Technical Memorandum

July 12, 2016

Prepared for: Battle Creek Alliance

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Subject: Topographic Characterization of Swales in Sierra Pacific Industries' Ponderosa Post-Fire Sediment Study, Shasta County, California

Sierra Pacific Industries (SPI) reported[1] on a study of hillslope erosion in relation to salvage logging and contour ripping following the September 2012 Ponderosa Fire in the Battle Creek Watershed of northern California. Sediment fences were constructed in the headwaters of a tributary (Rock Creek) along the axis of 10 swales to capture eroded soil. The study reported reduced erosion on logged sites that were treated with contour "subsoiling" (ripping), a treatment wherein a D6 or D7 tractor creates furrows at 7- to 10-foot intervals designed to interrupt water and sediment movement downslope. In addition to comparing logged sites with and without ripping, erosion was measured in 3 swales that were neither logged nor ripped. Erosion measured in these 3 swales was substantially higher than that measured in the various treated sites that had been instrumented in this study. Dr. James concluded that "the site disturbance (salvage logging plus biomass removal and contour subsoiling) substantially reduces overall average soil erosion and sediment delivery." Only trees larger than 12" diameter at breast height were removed in the salvage logging. Under the "biomass removal" treatment, all trees are removed, regardless of size.

On December 6, 2012, after a large series of storms, Central Valley Water Board (Water Board) staff inspected the study swales. Staff member Drew Coe (now with CalFire) issued a memorandum[2] on February 20, 2013 to Angela K. Wilson, Senior Engineering Geologist of the Water Board. The memorandum stated

> It was ocularly estimated during this visit that the hillslopes of the control swales were approximately 10 to 15 percent steeper than the logged sites. Also, the controls were more convergent than the logged sites and on slightly different aspects. These differences may result in more erosion potential for the controls as steeper hillslopes and more convergent topography can result in more erosive runoff. Aspect can be an important factor since the prevailing wind direction and wind speed can affect the rainfall energy applied to the hillslope. Further focus should be placed on determining whether the differences in site conditions are significant enough to confound differences between the various hillslope treatments.

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1 James, Cajun. "Post Wildfire Salvage Logging, Soil Erosion, and Sediment Delivery, Ponderosa Fire, Battle Creek Watershed, Northern California: Executive Summary". Sierra Pacific Industries, Sep 2014. Hereinafter referred to as the SPI Report.

2 Memorandum from Drew Coe to Angela K. Wilson, Central Valley Regional Water Quality Control Board. Subject: Inspection of Sierra Pacific Industries' Ponderosa Post-Fire Sediment Study, Shasta County California.

Mr. Coe summarizes

My overall observations from the inspection indicate that logged, salvaged, and ripped sites produce an order of magnitude less sediment than the unlogged controls. Despite some of the differences in site conditions, it is apparent in the field that contour ripping fundamentally changes the arrangement and length of flowpaths on the hillslope and therefore alters the dominant erosion process from rilling and channel incision to sheetwash. The additional surface roughness also provides a depositional environment on the hillslope.

It is less clear whether logging without ripping results in erosion reduction relative to unlogged areas. While the logged and unripped sites produced less sediment than the controls, the gentler slopes, less convergent topography, and different aspect may be responsible for some of the differences in observed erosion. Observations indicate that equipment tracks from logging machinery were relatively infrequent and did not provide strong visual evidence of modifying surface flowpaths and/or surface roughness. However, logging may have resulted in significant differences in surface cover, which is known to be an important control on post-fire erosion. Therefore, it is critical to review the data characterizing each swale to see if there are significant differences between the site scale variables critical for controlling erosion (e.g., drainage area, slope, degree of convergence, aspect) before the efficacy of the treatments can be fully evaluated.

It is fundamental that treatments be applied to groups of sites that are equivalent with respect to confounding factors and Mr. Coe is to be commended for recognizing these shortfalls in the study design and the limitations they place on interpretations. The inescapable conclusion is that, with regard to erosional differences between ripped and control sites, the relative importance of treatments and site conditions is unknown.

