BAGLEY FIRE

EROSION AND SEDIMENTATION INVESTIGATION INTERIM REPORT

Photo 1 (#7462) New sediments in the Squaw Creek Arm Shasta Lake SW of Madison Gulch; 9-26-13 JdlF

DECEMBER 26, 2013

SHASTA TRINITY NATIONAL RECREATION AREA, MOUNTAIN GATE, CA

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Executive Summary

1. **The Fire -** The Bagley Fire burned 46,000 acres, south of McCloud, CA in late summer 2012. There were soil burn severities of 11% high, 19% moderate, 48% low, and 22% very low. The fire suppression cost $35 million dollars.
2. **Storm Events -** Two intense storms traversed the fire area with estimated return intervals of 25-50 years. The first produced little erosion. Four day storm totals from the 11/29-12/2, 2012 event ranged from 38 to 56 cm (15-22 inches).
3. **Stream Flow -** The larger of the two storms (late November) is believed to have conveyed a 25 to 50-year flood event in Squaw Creek. Flood modelling based on USGS regression equations predicted discharge at Chirpchatter Campground in excess of 15,000 cfs for the 25-year flow event.
4. **Surface Erosion -** Substantial erosion occurred on all hillslopes that have been evaluated within the fire perimeter. Sheet erosion was the dominant erosion process, followed by rill erosion, then gully erosion. Erosion processes were most expressed on the steeper, longer slopes at midslope positions. A very high proportion of hillslope-derived sediment appears to have been delivered to the fluvial system. Initial analysis of transect data show that soil burn severity had surprisingly little influence on erosion response when compared to topographic slope variables such as slope length, gradient and position. This lack of correlation between burn severity and observed erosion is being further evaluated; results will be presented in the final report.
5. **Landslides, Debris Flows and Altered Channels -** Very few post-fire landslides have been identified, and these were small, shallow debris slides. Sediment laden flows occurred in most burned low order channels. However, classic debris flows that scour all vegetation from channel bottoms were rare. Altered channels, gullies and landslides mapped on air photos were concentrated in areas of high and moderate soil burn severity. However, field inventories revealed that some erosional features occurred outside those areas. Storm damage appeared to dissipate a short distance to the west, north, and east of the fire perimeter, but extended for a greater distance to the SE (>3 miles, east of the Pit River).
6. **Channel Response and Sedimentation -** Stream reaches with channel gradients less than 2 percent were aggraded with sand and gravel as a result of the 2012 storms. Post-event stream surveys showed significant loss of slow-water habitats (pools and glides) as a result of flood sedimentation. Pre- and post-flood riffle pebble counts from three Squaw Creek survey reaches revealed that riffles were characterized by cobble substrate prior to the fire and were fined by flood generated sands and gravels. Analysis of 1:4,000 scale 2013 air photos show that approximately 7 miles of Squaw Creek stored sediment from the 2012 storms with an average thickness of 0.5 meters. This equates to roughly 110,000 cubic meters of sediment (143,770 cubic yards). The 2013 air photos also revealed that only small amounts of wood were deposited in Squaw Creek, whereas field observations just after the storm event revealed that the Squaw Creek Arm of Shasta Lake received a large volume of wood. Forest personnel trapped this wood with a boom and moved the wood to a disposal area.
7. **Water Quality/Turbidity -** Elevated streamflow and turbidity levels persisted for months following the 2012 storms. Turbidity in Squaw Creek gradually diminished in late-Spring but rose sharply in late-June in response to a rare summer storm event.
8. **Reservoir Effects –** Squaw Creek, and to a lesser degree, the McCloud River, delivered a large volume of fine sediment and floating wood to Shasta Lake, making the water in the reservoir turbid. Field reconnaissance in the Squaw Creek Arm revealed that fine silt and dark organic material were deposited throughout the exposed floor of the reservoir, whereas sand was mostly confined to the vicinity of the main channel on the valley floor. The depositional sequence is very complex, making it difficult to differentiate post-fire sediments from older sediments likely associated with previous flood events such as those in 1964 and 1997.
9. **Sediment Budget -** Insufficient data are presently available to calculate a sediment budget. A budget will be developed in 2014 utilizing newly acquired LiDAR data to measure hillslope erosion and reservoir deposition.

10. **Effects on Other Resources -** Post-fire storms had a severe effect on the road system. Many road stream crossing culverts to failed, particularly in high severity burn areas. Severe erosion was observed below many roads. Some Cultural Resource sites were damaged. Invasive weed seeds were likely transported down streams. Effects on fisheries are being evaluated and will be presented in the final report.

Purpose & Background

The purpose of this interim report is to present preliminary findings based on work completed through August, 2013 to Forest and Regional Office staff. As such it is a progress report, and will be fully superseded by the Final Report, due for completion in the spring of 2014. The interim report does not address a sediment budget. It also does not validate BAER predictions of effects or evaluate effectiveness of post-fire treatments. All these topics will be covered in the final report.

The purpose of this investigation is to enhance our understanding of the relationships between wildfire, erosional processes and forest management practices. The Forest Service Regional Ecological Restoration initiative is based on restoring forest health through reduction of unnaturally high forest fuel loads that contribute to wildfire size and severity, while at the same time improving sustainable local economies and energy production through biomass utilization. A major controversy hindering the full implementation of our initiative concerns the relative impacts of wildfires and the fuels treatments intended to reduce wildfire size and severity on downstream aquatic resources. For example, the Sierra Nevada Framework Planning Amendment litigation, which has extended over 8 years, is focused on the question of whether fuel treatments will, in aggregate, have more adverse effects to aquatic resources than large and severe wildfires that occur in the absence of these treatments.

Owing to the relatively uncommon coincidence of severe fires and intense storms, we have limited information with which to demonstrate the benefits of ecological restoration for water resources and aquatic habitats. The 2012 Bagley Fire on the Shasta-Trinity National Forest is an unusual opportunity to document the adverse effects of a severe wildfire and intense storms on downstream aquatic resources and reservoir storage capacity.

The Bagley Fire burned about 46,000 acres (18,000 hectares) in late summer 2012 on the Shasta-Trinity National Forest, immediately south of McCloud, California (Figure 1). Suppression costs were around 35 million dollars, not including BAER analysis and treatments. A 2500-8 BAER report, related earth science reports, and a 2500-1 Large Event Recovery Plan were submitted. These reports identified the need for post-fire monitoring and acquisition of LiDAR data. Unfortunately, funding was not available at that time. As a result, the opportunity to acquire pre-winter data for the fire area was lost.

In November and December 2012, intense storms hit the fire area. Post-storm field reconnaissance revealed extensive sheet, rill and gully hillslope erosion, loss of most road stream crossings (within and outside of the fire area), scour of low-order channels, and delivery of large volumes of sediment and debris to high order streams. Lower gradient reaches were substantially aggraded with gravels and sands. Large volumes of sediment and woody debris were delivered to Shasta Lake reservoir.

These events provide an excellent opportunity to better understand how the fire area responded to intense winter storms and subsequent precipitation events. This improved understanding will have direct applications to future vegetation and road management activities in the fire area. A proposal for funding was submitted to the R5 Director of Ecosystem Management to investigate the erosion and sedimentation in the fire area (USDA Forest Service, 2013), and funding was granted in the spring of 2013.

