The Impact of Timber Harvest Using an Individual Tree Selection Silvicultural System on the Hydrology and Sediment Yield in a Coastal California Watershed

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Abstract
There is still widespread concern regarding the environmental impact of timber harvest. This is certainly true for timber harvest activities that occur on the Swanton Pacific Ranch, the school forest for the California Polytechnic State University, located in Santa Cruz County, California. A paired watershed study was carried out to help determine the impact of contemporary forest practices on the hydrology and sediment yield of the Little Creek watershed in the Swanton Ranch. Discharge and suspended sediment were measured at two gauging stations, the North Fork and South Fork of Little Creek, from 2002 to 2009. The calibration period extended from 2002 to 2008. Timber harvest occurred in the summer of 2008 and three storms occurred during the winter after timber harvest. During the summer of 2009, the Lockheed Fire occurred and significant portions of both watersheds were burned, thus the South Fork lost its value as a control watershed. Hourly peak flows, total storm quickflow volume, and total storm sediment yield were analyzed for 35 storms during the calibration period and for the three storms that occurred during the post-harvest winter. There was no evidence that the timber harvest had any impact on the hydrology or sediment yield of the Little Creek watershed.

Key words: hydrology, sediment yield, individual tree selection

Introduction

The impact of timber harvest on the hydrology and sediment yield of forested watersheds is a topic of ongoing concern and study. Research results from seminal paired watershed studies in the Pacific Northwest (PNW) show that timber harvest activities do affect annual water yield (Harris 1973, Rothacher 1970, Wright et al. 1990), peak flows (Harr et al. 1975, Jones and Grant 1996, Rothacher 1973, Ziemer 1981), and sediment yield (Brown and Krygier 1971, Fredriksen 1970, Lewis 1998). These results, for the most part, chronicle the environmental impact associated with a bygone era. In that era the trees to be harvested were very large, roads were constructed commiserate with the harvest, the logging machinery was large and had a significant environmental footprint, and finally, there were no Best Management Practices (BMPs) applied. In the ensuing 3 to 4 decades forest practices have changed drastically. Contemporary managed forests are made up of smaller, more uniform, harvest-regenerated stands, the road systems exist, the logging machinery is smaller and has a smaller environmental footprint, most importantly, timber harvest

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activities are highly regulated and BMPs are used. This is certainly the case for the Swanton Ranch in Santa Cruz County, California (Piirto et al. 1999). Nonetheless, there is still ongoing concern regarding the environmental impact of timber harvest activities. The objective of this project was to investigate the impact of timber harvest activities in harvest-regenerated redwood stands with an individual tree selection silvicultural system on the hydrology and sediment yield of the Little Creek watershed.

Methods

Study area

This paired watershed study was carried out in the Little Creek watershed located on the Swanton Pacific Ranch, which is the school forest for the California Polytechnic State University in San Luis Obispo. Swanton Ranch is located 18 km northeast of Santa Cruz near Davenport, California. The two watersheds that made up this study are the South Fork Little Creek (SF), which has an area of 106 ha and was the control watershed, and the North Fork Little Creek (NF), which has an area of 106 ha, was the control watershed (*fig. 1*).

The elevation of the study watersheds ranges from 100 to 580 m and average annual precipitation ranges from approximately 450 to 1400 mm from the outlet to the higher elevations (Gaedeke 2006). For the period of study, 2002 to 2010, the average annual precipitation was 875 mm at the outlet of the study watersheds to 1060 mm on the ridgelines. The soils in the study watershed are deep to moderately deep, well drained to somewhat excessively drained, and have a surface layer of loam, sandy loam, or stony sandy loam (Bowman and Estrado 1976). The forest on the Swanton Ranch in lower Little Creek is a harvest-regenerated stand of redwood (*Sequoia sempervirens*) and Douglas-fir (*Psuedotsuga menziesii*). The stand is, nominally, 100 years old and before harvest has 280 ft2 of basal area, 45 mbf/ac, and an incremental growth of 500 bf/ac/yr. The stands are comprised of 60 percent redwood, 25 percent Douglas fir, and 15 percent tanoak (*Lithocarpus densiflora*) (Piirto et al. 1999).

