

Post-Wildfire Salvage Logging, Soil Erosion, and Sediment Delivery—Ponderosa Fire, Battle Creek Watershed, Northern California

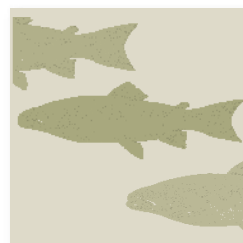
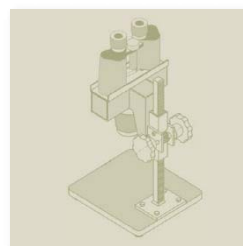
Preliminary Results

Cajun James, Ph.D.

Sierra Pacific Industries
September 2014

Sierra Pacific Industries
Post Office Box 496014
Redding, California 96049-6014

© 2014 Sierra Pacific Industries



Post-Wildfire Salvage Logging, Soil Erosion, and Sediment Delivery—Ponderosa Forest Fire, Battle Creek Watershed, Northern California—Preliminary Results¹

Cajun James, Ph.D.²

**Research and Monitoring Manager
Sierra Pacific Industries**

Introduction

Forest fires in California are natural events, but over the last decade they have become unnaturally large, burning with above-average intensities. Termed *catastrophic wildfires*, these fires affect hundreds of thousands of acres, cause unprecedented losses of life and property, require unbudgeted government expenditures, and degrade the natural environment. Recent studies document changes in fire characteristics and predict continuing increases in fire severity, frequency, and size.^{3, 4}

¹ A separate non-technical Executive Summary is also available: James, C. 2014. *Executive Summary—Post-Wildfire Salvage Logging, Soil Erosion, and Sediment Delivery—Ponderosa Forest Fire, Battle Creek Watershed, Northern California—Preliminary Results*. Research and Monitoring Department, Sierra Pacific Industries, 13pp.

² Contact information: Cajun James, Ph.D., Research and Monitoring Manager, Sierra Pacific Industries, P.O. Box 496028, Redding, CA 96049-6028; (530) 378-8000; cjames@spi-ind.com.

³ Collins, Brandon. *The Role of Fire in Managing California Mixed-Conifer Forests*. University of California—Berkeley and USDA Forest Service, Pacific Southwest Research Station. Available: http://www.calforests.org/wp-content/uploads/2014/02/140131_Collins_Managing_Fire.pdf.

⁴ Lenihan, J.M., R. Drapek, D. Bachelet, R. Neilson. 2003. Climate Change Effects on Vegetation Distribution, Carbon and Fire in California. *Ecological Applications* 13 (66):1667–1681.

Because of their size and burn intensity, catastrophic wildfires have an immediate negative impact on wildlife and wildlife habitats. In the months following a fire, there is also high potential for losses to timber and soil resources and degradation of stream habitats and water quality. When cover and soil properties are affected by wildfire, there is greater potential for sediment delivery from headwater swales down slope to higher order streams.

On private forestlands in California, trees damaged or killed by fire are often harvested soon after to recover their economic value. During this practice—termed *salvage logging*—actions are taken to mitigate fire damage and to implement all pre-harvest and operational provisions of the Forest Practices Act, including erosion control best management practices (BMPs). Compared to industrial private lands, public lands generally receive less post-wildfire salvage logging and restoration, and most of these actions occur several years after the fire. Consequently, investigations on private lands can provide important information on soil and watershed responses to wildfires and on the effects of salvage logging. While the benefit of recovering the economic value of trees is clear, more research is needed to determine and document the effects and potential restorative benefits of salvage logging, particularly in terms of soil erosion and water quality.

This preliminary report describes a study designed by Sierra Pacific Industries in collaboration with Dr. Lee MacDonald of Colorado State University.⁵ We examined the

⁵ See http://www.cwi.colostate.edu/csuwaterfaculty/?WF_ID=137.

effects of salvage logging after a catastrophic wildfire and various common treatments used by private industrial timber landowners in California to determine which BMPs might help mitigate post-wildfire erosion and water quality degradation. This study follows established protocols from previous wildfire erosion studies. Uniquely, however, it is the only study to our knowledge that actually performed salvage logging operations immediately following a catastrophic wildfire and implemented all aspects of the study prior to any rainfall occurring.

Research Setting

The Ponderosa Fire began on August 18, 2012, in the Greater Battle Creek Watershed, southeast of Manton, California.⁶ The fire burned 27,676 acres of mixed conifer forest, approximately 9% of the watershed. The fire began after a dry lightning storm passed over the region. The Ponderosa Fire was a natural disaster that severely impacted watershed resources as well as local residents. The fire burned 17,500 acres of forestland owned and managed by Sierra Pacific Industries, approximately 63% of the total fire area.

Soils within the fire area are a moderately deep sandy loam derived from volcanic parent material. Average annual precipitation is approximately 40–45 inches. Watercourses range from barely discernable channels to perennial flowing spring-fed streams that flow downstream 27.2 miles into Battle Creek, which drains to the Sacramento River south of Redding, California.