Contributors to this project (by discipline) included:
Geology - Ryan Mikulovsky, Juan de la Fuente, Melanie Stevens; **Hydrology -**Christine Mai, Steve Bachmann, Zack Mondry, Carlita Hallett, Linda Holden, Matt Swanstrom; **Soils & Range -** Brad Rust, Dave Young, Ashley Knight, Zach

Voigtman; Sabrina Hopton; **Fisheres -** Bill Brock, Joe Zustak, Margaret Harings, Jade Mitchell; **Cultural Resources-** Peter Schmidt; **Botany -** Martin Lenz, Julie Nelson,

Lusetta Nelson; **Engineering -** Justin Nettleton; **Wildlife** - Justin Mapula; **Student Conservation Association Interns** - Cara Appel, Bree Bender, Molly Breitmun; **Volunteer -** Jason Hope. Special thanks go to Troy Nicolls of the Mountain Gate office for use of the FS boat, and for his observations and accounts of the Squaw Creek Arm of Shasta Lake during the flooding in 2012.

Physiographic Setting

Geologic, Hydrologic, Soils Setting - The Bagley Fire occurred in steep, rugged terrain near the eastern margin of the Klamath Mountains Province (Figure 1). The area is underlain primarily by metasedimentary rock. Dominant soils are very gravelly sandy loams (Neuns Family). For a more thorough description of the physiographic setting, refer to the Squaw Creek and Lower McCloud Watershed Analyses (USDA Forest Service, 1999 and 2011). The Hydro-geomorphic regime has not been fully characterized, but this will be done and described in the final report. The final report will incorporate attributes such as soil K-factor, slope data, dominant geomorphic processes (as interpreted from geomorphic mapping), and channel network patterns. High resolution terrain from a new LiDAR-derived Digital Elevation Model will be used.

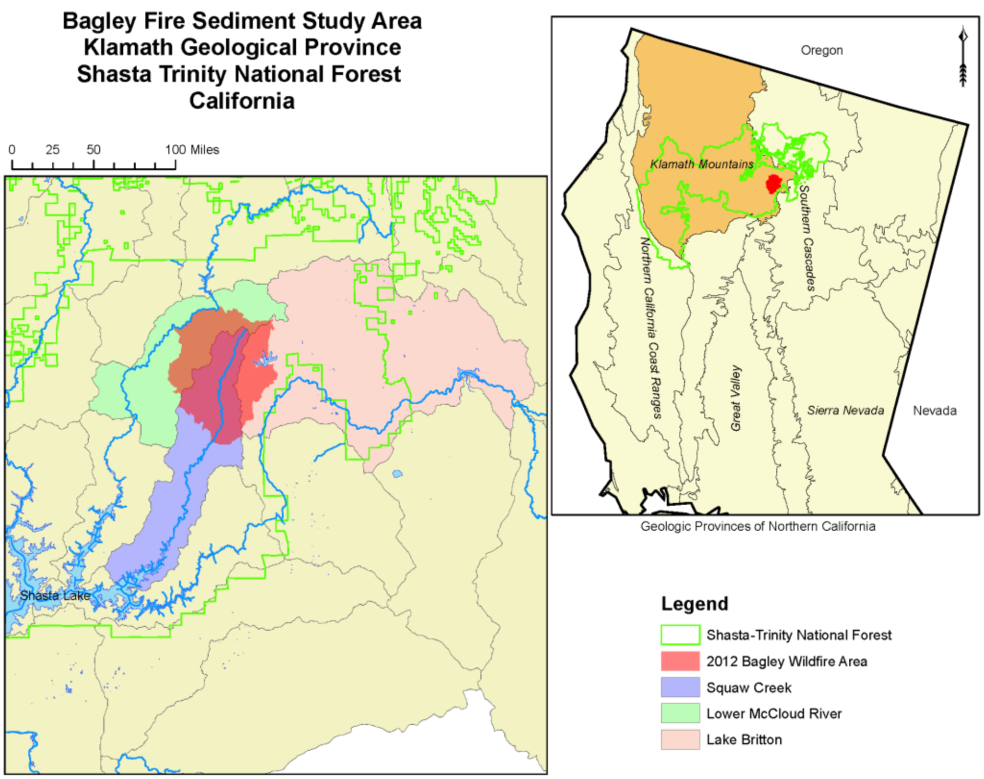

Figure 1 - Vicinity Map

Climate

The climate of the assessment area is typified by warm, dry summers and cool, wet winters. Substantial variation in temperature and precipitation occurs with elevation. Annual precipitation in the fire area is variable and ranges from 40 to over 80 inches depending on the water year. The highest precipitation occurs in the Upper Claiborne, West and North Forks Squaw, and Jessie Creek drainages, all of which experienced high-severity burn conditions. The majority of winter precipitation occurs as rain, although snow frequently falls at elevations above 4,000 feet. Almost all of the precipitation occurs between October and April and is subject to rain on snow events. Precipitation events are dominated by large Pacific storms during the rainy season. Convective storms occur infrequently during the summer months (USDA Forest Service, 2012).

Water Quality

Water quality in the project area is considered to be very good. Water quality concerns are limited to periods of winter runoff and are most commonly associated with increases in turbidity and fine sediment inputs during large winter storms. Burn severity was generally lower in Riparian Reserves than in the surrounding terrestrial uplands (Table 4; USDA Forest Service, 2012). The Jessie Creek-Horse Creek and West Fork Squaw Creek - Modin Creek HUC 7 watersheds had the greatest amount of high and moderate severity burn within Riparian Reserves. Other watersheds with appreciable amounts of high and moderate severity burn areas included Iron Canyon and Upper Claiborne Creek.

Study Goals

This investigation has four primary goals as follow:

1. **Precipitation, Stream Flow, Water Quality, Erosion, and Sedimentation -** Characterize the post-fire precipitation and stream flow events and resulting erosional and sedimentation processes. Quantify the amount of sediment eroded from hillslopes and deposited in streams and in Shasta Lake.

2. **BAER Predictions and Treatments -** Evaluate BAER predictions and treatments so that this information can be incorporated into future BAER work.

3. **Forest Staff Professional Development -** Provide hands-on experience to Forest staff in evaluating and monitoring post-fire watershed response with state-of-the-art tools.

4. **Adaptive Management -** Identify opportunities for adaptive management by using findings from this study to evaluate current Forest management practices which can influence post-fire erosion. This will allow reinforcement of those practices which are sound, and modification of those which are not.

Methods

Methods included review of previous studies, compilation of existing data, interpretation of pre- and post-fire air photos, and field investigations on National Forest lands within the fire area, along Squaw Creek, and in Shasta Lake. More information on these steps follows. High resolution terrain data derived from a LiDAR survey were not available for this Interim Report, but that information will be presented in the Final Report, due for completion in Spring 2014.

Precipitation Data - Rainfall data were compiled from RAWS stations and Pacific Gas & Electric (PG&E) gages. NEXRAD Level 3 Doppler was accessed using NOAA's Hierarchical Data Storage System (HDSS) and displayed using NOAA's free Weather and Climate Toolkit program. Precipitation from RAWS and PG&E gages were compiled and analyzed.

Stream Flow Data - Stream flow data for the interim report was obtained from a USGS gage site on Squaw Creek and was modelled for other sites with regression equations via the USGS StreamStats website. In addition, high water marks were surveyed in channel monitoring reaches and used for initial estimates of instantaneous flood peak discharges.

Coordination - Sierra Pacific Industries owns about 30% of the land within the fire area, and they were kept informed of this investigation.

Previous Investigations - Previous investigations conducted in the fire area were reviewed. These included the Squaw Creek Watershed Analysis (USDA Forest Service, 1999), the Lower McCloud Watershed Analysis Update (USDA Forest Service, 2011), the Bagley Fire BAER investigation (USDA Forest Service, 2012), as well as investigations by PG&E done as part of FERC licensing (Pacific Gas & Electric, 2009).