Timber harvest treatment

During the summer of 2008, timber harvest took place on 116 ac (47 ha) of the Swanton Ranch property above the gauging station on the NF Little Creek. The silvicultural system used was an individual tree selection system in compliance with the Santa Cruz County Rules of the California Forest Practice Regulations. The timber harvest removed 728 trees that accounted for 3,882 ft2 of basal area and 824 mbf (gross scale) of volume. Timber harvest removed, on average, six trees per ac that accounted for 33 ft2 of basal area and 7,103 bf per ac. Those values represent 23 percent of the basal area and volume in unmanaged redwood stand in lower Little Creek. The harvest was carried out with ground based systems, tractors, and aerial systems, slackline skyline. Approximately 62 percent of the volume was harvested with tractor systems and 38 percent was harvested with cable systems. Harvest operations took place, for the most part, off of existing roads.

Data collection

Precipitation was measured with four tipping bucket rain gauges located in the Little Creek study watersheds (*fig. 1*). Streamflow, turbidity, and suspended sediment concentration (SSC) were measured at two gauging stations located at the outlets of the NF and SF Little Creek for the study period (*fig. 1*). Pressure transducers were used to measure stage that was stored on data loggers and converted to discharge with empirical stage vs discharge relationships. Turbidity was measured with real-time, instream turbidity probes. Automatic pump samplers were used to collect water samples during storms that were later analyzed for suspended sediment concentration. Streamflow was measured year round but values of turbidity and water samples for SSC were taken hourly just during storms.

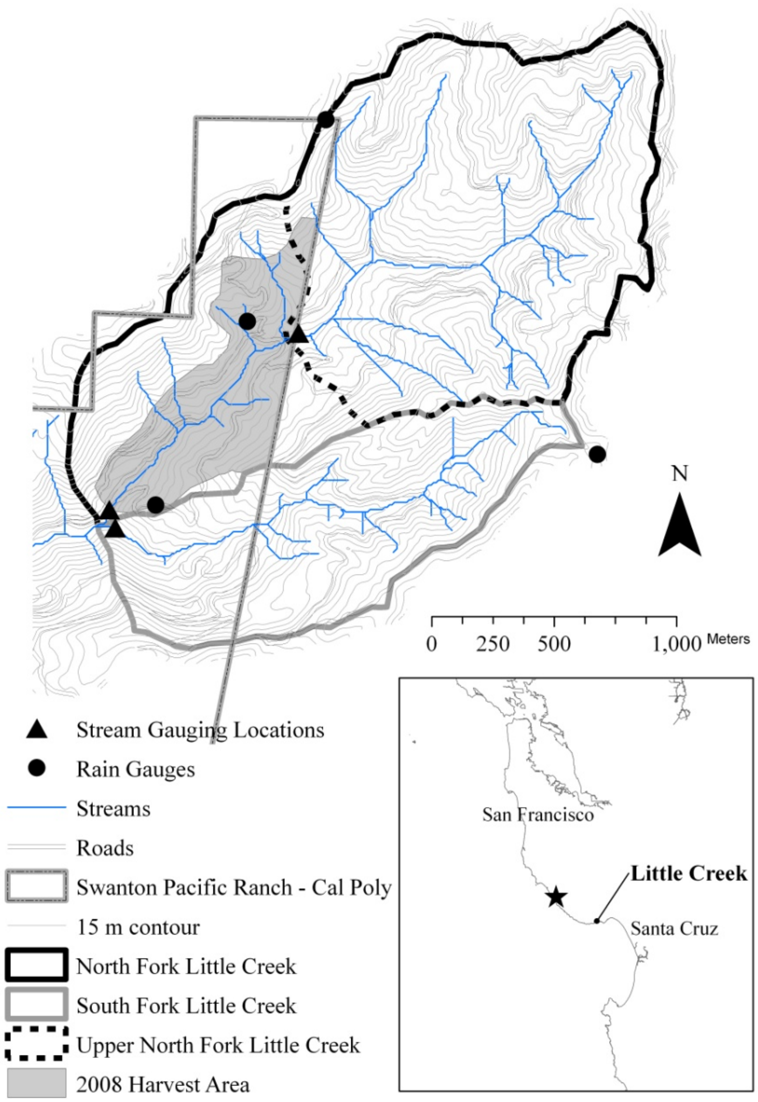

Figure 1—Little Creek study watersheds, California.