The forest vegetation within the Ponderosa Fire area is composed of the mixed conifer forest type. Six tree species primarily comprise this forest type: ponderosa pine, sugar pine, Douglas-fir, incense cedar, white fir, and black oak. The understory is composed of a variety of small trees, shrubs, forbs, and grasses and is frequently dominated by species of ceanothus and manzanita.

According to the U.S. Forest Service (USFS) Burned Area Reflectance Classification (BARC) Maps,⁷ most of the Ponderosa Fire burned at a high and moderate severity including critical areas next to streams. *High severity* is defined by several characteristics: complete removal of surface fuels, surface vegetation, and the soil duff layer; greater than 6.6- to 13.2-foot (2- to 4-meter) char height on tree trunks; and 90–100% charred tree canopy.^{8, 9}

Often fires of this severity immediately kill trees by scorching their cambium and preventing uptake of nutrients and water. Usually all foliage on the tree is also consumed. Trees not immediately killed by the fire are severely stressed and later die due to insect attack. Post-wildfire timber harvesting is often called salvage logging because the dead and dying timber is salvaged (removed) before further losses to a tree's lumber value occurs.

Following a catastrophic fire, vegetation cover and soil cover (including organic

⁷ See <http://www.fs.fed.us/eng/rsac/baer/barc.html>.

⁸ See ftp://165.235.69.100/pub/outgoing/ponderosa_fire/ponderosa_barcode_93version2.pdf.

⁹ Parsons et al. 2010. *Field Guide to Mapping Post-Fire Soil Burn Severity*. U.S. Forest Service, General Technical Report RMRS-GTR-243.

⁶ California Department of Forestry and Fire Protection. *Ponderosa Fire Incident Information*. Available: http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=722.

matter)—which typically store water and protect hill slopes from erosion—are often no longer present. Soil structure is compromised, and infiltration capacity is often reduced. The diminished functionality of the soil can exacerbate rainfall runoff and hill slope erosion, consequently increasing potential sediment delivery to streams and rivers.

The high-severity characterization of the Ponderosa Fire indicates a substantial loss of vegetation and soil cover, including in critical areas next to streams. These changes mean the ability of the soil to hold water and to protect the hill slope from erosion is critically diminished. Because fires, like other natural disasters, are known to decrease environmental quality, questions arise about the potential cumulative impacts resulting from salvage logging the burned timber and about which BMPs might be used to help mitigate post-wildfire erosion and water quality degradation.

Study Objectives and Implementation Schedule

The Ponderosa Fire burned where Sierra Pacific Industries has collected over a decade of baseline in-stream continuous water quality monitoring data.¹⁰ The study objectives were to quantify the amount of post-wildfire hill slope erosion produced in small headwater swales due to different logging and ground treatments and to link the hill slope erosion results with concurrent in-stream water quality measurements. Another

critical objective was to capture all post-wildfire precipitation effects by implementing the study as close to October 1, 2012, as possible. That date started the beginning of the new Water Year 2013 (WY 2013) as defined by the U.S. Geological Survey,¹¹ and it occurred before any precipitation fell within the study area.

Therefore, within 40 days of the Ponderosa Fire being contained on August 31, 2012, this study was completely designed and implemented: the fire area was evaluated and the study area was defined, experimental salvage logging and ground treatments were performed, sediment fences were constructed with associated instrumentation in place, and weather stations were installed. Field measurements of ground cover, soil, and disturbance were collected before the experimental salvage and ground treatments were performed and then replicated after treatment.

This preliminary report:

- Defines the different logging and ground treatments employed in this study
- Describes the methods used and timing of the experiment
- Includes hill slope erosion results for WY 2013 by comparing average total pounds per acre for unlogged, non-treated control sites and different salvage logging and ground treatments within treatment sites
- Provides examples of the type and timing of precipitation events that to date have triggered hill slope erosion events

¹⁰ James, C. and L. MacDonald. 2012. *Greater Battle Creek Turbidity Monitoring: Update and Additions*. Research and Monitoring Department, Sierra Pacific Industries, 25pp. Available: <http://www.spi-ind.com/research/JamesMacDonaldCOMBINED.pdf>

¹¹ U.S Geological Survey. 2014. *Explanations for the National Water Conditions*. Available: http://water.usgs.gov/nwc/explain_data.html.

- Includes maps, images, and video links to document precipitation events and sediment fence clean-out methods
- Provides documentation of where ground-based logging equipment and different ground treatments influenced hill slope erosion processes and infiltration, and
- Examines the roles different salvage logging and ground treatments could play in mitigating post-wildfire hill slope erosion and water quality degradation.

These preliminary results identify which types of BMPs are most effective during post-wildfire salvage operations to help mitigate hill slope erosion and water quality degradation due to catastrophic forest fires. The data analysis also shows the relationship between storm intensity and sediment production, thereby relating BMP effectiveness to storm intensity.