Air Photos and LiDAR - Air photos were acquired in April of 2013, and included 1:24,000 color infrared (CIR) photos of the fire area, and 1:4,000 color photos of the Squaw Creek channel extending southward from the fire area to Shasta Lake. LiDAR of the fire area and a corridor along Squaw Creek was acquired in late August and September of 2013. The 1:24,000 CIR photos were used to map large gullies and "altered channels". "Altered channels" were mapped where scour was evident within a stream channel or swale (Figure 12). Similar areas of scour visible on hillslopes, outside of defined channels, were mapped as "gullies". Features were first mapped onto 7.5' USGS Topographic maps and then transferred into a GIS database. The 1:4,000 natural color air photos were used to identify depositional areas and log jams along Squaw Creek (Figure 13). The LiDAR data will be used in the final phase of this investigation to estimate the sediment volume produced by large gullies and debris slides, and to characterize depositional areas along streams and in the bottom of Shasta Lake above the water line.

Field Work - Field work was limited to National Forest System lands. Remote sensing data were utilized across the entire fire area and along Squaw Creek to Shasta Lake. National Forest System lands occupy about 70% of the fire area. Field work included:

1. **Inventory of Landslides and Gullies -** A wide variety of sites were examined in the field and measurements taken of gully dimensions, channel scour/deposition widths, and sediment thickness. Site selection was based on a combination of accessibility, fire severity, rock/soil type, steepness, and severity of post-fire watershed response. Site level inventory data were collected at hundreds of locations on National Forest System lands, primarily within ¼ mile of a road and along some stream channels. Additional field sites will be visited in 2014.
2. **Soil Erosion Transects -** Twenty-seven representative soil transects were selected, based on a variety of characteristics such as fire severity, elevation, soil type, slope gradient, road accessibility, etc. These were located with GPS, sampled, and photographed. Site data included unit, soil type, surface texture and structure, soil burn severity, water repellency, slope length, slope gradient, and slope position. Transects measured depth of sheet erosion by pedestal height and width, depth of rills and gullies, as well as sediment re-deposition features (with precise transect intercept locations for each feature). The objectives of the soil transects were to measure hillslope erosion by using 100 meter transects cross-slope to record sheet, rill, and gully depth and width in low, moderate, and high soil burn severity locations throughout the fire. Transects were located mostly on the Neuns sandy loam soils, located throughout the fire, on many aspects and at various elevations to evaluate spatial storm intensity variations by magnitude of the erosion response.
3. **Stream Condition Inventories (SCI) -** The USFS Region 5 Stream Condition Inventory (SCI) protocol was used to characterize changes to three main stem Squaw Creek reaches. Channel slope, cross-section, and pebble count data were obtained in 2013 for three response reaches that had been surveyed prior to the 2012 flood. While the datum for some cross sections was compromised by flooding, 2013 data was generally comparable with pre-flood data.
4. **Water Quality -** Data on stream temperature were collected during the summer of 2013. These data will be compared to earlier water temperature data to determine how water temperature was affected by the hillslope and channel disturbances. Turbidity was not measured, but visual observations of turbidity will be used to characterize the extent and duration of turbidity events.
5. **Electroshock Fish Inventories -** Standard electroshocking inventories were conducted in late summer 2013. Compilation of data is in progress. Results will be analyzed and presented in the final report.
6. **Reservoir Sediment-** Reservoir sediments in the Squaw arm of Shasta Lake were examined on 7-1-13 when the reservoir level was at 1004 feet above sea level. Pits were dug with shovels along a transect line on the west bank about a half mile SW of the mouth of Madison Canyon. On September 26, when the reservoir was slightly above

950 feet in elevation, an augering transect was accomplished immediately SE of the mouth of Winston Gulch. Large bodies of sand were encountered with no clear strata which could be associated with large depositional events such as those in 1964 and 1997. Further study and interpretation is needed to do this. Further examination of sediments occurred on 10-16-13, from Fowler Gulch to Dark Canyon, and on 10-18-13, between Madison Canyon to about ½ mile south of Dinner Gulch.

7. **Bathymetric Surveys -** Bathymetric data were collected on July 1, 2013 (lake level 1004 feet), ~10 miles or ~16 km downstream of the Bagley Fire in the Squaw Creek Arm of Shasta Lake using a Forest Service operated boat. Depth data were read from a Lowrance HDS 5 at 200 kHz. Horizontal positions of each depth measurement were recorded as waypoints using a Garmin ETrex 30 using both U.S. GPS and Russia's GLONASS. Boat drift and GPS error are expected in the horizontal data since they could not be differentially corrected. Additional bathymetric data were collected on September 26, 2013.
8. **Road Inventories -** Road inventories were conducted immediately after the 2012 November-December storms by an extended Forest Service BAER team. Additional information was collected by engineering staff during the summer of 2013. These inventories identified specific road issues along approximately 90% of the road system.
9. **Cultural Resources-** The focus of field investigation was on sites located adjacent to Squaw Creek within the Bagley Fire area. Eight known sites are located on Forest Service System lands, within the Bagley Fire perimeter, and adjacent to Squaw Creek or its tributaries (Table 7).
10. **Botany/Invasive Plants -** Post-fire weed surveys were conducted on the dozer lines constructed to fight the fire. No surveys were done on roads, open burned areas, or water courses. During the summer of 2013, watershed personnel observed star thistle growing on 2012 flood deposits in a tributary to Iron Canyon Creek more than a mile downstream from the nearest road. Follow-up surveys have been recommended and, if carried out, may provide a better understand of fire and storm-related spread of invasive weeds. Efforts need to be made to obtain information on unsurveyed areas within the burn area.

Preliminary Findings

Precipitation

Intense storms impacted the fire area with estimated return intervals of 25-50 years based on a 4-day storm (11/29-12/2 2012) with totals ranging from 38 to 56 cm. NEXRAD Doppler showed that rains were generally steady, measuring an average of about 0.1 inches per hour for long durations of time (Table 2). One string of strong storms occurred on November 30 around 5 A.M. This string of storms lasted about two hours. It is important to note that Doppler has serious limitations of range due to curvature of the earth and shadowing effects in mountainous terrain. Thus storm intensities derived from Doppler appear greatly under estimated. Indeed, compared to rain gage storm totals, Doppler vastly underreported rain intensities and storm accumulations. Thus as a tool, Doppler in this case can only affirm overall weather patterns.