On Mar. 4, 2013, Tom Myers, Ph.D., wrote another technical memorandum[3] criticizing the SPI study design. Myers argued that the swales were not comparable because (1) they may have been dissimilar with regard to burn severity, aspect or drainage area, (2) the control sites were steeper and more convergent than the treated sites, and (3) treatments were not randomly assigned to sites. He also suggested that if soil furrowing and ripping increased infiltration rates, those benefits are likely to be short-lived as the furrows will fill with sediment. His conclusion states

... the inspection report and the study it reports on proves nothing. The study design is inadequate because the control sites are too steep, not comparable to the sites that received a logging treatment. The inspection report does not provide sufficient data with which to assess their comparability...

My memorandum quantifies the differences among the swales with regard to slope steepness and some of the characteristics that were discussed by Drew Coe and Tom Myers.

[3] Technical memorandum from Tom Myers to Battle Creek Alliance in response to Water Board's inspection of SPI's Post-Fire Sediment Study. Mar. 4, 2013.

The sediment fences and collection basins are visible on Google Earth (May 2014 image) and the boundaries of the treatment areas are fairly clear, in part due to exclusion of herbicides from the study. The swale boundaries were digitized using SPI's study area map and drainage areas as a guide wherever boundaries were unclear in the images. Topographic characteristics were derived from the 10m DEM (USGS digital elevation model), projected into UTM coordinates. Aspect, slope steepness and planform and profile curvature were derived using ArcGIS raster functions. Planform curvature measures curvature along the contour, with negative values (concavity) corresponding to convergent areas. As defined in ArcGIS, negative values of profile curvature denote convexity along the slope gradient and correspond to acceleration of flow.

Table 1 shows the treatments and basic topographic characteristics of each site. Drainage area and aspect are included as these have been mentioned by both Drew Coe and Tom Myers as possible factors affecting the study results.

Table 1. Treaments and topographic characteristics of the study swales.

Swale	Area (ac)	Mean aspect (degrees azimuth)	Mean Slope (%)	Mean Planform Curvature (km^{-1})	Mean Profile Curvature (km^{-1})	Logged	Biomass Removal	Contour Ripping
1	0.97	152	15.1	0.47	0.98	X	X	X
2	1.28	126	5.9	-0.19	0.06	X	X	
3	1.23	134	6.9	-1.12	-1.74	X	X	X
4	1.40	171	3.9	-0.85	-0.66	X	X	
5	1.37	243	7.9	-0.41	-2.12	X		X
6	1.26	260	13.0	-1.53	-3.00	X		
7	1.17	149	11.2	-1.15	-2.38	X		X
8	1.26	205	20.2	-4.43	-4.47	control		
9	0.92	181	24.5	-3.95	-1.95	control		
10	0.80	216	25.8	-3.42	-2.42	control		

Estimates of drainage areas apparently were not available at the time they wrote their memoranda, but they were stated in the SPI Report. Drainage area is no greater at the controls than at the treated sites. In fact sites S9 and S10 appear to have the smallest drainage areas of all the swales. However, because these are very small areas in subdued terrain with porous bedrock, true catchment areas are difficult to ascertain from topographic maps and actual drainage may not correspond very well at all to surface topography.

Drew Coe speculated that aspect could be important because "prevailing wind direction and wind speed can affect the rainfall energy applied to the hillslope". Table 1 shows that the range in aspect is 126 to 260 degrees azimuth, which spans only about 37% of a full circle. All aspects have a southerly component, varying from slightly south of W to SE (Figure 1). Wind's interaction with aspect is one of many factors including raindrop size, canopy closure, and canopy height that can affect raindrop velocity.   With such small variation in aspect among the swales, its influence on the erosion results is very probably negligible.

