Watershed-Scale Evaluation of Humboldt Redwood Company's Habitat Conservation Plan Timber Harvest Best Management Practices, Railroad Gulch, Elk River, California[1]

Andrew Stubblefield,[2] Shane Beach,[3] Nicolas M. Harrison,[3] and Michelle Haskins[2]

Abstract

The objective of this study is to test the effectiveness of California Forest Practice Rules and additional best management practices implemented as part of Humboldt Redwood Company's Habitat Conservation Plan and Watershed Analysis prescriptions, in limiting the delivery of management-derived sediment. A paired watershed study format is being utilized to evaluate sediment sources: road surfaces, watercourse crossings, landslides, channel incision and bank erosion, and tributary channel head-cutting. The study compares the West Branch (1.48 km^2, 365 ac) and the East Branch (1.28 km^2, 314 ac) of Railroad Gulch, a tributary to the Elk River (152 km^2) which flows into Humboldt Bay just south of Eureka, California. The watershed has been intensely logged in the past and is underlain by two erodible geologic terranes, the Pleistocene age Hookton Formation and the late Miocene to middle Quaternary age undifferentiated Wildcat Group.

Forty seven percent of the East Branch was logged in the summer of 2016 under Timber Harvest Plan 1-12-110 HUM, with 32 ha (80 ac) of single tree selection, 18 ha (45 ac) of group selection, and 10 ha (24 ac) of no-cut zone left as buffer strips along Class I and II watercourses. A new native surfaced seasonal road was constructed in the summer of 2015. Several existing roadways were reopened during the same time period. All of these roads are appurtenant to the plan and were utilized for hauling throughout the summer of 2016. Cable yarding systems were used.

No timber operations will occur within the West Branch, which will serve as the study control. Methods used to evaluate prescription performance include: pre- and post-construction road inventory and characterization, turbidity synoptic sampling during storm events, landslide inventories, channel cross-section surveys, pebble counts, continuous turbidity, stage, and rainfall monitoring, peak flow analysis, and an analysis of Beryllium-10 (Be-10) isotopes to estimate for long-term (e.g., 1000 to 10,000 year) erosion rates.

Data collection for the study began in earnest in 2014, with limited streamside landslide data collected in 2013. Sediment loads were well correlated between the two branches during an extremely dry water year (WY) and a below average water year. In WY 2014 the total annual suspended sediment load equaled 49 Mg (metric tons) km^{-2} (0.22 t ac^{-1}) in the East Branch and 38 Mg km^{-2} (.017 t ac^{-1}) in the West Branch. Loads were tenfold higher in WY 2015 in conjunction with a single large storm event which triggered several debris torrents in addition to several streamside failures. The WY 2015 total annual sediment load equaled 861 Mg km^{-2} (3.8 t ac^{-1}) in the East Branch and 716 Mg km^{-2} (3.2 t ac^{-1}) in the West Branch. Historically active debris slides and earthflows cover approximately 6 percent of the study basin. Five active upland failures have been detected during the project period; two in WY 2014 and three in WY 2015. Several of these active landslides are hydrologically connected and at selected sites were observed to strongly influence downstream turbidity. Cross-sectional surveys indicated that channel banks remained stable with limited thalweg scour between 2014 and 2015. Post-harvest monitoring will continue through 2019.

---

[1] A version of this paper was presented at the Coast Redwood Science Symposium, September 13-15, 2016, Eureka, California.

[2] Dept. of Forestry and Wildland Resources, Humboldt State University, One Harpst Street, Arcata, CA 95521.
[3] Humboldt Redwoods Company 125 Main Street, Scotia, CA 95565.
Corresponding author: aps14@humboldt.edu.

Introduction

Improved harvesting techniques such as selective harvesting, cable yarding and protection of soil with slash placement, combined with better road construction and maintenance practices, have been implemented by California timber companies in recent years in compliance with California Forest Practice Rules. The rule changes have come in response to declining salmonid populations and the 303d listing of many North Coast rivers for impairment of beneficial uses by sedimentation. In addition, Humboldt Redwood Company (HRC) has implemented best management practices as part of a Habitat Conservation Plan (HCP) and Watershed Analysis prescriptions. There is a need to investigate whether these new practices are having the desired effect in preventing discharge of sediment into rivers and minimizing the activation of erosion sources on forested landscapes.

The approach of this project is to implement a paired watershed study with a control and treatment basin that retain similar geologic, geomorphic and hydrologic traits and to collect monitoring data before, during and after road-building and harvest activities occur. The main goal of this study is to quantify the effects of land use on stream suspended sediment loads and turbidity levels, and through detailed monitoring of stream, road and hillslope condition, be able to identify the sources of any observed elevated sediment. The study will also evaluate changes to peak flow magnitude and timing resulting from timber operations, and evaluate long-term basin wide erosion denudation rates. These latter analyses and road condition surveys will be reported separately. This article reports on suspended sediment loads and sediment sources for the first two years of the study before road building and harvest activities occurred.