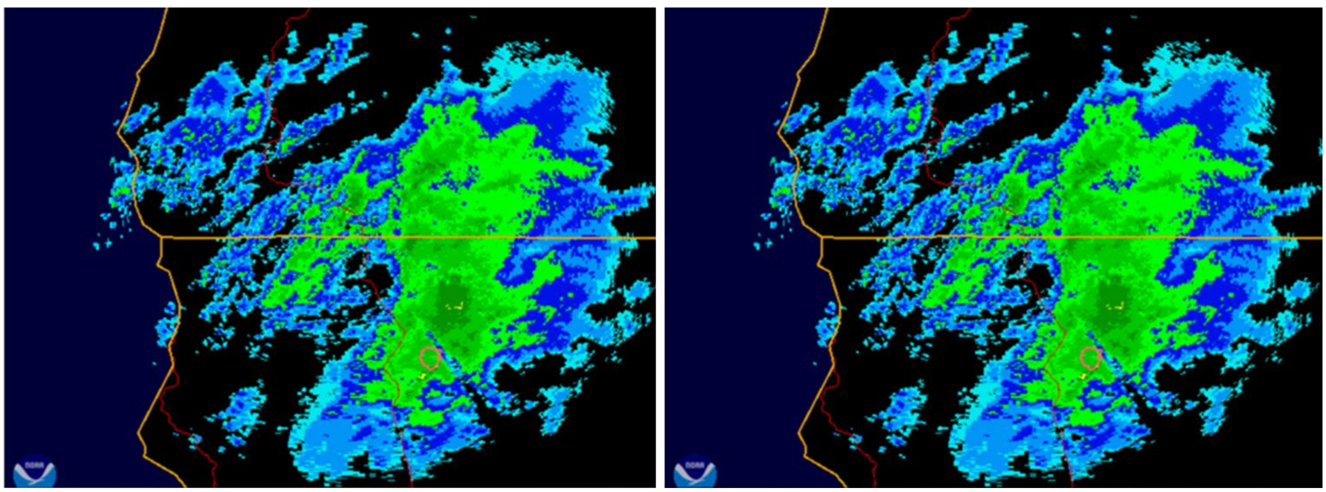

Figure 2 (above): NEXRAD Doppler on Nov 29, 2012 around Midnight PST. The Bagley burn area is outlined in salmon-pink. I-5 is the line up through the middle of the images. The Doppler returns, when animated, show a clear north east movement of precipitation for most of the storm. The 2 images are taken about 6 minutes apart. Figure 3 (below): a strong line of storms go through the southern edge of the Bagley burn area around 5 A.M. Nov 30, 2012. The storm moved in a north-easterly direction. The 2 images are taken about 11 minutes apart.

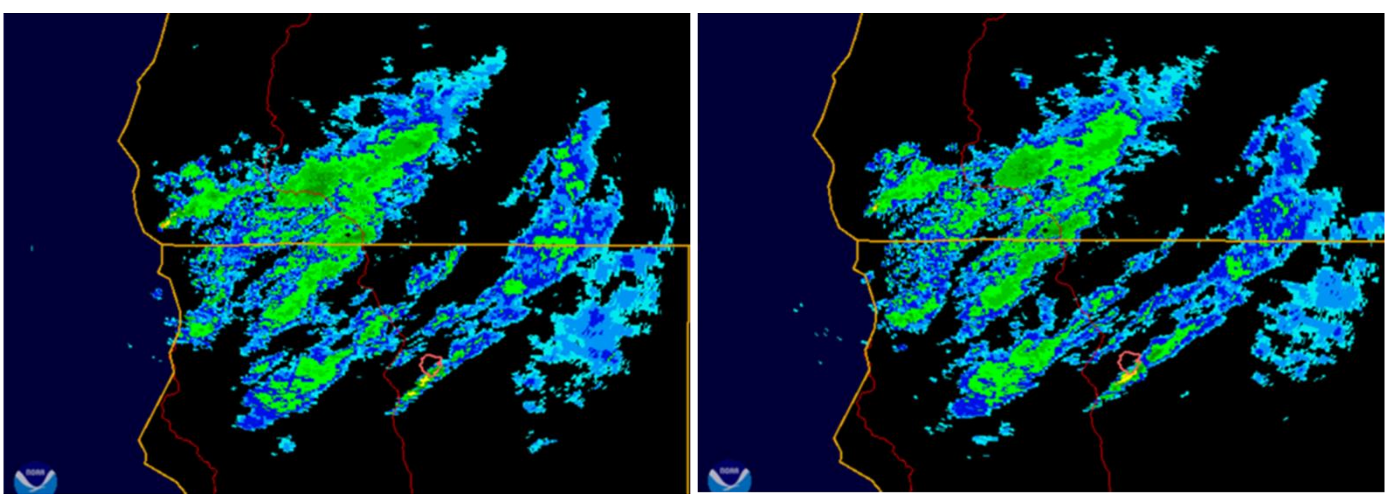

Table 1 - Summary of Long-Duration Rain within the Bagley Study Area. Convert to PST by subtracting 8 hours.

Summary of Long-Duration Rain for Bagley Burn Scar using Level III NEXRAD Doppler (NOAA)																								
GMT Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
28-Nov																Scattered very light showers								
29-Nov									0.1in/hr												Periodic light rain			
30-Nov		Very light to light scattered showers										Storm strand within Southern Bagley												
1-Dec	Very light to light scattered showers throughout the day																							
2-Dec			0.1in/hr					Very light to light scattered showers																
		Generally constant light rain									Periodic light rain													

The doppler image in Figure 3 indicates that the southern half of the fire area experienced the most intense rainfall during theNovember 30 storm. However, rain gage data displayed in Figure 4 shows that cumulative rainfall through December 2, 2012 was higher in the northern part of the fire area (McCloud Dam gage) than in the southern part (Oak Mt. gage). Doppler radar data for December 1 & 2 reveals lower rainfall intensity/duration rainfall in the fire area (Table 1) than for November 28-30. In summary, the doppler data clearly show that the storms moved in an northeasterly direction (north 50 degrees east), and suggest that the highest intensities and durations occurred in the SW part of the fire area on November 30. Again, this observation as currently interpreted conflicts with cumulative rain gage data.

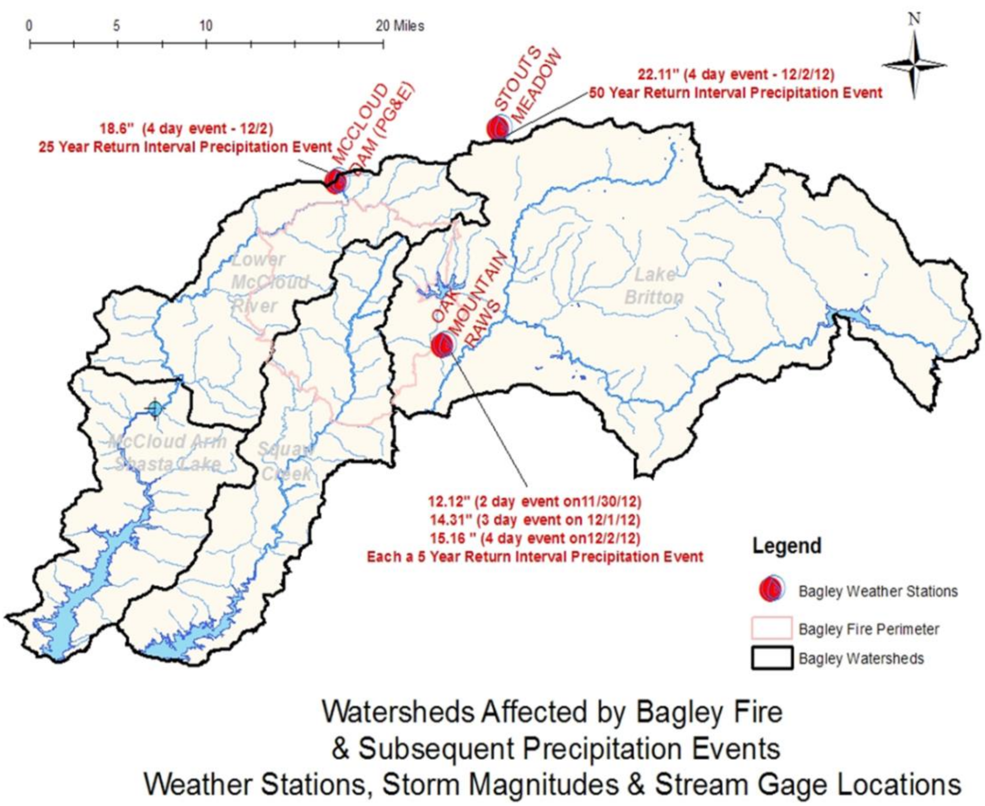

Figure 4 - Squaw Creek watershed and catchments and weather stations adjacent to the study area.

