Assessing Effects of Changing Land Use Practices on Sediment Loads in Panther Creek, North Coastal California[1]

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Abstract

Revisions to the California Forest Practice Rules since 1974 were intended to increase protection of water quality in streams draining timber harvest areas. The effects of improved timber harvesting methods and road designs on sediment loading are assessed for the Panther Creek basin, a 15.4 km^2 watershed in Humboldt County, north coastal California. We compute land use statistics, analyze suspended sediment discharge rating curves, and compare sediment yields in Panther Creek to a control (unlogged) stream, Little Lost Man Creek. From 1978 to 2008, 8.2 km^2 (over half the watershed) was clearcut and other timber management activities (thinning, selection cuts, and so forth) affected an additional 5.9 km^2. Since 1984, 40.7 km of streams in harvest units received riparian buffer strip protection. Between 2000 and 2009, 22 km of roads were upgraded and 9.7 km were decommissioned, reducing potential sediment production by an estimated 40,000 m^3. Road density is currently 3.1 km/km^2. Sediment rating curves from 2005 to 2010 indicate a decrease in suspended sediment concentrations when compared to the pre-1996 period, although Panther Creek still has a higher sediment yield on a per unit area basis than the control stream.

Key words: suspended sediment rating curves, timber harvest, watershed assessment, sediment yield

Introduction

Historically, timber harvest and related road construction have caused accelerated hillslope erosion and sediment delivery to streams, impacting salmonid habitat in California and the Pacific Northwest (Meehan 1991, Murphy 1995). In recognition of these problems, several regulatory efforts have been implemented to ameliorate the effects of land use activities on streams. For example, revisions to the modern California Forest Practice Rules, implemented beginning in 1974, were intended to increase protection of water quality in streams draining timber harvest areas. Protective measures included use of improved riparian buffers, where timber harvest operations are limited, and improved standards for newly constructed and upgraded roads. In July 2000, the California Forest Practice Rules changed watercourse crossing sizing requirements for new or reconstructed permanent stream crossings from a 50-year storm to a 100-year storm (CDF 2001), thus gradually reducing the risks of culvert failure and resultant gullies and landslides as new larger culverts are installed. Forest Practice Rule changes in 1983 changed how streams were classified and increased tree retention along Class I (fish bearing) and Class II (habitat present

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[1] This paper was presented at the redwood science symposium: coast redwood forests in a changing California. June 21-23, 2011. Santa Cruz, California.

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for non-fish aquatic species) streams. Class III streams contain no aquatic life and receive the least protection.

In addition, Section 303(d) of the federal Clean Water Act of 1972 requires states to identify water bodies that do not meet water quality standards and are not supporting their beneficial uses. Redwood Creek in Humboldt County, north coastal California, was 303(d) listed as sediment impaired in 1996, and a Total Maximum Daily Load (TMDL) was developed for the watershed in 1998 (CRWQCB 1998a, 1998b). The Redwood Creek Sediment TMDL identified major sediment sources to Redwood Creek as streamside landslides, gully erosion, and cutbank and fillslope failures on unpaved logging roads. Although state forest practice rules do not require long-term road inspection and maintenance, the TMDL included targets for desired watershed conditions with respect to road design, location, inspection, and maintenance along with timber harvest practices in sensitive streamside areas. In recent years landowners in the basin have conducted several erosion control projects on their lands to address erosion concerns. Madej et al. (2007) evaluated sediment loads in the mainstem of Redwood Creek in the context of the TMDL, but trends in sediment yields in tributary basins of Redwood Creek have not yet been analyzed to that extent.

In Panther Creek, a tributary of Redwood Creek, timber harvest has been the primary land use since the 1930s. Green Diamond Resource Company (GDRCo), the current landowner, began implementing an Aquatic Habitat Conservation Plan (AHCP) in 2007, which includes the Panther Creek basin. During the past decade, GDRCo has completed several road assessments, road upgrades and road decommissioning projects in the watershed. Since 1980, the U.S. Geological Survey (USGS) and Redwood National Park (RNP) have operated a stream gaging station at the mouth of Panther Creek, where stream discharge and suspended sediment are measured. Consequently, it is an opportune time to evaluate sediment yields measured at the gaging station to determine if sediment reduction goals have been met. The objective of this paper is to evaluate possible changes in sediment loading in Panther Creek due to improvements in timber harvest methods and road designs and maintenance by analyzing shifts in suspended sediment discharge rating curves, and comparing sediment yields in Panther Creek to a nearby control (unlogged) stream.