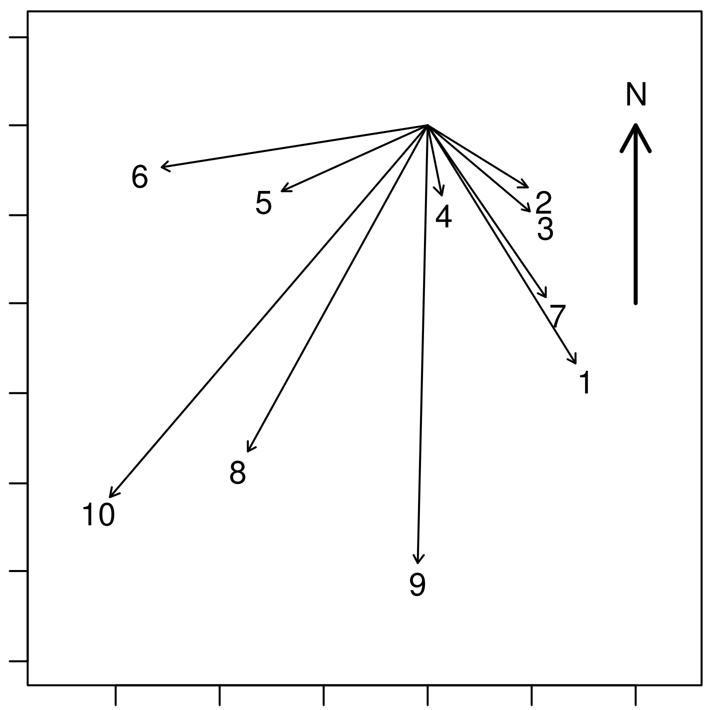

Figure 1. Swale gradients. The directions of the vectors represent aspect, the lengths are proportional to slope steepness, and the numbers are the site IDs.

The major differences between the controls and the treated sites are, as Drew Coe observed, in slope steepness and curvature. Figures 1 and 2 show that the controls (S8, S9, and S10) are by far the steepest sites. The steepest treated site is significantly less steep than the gentlest control (p=0.009). The mean slope of the controls is 23.5% (median 24.5%), while that of the treated areas is 9.1% (median 7.9%). Confidence intervals for the mean are computed from the individual pixel slopes in each swale. Some of the differences in runoff and erosion among study sites that was reported by SPI are certainly due to reduced infiltration that results from faster runoff on steeper slopes. Slope steepness is universally recognized to be a very important control and no erosion study is complete without a consideration of this factor. There is not a word about slope steepness in the SPI Report and it is an egregious omission.

In addition (Figure 3) the control sites are the most convergent sites (concave in planform curvature) and are among those with the greatest acceleration of flow (convex in profile curvature) of any of the study swales.