Four day rainfall totals ranged from about 15" at the Oak Mountain RAWS station east of Squaw Creek to over 22" of rain at the Pacific Gas and Electric weather station at Stouts Meadow just north of the Squaw Creek headwaters. Based on these data we interpret the 2012 storm event as having a 25 to 50-year recurrence interval. It is noteworthy that field reconnaissance across the fire area after the early November storm (Figure 5) did not initiate severe erosion. This observation suggests that this storm did not exceed threshold values of intensity or duration which lead to widespread erosion. This is valuable information for future BAER assessments in this hydro-geomorphic regime.

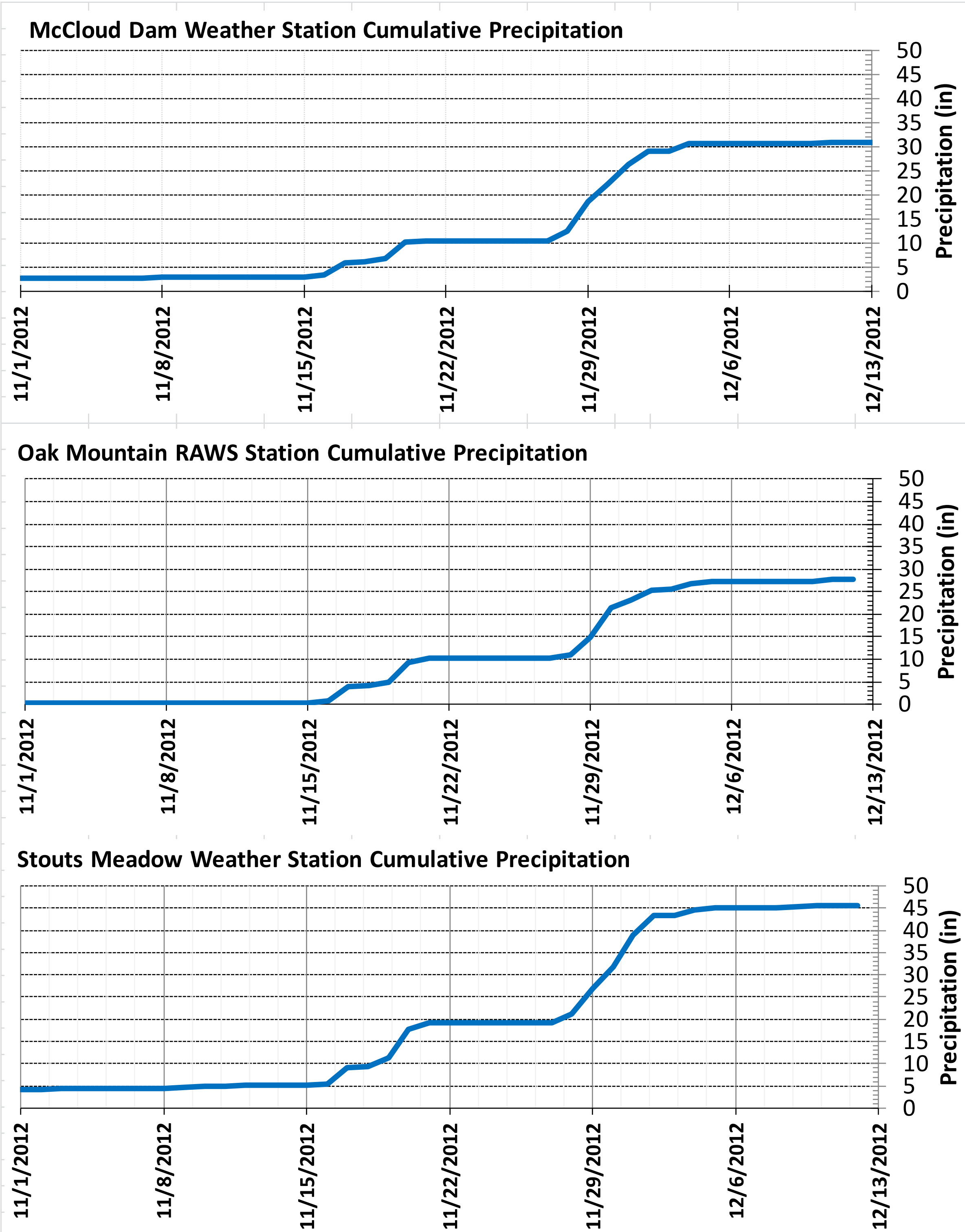

Figure 5 - Cumulative precipitation data from three weather stations adjacent to the Squaw Creek watershed for the period 11/1/13 to 12/13/13. An initial storm beginning on 11/16 produced in excess of 7" of rain at all three stations. The subsequent storm was much larger and produced from 15" to 22" of rain over a four day period.

McCloud Dam	Average recurrence interval (years)						
Duration	1	2	5	10	25	50	100
1-day	(4.47-5.82)	(5.43-7.08)	(6.59-8.63)	(7.44-9.89)	(8.33-11.8)	(8.96-13.2)	(9.51-14.6)
2-day	(6.20-8.07)	(7.59-9.90)	(9.29-12.2)	(10.5-14.0)	(11.9-16.8)	(12.8-18.8)	(13.6-20.9)
3-day	(7.41-9.63)	(9.12-11.9)	(11.2-14.7)	(12.8-17.0)	(14.4-20.4)	(15.6-22.9)	(16.6-25.6)
4-day	(8.39-10.9)	(10.4-13.5)	(12.7-16.7)	(14.5-19.3)	(16.4-23.2)	(17.7-26.1)	(18.9-29.1)
7-day	(10.7-14.0)	(13.2-17.2)	(16.2-21.2)	(18.4-24.4)	(20.7-29.2)	(22.3-32.8)	(23.8-36.5)
10-day	(12.3-16.1)	(15.2-19.8)	(18.6-24.3)	(21.0-28.0)	(23.6-33.4)	(25.4-37.3)	(27.0-41.5)

Oak Mtn RAWS	Average recurrence interval (years)						
Duration	1	2	5	10	25	50	100
1-day	(4.64-6.02)	(5.55-7.22)	(6.67-8.73)	(7.51-9.97)	(8.38-11.8)	(9.02-13.2)	(9.57-14.7)
2-day	(6.66-8.65)	(8.02-10.4)	(9.68-12.7)	(10.9-14.5)	(12.2-17.2)	(13.1-19.2)	(13.9-21.4)
3-day	(8.17-10.6)	(9.90-12.9)	(12.0-15.7)	(13.5-18.0)	(15.1-21.4)	(16.3-23.9)	(17.3-26.6)
4-day	(9.37-12.2)	(11.4-14.8)	(13.8-18.1)	(15.6-20.7)	(17.5-24.7)	(18.8-27.6)	(19.9-30.6)
7-day	(11.9-15.5)	(14.5-18.8)	(17.6-23.0)	(19.9-26.4)	(22.3-31.4)	(23.9-35.2)	(25.4-39.1)
10-day	(13.7-17.8)	(16.6-21.7)	(20.3-26.5)	(22.9-30.4)	(25.6-36.2)	(27.6-40.5)	(29.2-44.9)

Stouts Meadow	Average recurrence interval (years)						
Duration	1	2	5	10	25	50	100
1-day	(4.37-5.66)	(5.33-6.92)	(6.51-8.49)	(7.37-9.77)	(8.28-11.7)	(8.94-13.1)	(9.52-14.6)
2-day	(6.19-8.02)	(7.63-9.91)	(9.39-12.3)	(10.7-14.2)	(12.1-17.0)	(13.0-19.1)	(13.9-21.3)
3-day	(7.53-9.76)	(9.35-12.1)	(11.5-15.1)	(13.2-17.5)	(14.9-21.0)	(16.1-23.7)	(17.2-26.4)
4-day	(8.62-11.2)	(10.7-13.9)	(13.2-17.3)	(15.1-20.0)	(17.1-24.1)	(18.5-27.1)	(19.8-30.3)
7-day	(11.1-14.3)	(13.7-17.8)	(16.8-21.9)	(19.1-25.3)	(21.5-30.3)	(23.2-34.0)	(24.7-37.9)
10-day	(12.8-16.5)	(15.7-20.4)	(19.2-25.1)	(21.8-28.9)	(24.4-34.5)	(26.3-38.6)	(28.0-42.9)

Table 2 - Rainfall intensity-duration-frequency data for three weather stations in the study area. Four-day cumulative precipitation ranged from approximately 15 to 22".

