An Approach to Study the Effect of Harvest and Wildfire on Watershed Hydrology and Sediment Yield in a Coast Redwood Forest

Christopher G. Surfleet[1], Arne Skaugset[2], and Brian Dietterick[3]

Abstract

The Little Creek watershed, within California State Polytechnic University's Swanton Pacific Ranch, is the location of a paired and nested watershed study to investigate the watershed effects of coast redwood forest management. Streamflow, suspended sediment, and stream turbidity have been collected during storms at two locations on the North Fork Little Creek and at the outlet of South Fork Little Creek from 2002 until present. In 2008, the watershed area between the two monitoring stations on the North Fork Little Creek watershed was harvested with an individual tree selection silvicultural system within the Santa Cruz County Rules of the California Forest Practice Rules. The South Fork Little Creek was left unharvested to serve as a control. In 2009, the Little Creek watershed was burned by a wildfire. The wildfire eliminated our control watersheds for the proposed Before After Control Intervention (BACI) study design. We present an alternative approach at detecting harvest and fire effects that uses rainfall/runoff models, soil erosion models, and sediment runoff relations to simulate runoff and sediment yield from the watersheds. The models and sediment runoff relationships will be developed within the framework of an uncertainty assessment to simulate pre-harvest and pre-fire conditions for the North and South Forks of Little Creek. The modeled results will be used as the control for the study which had been eliminated due to the wildfire in 2009. We use the HBV hydrologic model and sediment runoff relations to demonstrate our approach. An example of post-harvest and post-fire runoff and sediment changes within the uncertainty of the approach are demonstrated.

Key words: streamflow, suspended sediment, stream turbidity, harvesting, modeling

Introduction

The Little Creek watershed, near Santa Cruz, California has been the location of a paired watershed study investigating the watershed effects of coast redwood forest management. The classic method for evaluating forest watershed effects has relied on paired watershed studies (e.g., Bates 1921; Hewlett 1971; Rice et al. 1979) using statistical analysis within a Before After Control Intervention (BACI) study design. In 2009 a fire burned both the treatment and control watersheds of Little Creek. With the loss of a true control watershed following the 2009 Lockheed fire we propose an alternative approach using hydrology and sediment models to discern forest harvest and fire effects on watershed hydrology and sediment yield. A modeling approach to discern treatment effects on watershed hydrology in paired watershed studies has been used in other studies (e.g., Lørup et al. 1998, Seibert and McDonnell 2010, Zegre et al. 2010). The modeling approach offers the benefit of eliminating the need

[1] Research Associate, Oregon State University, Corvallis, OR. 541-737-4952.
[2] Associate Professor, Oregon State University.
[3] Director, Swanton Pacific Ranch, Cal Poly State Univ., San Luis Obispo, CA.

for control watersheds, allows testing of alternative treatments, or the ability to evaluate long time durations not easily achieved in field experiments. However, the use of models represents additional uncertainty depending on model capabilities to represent the physical processes or the accuracy or availability of input data to the model. Therefore watershed study using models cannot be used in all situations and results need to be interpreted within the uncertainties associated with model use.

Methods

Study area

The Little Creek study watersheds are located on the Swanton Pacific Ranch, owned and operated by California Polytechnic State University, San Luis Obispo, approximately 18 km northeast of Santa Cruz, California (*fig. 1*). The study portion of the watershed is divided into the 281 ha North Fork Little Creek (NF), the 106 ha South Fork Little Creek (SF), and 191 ha Upper North Fork Little Creek (UNF) sub-basins. Elevations at the study watersheds range from 100 to 580 m. Mean annual precipitation ranged from 875 mm near the outlet of the study watersheds to 1060 mm on the ridgeline during the study period 2002 to 2010. The overstory vegetation is primarily second-growth redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii*), with redwood comprising the majority of the vegetation cover. The soils in the study watershed are deep or moderately deep and well drained or somewhat excessively drained. They have a surface layer of loam, sandy loam, or stony sandy loam (Bowman and Estrado 1976).

Data measurement

Three monitoring stations (NF, SF, and UNF) were used to measure streamflow, turbidity, and suspended sediment (*fig. 1*) for the entire study time period. Electronic stage monitoring equipment, instream turbidity probes, and automated pump samplers were deployed at each site. The portion of the North Fork below the Upper North Fork monitoring station was intended as the treatment area, where logging occurred in 2008, while the South Fork and Upper North Fork were intended as the control watersheds.

Streamflow was measured year round; suspended sediment and turbidity were measured during storm events. Relationships between Turbidity and SSC measurements were developed by storm. The total mass or load of sediment for each storm was calculated by multiplying the hourly streamflow volume by the SSC then summing the hourly loads for the storm. Precipitation was measured with tipping bucket gauges at four locations within the Little Creek study watersheds for the study time period (*fig. 1*). Air temperature measurements were from the California Department of Forestry and Fire Protection Ben Lomond climate station (CDEC 2011) approximately 6 km from Little Creek.