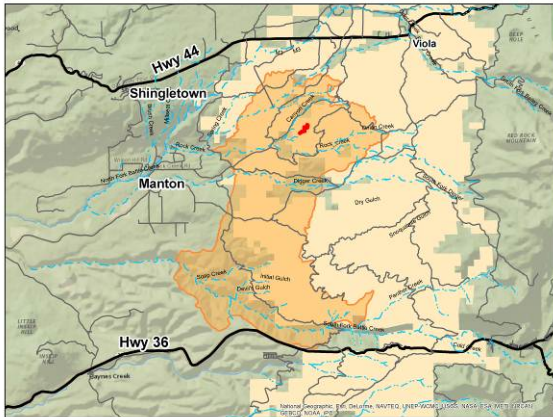


Figure 1. The extent of the Ponderosa Fire within the Greater Battle Creek Watershed is shown in orange. The Sierra Pacific Industries property is shown in tan, and its overlap with the Ponderosa Fire area is shown as a variation of the orange color. The erosion study area is shown in red.

Study Design

The experimental design called for selecting headwater swales as locations for applying experimental salvage logging and ground treatments and sampling erosion rates within

the fire perimeter. *Headwater swales* are topographic depressions immediately below a ridgeline where water collects to a central point before traveling downslope and eventually forming a defined channel (Figure 2). Ten sites—three control sites and seven treatment sites—were selected.

Site selection required searching ridgelines for headwater swales that met the following characteristics: smaller than 2 acres; slope gradient less than 40%; well defined ridgelines that clearly separated drainages; no existing or immediately adjacent roads; and high burn intensity. Additionally, a standing forest inventory needed to be available for land managers, and the overall study area had to be large enough to contain a minimum of 10 study sites that met the selection criteria, so that all sites were in close proximity and therefore exposed to similar weather events. Three potential areas were identified within the fire perimeter, from which the study area was selected and the 10 study sites established (Figure 3).

Headwater swale

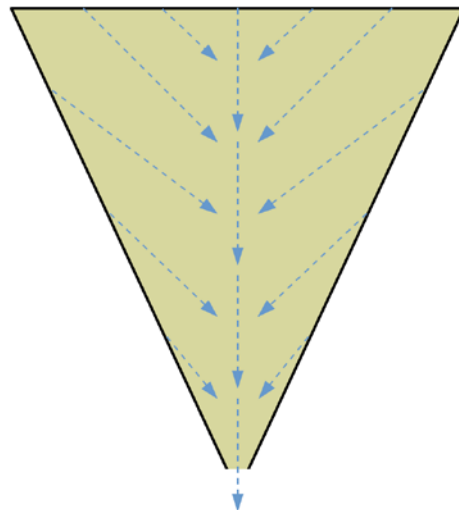


Figure 2. In this diagram of a typical headwater swale, the black boundary represents a geographic feature that separates drainage patterns (i.e., a ridgeline). Blue arrows represent drainage within the swale.

Salvage logging logistics determined which sites received treatments and which were control sites. Review of the treatment sites with the Licensed Timber Operator (LTO)¹² revealed that because the way the salvage logging equipment would access the slopes, it was necessary to keep the control sites separate from the treatment sites to ensure no accidental equipment disturbance occurred. If the equipment were to disturb the control sites, they would no longer represent an untreated swale.

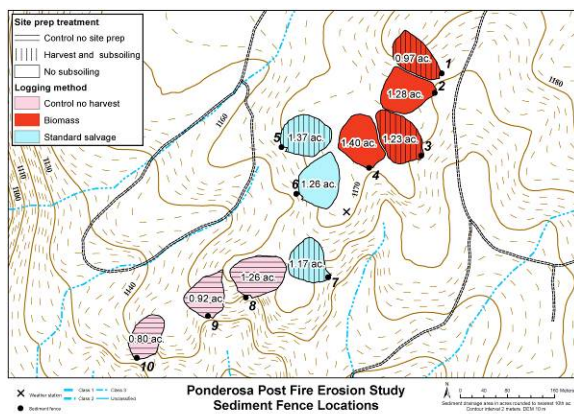


Figure 3. This map of the study area shows the distribution, size, and treatment assignments for the 10 study sites. It also shows sediment fence locations, topographic contours, stream channels, and logging roads. Seven of the sites were treated with a combination of two treatment types: logging intensity and contour subsoiling; the remaining three sites were designated as controls with no treatments. The weather station location is shown by the 'X'.

Methods

Sediment Fences

Sediment fences were constructed in each of the 10 study sites. The fences were built large enough to capture all sediment generated during precipitation events from the entire drainage area of each swale. Pressure-treated posts and 2-inch by 4-inch

cross braces were used to build the frame. Welded wire fencing was installed as a backing to provide strength. Sediment fence fabric was used to line the inside of the fences and the immediately adjacent ground enveloped by each fence. Details of the constructed fences are shown in Figures 4 and 5. Care was taken to ensure the leading edge of the fabric and the bottom were secured to the ground to prevent undermining of the structure by flowing water which would also have allowed sediment escape. A spillway was centered just below the height of two wing walls to allow water to escape the fences during extremely high precipitation events. Each fence was sized according to the size of its associated headwater swale.



Figure 4. This photograph shows the back of a sediment fence. In this view, both the sediment fence structure and the swale can be seen. The spillway is evident, and the fence is braced with a post to counter the weight of captured water and sediment.

⁹ See http://www.fire.ca.gov/resource_mgt/downloads/2014_FP_Rulebook_w_TRA_No.1.pdf (1022 License [p. 157], 4524 License [p. 254], and 4571 Necessity of license [p. 261]).