Methods

Study Site

The Railroad Gulch drainage, a tributary to the Elk River, Humboldt County, California, was selected for study. It contains a West Branch and East Branch of approximately equal size (1.48 km^2 and 1.28 km^2 respectively), aspect (N-facing), drainage networks, slopes and geology. Railroad Gulch is underlain by sediments associated with the Middle to Late Pleistocene aged Hookton Formation and the Miocene to Late Pliocene aged Undifferentiated Wildcat sediments. These bedrock types are highly erodible and subject to both shallow and deep-seated mass movements. The subject basins are within Humboldt Redwoods Company’s ownership.

Following initial clear-cutting and railroad harvesting in the early 1900s, this basin became restocked with dense second-growth stands comprised of various types of conifer and hardwoods. Stands are currently composed of approximately 85 percent redwood (*Sequoia sempervirens* (D. Don) Endl.), 12 percent Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), 2 percent grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), and Sitka spruce (*Picea sitchensis* (Bong.) Carrière, and 1 percent hardwoods (primarily red alder, *Alnus rubra* Bong.). Selection and even-aged silvicultural practices were applied to the second growth stands within the study area between 1987 and 2002. Between 2001 and 2008, 25.9 ha (64 ac), distributed between both branches, were clearcut. Current stands are primarily even aged.

Forty seven percent of the East Branch was initially entered in the summer of 2015 to open existing roadways and to construct new road. These roads are natural surfaced seasonal haul roads that were constructed and storm-proofed in accordance with HRC’s HCP prescriptions. Approximately 500 m of this haul road network does pass through the lower reaches of the West Branch basin (control). Road surfaces along this segment that fall within Riparian Management Zone (RMZ) were rocked and erosion-control wattles (rolls of absorbent coconut fiber batting) were installed across all water bars, diversion potential dips, and rolling dip outfalls that directed surface water toward the West Branch to discourage road-derived sediment from entering the control basin.

In the summer of 2016, timber in the East Branch was harvested under Timber Harvest Plan 1-12-110 HUM during. Silvicultural prescriptions consist of 32.4 ha (80 ac) of single tree selection, (18.2

ha (45 ac) of group selection, and 9.7 ha (24 ac) of Class I and II watercourse RMZs. These RMZs act as buffer strips along the larger order waterway and were designated as “no-cut” areas per HRC’s HCP and watershed analysis prescriptions. Cable yarding systems were used.

New seasonal roads were constructed in the summer of 2015, and existing roadways reopened. All new and re-opened roadways were utilized for hauling during 2016 logging operations.

Procedures

Stream and Road Crossing Turbidity

Continuous suspended sediment concentration (SSC) data are obtained during the wet season (October through May). Data is obtained using in situ turbidometers and autosampling equipment and turbidity threshold sampling methods as described in Lewis and Eads (2001). Auto-samplers installed at gaging stations at the outlet of each subbasin, in conjunction with a staff plate and stage logger. Autosampling is triggered by field technicians in advance of storms expected to exceed 2.5 cm of precipitation in a 24 hour period. Manually triggered sampling was found to be more reliable than turbidity threshold sampling for this watershed. Water samples collected during storm events are processed for SSC using gravimetric methods (Gray et al. 2000). Annual suspended sediment yields are calculated by multiplying stream discharge times the storm-specific turbidity-suspended sediment relationships. Peak flow data will be analyzed in subsequent reports to explore any potential changes due to harvest. Bedload was not measured for this study. Samples of channel alluvium and hillslope sediment were taken for estimation of long-term denudation rates using Be-10 dating methods (Balco et al. 2013, Ferrier et al. 2005). However results from that analysis are not yet available.

Synoptic samples are collected during storm events that surpass the 2.5 cm rainfall threshold. Storms of this magnitude occur an average of nine times per year. Synoptic samples are also collected at specified locations along the main stems of both basins. Beginning at the confluence at the same time, team members walk upstream in each branch and collect water samples from the mainstem, tributary channels. Samples are also collected above and below newly constructed, newly reconstructed, and existing road crossings. Refer to fig. 1 for synoptic sample locations. Samples are then processed for turbidity level using a benchtop turbidimeter (Hach Instruments, Loveland, CO).

Streamside Landslide and Bank Erosion

A survey is conducted annually along an approximately 792.5 m (2,600 ft) reach of both the West and East Branches to identify active streamside failures. Landslide sediment contributions are determined by measuring the void created by the streamside mass movement. Movement depths are ascertained by visually reconstructing the pre-slide slope configuration and estimating the maximum thickness of the material lost. Percent delivery is based on ocular estimates and the amount of debris remaining at the toe of the subject failures. All active slides are photographed, flagged, labeled, and painted for identification for subsequent site visits.