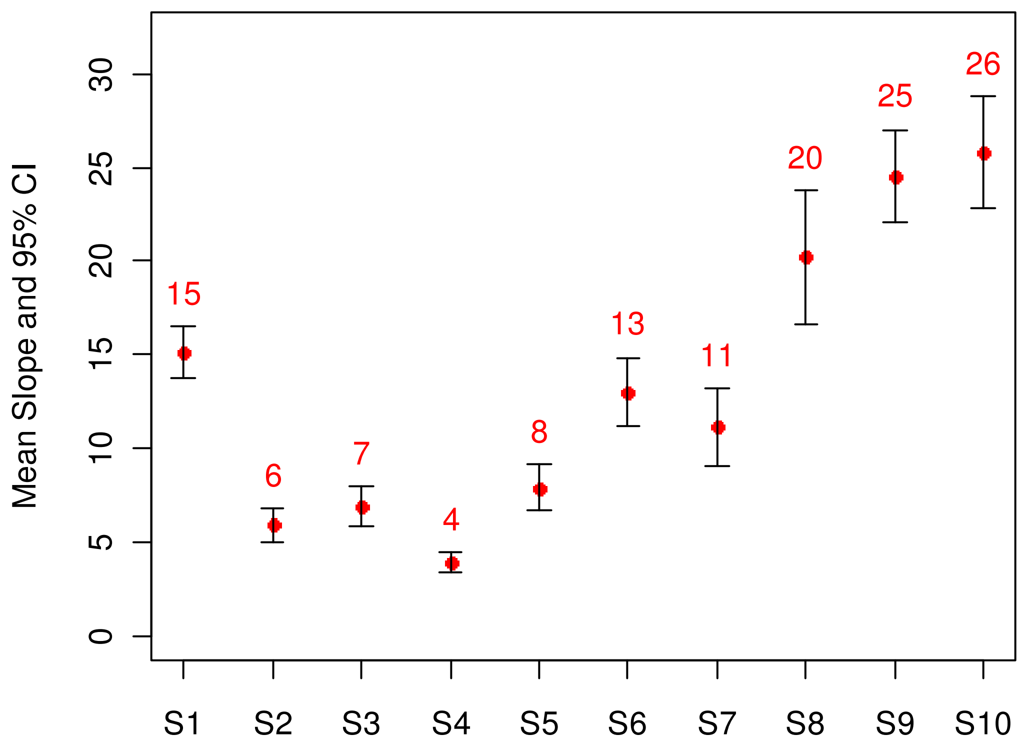

Figure 2. Slope steepness (%), with 95% confidence intervals for the mean

Unfortunately, the SPI Report does not show the erosion rates for the individual swales so it is difficult to quantify the extent to which differences in observed runoff and erosion among the treated sites might be attributable to differences in slope steepness and convergence. However, the observed differences in runoff correspond to these variables in an ordinal sense (i.e. by ranks). Figure ES-8 of the Report (shown below) depicts runoff at 6 of the 10 sites. The specific sites are not identified, but the treatments are stated. The greatest runoff (brown line) is from one of the controls, and we know that, regardless of which is shown, it is steeper and more convergent than any of the treated sites. The second greatest runoff (red line) is from the site that received salvage logging and no contour subsoiling, so we know that to be site 6, which is the second steepest treated site (13.0%), and the most convergent of the treated sites. The third greatest runoff (green line) is from a site that received salvage logging and contour subsoiling but no biomass removal, so it must be S5 or S7 which are the next steepest (7.9% and 11.2%). The fourth ranked site with respect to runoff (black line) was salvage logged with biomass removal but no ripping, i.e. S2 or S4. Their slopes are very gentle (5.9% and 3.9%), and they are among the least convergent sites.

The site with the least runoff (blue line) is one that had all the treatments, i.e. S1 or S3. It's tempting to guess that it was S3 (6.9% slope), since S1 was the steepest of the treated sites, but on the other hand S1 barely qualifies as a swale – it is the only site with mean planform curvature greater than 0. On a divergent slope water disperses, so one would expect to collect little or no runoff at its lowest point. In summary, the ranking of sites by runoff (Figure ES-8 of the SPI Report) can be explained solely on the basis of their slope steepness and convergence, therefore could have nothing at all to do with the treatments.