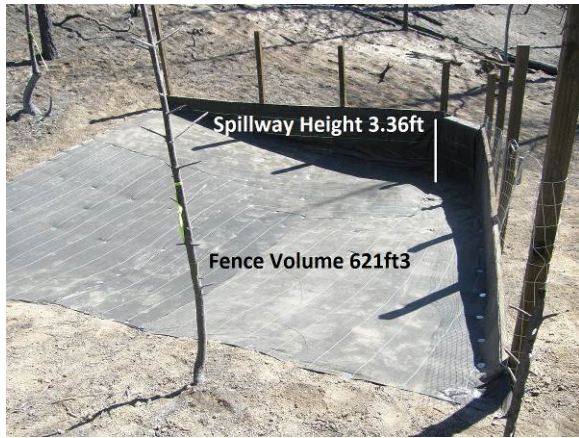


Figure 5. This photograph shows the upslope side of the sediment fence shown in Figure 4. Here one can see that the fabric is continuous between the ground within the fence and the fence structure itself.

Regulatory Requirements

Of the 10 study sites, 7 were salvage-logged. All logging performed in this study complied with the State of California's Forest Practice Rules and followed erosion control measures for standard waterbreak spacings^{13,14} (California Forest Practice Rule 934.6 G). All forest harvest operations conducted in this study were covered under a Notice of Emergency Timber Operations (RM-67), filed by Sierra Pacific Industries and accepted by the California Department of Forestry and Fire Protection. Timber operations conducted under Emergency Notice must comply with all operational provisions of the Forest Practice Act and District Forest Practice Rules applicable to Timber Harvest Plans. Wildlife and archaeological resources must also be evaluated and considered prior to operations. The emergency salvage logging operations conducted on the Ponderosa Fire

¹³ See http://calfire.ca.gov/resource_mgt/resource_mgt_forestpractice.php.

¹⁴ See http://calfire.ca.gov/resource_mgt/downloads/2013_FP_Rule_book_with_Tech_RuleNo1.pdf.

and for this study followed these requirements.

Treatments

Table 1 lists the 10 study sites and identifies the control sites and treatment sites. Figures 6–16 are photographs showing the treatments and some of the equipment used.

On the seven treatment sites, combinations of two treatment types were applied—logging intensity and contour subsoiling—yielding four different treatment groups.

The two levels of logging intensity consisted of:

- **Salvage Logging:** This lower-intensity logging method involved mechanical removal of all merchantable timber defined by the landowner as trees 12 inches diameter breast height (DBH) or greater. All standing trees meeting this criteria were harvested (Figures 11, 14, and 16).
- **Salvage Logging Plus Biomass Removal:** This higher-intensity logging method involved mechanical removal of all merchantable (greater than 12 inches DBH) and sub-merchantable trees (less than 12 inches DBH) (Figures 9 and 12).

Contour subsoiling was applied to some of the salvage logged sites:

- **Contour Subsoiling / No Contour Subsoiling:** A D7R CAT dozer with winged rippers (Figure 6) contour tilled to a depth of 20 inches with furrows approximately 7–10 feet apart (Figures 7, 8, 10, 12, 13, 16). Figure 12 shows a study site that was not treated with contour subsoiling.

On the three control sites, no salvage logging or contour subsoiling occurred (Figure 13).

In order to characterize the burn severity of the study sites, we analyzed USFS BARC maps. The USFS BARC makes an initial assessment of fire intensity and classifies post-fire vegetation condition using infrared satellite imagery. In addition to using these remotely sensed data to determine burn severity, we performed field testing to determine soil *hydrophobicity*—i.e., water repellency—within each of the 10 study sites.



Figure 6. A D7R CAT dozer with winged rippers prepares to contour subsoil a treatment site.



Figure 7. This photograph shows contour subsoiling with furrows being installed by a D7R CAT dozer at a treatment site.



Figure 8. This photograph shows furrows made along the contour by subsoiling.



Figure 9. This photograph shows salvage logging plus biomass removal operations occurring upslope of sediment fence.



Figure 10. This photograph shows subsoiling done on the contour following salvage logging plus biomass removal.



Figure 11. This photograph shows salvage logging using a mechanical harvester.



Figure 12. This photograph shows salvage logging plus biomass removal with no contour subsoiling. Equipment tracks in the immediate foreground were created during tree removal.



Figure 13. This photograph shows salvage logging plus biomass removal and contour subsoiling. Equipment tracks are in immediate foreground, with contour subsoiling furrows behind.



Figure 14. This photograph shows salvage logging with no contour subsoiling. The equipment tracks in foreground were created during tree removal.



Figure 15. This photograph shows contour subsoiling in a salvage logged treatment site with no biomass removal.



Figure 16. This photograph shows a control site (no salvage logging; no contour subsoiling). Note the relatively uniform nature of the soil surface which is covered by ash, the remnant dead trees evident throughout the burned swale and that there is no obvious stream channelization in the swale prior to the occurrence of post-wildfire rain.