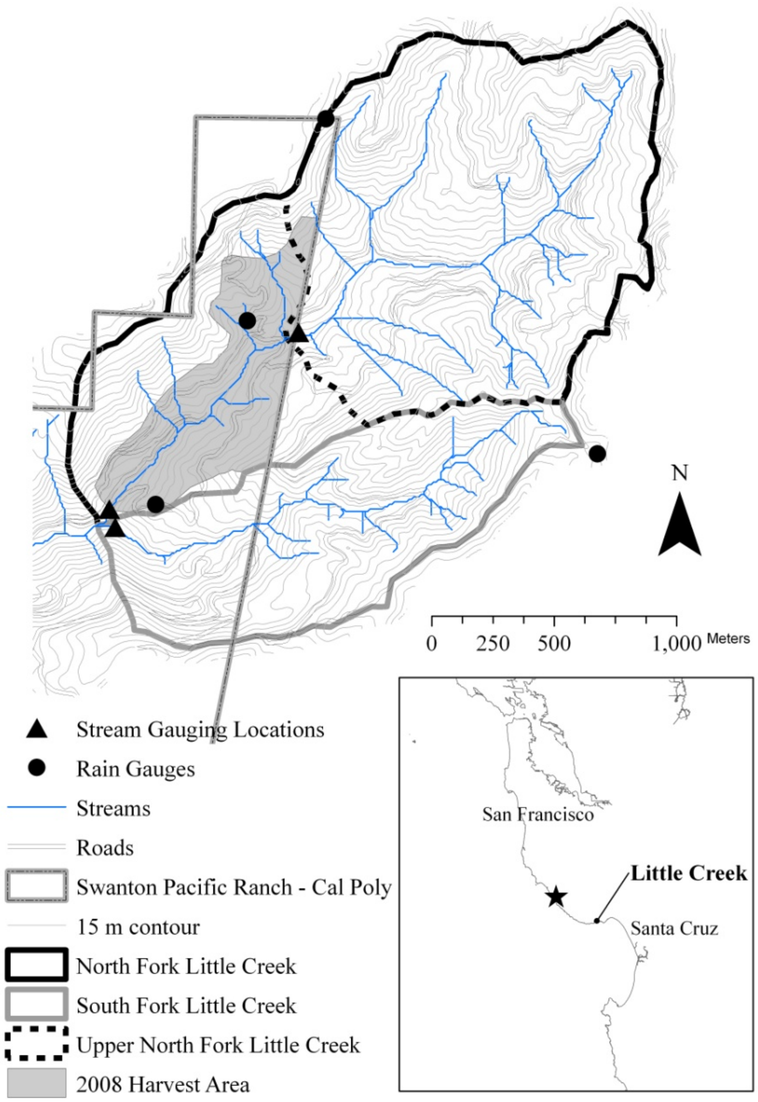


Figure 1—Little Creek study watersheds, California.

Approach to change detection study

A modeling approach will be used to determine if there was change in runoff and storm sediment loads due to disturbances of forest harvest and wildfire. The approach will use the measured runoff and sediment from the pre-treatment time period of 2002 to 2008 water years (WY) for the NF and 2002 to 2009 WY for the SF and UNF to fit hydrologic and erosion models. The differential evolution adaptive metropolis approach (DREAM) (Vrugt et al. 2009) or the Generalized Likelihood Uncertainty Evaluation (GLUE) (Beven and Binley 1992) will be used to address parameter and forcing data (precipitation and meteorological data input to models) uncertainty in the model simulations. The output from each model following the uncertainty analysis will be a range of acceptable answers from the models; this range represents the uncertainty in model use. The model uncertainty in our evaluations will be represented by using the median, 2.5 percentile, and 97.5 percentile model results for each model time step.

Our data analysis approach will be similar to what has been previously used in paired watershed studies. In paired watershed studies statistical models (commonly linear regression) are fit to pre-disturbance measurements for the control and treated watershed. Post-disturbance statistical models between the control and disturbed watershed measurements are compared to pre-disturbance for detection of change. Because our control watershed was disturbed by wildfire we will fit hydrologic and erosion models to the pre-disturbance time period for each station. We will develop regression models between the simulated response (from models) and the measured response. We will use the hydrologic and erosion models fit to the pre-disturbance measurements to model the post-disturbance time period. We then develop post-disturbance regression models between the simulated response, as if harvest or fire had not occurred, with the measured response from harvest and fire disturbance. Prediction intervals will be developed for each of the regression relationships. Change from pre-disturbance will be determined by whether the post- disturbance regression model and model innovations (individual events) are outside the pre-disturbance prediction intervals. This will be replicated for the median, 2.5 percentile, and 97.5 percentile relationships to provide a measure of range of detectability under model uncertainty (Zegre et al. 2010).