Field area

Panther Creek has a drainage area of 15.4 km^2 (*fig. 1*). Total basin relief is 600 m. The bedrock is a quartz-mica schist of the Franciscan assemblage. Aerial photographs taken in 1936 show that about half of the basin was covered with old-growth redwood and Douglas-fir forests, but upper hillslopes had been clearcut logged and yarded using steam donkeys (steam-powered winches that dragged logs across the hillslopes) and railroad equipment. Harvest operations accelerated in the 1950s with increased demand for timber products following World War II. Beginning in the late 1940s and continuing into the 1980s ground based equipment, such as crawler tractors, were used for skidding. By the early 1980s nearly all of the old-growth forest had been harvested. Second-growth harvest activities began in the 1980s utilizing commercial thinning and rotational harvests as the timber reached commercial size and age. The majority of roads in Panther Creek were constructed before implementation of the Z'berg-Nejedly Forest Practice Act beginning in 1974, which provided for more stable road designs in subsequent years. In addition, the early old-growth harvesting retained very minimal riparian protection along streams.

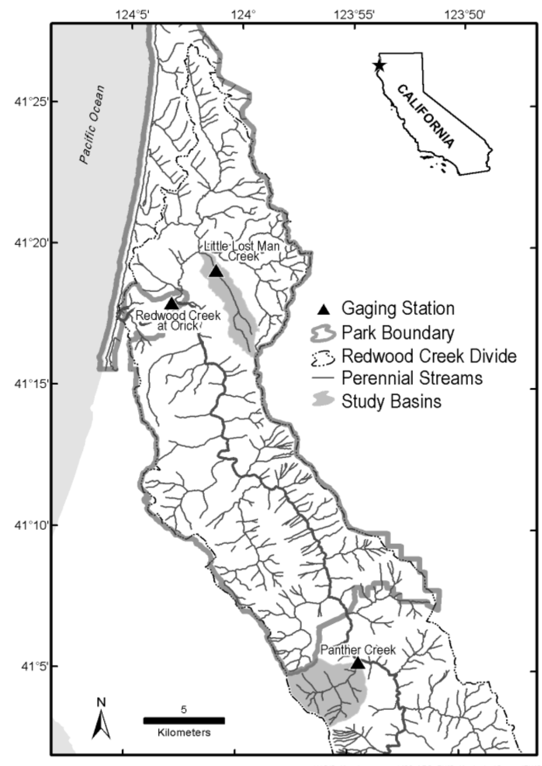

Figure 1—Location map.

In 1980 the USGS, in cooperation with Simpson Timber Company (later renamed Green Diamond Resource Company), established a gaging station on Panther Creek (Station #11482125). In addition, the USGS established a gaging station on an unlogged tributary in the lower Redwood Creek basin, Little Lost Man Creek (Station #11482468) in 1975 (*fig. 1*). Little Lost Man Creek (9.1 km^2) is underlain by sandstones and mudstones of the Franciscan assemblage. Basin relief, at 610 m, is similar to Panther Creek, and both basins exhibit similar erosion processes (primarily shallow debris slides and debris flows). Continuous streamflow and storm flow suspended sediment samples were obtained at both stations. RNP assumed operations of the gaging stations in 1993. In 2006 RNP installed turbidity sensors at the gaging stations to supplement the suspended sediment sampling program.

The Panther Creek basin receives an average of about 2,000 mm of precipitation annually, most of which falls as rain between October and March. Annual mean flow is 0.68 cms. The highest peak flow of the 30-year record, 57 cms, occurred on January 1, 1997, although based on records from Redwood Creek, peak flows in the 1960s and 1970s were probably larger (*fig. 2*). The storm in January, 1997 initiated 13 landslides > 400 m^2 in area in the Panther Creek basin, which mobilized about 24,000 m^3 of material. About 80 percent of this volume was generated by landslides associated with roads and landings, including a 9,000 m^3 debris flow that severely scoured the channel (Curren 2007). Several smaller landslides occurred the previous year as well. Annual rainfall in Little Lost Man Creek basin is 1,700 mm and mean annual flow is 0.34 cms. No landslides were detected here on 1:6,000 air photos following the 1997 storm.