Landslide Inventory

Five sets of stereo-paired aerial photographs dated between 1948 and 2010 were used to identify recently active landslides for each photo year. Numerous deep-seated, compound failures and shallow debris slides were noted and subsequently verified through field surveys. During the verification surveys numerous small scale failures, not identified through aerial photograph analysis, were encountered and mapped. A compilation map containing all those failures identified during recent and past investigations as dormant-historic in age (equal to or less than 100 years in age per Keaton and DeGraff 1996) are shown on fig. 2. Annual resurveys are conducted to detect new or reactivated landslides.

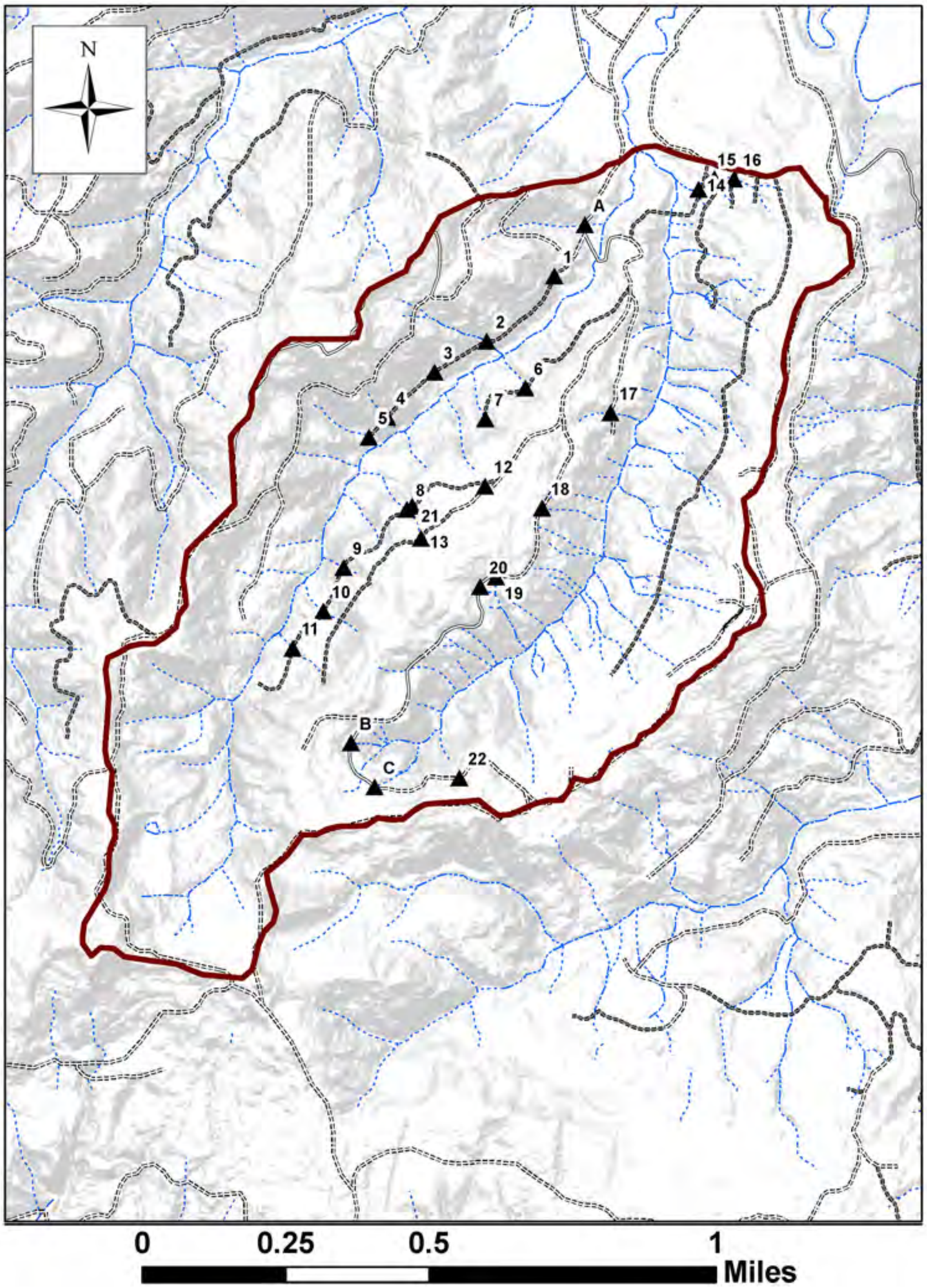

Figure 1—Synoptic sampling locations at road construction sites, Railroad Gulch, Elk River, California. Brown line: project boundary; blue lines: watercourses; dashed black lines: roads; black triangles: synoptic sampling locations at road construction sites.