Data analysis

Three parameters were selected to use for analysis of the streamflow and sediment yield data; peak flow, total storm quickflow volume, total storm sediment yield. Gaedeke (2006) described how storms were selected from the time series streamflow data. Subsequent analysis of the streamflow data used his approach. Once a storm was defined, the peak flow is the maximum hourly flow in the storm hydrograph and is reported in l/s/ha. A standard hydrograph separation (Hewlett and Hibbert 1967) was performed to determine the total storm quickflow volume and this value is reported in mm. Finally, turbidity vs SSC relationships were developed so SSC values could be estimated. SSC in mg/l were multiplied by hourly discharge in l/s to give an hourly sediment discharge, which were summed to give the mass of sediment for the storm, expressed in kg. Unique relationships between turbidity and SSC were storm and watershed specific. Examples of these relationships and how they were developed is presented in Gaedeke (2006).

For the calibration time period, 2002 to 2008, pairs of values from the control (SF) and the treatment (NF) watershed for peak flow, total storm quickflow volume, and total storm sediment yield were plotted. These data were not homoscedastic, thus a log transform was performed on the variable values to satisfy that assumption. A linear regression was performed on the transformed data and plotted with the data. Then values of the 95 percent prediction limit were calculated and added to the graphs. Log transform values for peak flow, total storm quickflow volume, and total storm sediment yield for the three storms that occurred during the post-harvest water year were added to the plots. The location of the post-treatment data points relative to the 95 percent confidence limits were used to evaluate if a statistically significant, post treatment effect occurred the first winter after timber harvest.

During the summer of 2009 the Lockheed Fire occurred. Significant portions of the NF and SF of Little Creek were involved in that fire. The SF Little Creek no longer had value as a control watershed for the study. Thus, no further post-harvest data are available.

Results

The data set that was analyzed for this study consisted of 38 storms that occurred between December 2002 and March 2009. Of these 38 storms, 35 occurred during the calibration period between December 2002 and February 2008. Three storms occurred during WY 2009 after timber harvest was carried out.

For the calibration period for the SF Little Creek, the control watershed, the average peak flow was 1.08 l/s/ha and the values ranged from 3.46 to 0.13 l/s/ha. The three peak flows for the post logging period were 0.39, 1.34, and 1.02 l/s/ha for an average of 0.92 l/s/ha. For the calibration period for the NF Little Creek, the treatment watershed, the average peak flow was 1.28 l/s/ha and the values ranged from 4.79 to 0.14 l/s/ha. The three peak flows for the post logging period were 0.49, 1.53, and 0.86 l/s/ha for an average of 0.96 l/s/ha. All three of the peak flows that occurred after logging during WY 2009 were within the variability exhibited by the population of calibration peak flows (*fig. 2a*). There was no observed impact of the timber harvest on peak flows.

For stormflow volumes the control watershed, the SF Little Creek, for the calibration period had an average of 16.2 mm and the values ranged from 67.5 to 0.2 mm. The three storms for the post logging period had quickflow volumes of 0.6, 11.8, and 9.9 mm for an average of 7.4 mm. For the treatment watershed, the NF Little Creek, for the calibration period storm quickflow averaged 11.1 mm and the values ranged from 51.4 to 0.4 mm. The three storms in the post logging period had quickflow volumes of 0.2, 14.5, and 10.5 mm for an average of 8.3 mm. Once again, the values of storm quickflow for the three post logging storms fell within the variability exhibited by the calibration data (*fig. 2b*). There was no observed impact of timber harvest on storm quickflow volumes.