Stream Flow

The largest peak flows measured at the Chirpchatter gauge in Squaw Creek (period of record 1945-1980) were 17,800 cfs in both December 1955 and January 1974. These flows were determined to be events with a return interval on the order of 25-years. No discharge data are available for Squaw Creek post-1980 and it is likely that the January 1997 flood event exceeded all of the earlier measured peak flows. This assumption is supported by discharge data from the adjacent McCloud River watershed that shows that the 1997 Flood was the largest recorded peak flows on the McCloud River for the entire period of record (1945-2014). Observations of Forest Service staff with long tenures in the McCloud area suggest that the magnitude of flows in Squaw Creek in December, 2012 were similar to those of January, 1997. These observations, plus the determination that the precipitation event associated with the December 2012 peak flows had a return interval of 25-50 years strongly suggest that the flood event of 2012 also had a return interval on the order of 25-50 years.

Post-fire infiltration capacity was reduced due to high-severity burning in portions of Squaw Creek, and the effect of post-fire soil water repellency on increased peak flow is expected to be significant in the first few years post-fire for more frequent storms such as the 2- and 5-year events. Squaw Creek experienced a longer-duration, less frequent storm, and the catchment areas contributing to the channel monitoring reaches integrated large patches of low-severity burn and/or unburned forest. As such, 2012 flood peak discharges at Madrone Campground and Chirpchatter may not have been significantly increased by fire effects. This hypothesis will be investigated further and elaborated upon in the final report in 2014.

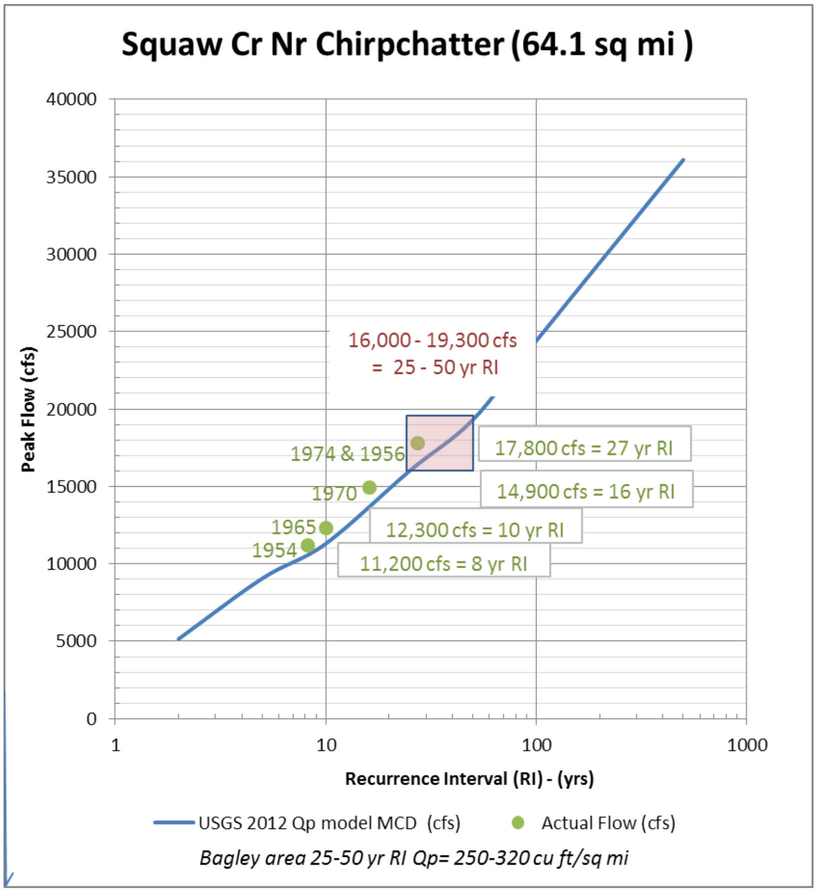

Figure 6 - Measured and modeled stream peak flows from the Squaw Creek US Geological Survey stream gauge site near Chirpchatter (now inactive). Note that there is some uncertainty about the data point for 2007 (under review). The model predicts discharge at Chirpchatter in excess of 15,000 cfs for the 25-year flow event. Repeat channel survey (SCI) reaches were located significantly upstream of Chirpchatter.

Pour Point	Drainage Area (square miles)	Q25 (cfs)	Q25 Yield (cfs/square mile)	Q50 (cfs)	Q50 Yield (cfs/square mile)
Above Modin Creek	23.5	6,330	269	7,790	331
Madrone Campground	37.8	9,920	262	12,100	320
Chirpchatter gauge site	64.1	16,000	250	19,300	301

Table 3 - US Geological Survey StreamStats model estimates of 25 and 50-year discharge for Chirpchatter and two repeat channel survey (SCI) reaches upstream in Squaw Creek. The model relies on regression equations from Waananen and Crippen (1977).

Water Quality

Conditions for good water quality declined following the winter storms due to the large amounts of fine sediments that were delivered to channels. Fine sediments were transported through the channel network to downstream reaches of Squaw Creek and other large tributaries. The amount of sediment delivered to Squaw Creek resulted in the creek running continuously turbid for over 2 months following the November/December storms. All of the affected channels cleared over the spring and water quality improved to pre-fire conditions once flow returned to base flow conditions. Water quality will likely degrade during future winter high flow events as accumulated sediments are mobilized and transported through the channel network. A summer storm in June of 2013 resulted in increased runoff and higher turbidity levels in Squaw Creek for several weeks. The source of the turbidity can be attributed to the sediment that was introduced to the channel during the previous winter's storms. Burn severity was generally lower in Riparian Reserves than in the surrounding terrestrial uplands (Table 4; USDA Forest Service, 2012). The Jessie Creek-Horse Creek and West Fork Squaw Creek - Modin Creek HUC 7 watersheds experienced the greatest amount of high and moderate severity burn within Riparian Reserves. Other watersheds with appreciable amounts of high and moderate severity burn areas included Iron Canyon and Upper Claiborne Creek.

Photo 2a (top) and 2b (bottom) - Squaw Creek Turbidity and Deposition (Photo 2a taken in April, 2013, and 2b in July, 2013)

Squaw Creek displayed high turbidity levels on April 11th and July 1st 2013. Elevated streamflow and turbidity levels persisted for months following the 2012 storms. Turbidity in Squaw Creek gradually diminished in late-Spring but rose sharply in late-June in response to summer precipitation. Water temperature data acquired before and after the fire have not yet been analyzed, but will be addressed in the final report.

Hillslope Processes

Field observations found that erosional processes were dominated by sheet, rill, and gully erosion. The resulting sediment delivered to channels was rich in gravel and finer particles. Very few post-fire landslides have been identified, and these were shallow debris slides. Sediment laden flows occurred in most burned low order channels. However, classic debris flows that scour all vegetation from channel bottoms were very uncommon. Field surveys and LiDAR data interpretation are underway to refine mapping and classification of erosional features, and findings will be included in the final report.