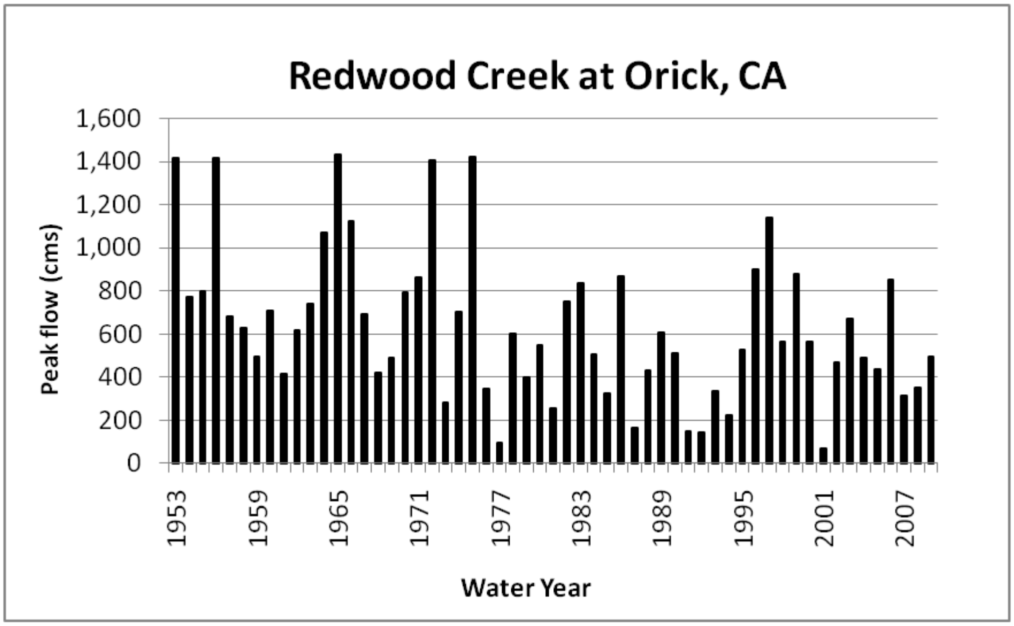

Figure 2—Peak flows at Redwood Creek at Orick, CA.

Methods

We used timber harvesting plans approved by California Department of Forestry and Fire Protection (CAL FIRE), aerial photographs, and field-based road inventories to compile land use statistics for the Panther Creek watershed. Because work proposed in a timber harvesting plan may be implemented any time within three years of plan approval, exact dates of some timber harvest and road work are not known. Attributes included the timing and size of timber harvest, silvicultural and yarding methods, and level of streamside protection (RNP, unpublished data). Little Lost Man Creek is almost completely unlogged, with no change in land use during the study period.

Gaging stations in Panther Creek and Little Lost Man Creek record water stage at 10-minute intervals. Stage data are converted to discharge values using individual stage-discharge rating curves for each station, based on occasional discharge measurements that relate recorded stage to water discharge. Since 2006, electronic turbidity sensors mounted on articulating booms have measured turbidity in the water column at 10 minute intervals. Before 1992 suspended sediment samples were collected manually at high flows, whereas after 1992 an electronic pumping water sampler collected samples according to changes in turbidity or stage (Klein 2003). Water samples were processed in USGS or RNP laboratories to obtain suspended sediment concentrations. Accuracy of suspended sediment load computations most likely improved greatly with the addition of automated pumping samplers and turbidity-controlled sampling (Lewis 1996).