For total storm sediment yield the SF Little Creek, the control watershed, for the calibration period had and average of 31.8 kg/ha and a range from 396 to 0.1 kg/ha. The three storms for the post logging period had total storm sediment yields of 4.9, 64.9 and 9.5 kg/ha for an average of 26.4 kg/ha. For the treatment watershed, the NF Little Creek, for the calibration period the total storm sediment yield averaged 35.9 kg/ha and ranged from 331 to 0.1 kg/ha. The three storms during the post logging period had total storm sediment yields of 0.3, 5.2, and 1.5 kg/ha for an average of 2.3 kg/ha. The total storm sediment yield from the post logging period fits well within the variability exhibited by the calibration data (*fig. 2c*). There was no observed impact of timber harvest on total storm sediment yield.

Discussion

It should not be surprising that there is no detectable impact of the timber harvest that occurred in the NF Little Creek in 2008 on the hydrology and sediment yield of the NF the first winter after logging. The reasons for this are the scale and intensity of the timber harvest operations in the NF Little Creek watershed. In published results from the seminal watershed studies the size of the treatment watersheds were often very small, 70 to 101 ha, compared to the size of the NF Little Creek watershed, 291 ha (Brown and Krygier 1971, Rothacher 1970). The Caspar Creek study watersheds had comparable sizes, 508 and 425 ha (Lewis 1998).

But more important than the scale of the timber harvest activities is the intensity. In all of the seminal paired watershed studies the silvicultural system was clearcut and the percent area affected ranged from 30 to 100 percent (Brown and Krygier 1971, Fredriksen 1971). The exception, again, is the Caspar Creek study where the South Fork was harvested with an individual selection system but 100 percent of the area supported operations and 59 percent of the volume was removed (Lewis 1998). The silvicultural system for the NF Little Creek was individual tree selection, harvest operations were conducted on only 20 percent of the area above the gauging station and only three percent of the volume and basal area of the forest above the gauging station was removed.

Bosch and Hewlett (1982) report that it takes removal of forest canopy on at least 20 percent of the area of a watershed to detect an impact on annual water yield. While this analysis did not investigate annual water yield, the 3 percent volume and basal area removed is well below the published threshold of 20 percent. The scale and intensity of the harvest operations essentially precluded a significant effect on hydrology.