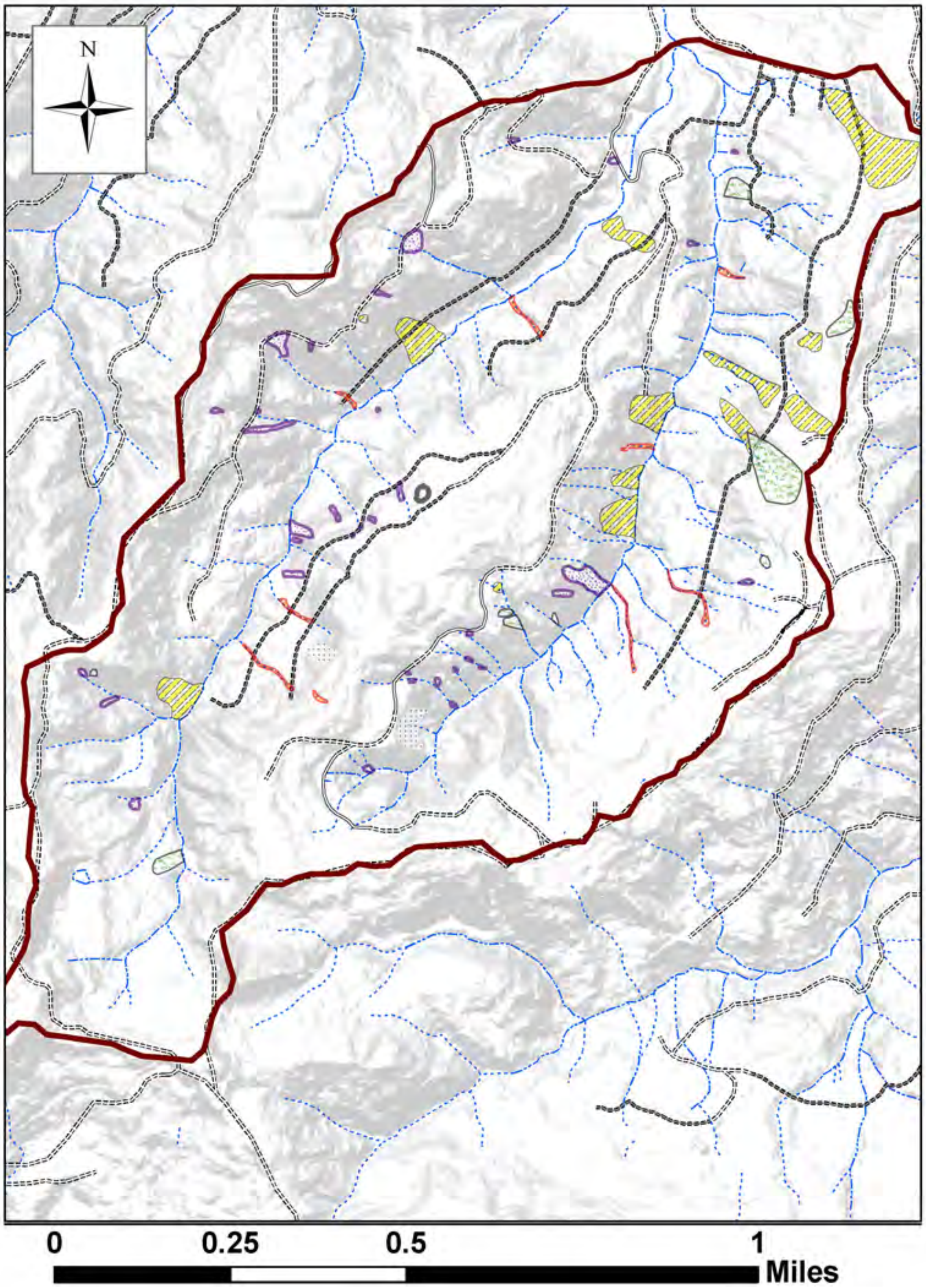

Figure 2—Landslide locations, Railroad Gulch, Elk River, California. Brown line: project boundary; blue lines: watercourses; dashed black lines: roads; red outlines: debris flows; thick grey outlines: disrupted ground; polka dots with purple outlines: debris slides; polka dots (no outline): debris slide slopes; yellow patterns: earthflows; green patterns: trans/rotational landslides.

Channel Head Migration

Channel head migration is monitored by annually assessing rebar monuments established at the upper most point of recognizable erosion (knickpoint, rill, soil pipe, etc.) on first order watercourses. Thirty-eight sites were geo-referenced, characterized, and flagged; 20 new plots were added in the summer of 2015. Several of the plots installed in 2013 were found during the 2015 survey to terminate in some type of hardscape (woody debris, bedrock, etc.) or were not located at the upper most point of erosion. This study reports on the findings relating to the summer 2015 inspection of the initial thirty eight plots.