We will use four models for our change detection analysis, two hydrologic models and two watershed erosion models. The hydrologic models to be used are HBV-EC, a conceptual hydrologic model (Canadian Hydraulic Centre 2010), and the Distributed Hydrology Soil Vegetation Model (DHSVM) (Wigmosta et al. 1994) a physically-based distributed model. The watershed erosion models will be the process based model, DHSVM-Sediment (Dooten et al. 2006), and the surface erosion model Water Erosion Prediction Project (WEPP) (Flanagan et al. 1995). Change detection will be analyzed for the storm runoff volume, daily streamflow, monthly streamflow, and storm sediment load. Simple linear regression can be used for evaluating storm runoff volume and sediment load because storm events satisfy the independence requirements of regression analysis. When evaluating daily and monthly streamflow serial auto correlation will be present and will have to be accounted for and used within a generalized linear regression analysis.

Two approaches will be utilized to simulate storm sediment load. The first approach will use the relationship between HBV-EC and DHSVM simulated storm runoff and measured storm sediment load. In the first approach storm sediment load will be calculated by two different methods. The first method simulated storm runoff will be used for linear regression relationships with measured storm sediment load. In the second method simulated storm sediment load calculated from simulated runoff will be used for linear regressions relationships with measured storm sediment load. The second approach to storm sediment load change detection will use two different watershed erosion models to estimate storm sediment load. The second approach to storm sediment load change detection will use two different watershed erosion models to estimate storm sediment load. DHSVM-Sediment and WEPP will be used to estimate storm sediment loads. Simulated storm sediment load calculated from the erosion models will be used for linear regressions relationships with measured storm sediment load. Additionally we will make adjustments to the vegetation, hydrology, and ground cover in DHSVM-Sediment and WEPP to represent both the forest harvest (2009 water year for the NF) and the wildfire (2010). These manipulated models will be run for the post-disturbance time periods for comparison to measured response.

In paired watershed studies the control-treatment watersheds are located as close as possible to eliminate climate variations between the watershed pairs. In our modeling approach we compare pre-and post-disturbance which are independent time frames. The unaccounted variations in climate make possible a rejection or acceptance of the null hypothesis when it should not be, Type I or II errors respectively. To test if climate variation differs in the post-disturbance time period from pre-disturbance total precipitation and mean temperature for storm events for the pre-disturbance (2002 to 2008) and post-disturbance time periods of forest harvest (2008) and wildfire (2009 to 2010) will be tested for difference using a Wilcoxon Rank Sum test.

Example of modeling approach for storm sediment load and runoff using HBV-EC

The HBV-EC hydrology model was applied to NF and SF at an hourly time interval to demonstrate change detection of storm runoff and one method of storm sediment load analysis. Comparison of measured and HBV-EC simulated storm runoff volume for the two watersheds in Little Creek, NF and SF indicates that no change is detectable between the pre-harvest relations and the one post-harvest water year for NF (2009) and one post-fire water year for both NF and SF (2010) (*fig. 2*). All innovations of post- disturbance storm runoff volume were found within the 95 percent prediction interval of the pre-harvest regression model, with the exception of one storm from the post- harvest year of the NF, which was lower than pre-harvest values. This was true for the entire range of HBV-EC simulated runoff (median, 2.5 percentile, and 97.5 percentile values).

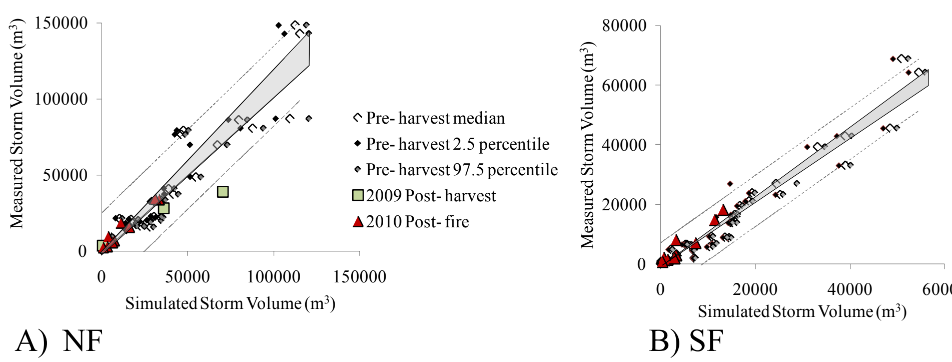
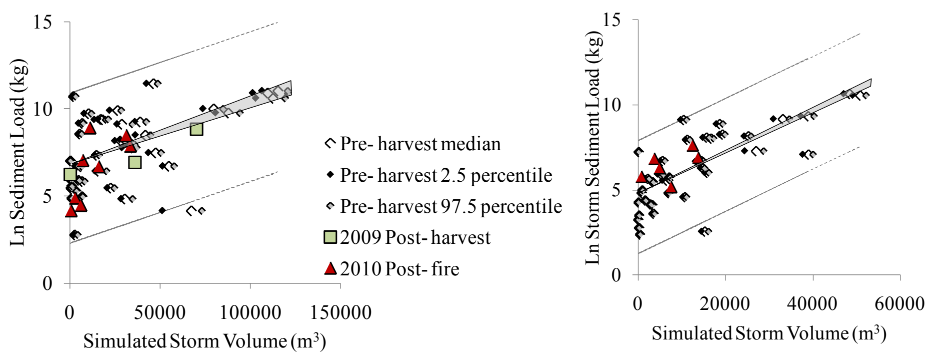