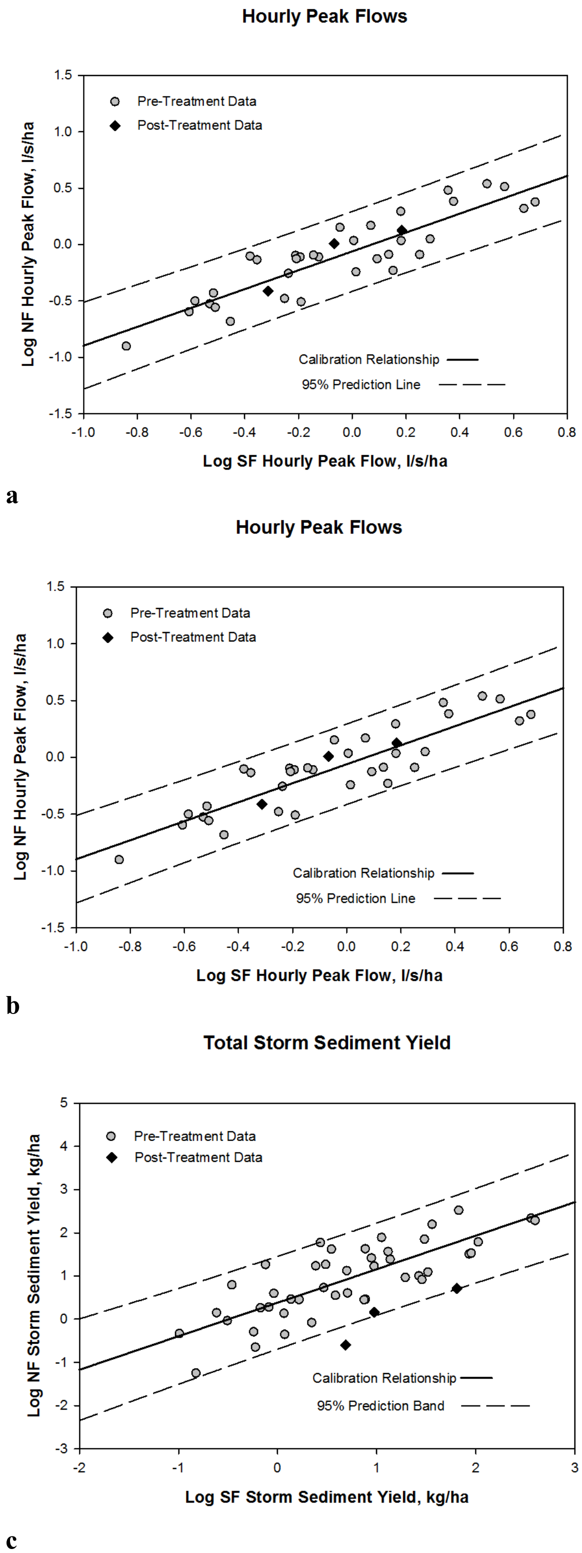

Figure 2—Three graphs showing data for the control (SF) vs the treatment (NF) watersheds for the pre-treatment and post-treatment data for a) hourly peak flows, b) total storm quickflow, and c) total storm sediment yield.

There is a concern that given the paucity of post-harvest data this study may not give a true test of the impact of the forest practices used in the NF Little Creek on the hydrology and sediment yield of the watershed. This is not the case. While there are differing opinions regarding the impact the timber harvest on peak flows, those differing opinion are usually with regard to large peak flows (Grant et al. 2008). There is widespread agreement that timber harvest can and does affect small peak flows (Ziemer 1981) or the peak flows that may occur many times a year, the first winter after timber harvest occurs. The mean annual flood (MAF) for the NF Little Creek during the period of record, was 1.94 l/s/ha and the three post harvest peak flows, 0.49, 1.53, and 0.86 l/s/ha, were all below the value of the MAF. These are the size flows that could and should be affected by timber harvest the first winter after logging occurs. These flows represent an excellent opportunity to evaluate the impact of timber harvest on the hydrology of a watershed.

While the scale and intensity of the harvest combined with the size of the post-harvest peak flows may help explain the lack of an impact to the hydrology of the NF Little Creek, it doesn't necessarily explain away the lack of significance in the sediment yield data. It does explain part of the lack of significance in the sediment yield data because sediment yield and streamflow are very tightly correlated. In all of the seminal paired watershed studies an increase in sediment yield was always accompanied by an increase in water yield and storm flow. However, the degree that the increased sediment yields are a function of increased stream power versus an increase in the erosion rate of the watershed has never been fully investigated.

Nonetheless, the two harvest entries for the Caspar Creek Watershed Study did conclusively exhibit the importance of contemporary Best Management Practices in mitigating increases in sediment yield associated with timber harvest. Accelerated erosion associated with timber harvest was reduced by roughly an order of magnitude when contemporary BMPs were used in the 1990s compared with the practices used in the 1960s and 1970s. A compelling hypothesis to put forward is that the combination of the reduced scale and intensity of timber harvest activities in conjunction with the use of contemporary BMP's resulted in levels of accelerated erosion, which must occur, that remained within background variability.

Conclusion

Hourly peak flows, total storm quickflow volume, and total storm sediment yield were analyzed for 35 storms that occurred prior to timber harvest activities and three storms that occurred during the winter after timber harvest occurred. There is no evidence in any of the results that the timber harvest activities had any impact on the hydrology or sediment yield of the NF Little Creek watershed. This finding should not be surprising given the scale and intensity of the timber harvest activities. Timber harvest removed only about two percent of the basal area in the NF Little Creek watershed above the gauging station effectively negating a discernable impact on the hydrology. It is hypothesized that in the absence of a significant impact on the hydrology, the forest practice regulations and BMP's were effective in keeping the accelerated erosion, which must occur, within background variability.

Acknowledgments

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