Road Surface Erosion

Road surveys were conducted for control, pre-treatment and post-harvest road segments to estimate rill and gully erosion occurrence and potential for delivery to the stream network. Road condition and grade were recorded for each road segment using methodology similar to MacDonald and Ramos-Scharrón (2005). Road segments were defined as lengths between naturally occurring (i.e., ridgetops) and structural (i.e., water bars) hydrologic divides. Road survey analysis will be reported in subsequent articles.

Stream Channel Stability and Composition

Sets of stream channel cross-sections were surveyed at low, middle and upper sections of the main watercourse within each branch of Railroad Gulch (total = 13 cross-sections per branch). Annual surveys allow for the detection of trends in channel incision and aggradation. Pebble count measurements are conducted annually to detect trends in streambed particle-size distribution. Two hundred sediment particles are measured at pre-specified locations across 20 transects placed within the general location of each set of cross-sectional survey locations. Transects span the bankfull width of the channel. Pebble counts span habitat features (pools and riffles) as they are not easily delineated due to the incised nature of the channels and quantity of large wood.

Results and Discussion

Sediment Yield

We report on the first 2 water years (WY) of the study. WY 2014 was an extremely dry year as mean and peak streamflow values were 1/4 to 1/3 those values recorded for WY 2015, respectfully (table 1). Suspended sediment yields in WY 2014 were only 1/17th the size of the WY 2015 yields (table 1). The percent of time that turbidity exceeded 25 nephlometric turbidity units (NTU) doubled in WY 2015 for both basins. The turbidity, autosampling and stage recording equipment were operated without incident in both monitoring periods. Examples of monitoring period discharge, turbidity and SSC from stream samples are shown in figs 3 and 4. In both years, a high percentage of the sediment yield resulted from one or two large storm events. For WY 2014, 77 percent of the measured sediment load was delivered on March 28, 2014. For WY 2015, 40 percent was delivered on February 15th, 2015, and 30 percent on April 13, 2015. During both dry and wet years, discharge, turbidity and sediment yields in control and treatment watersheds closely tracked each other (table 1). This result is not surprising as the basins are quite similar in size, vegetation, geology and land use history. It establishes a firm basis of comparison for evaluating impacts from the subsequent road and harvest activities. Both basins produce extremely high sediment loads and high levels of chronic turbidity. Along with neighboring Tom’s Gulch, these are the highest measured loads in the Elk River watershed. The lower mainstem of the Elk River averages 250 Mg/km^2 annual suspended sediment load.

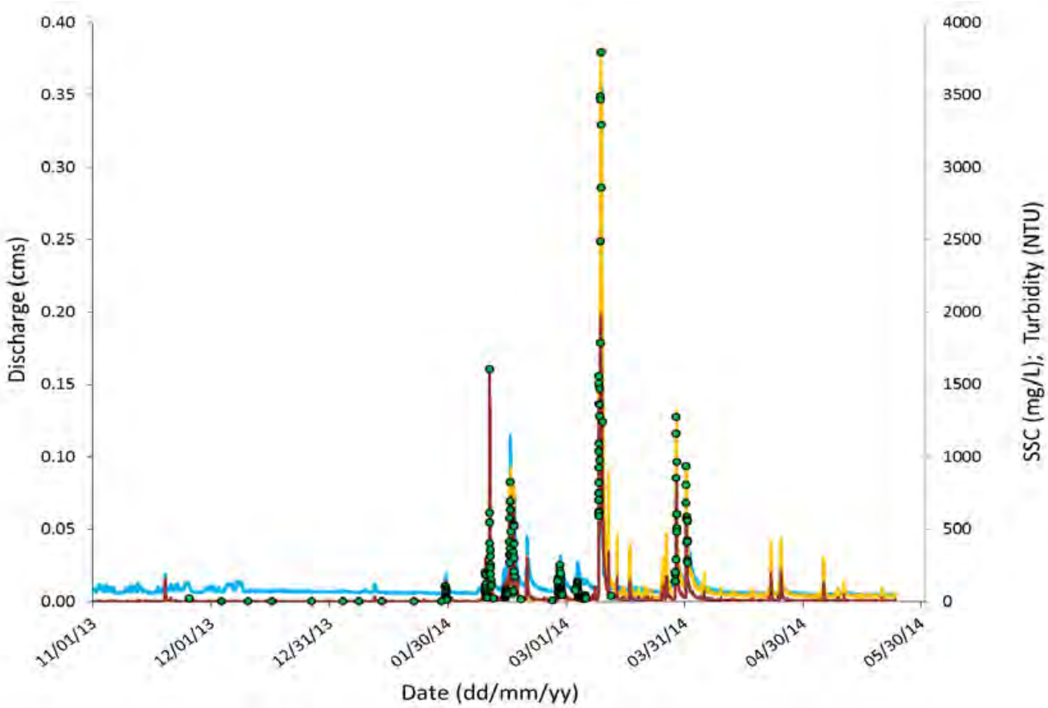

Figure 3—Annual streamflow and turbidity, WY 2014, West Branch Railroad Gulch, Elk River, California. Blue line: discharge (cms); tan line: SSC (mg/L); green circles: SSC measured in collected stream samples.