We constructed suspended sediment rating curves by plotting sediment concentration (SSC, mg/l) against instantaneous discharge (cms) on a logarithmic scale for five time periods, based on groupings of water years that were wetter (w) or drier (d) than normal (n): pre-1986 (w), 1987 to 1995 (d), 1996 to 1998 (w), 1999 to 2005 (d), and 2006 to 2010 (n). (A water year (WY) extends from October 1 to September 30). We ran an ANCOVA model on the sediment data, using log(discharge) as the independent covariate, log(suspended sediment concentration) as the dependent variable, and time period as a categorical factor. An interaction variable of [time period * log(discharge)] was included to assess possible differences in intercepts and slopes of the sediment rating curves.

Annual suspended sediment loads were available for most years for WY1980 to 2010 for Panther Creek from either computations by RNP (WY1992 and later) or from the USGS (before WY1992). Annual loads also exist for most of this period for Little Lost Man Creek, with the exception of two periods (WY1983 to 1984 and WY1990 to 1992). Prior to the use of continuous recorded turbidity as a surrogate for SSC, the sediment rating curve approach was used for computing loads.

Results

Based on CAL FIRE-approved harvesting plans, the cutting rate in Panther Creek from 1978 to 2008 ranged from 0 to about 7 percent of the watershed annually, and averaged about 3 percent per year. Even-aged management (clearcut, rehabilitation, and so forth) was applied to more than 60 percent of the watershed. Non-even-aged management (thinning, selection, and so forth) was applied to an additional 30 percent during this period. For the same period, about 60 percent of the harvested area was yarded by tractors, 30 percent by cable systems and 10 percent by a combination of helicopters and feller-bunchers. In 2006 GDRCo stopped all use of tractors for ground-based yarding operations in favor of feller-bunchers, which appear to minimize ground disturbance.

Road density in the Panther Creek basin is currently 3.1 km/km^2, down from 4.2 km/km^2 in 2000. Since 2000, 24.5 km of road have been upgraded and 15.7 km have been decommissioned. The potential sediment savings associated with this work is about 40,000 m^3 (Bundros and Short 2011). Based upon road assessment data from 2004, one third of all roads assessed in Panther Creek were being maintained. In 2009, reassessment showed that three-fourths of the assessed roads were being maintained (or were maintenance-free because they have been decommissioned). GDRCo's AHCP contains standards that require road inspections and maintenance of mainline roads every year and secondary roads every 3 years for the 50-year life of the permit (GDRCo 2006), which are more stringent standards than the state forest practice rules.

Watercourse and Lake Protection Zone (WLPZ) rules were adopted by State Board of Forestry and Fire Protection and implemented in 1974, following the passage of the Z'berg-Nejedly Forest Practice Act of 1973 by the State Legislature. The rules and classification criteria for streams have changed several times, with significant changes occurring in 1983 (Berbach 2001). Since 1984, 57.6 km of streams have been included in timber harvest plans in the Panther Creek basin, of which 7.3 km were classified as Class I. Of the remaining stream length, for the period of 1984 to 1993, 44 percent (16.5 km) were classified as Class II, and 9.3 km classified as Class III. For the period 1994 to 2008, 26.2 km of stream were classified as Class II (78 percent) and only 7.6 km classified as Class III. Consequently a higher percentage of stream length received increased riparian tree retention and protection in recent years.

Sediment rating curves were constructed for five time periods (*fig. 3*). The sediment records exhibit high variability, as is typical of mountainous, forested watersheds (Sadeghi et al. 2008). Nevertheless, we can discern some statistically significant trends in the results. The results of the ANCOVA analysis show that time period is a significant variable in explaining the trends ($p < 0.001$). The earliest period (WY1980 to 1986, #1) had the steepest slope, which can indicate that new sediment sources became available when discharge increased (Asselman 2000).