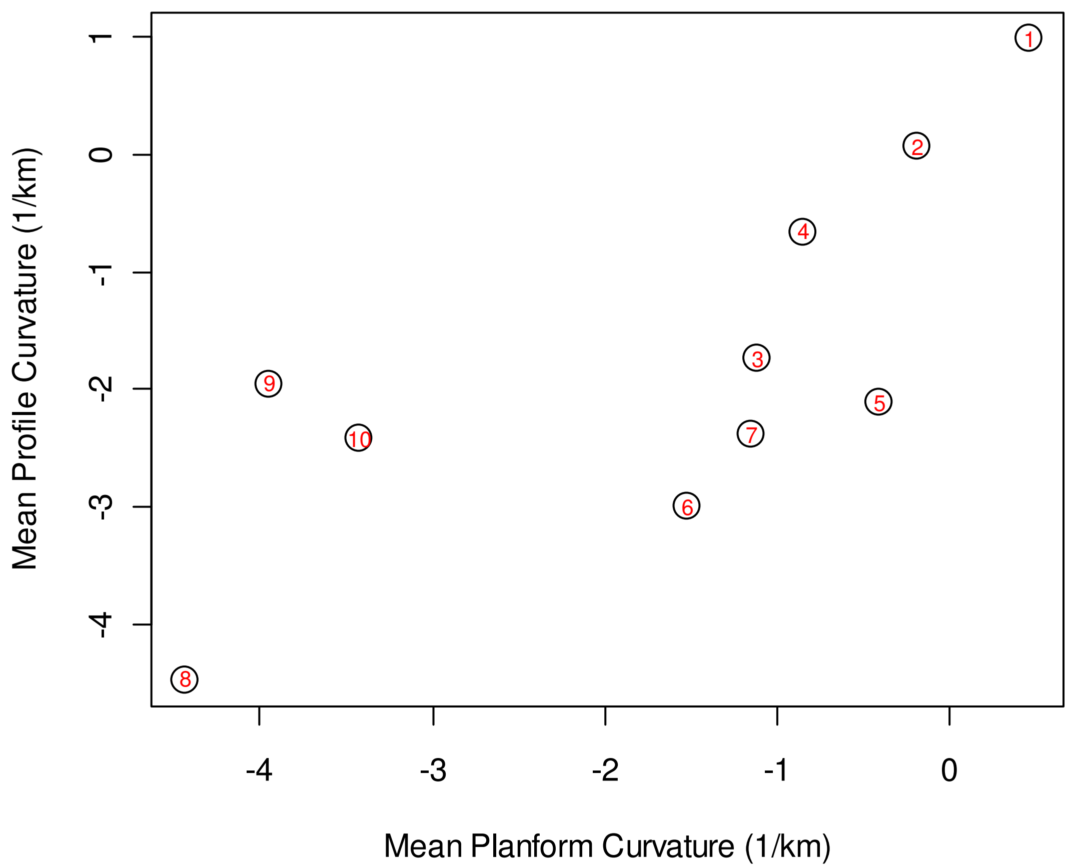

Figure 3. Slope curvature (profile and planform) for each of the 10 study swales. Negative values of planform curvature correspond to convergent slopes (concave on the contour), while negative values of profile curvature correspond to slopes with accelerating flow (concave in the direction of the slope gradient).

Figure ES-8 from the SPI Report is reproduced below.

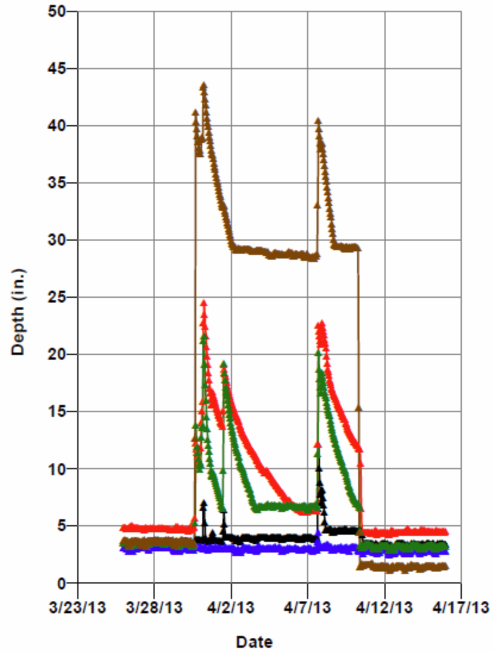

Figure ES-8. This graph shows the water depths for five sediment fences during a rainstorm between March 30 and April 9, 2013. These water depths are a measure of each site's water runoff volume. The most significant difference between the sites is the relatively large amount of water runoff measured in the control site (the brown line) and the smaller amounts of water runoff measured in the treatment sites. The brown line is highest, and all other lines show much lower water depths (runoff volume). The amount of water runoff affects the amount of soil erosion that can occur in a site. The cumulative water runoff from the sites over the winter season is a major determinant of the amount of soil erosion (average sediment weight per acre) that occurred, as shown in Figure ES-7. The brown line shows a control site (no salvage logging or contour subsoiling); the blue line shows a site that received salvage logging plus biomass removal and contour subsoiling; the black line shows a site that received salvage logging plus biomass removal but no contour subsoiling; the green shows a site that received salvage logging and contour subsoiling; and the red line shows a site that received salvage logging and no contour subsoiling.

SPI should include information such as that presented in Table 1 in any reports of their post-wildfire study, and they should include a column for erosion rates so that anyone looking at the results can evaluate them properly. Due to the choice of control sites, it is clear that the study cannot be used to evaluate the effects of salvage logging. On the surface, the comparisons between ripped and unripped sites that were salvage logged (S5 and S7 vs S6) , and between ripped and unripped sites that were totally denuded (S1 and S3 vs S2 and S4) seem more reasonable. However, the sample sizes of 1 and 2 make this a case study, and no inference can be made to a greater population. It would be useful if SPI would continue reporting erosion results at these sites, so the longevity of erosion control treatments can be assessed.