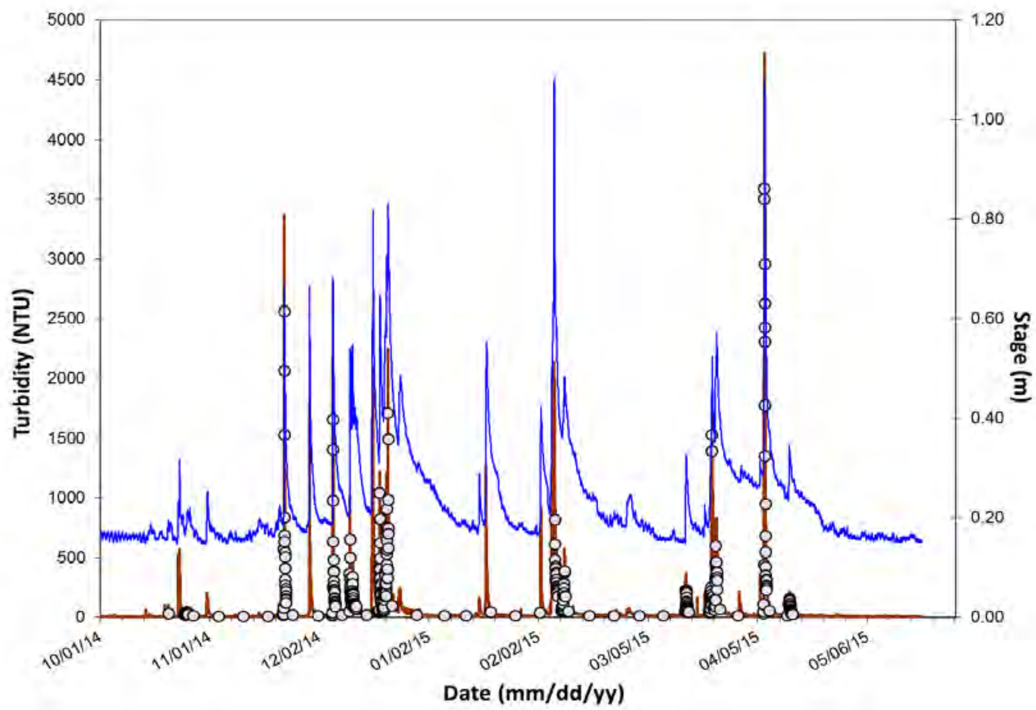

Figure 4—Annual streamflow and turbidity, WY 2015, East Branch Railroad Gulch, Elk River, California. Blue line: stage (m); brown line: turbidity (NTU); white circles: turbidity (NTU) measured in collected stream samples.

Table 1—Summary data for East Branch (treatment) and West Branch (control), Water Year 2014 and 2015, Railroad Gulch, Elk River, California

Time period	basin	Basin area (km^2)	Sediment load (Mg)	Sediment yield (Mg/km^2)	% time turbidity > 25 NTU	Mean discharge (m^3/s)	Peak discharge (m^3/s)	Peak discharge ($m^3/s/km^2$)
Nov. 1, 2013 – May 23, 2014	East Branch	1.28	63	49	16%	0.01	0.42	0.33
	West Branch	1.48	57	38	15%	0.01	0.36	0.24
Oct. 1, 2014 - May 21, 2015	East Branch	1.28	1102	861	28%	0.03	1.6	1.2
	West Branch	1.48	1060	716	30%	0.04	2.0	1.3

Stream and Road Crossing Turbidity

Synoptic samples were collected for five events in WY 2014 and eight events in WY 2015. Turbidities were higher below road crossings than above for numerous locations and events. Differences ranged from zero to 110 NTU. These results would suggest chronic sediment loading from road crossings is occurring. A debris torrent, triggered by the February 2, 2015 storm, came down the tributary stream crossed by site 11 (fig. 1). The debris torrent discharged woody debris and sediment onto and across the crossing. Synoptic samples showed very high turbidity above the crossing resulting from the torrent, ~16,000 NTU on February 6, 2015 and ~26,000 NTU on February 7, 2015. Turbidity prior to the event was consistent with other sites at 40 to 120 NTU. These results support literature findings regarding the importance of roads (McCashion and Rice 1983) and landslides and debris torrents (Kelsey 1980) as sediment sources in this region. As reconstruction and regrading activities took place in summer 2015, results from monitoring of these activities at sites A, B, C, 17, 18, 19, 20, and 22 (fig. 1) will be reported in subsequent articles. The turbidity samples do not allow for quantification of sediment loads as the samples were not concurrently analyzed for SSC. As such they provide an indication of sediment sources within the watershed, but do not inform a quantitative sediment budget.

