheds, which are currently underway. At the end of February 2018, an additional ISCO autosampler was installed just upstream from the South Fork weir to provide additional data for the entire South Fork Caspar Creek watershed to assess nutrient fluxes and downstream effects in response to harvest treatments. Chemical analysis of samples obtained between May 2017 and present is ongoing, as is discharge data analysis, which is in the process of being checked for quality control by Caspar Creek Watershed staff. We will continue to collect and analyze water samples throughout the remainder of the 2018 water year, and into the 2019 water year, as harvest treatments progress.

5.2 Future collaborations and planned experiments

On May 9, 2018 the PSW Research Station hosted the 2018 Caspar Creek Annual Meeting, at which Dr. Randy Dahlgren and Seanna McLaughlin, a Masters student in Soil and Biogeochemistry, were in attendance. Seanna presented a summary of our current research, in addition to presentations made by a number of other research groups who are also conducting third-phase research experiments at Caspar Creek. The meeting presentations included a Plant-Soil-Water Dynamics and Water Worlds talk by Dr. Salli Dymond, and update of the DHSVM modeling being conducted by Julie Ridgeway and Dr. Chris Surfleet, a Bedload Analysis of the South Fork by Dr. Paul Richardson, and a Bioassessment study update being conducted by DFW by Dr. Bob Danehy, among many others. These presentations and discussions were particularly relevant to the nutrient dynamics and biogeochemistry research that we are conducting. The Plant-Soil-Water dynamics study are focusing on the same four sub-watersheds (TRE, UQL, WIL and ZIE) and is currently collecting sap flow, soil moisture, piezometric, temperature, relative humidity, bulk precipitation and fog water measurements, as well as tree measurements in five discrete locations in these sub-watersheds on an elevation transect. These data will potentially inform some of the streamwater chemistry findings investigated here as the experiment progresses. Additionally, at the meeting, an update from CAL FIRE staff was given, who are overseeing the logistics of the logging treatments. At this point, the matrix harvest (i.e. harvest of trees within the South Fork Caspar Creek watershed outside the studied sub-watersheds) is complete, and sub-watersheds POR, ZIE and SEQ harvests are underway as of March 2018. CAL FIRE staff are optimistic that remaining harvesting activities will be completed before the 2018-2019 winter, but there is a good possibility that this timeline may be extended.

A nutrient dynamics study is in the planning phase, and will be implemented this summer in early August. We plan to use an injection pump to inject known concentrations of NO_3^-, along with a known concentration of Br^-. Bromide will be used as a conservative tracer, alongside NO_3^- and possibly NH_4^+. We hope to observe the temporal and spatial dynamics of Nitrogen along a representative stream section of one of the treatment sub-watersheds in the South Fork (TRE, UQL, or ZIE). We are interested to observe in-stream uptake and transformations of Nitrogen, before and after harvest treatments. This data will allow quantification of *in situ* biogeochemical reactions in the hyporheic and riparian zone that influence the overall loss in nutrient export from the headwater catchments to the sea. We plan to conduct similar injection experiments in two sections of the stream, during two times of the year.

Thus far, the combination of streamwater chemistry analysis, as well as hydrologic analysis for two years of baseline data, indicate that the four targeted sub-watersheds, TRE, UQL, WIL and ZIE have behaved similarly. Our current dataset, spanning two hydro-climatically very different years, have given us strong evidence that our watersheds behave predictably in terms of relative amounts of nutrient export observed during discrete storm events, as well as on an annual basis. Stream discharge data show strong correlation between all three treatment watersheds and the control watershed. This suggests that these watersheds can be considered adequate “pairs”, and that differences in hydrologic/chemical behavior, if detected, should be able to be attributable to the observed treatments.

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