Figure 2—Storm runoff comparison pre- and post-disturbance for A) North Fork Little Creek, and B) South Fork Little Creek. Grey shaded area represents range of linear regression relationships between simulated 2.5 and 97.5 percentiles and measured storm volume, thick dashed line is regression line post-fire, thin dashed lines are 95 percent prediction intervals for median regression line.

Similarly, comparison of the natural log of measured sediment load and HBV-EC modeled storm runoff volume for the two watersheds in Little Creek, NF and SF, indicates that no change is detectable between the pre-harvest relations and the one post- harvest water year for NF (2009) and one post-fire water year (2010) for both NF and SF (*fig. 3*). All innovations of post-disturbance storm runoff volume were found within the 95 percent prediction interval of the pre-harvest regression model. This was true for the entire range of HBV-EC simulated runoff (median, 2.5 percentile, and 97.5 percentile).



A) NF B) SF

Figure 3—Storm sediment load comparison pre- and post-disturbance for A) North Fork Little Creek, and B) South Fork Little Creek. Grey shaded area represents range of linear regression relationships between simulated 2.5 and 97.5 percentiles and measured storm volume, thick dashed line is regression line post-fire, thin dashed lines are 95 percent prediction intervals for median regression line.

The demonstration of the modeling approach, using the hydrology model HBV-EC, for evaluating harvest and fire hydrologic and sediment effects in Little Creek did not find detectable changes. However, only one year of post-harvest and post-fire events were used. In both these years no large storm events occurred and the number of storm events was low. When you look at the data using only the smaller storm events (< 1 year recurrence), events of similar size for both the pre- and post-disturbance time periods a potential effect from the fire is observed (*fig. 4*). However, we emphasize we do not have evidence this effect occurs for larger events.

Future years of measurement will make the post-disturbance data set more robust and provide more complete results. The analysis does suffer from the results of using one hydrology model. The HBV-EC model is a simple model and did not always quantify the hydrology of Little Creek accurately; see the comparison of pre-harvest measured and modeled storm runoff volumes (*fig. 2*). HBV-EC poorly predicts a few of the storm events creating an artificial variability to the pre-harvest data set. Additional effort at model parameterization would improve the model. Integrating other models into our analysis will allow contrast of the different results and strengths and weaknesses of each model providing improved interpretations of the watershed response.

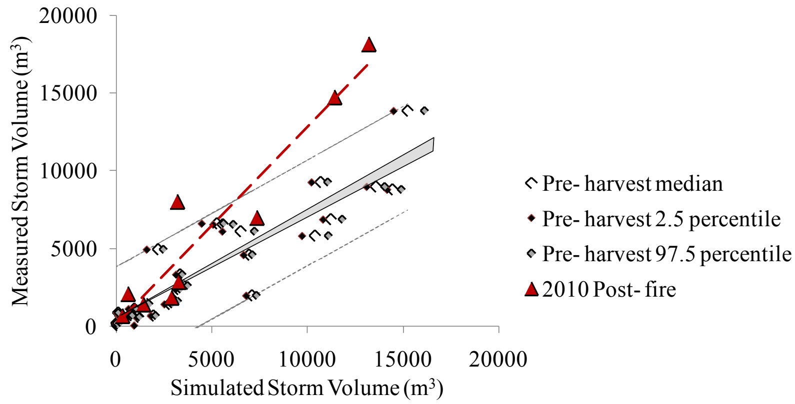


Figure 4—Small storm runoff (< 1 year event) comparison pre- and post-fire for South Fork Little Creek. Grey shaded area represents range of linear regression relationships between simulated 2.5 and 97.5 percentiles and measured storm volume, thick dashed line is regression line post-fire, thin dashed lines are 95 percent prediction intervals for median regression line.

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