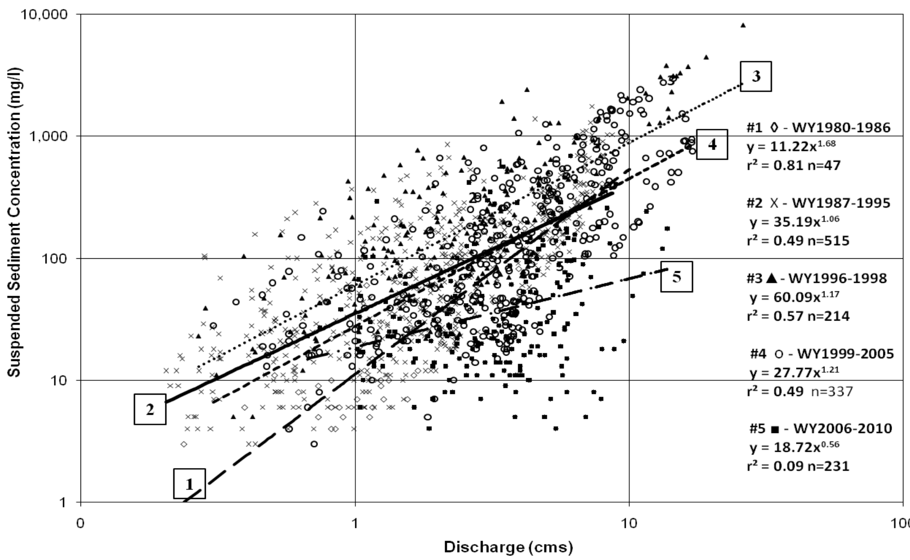

Figure 3—Sediment rating curves for Panther Creek for five time periods.

However, because of logistic difficulties in manual sampling, this early period also had far fewer samples (47) than other periods. The slope of the rating curve decreased in the following period (WY1987 to 1995, #2), showing that sediment concentrations were lower at high discharges than in the earlier period. The period with high landslide activity (WY1996 – 1998, #3) had a significant upward shift in the sediment rating curve, with higher sediment concentrations across the range of flows. These elevated levels did not persist long, however, and the curve for the period WY1999 to 2005 (#4) lowered to the WY1987 to 1995 level (intercepts were not significantly different). The most recent period (WY2006 to 2010, #5) has the lowest rating curve. Even though the relationship between suspended sediment concentration and discharge is weak for this time period (r2 of only 9.3 percent), it is still significant at the 95 percent confidence level (p-value of < 0.001).

Annual suspended sediment loads differed substantially between Panther Creek and the control stream, Little Lost Man Creek, during the common years of operation. The annual suspended sediment load for Panther Creek ranged from a low of 23 Mg to a high of 36,000 Mg. Average sediment load for Panther Creek was 220

Mg/km^2 versus 56 Mg/km^2 for Little Lost Man Creek. We compared the ratio of sediment loads for each year (Panther load divided by Little Lost Man load, *fig. 4*). The average ratio was 4, with a maximum of 20 during the high flow year of WY1997. In WY1981, 1999 and 2001 the normalized sediment load in Panther Creek was less than that of Little Lost Man Creek. In WY1999, several inner gorge landslides temporarily elevated loads in Little Lost Man Creek, thus reducing the ratio for that year. WY2001 had the lowest annual flow and the lowest sediment load values in the Panther Creek record, so the small differences between Panther and Little Lost Man creeks in low flow years (0.3 Mg/km^2) probably are not meaningful.