Streamside Landslides and Bank Erosion

Over 50 independent slides and points of scour were identified between WY 2013 and 2015. Streamside sediment sources are currently dominated by relatively shallow bank slumps and zones of channel scour. Bank slumps are a product of observed stream bank undercutting and not a result of soil saturation from rainfall. These failures are typically discrete landslides that occurred in association with impinging flow in response to flow deflection by large woody debris. Scour tends to occur in areas where streamside slopes are composed of fine grain relatively stiff soils. These erosional features are commonly very shallow (30 to 80 cm) and less than 4.5 m wide. Scouring was observed along straight reaches as well as in reaches with high curvature. Woody debris also appears to play role in the location of these erosion points.

Streamside landslide displacement and delivery volumes for WY 2013, 2014, and 2015 are provide in table 2. Over the study period the West Branch delivery volume per year are nearly double those recorded in the East Branch. This general relationship tracks consistently through the moderate, dry and wet years of WY 2013, 2014 and 2015, respectively. The roughly uniform nature of the pre-treatment data should help in identifying variations (if any) in future landslide rates.

Table 2—Sediment (yd^3) displaced and delivered from streamside landslides and bank erosion, for East Branch (treatment) and West Branch (control), Water Years 2013, 2014, and 2015, Railroad Gulch, Elk River, California

	East Branch		West Branch	
Water year	Displacement (m^3)	Delivery (m^3)	Displacement (m^3)	Delivery (m^3)
2013	4.6	4.6	8.7	8.6
2014	0.2	0.2	0.5	0.5
2015	6.7	6.7	15.7	9.8

Landslide Inventory

Landslide activity in the project area appears to be concentrated along roadways and the sidewalls/headwalls of the more deeply incised watercourses. Movement is dominated by landslide mechanisms affiliated with translational failures, therefore the majority of the slides on fig. 2 have been classified as debris slides/flows. Although smaller in number, deep-seated compound failures (earthflows, trans/rotational, etc.) were found to be significantly larger in magnitude compared to their debris slide counterparts. These larger deep-seated events are commonly confined to toeslopes along the valley walls of the study basins.

Seventy-one historically active landslides were identified within the project area (West Branch = 34; East Branch = 37). The size of the landslides is variable, ranging from very small (80 m^2) to covering multiple acres (6500+ m^2). Landslides, in total, cover nearly 18 ha which represents approximately 6 percent of the study area (5 percent West Branch; 7 percent East Branch). About 13 percent of the study area is underlain by landslide deposits that were identified by previous work as dormant-young or older age. Several of these queried landforms have not, to date, been substantiated.

Five active failures have been mapped; two in WY 2014 and three in WY 2015. All of these features are confined to slopes within the control basin with none observed in the East Branch during this time period. Only two of these features delivered sediment to a watercourse, while debris associated with the other slides was captured by roadways or forested hillslopes. Each failure was classified as debris slides/flows with three of them being categorized as reactivations.

The largest of these failures is estimated to have discharge about 40 m^3 into the adjoining watercourse. This slide occurred following periods of heavy rainfall between February 5 and 6, 2015. The rain gage position in the headwater of the West Branch recorded 9 cm of precipitation between the 5th and 6th. Two smaller slides (7 m^3 and 15 m^3) also occurred in response to this same rain event.

Channel Head Movement

The thirty-eight plots installed in WY 2013 were revisited subsequent to the conclusion of WY 2015. The post-WY 2015 surveys found no evidence of channel erosion or headward migration. It was also noted that a majority of the subject watercourse channels (regardless of basin) did not appear to have passed much if any surface flow during WY 2015.

Stream Channel Stability and Composition

The lower (downstream) section of the East Branch appears to have been relatively stable from WY 2014 to WY 2015 with limited scour and channel widening occurring at one cross-section (4) at the top of the lower section. This was the only cross-section throughout the East Branch where notable channel widening was documented. Overall stream channel conditions in both the East and West Branch appear to be heavily dominated by the presence of in-stream wood. When large wood is present in narrow channels with unconsolidated beds and banks it can obstruct and re-direct streamflow during storm events resulting bank under-cutting and bed scour. The middle section of the East Branch appears to have remained largely static. The uppermost (upstream) reaches experienced some thalweg scour. However, the channel is more incised in these sections as the stream transitions from a Class I to a Class II (non-fish bearing) watercourse between cross-sections 9 and 10. Channel conditions at the East Branch gaging station were relatively stable between WY 2014 and WY 2015 with slight thalweg aggradation and scour along the left bank. Stability is important at this location for developing discharge rating curves.