Following Robichaud et al.,¹⁵ we designed our study so that the sediment trapped in the fences is weighed throughout a 1–3 year period. Cleaning out all the fences is labor intensive: each clean-out takes 20 people between 25 and 30 hours. All trapped sediment is shoveled into 5-gallon buckets and weighed in the field providing its wet weight. The dry weight and percent organic matter is determined in the lab based on a subsample of the wet sediment.

Figures 17, 18, and 19 illustrate one of the clean-out events. Below is a web link to a time lapse camera video of a sediment fence clean out in one of the control sites done in February 2014. During the clean-out, the images were recorded every minute to capture work activity (http://www.spi-ind.com/research/Control_Sediment_Fence_Cleanout_Feb_2014.mp4).



Figure 17. Cleanout crew removing material trapped behind fence and placing into buckets for weighing.



Figure 18. Following the clean-out, the extracted sediment was covered with fabric to protect it from rain.

¹⁵ See <http://www.fs.fed.us/research/people/profile.php?alias=prohichaud>.



Figure 19. This photograph shows an upslope view during a clean-out. Weighed sediment is piled on the sides and downslope of the fence. This image is of control site 8. The sediment piled to the sides was removed during the first round of cleanouts in December 2012. The sediment pictured accumulated during the first 3 months following fire containment. Note that on the control sites rill erosion features began forming on the burned hill slopes immediately after rainfall events. At this control site a main channel has begun to form; it shows as the lighter brown streak extending uphill from the fence through the middle of the swale.

Table 1. Control Sites and Treatment Sites

	Site Number (Acres)									
	1 (0.97)	2 (1.28)	3 (1.23)	4 (1.40)	5 (1.37)	6 (1.26)	7 (1.17)	8 (1.26)	9 (0.92)	10 (0.80)
Control Sites										
Control: no salvage logging, no contour subsoiling								X	X	X
Treatment Sites										
Salvage logging, no contour subsoiling						X				
Salvage logging plus biomass removal, no contour subsoiling		X		X						
Salvage logging, contour subsoiling					X		X			
Salvage logging plus biomass removal, contour subsoiling	X		X							

Data Collection

This study uses electronic instrumentation, dataloggers, and cameras to record all weather events that occur within the study area. Using this equipment is essential to capture all of the post-wildfire rain events and significantly improves the ability to analyze the response of the hill slopes and streams to different rainfall events.

Depth sensors¹⁶ were installed on the spillway of each fence to track and quantify changes in the depth of water (i.e., rainfall accumulation) and sediment production for individual precipitation events (Figure 20).

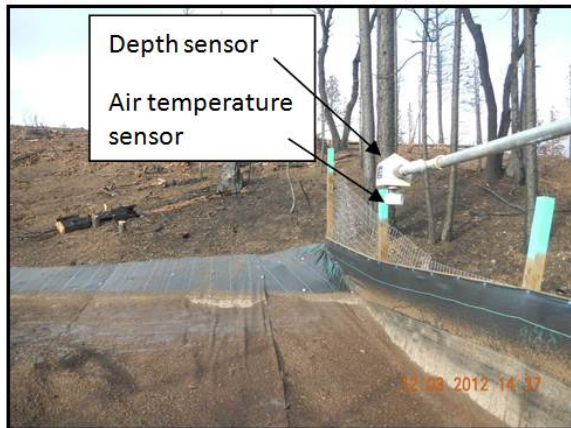


Figure 20. A depth sensor is attached to the spillway and measures changes in the depth of sediment and water during and after precipitation events.

Air temperature sensors are located within the depth sensors. Additionally, a meteorological station was installed within the study area to measure precipitation, air temperature, relative humidity, soil moisture, soil temperature, wind speed, wind direction, fuel moisture, fuel temperature, and photosynthetically active radiation (PAR) (Figures 3 and 21).



Figure 21. This photograph shows the portable weather station deployed within the study area.

Time-lapse cameras were mounted on all sediment fences to capture responses to different precipitation events and to provide images of how those events influence erosion processes associated with each swale (both control and treatment sites) (Figure 22). Each camera captures an image every 30 minutes, and these images are chronologically ordered using sequencing software to create a video of the events within the swales. The viewer can see the fence filling with water and sediment in response to precipitation events occurring upslope and then emptying and drying over time. The following time-lapse video shows the activity recorded within a control site fence from February 17 to March 18, 2014 (http://www.spi-ind.com/research/Control_Sediment_Fence_Feb_18_through_Mar_12_2014.mp4).

¹⁶ See the ultrasonic depth sensor at <http://juddcom.com/>.



Figure 22. Time-lapse cameras were mounted on the wing walls of the sediment fences to document water and sediment accumulation during rain events.

Ground Data Collected

Before treatments began, percent ground cover and soil hydrophobicity surveys were conducted. Immediately following the logging and contour subsoiling, and prior to any rainfall events, percent ground cover and soil hydrophobicity were surveyed again. Ground cover measurements will continue to be measured twice per year to track vegetation recovery. Slope measurements were taken in each swale on 40-foot increments up the central axis and along both sides.