Surface Erosion, Rills and Gullies

Early findings were that sheet and rill erosion were the most common processes, due to warm early-season storm events that hit in late November and early December of 2012, when soils were only slightly moist and had water repellant layers 6 or more inches deep. The first storm dumped 9 inches in 3 hours, then 1 week later 13 inches in 24 hours, then in two days 4 inches in 6 hours. These events caused deep rilling and gullying but few debris flows or landslides. The term "gully" is applied to those features deeper than 0.5 meters and "rill" to those shallower than 0.5 meters (Soil Science Society of America, 2001). Debris flows typically occur in response to late season storms in the spring when soils are saturated. But in this case it was a series of early season storms that most likely only saturated the soil to the water repellant layer at 6 to 12 inches deep. This caused sheet erosion and deep rilling that coalesced into deep gullies on slopes greater than 50% gradient.

Middle Squaw Creek rilling and sheet erosion.	Upper Squaw Creek deep rilling and gully erosion.

Photo 3a (left) and 3b (right) August, 2013 BR

Soil Survey Results

There were 27 hillslope erosion transects completed with a range of site variables documented to examine "controlling factors" relating to magnitude of observed erosion. Erosion features (rill, gully, sheet) as well as re-deposition features were measured (width and depth in cm) along 100 meter transects. Unfortunately not all transects had comprehensive data due to an 'evolution' in training and data collection methods during the measurement season. All 27 transects have rill and gully data; 18 have re-deposition features documented; 14 have sheet erosion documented, as evidenced by depth of pebble “pedestal” features. Thus some of the following results are reported as including all transects or a subset of transects, as appropriate; this limits the statistical rigor, but it’s what we resulted with.



Typical deep riling in severely burned landscape on south-facing slopes	Steep landscapes with long slopes lengths had deep rills and gullies	Sheet erosion was evident by extensive pedestals up to 2 inches

Photo 4a (left) 4b (center) and 4c (right) - August, 2013 by Brad Rust



Typical deep riling in medium burned landscape on east-facing slopes.	Transect data collection measuring depth and width of riling.	Typical soil pedestal measuring 2 to 3 inches in height.

Photo 5a (left) 5b (center) and 5c (right) - August, 2013 by Brad Rust

The primary erosion metric of interest is cross-sectional area in a 2-D vertical plane along transects, equivalent to eroded volume but without the 3^{rd} dimension. Relative contribution of different erosion processes are examined, as well as correlation to several categorical site variables: soil burn severity, slope length, slope gradient, slope position, aspect, soil texture, soil water repellency, surface rock cover, and total ground cover. It was also desired to compare salvage logged areas with non-salvaged areas, but the salvaged lands were restricted to private lands.

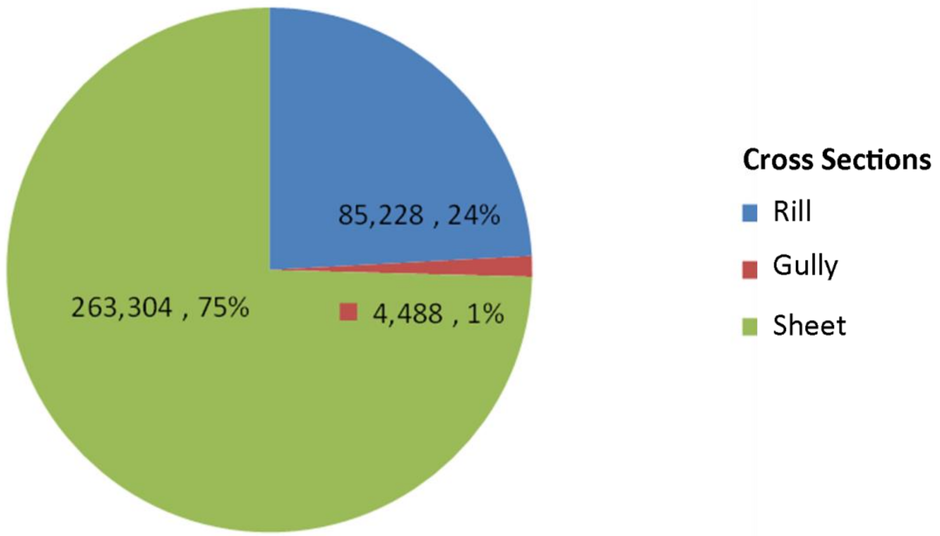

Figure 7 - Total erosion cross-sectional area (cm^2) and relative contribution of erosion processes. Data from 14 of 27 transects, where sheet erosion was measured.

In terms of observed erosion processes (on the 14 transects with comprehensive data), sheet erosion dominated (75%), followed by rill erosion (24%) and then gully erosion (1%) (Figure 7). Re-depositional features were equivalent to about 2% of total erosion features. Despite some dramatic gullies observed in the fire area, only 4 gully features were encountered on all transects, and only 1 of the 14-transect subsets. Looking at all transects, rill erosion was almost exactly double gully erosion, not 20-fold as seen in Figure 7. Thus the relative contribution of gully features is difficult to pinpoint without many more transects, by virtue of being infrequent, large occurrences in this fire area. LiDAR data from 2013 will be used to measure volumes for many of the gullies, and this information should refine our understanding of the relative importance of each of these processes. Fire-wide anecdotal observations indicate that gullies were closely correlated with roads.

In terms of explanatory site variables, erosion response had no discernable relationship to soil burn severity (SBS), soil texture, water repellency, rock or total surface cover, or aspect. It was expected that SBS would be an operative factor, that is, more intense erosion would be seen where fire severity was higher, but the transect data did not indicate this. There are at least two possible explanations: 1) Sheet erosion dominated in all instances where it was measured, and it was not measured on about half the transects, including all of the high SBS, so SBS effects may be masked by this error; 2) It is possible that the magnitude of the storm events overwhelmed fire effects in terms of soil damage or soil cover – all hillslopes encountered sufficient overland flow to produce a substantial erosion response, regardless of these variables. Thus the role of soil burn severity in resulting hillslope erosion was not clarified here. This question will be examined in greater depth prior to completion of the final report.

The site variables that did have a strong relationship to erosion response were the topographic slope variables – slope length, gradient, and position (Figures 8, 9, 10). This makes sense, in that virtually all physical hillslope processes are fundamentally tied to topography to some extent.

Interactions between site variables have not yet been examined, particularly the slope variables, i.e. foot slopes may have lower gradients, upper slopes shorter slope lengths, and mid slopes may more commonly have a combination of steeper slopes with longer runs. Hopefully site and slope variables and their interactions can be teased out with further analysis.