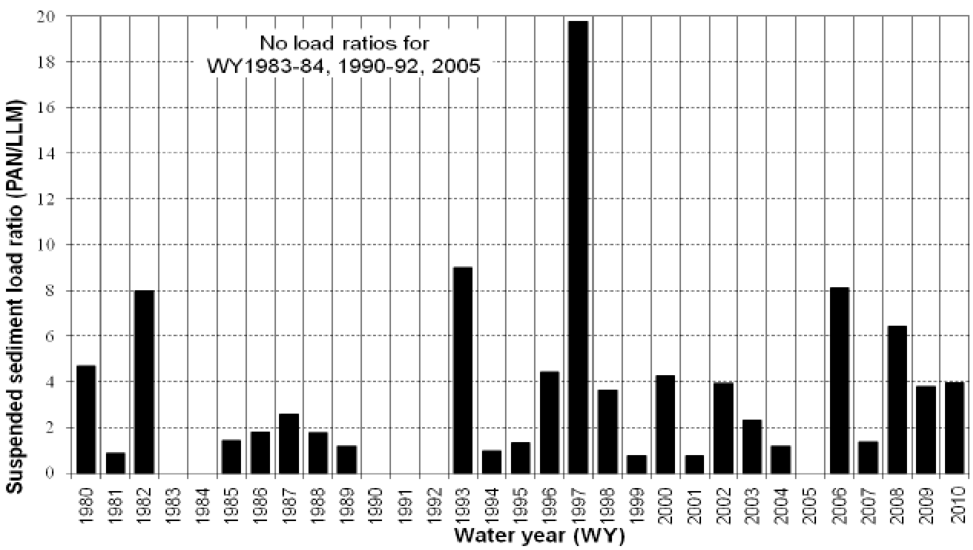

Figure 4—Comparison of annual suspended sediment yields between Panther Creek (PAN) and a control stream, Little Lost Man Creek (LLM).

Discussion

Sediment supply to rivers in forested mountainous terrain is commonly episodic in nature through such processes as mass movement and gullying. Large storms are usually needed to trigger severe erosion events, and the landslide-producing storm in Panther Creek in 1997 is an example of such an event. In the Redwood Creek basin, once material is delivered to steep low-order channels, much of it is routed downstream within a few years (Pitlick 1995). In recent years land managers have implemented erosion control work on the hillslopes of the Panther Creek basin to decrease sediment input to streams and provide more protection to sensitive streamside areas. Nevertheless, most of these treatments were implemented post-1997 and have not been “tested” by a large storm (20-year return period or greater). We would not expect reductions in erosion to be detected at the mouth of Panther Creek until such a test occurs.

Sediment rating curves shifted upward during and immediately after a period of high landslide activity in 1996 to 1998. Since then, suspended sediment concentrations at moderate to high discharges have decreased. Even so, the sediment records exhibit high variability. This variability problem may be addressed by further investigations, such as separating data by storms or hydrograph limbs. Sediment loads are still higher in Panther Creek than in the control stream, but are less than half that of the Redwood Creek basin average (600 Mg/km^2 measured at the Redwood Creek at Orick gaging station).

Assessing the influence of land use practices and hillslope improvement work on sediment loads is complicated by factors such as the lag time between implementing erosion control work and sediment transport events, the effect of legacy features from past timber harvest, and the occurrence of extreme events. The high volume of material mobilized from road-related landslides in the 1997 storm attests to ongoing sediment production from remaining legacy roads. On the other hand, current policies such as increasing riparian protection, decreasing timber harvest on inner gorge slopes, and reducing controllable sediment sources along roads may reduce sediment loads in future storms. Continued stream and hillslope monitoring will help elucidate such linkages.

Conclusions

The Panther Creek basin is an actively managed watershed with an average timber harvest rate of three percent of the watershed per year. Improvements in timber harvest techniques, streamside protection, road design and maintenance implemented in the Panther Creek basin in recent years appear to have caused a downward shift in the sediment rating curve and reduced sediment loads relative to those of decades earlier. Results from sediment sampling indicate that sediment loads were highest during a period of high landslide activity in 1996 to 1998; most of the sediment volume was contributed by landslides associated with roads and landings. Consequently, the effect of untreated legacy erosion problems in a basin can obscure the beneficial effect of improved erosion control work and improved timber harvest practices elsewhere in a watershed. Since 1998 suspended sediment rating curves for Panther Creek have shifted downward, indicating a general decrease in sediment concentrations. Annual suspended sediment yields remain about four times higher than in a control (unlogged) watershed. Hydrologic stresses during a large storm with a discharge having greater than a 20-year recurrence interval are needed to test the effectiveness of recent erosion control work and improved timber harvest methods on the hillslopes and to realize the time-delayed benefits. Adaptive land management involves monitoring the effects of management activities, and modifying land management approaches and techniques based on what is found to be effective. The data set for Panther Creek provides an excellent baseline for future assessments of improved management actions.

Acknowledgments

We are grateful for the field and technical support from Tom Marquette, and the meticulous laboratory analysis of Carrie Jones, both of Redwood National Park. Green Diamond Resource Co. provided access to the Panther Creek gaging station. Julie Yee and Philip van Mantgem provided statistical guidance, and reviews by Darci Short, Matt House, and two anonymous reviewers improved the manuscript.

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