As discussed previously, the USFS BARC map makes an initial assessment of fire intensity and classifies post-fire vegetation condition using infrared satellite imagery. The soil hydrophobicity testing measurements provided another burn intensity measure. Hydrophobicity was measured in the same fashion as described by Huffman, MacDonald, and Stednick (2001).¹⁷

A comprehensive and detailed measuring effort was undertaken during summer 2013 in each of the 10 study sites. A 40-foot by 40-foot grid was constructed in each swale with low-stretch mule tape and concrete stakes to measure rills and ground disturbance levels. All existing rills greater than 0.8 inch deep and 0.8 inch wide were measured and mapped to determine total area and volume of rills. Where evident, the point of initiation for the rills was documented. Waterbreaks and subsoiling furrows were mapped with GPS and geographically associated with surveyed rills in ArcView GIS (see Figure 23 for an example). This information will help us better track and understand hill slope erosion processes following fires, and the extent to which logging practices and contour subsoiling affect them.

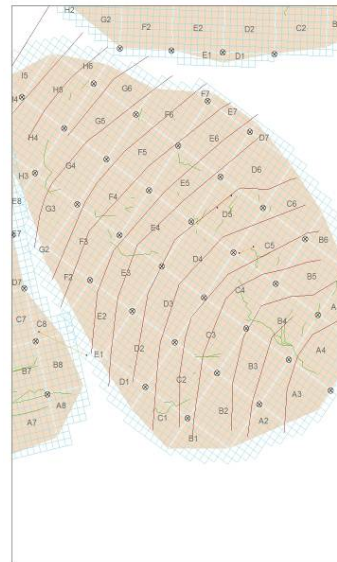


Figure 23. This diagram shows a swale with biomass removal treatment and contour subsoiling. Red lines are contour furrows, and green lines are rill patterns following WY 2013.

¹⁷ Huffman, E., L. H. MacDonald, and J.D. Stednick. 2001. Strength and Persistence of Fire-Induced Soil Hydrophobicity under Ponderosa and Lodgepole Pine, Colorado Front. *Hydrological Processes* 15:2877–2892. DOI: 10.1002/hyp.379.

Preliminary Results and Observations

We measured 35 inches of precipitation in the study area during WY 2013. There were 20 rain events with 0.5 inch or more falling in 24 hours. Two of those events produced more than 1 inch of precipitation in 24 hours. These two rainfall events were significant sediment producers that necessitated fence clean-out in order to maintain fence capacity to collect additional sediment.

The largest rain event occurred on December 4, 2012. This event was a short duration, high intensity storm that deposited 7 inches of precipitation within approximately 72 hours. That rainfall event produced more hill slope erosion than any other precipitation event within the WY 2013. Drew Coe, a Timber Unit staff member from the Central Valley Regional Water Quality Control Board, was present on December 6, 2012, during the first fence clean-out and issued an Inspection Report on February 20, 2013¹⁸

Preliminary average erosion results for WY 2013 are presented in Figure 24. These results show that immediately following the fire, the control sites produced more sediment than the treatment sites. Overall the controls produced the most sediment, averaging greater than 30,000 pounds per acre. The salvage logging plus biomass removal treatment combined with contour subsoiling produced the least amount of sediment. Detailed information on each treatment type and swale will be discussed in the final study report. To date results for WY 2014 show the same pattern shown in WY

2013. Preliminary results from WY 2013 were presented to the California Board of Forestry Monitoring Study Group in Willows, California, on March 20, 2013.¹⁹

¹⁸ Coe, D. 2013. Inspection of Sierra Pacific Industries' Ponderosa Post-fire Sediment Study, Shasta County, California. Central Valley Regional Water Quality Control Board, February 20, 2013. 25pp. Available: http://www.spi-ind.com/research/Drew_Coe_CVRWQCB_SPI_Post-Fire_Sediment_Study_Inspection.pdf

¹⁹ See http://www.bof.fire.ca.gov/board_committees/monitoring_study_group/meeting_minutes/2013_msg_meeting_minutes/msg_meeting_minutes_03-20-13_final-a.pdf