Overall scour was minimal and banks were generally stable within the West Branch. The lower (downstream) to middle sections of the West Branch appear to have been very stable both in terms of thalweg elevation and bank stability from WY 2014 to WY 2015. Some thalweg scour was observed in the lower portion of the most upstream section. This was not observed in the most upper reaches which remained very stable. Like the East Branch the West Branch transitions from Class I to II between cross-sections 9 and 10. This is largely due to the presence of a large landslide with the channel becoming extremely incised above cross-section nine. The West Branch gaging station profile suggests some bank erosion with minimal thalweg scour. This level of erosion is not particularly large (nor unexpected) given the poorly indurated nature of the underlying bedrock and soils.

Pebble counts were first conducted in fall 2015 prior to WY 2016. East Branch pebble count surveys depicted channel reaches that primarily consisted of medium sand (< 2 mm size category). West Branch pebble count surveys depicted channel reaches that were also predominantly made up of coarse sand, however there was a small component (~12 percent) of fine gravels (2 to 4 mm) and coarse gravels (4 to 64 mm).

Channel substrate observed in the subject reach appears to be influenced by the composition of the underlying geology. The geologic map being developed for the project area indicates that the Hookton Formation sequence underlying the West Branch has a larger constituent of coarse sands and fine gravel than that in the East Branch. This is reflected in the larger grain sized recorded in the West Branch than the East Branch.

The cross-sectional survey indicates that streambeds in the two basins are not systematically incising nor aggrading during the time period of this portion of the study. More erosion would be expected in wetter years. We cannot evaluate whether the size composition of the substrate is changing at this time, however the data provides a baseline for future comparisons, establishes the similarity between the control and treatment watersheds before the treatment was applied, and suggests that that underlying geology does appear to directly influence stream bed particle sizes.

Conclusions

The control and treatment basins of Railroad Gulch appear to behave similarly during dry and moderate conditions over the first 2 years of the study, before roads or timber harvest were completed. Discharge, sediment loads and turbidity, volumes of streamside landsliding, and bank and bed scour were consistently similar. Sediment loads on both basins were tenfold higher in the second year of the study (WY 2015) as a result of a large storm event which triggered debris torrents and streamside failures. Both basins produce extremely high sediment loads and turbidity. In both years, a high proportion of total annual sediment loads occurred in one or two storm events. Turbidities below road crossings in both watersheds were elevated from turbidity recorded above, indicating chronic sediment inputs from this source. Historically active landslides covered 6 percent of the watershed area, with five active slides identified, two of which delivered sediment to watercourses. Channel head migration was not observed on either basin during this time period. Minimal bed scour was observed. Pebble counts indicated predominantly medium sand in both basins with a small component of fine gravels on the West Branch. In summary, the data collected establishes a strong basis for detailed comparisons and documentation of any changes resulting from the East Branch timber harvest.

Literature Cited

Balco, G.; Soreghan, G.S.; Sweet, D.E.; Marra, K.R.; Bierman, P.R. 2013. Cosmogenic-nuclide burial ages for Pleistocene sedimentary fill in Unaweep Canyon, Colorado, USA. Quaternary Geochronology. 18: 149–157.

Ferrier, K.L.; Kirchner, J.W.; Finkel, R.C. 2005. Erosion rates over millennial and decadal timescales at Caspar Creek and Redwood Creek, northern California Coast Ranges. Earth Surface Processes and Landforms. 30(8): 1025–1038.

Gray, J.R.; Glysson, G.D.; Turcios, L.M.; Schwarz, G.E. 2000. Comparability of suspended-sediment concentration and total suspended solids data. Water-Resources Investigations Report 00-419. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 20 p.

Keaton, J.R.; DeGraff, J.V. 1996. Surface observation and geologic mapping. In Turner, A.K.; Schuster, R.L., eds. Landslides investigation and mitigation. National Research Council Transportation Research Board Special Report 247. Washington, DC: National Academy Press: 178–230.

Kelsey, H.M. 1980. A sediment budget and an analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941–1975. Geological Society of America Bulletin. 91(4): 1119–1216.

Lewis, J.; Eads, R. 2001. Turbidity threshold sampling for suspended sediment load estimation. In: Proceedings of the seventh federal interagency sedimentation conference. Federal interagency project, Technical Committee of the Subcommittee on Sedimentation: III-110–III-117.

MacDonald, L.H.; Ramos-Scharrón, C.E. 2005. Measurement and prediction of sediment production from unpaved roads, St John, US Virgin Islands. Earth Surface Processes and Landforms. 30(10): 1283–1304.

McCashion, J.D.; Rice, R.M. 1983. Erosion on logging roads in northwestern California: How much is avoidable? Journal of Forestry. 81(1): 23–26.