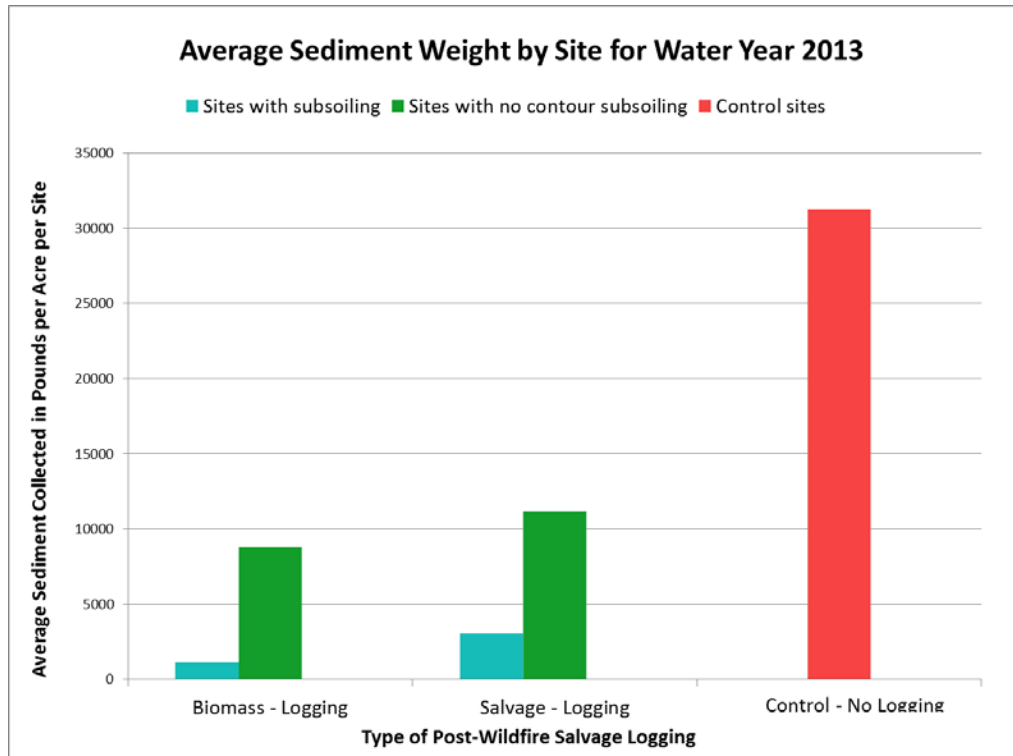


Figure 24. This bar chart shows the results of the first winter season average sediment weight (pounds per acre) for the controls and the treatment groups. Although undisturbed except for the Ponderosa Fire, the control sites (the red bar labelled Control—No Salvage Logging) showed the most soil erosion, producing an average of more than 30,000 pounds of sediment per acre. The sites with treatments having the most disturbances—salvage logging and contour subsoiling, with or without biomass removal—had the least amount of soil erosion (the light blue bars).

During individual rain events, the depth sensors recorded the amount of water and sediment accumulating behind the fences, which is an indicator of how much runoff was occurring. The time-lapse photographs provided a visual depiction of how much water and sediment was produced during an individual rain event. Figure 25 displays the different depths (in inches) of water and sediment accumulation between March 26 and April 16, 2013. Each line represents results from one sediment fence. The depth represented by the lines and the general area under each line represents the total combination of water and sediment that flowed down from the hill slopes in response to a series of rainstorms in the study area.

The two highest peaks at March 30 and April 8 represent the most intense periods of the storms and the associated runoff in the swales. A few smaller events occur in between as shown by smaller peaks. The gradual decline in the lines after the storm peaks represent the rate of water draining from the sediment fences. The depth of sediment deposited within the fences is denoted where the lines level out, indicating that all the water has drained. From April 10 to 12, 2013, the fences were cleaned out and the depth sensor equipment was reset to allow for future measurements to be collected.

Figure 25 also allows a comparison of the differences in the depths of water and sediment delivered to the fences related to

their site's respective non-treatment or treatment. The most significant difference between the sites is the relatively large amount of water and sediment measured in the control site (the brown line) and the smaller amounts of water and sediment measured in the treatment sites. Note that the brown line is highest and all other lines show much lower depths. The fences in the swales that received the contour subsoiling (blue line and green line) captured the least amount of water and sediment.

The difference in water accumulation in the fences represents the total amount of runoff generated by individual headwater swales and is indicative of varying hill slope infiltration rates. The higher the infiltration rate on the hill slope, the less total runoff is generated.

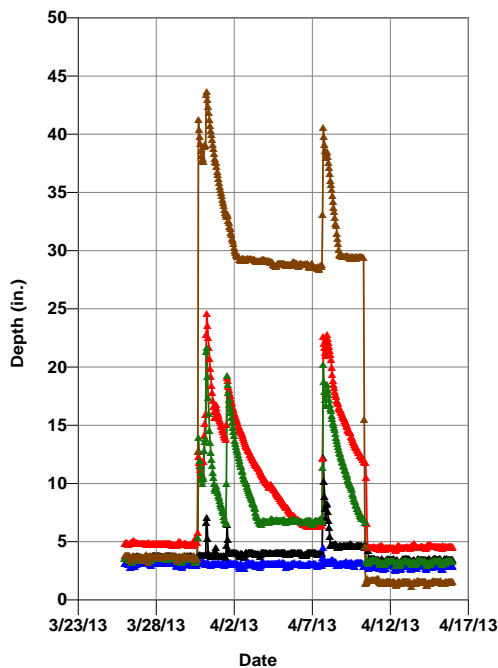


Figure 25. The brown line shows a control site (no salvage logging or contour subsoiling); the blue line shows a site that received salvage logging plus biomass removal and contour subsoiling; the black line shows a site that received salvage logging plus biomass removal but no contour subsoiling; the 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.

The increased infiltration is due to the contour subsoiling ground treatment. Contour subsoiling breaks up slope continuity, eliminates soil hydrophobicity, increases soil surface roughness, and increases the effective surface area where infiltration can occur. These factors serve to decrease water velocity and increase water infiltration rates in the soil. Contour subsoiling breaks slope continuity by decreasing the distance the water travels over land before being intercepted, and its velocity slowed, by a furrow. Because the furrows are only 7–10 feet apart, water received from upslope moves only a short distance before encountering a furrow, where water ponds and infiltrates. Any runoff that escapes an individual furrow is added to the runoff generated by the next “inter-furrow” distance and again moves only a short distance before encountering the next furrow, again ponding and infiltrating. In addition to this furrow ponding and infiltration, some additional infiltration occurs in the inter-furrow area because the salvage logging and the soil treatments combine to eliminate soil hydrophobicity and increases soil surface roughness. Consequently, the cumulative amount of runoff is lowest on the treatment sites with contour subsoiling following salvage logging.

A direct consequence of the higher infiltration rate and reduced runoff generation is reduced runoff velocity. Reduced runoff velocity decreases the amount of soil erosion that occurs over the inter-furrow area compared to equivalent distances on non-subsoiled slopes. Additionally, soil particles that are eroded and moved downslope cannot move a significant distance down the hill slope before they encounter another furrow, where the water collects and infiltrates and a large percentage of the eroded soil particles are

then deposited. Consequently, the overall amount of sediment delivery to the fences is reduced in the subsoiled swales. The increased infiltration rates and reduced water volume as well as the reduced sediment displacement, transport, and delivery resulting from contour subsoiling are displayed in Figures 24 and 25.

Field visits and time lapse video clearly show that infiltration rates increased in swales with either of the two logging treatments. These observations indicate that the logging treatment, even without subsoiling, also generally increased soil infiltration. This increased infiltration occurred because ground equipment and harvest methods broke up the surface soil hydrophobicity over large continuous areas and created small-scale roughness that slowed runoff. If the swale was logged and contour subsoiled, the infiltration rates increased even further because the soil surface was fractured—broken up to 20 inches deep—and the hill slope length was shortened to a maximum of 10–20 feet.

Sites 1, 3, 5 and 7 were treated with contour subsoiling (Figures 27, 28, 29). Sites 2, 4, and 6 did not receive subsoiling (Figures 30, 31, 32). Comparing those figures, it is clear that sites 1, 3, 5, and 7 had significantly higher infiltration rates (less runoff) than the sites that did not receive contour subsoiling. Comparing all the treatment sites (Figures 26–31) to the control sites (e.g., Figure 26), it is clear that any treatment greatly reduces the amount of erosion occurring in the year immediately following a catastrophic wildfire (Figure 24).



Figure 26. This photograph shows the sediment fence of a control site (site 9), where no salvage logging or contour subsoiling was performed.



Figure 27. Salvage logging plus biomass removal with subsoiling, WY 2013 (site 3).



Figure 28. Salvage logging with subsoiling, WY 2014 (site 5).



Figure 29. Salvage logging plus biomass removal with subsoiling, WY 2014 (site 1).



Figure 30. Salvage logging plus biomass removal without subsoiling, WY 2013 (site 2).



Figure 31. Salvage logging without subsoiling, WY 2014 (site 6).



Figure 32. Salvage logging with biomass removal without subsoiling WY 2014 (site 2).

Conclusion and Next Steps

A great deal of time, effort, and expense has gone into this study. Preliminary results have been insightful as to the effects of precipitation events of varying intensity and duration on post-wildfire salvage logging hill slope erosion. The results clearly show the benefit of forest management on increasing infiltration rates and reducing hill slope length and thereby limiting hill slope erosion and downslope sediment delivery. Results to date in WY 2014 present a similar pattern to those from WY 2013. Although 2014 has had significantly less precipitation, we have seen the same response to high intensity, short duration storms in significant erosion production; the harvested and treated swales showed increased infiltration, less erosion, and less sediment delivery than the untreated control swales.

Changes to the presence and degree of hydrophobic conditions will be analyzed over time and compared to erosion and runoff data to provide insight into post-wildfire hill slope processes.

Existing research examining trends in the production of post-wildfire erosion have shown that 60% ground cover and above

leads to decreases in erosion²⁰ (i.e., significant ground cover means less sediment eroding on the hill slope). Results from this study will be analyzed to ascertain if there is any correlation between an increase in percent ground cover and a reduction of sediment accumulation in the fences. Overall percent ground cover in the seven treatment sites increased 45–65% during the 13-month period following containment of the Ponderosa Fire even though they were all salvaged logged. Percent ground cover in the control sites where no salvage logging was performed increased 60–80%. A comparison of percent ground cover, percent ground disturbance, and erosion rates in WY 2013 and WY 2014 will be considered in subsequent reports.

Please check the Sierra Pacific Industries webpage for updates on this project.

Acknowledgements: Many people have contributed to this project including ongoing peer review by several scientists. We wish to acknowledge Dr. Lee MacDonald and Dr. Joe Wagenbrenner who have provided insights and visited the study area. Highlanders Forestry, the Sierra Pacific Research and Inventory crews, and Lassen District foresters all worked very hard to ensure this project was quickly implemented following fire containment. Throughout the last 22 months, everyone who has participated in this study has shown a commitment to the collection of high quality field data under very tight time constraints “no matter what it took.”

²⁰ Spigel, K. M., Robichaud, P. R. 2007. First year post-fire erosion rates in Bitterroot National Forest, Montana. *Hydrological Processes* 21:998–1005.