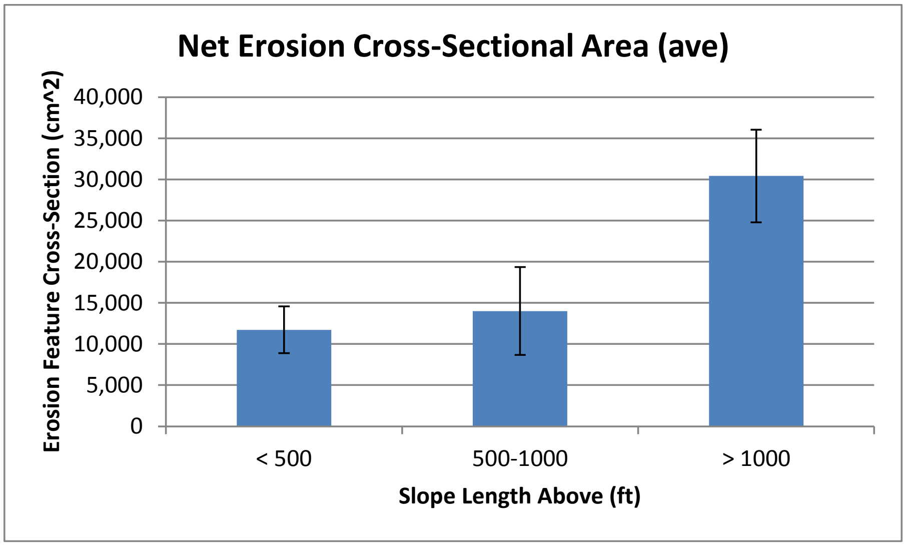

Figure 8 - Erosion Area by Slope Length

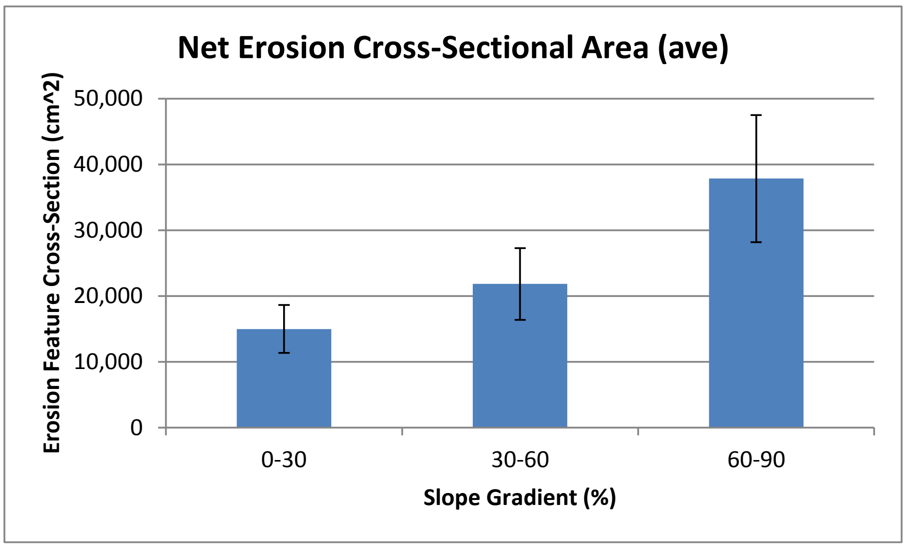

Figure 9 - Erosion Area by Gradient

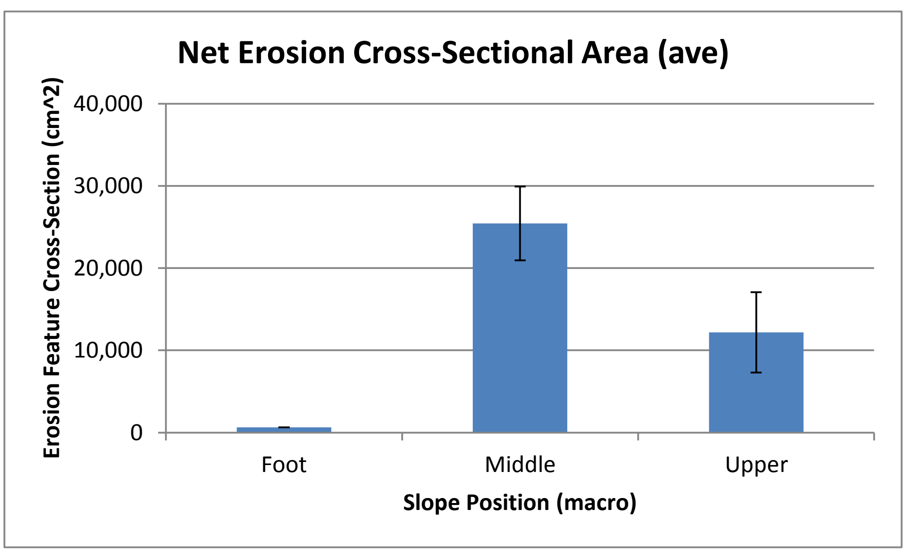

Figure 10 - Erosion Area by Slope Position

Conclusions

Erosion monitoring efforts show that all hillslopes evaluated had substantial erosion, with sheet erosion being more prominent than expected.

- Sheet erosion > Rill erosion > Gully erosion > Re-deposition.
- Relative contribution of gully erosion was not well quantified, limited by sample size.
- Greatest erosion was on steeper, longer slopes at midslope position in the watershed.
- The great majority of hillslope-derived sediment appears to have been delivered to the fluvial system.

Note: Additional information is available in a stand-alone Draft Soils Report (December, 2013), prepared by Dave Young and Brad Rust for this project.

Transect	Texture	W.Rep.	WR_start	WR_thick	IR_num	IR_width	R_num	R_width	R_depth	R_Xsec	G_num	G_width	G_depth	G_Xsec	D_num	D_width	D_depth	D_Xsec	S_depth	S_Xsec	Net_Xsec	Sed_Prod
1	SL	Weak	-	-	66.0	118.3	65.0	33.7	6.4	14059.0	0.0	-	-	0.0	-	-	-	-	-	-	14059.0	62.7
2	SL	Weak	-	-	41.0	196.3	38.0	39.2	14.9	22899.0	2.0	230.0	124.0	55828.0	-	-	-	-	-	-	78727.0	351.2
3	SL	Strong	0.00	5.10	15.0	608.0	13.0	43.1	12.3	8330.0	1.0	320.0	186.0	50592.0	-	-	-	-	-	-	58922.0	262.8
4	SL	Weak	0.00	10.20	14.0	695.7	13.0	20.0	6.2	1432.3	0.0	-	-	0.0	-	-	-	-	-	-	1432.3	6.4
5	SL	Weak	0.00	10.20	28.0	337.7	27.0	20.2	4.0	2180.2	0.0	-	-	0.0	-	-	-	-	-	-	2180.2	9.7
6	SL	Weak	0.00	5.10	46.0	184.2	45.0	33.9	9.7	16413.5	0.0	-	-	0.0	-	-	-	-	-	-	16413.5	73.2
7	SL	Weak	0.00	4.20	27.0	325.9	26.0	46.2	12.5	27404.0	0.0	-	-	0.0	-	-	-	-	-	-	27404.0	122.2
8	L	Moderate	0.00	7.60	44.0	191.1	43.0	37.0	5.7	11908.5	0.0	-	-	0.0	-	-	-	-	-	-	11908.5	53.1
9	SL	Weak	0.00	2.50	12.0	815.4	11.0	19.5	6.1	1695.8	0.0	-	-	0.0	-	-	-	-	-	-	1695.8	7.6
10	SL	Strong	0.00	3.40	25.0	358.0	24.0	43.8	3.8	3723.0	0.0	-	-	0.0	0.0	-	-	0.0	-	-	3723.0	16.6
11	SL	Strong	5.10	4.20	6.0	1629.2	5.0	45.0	6.8	1411.0	0.0	-	-	0.0	0.0	-	-	0.0	0.6	5865.0	7276.0	32.5
12	SL	Strong	2.50	4.20	48.0	178.3	47.0	30.6	7.3	12078.5	0.0	-	-	0.0	0.0	-	-	0.0	1.9	16264.0	28342.5	126.4
13	CSL	Strong	3.80	5.50	53.0	155.5	50.0	35.2	5.7	9073.8	0.0	-	-	0.0	0.0	-	-	0.0	1.3	10712.0	19785.8	88.3
14	SL	Strong	4.20	17.80	71.0	102.6	70.0	38.8	6.0	16252.0	0.0	-	-	0.0	0.0	-	-	0.0	-	-	16252.0	72.5
15	SL	Strong	3.40	5.10	24.0	382.7	23.0	35.4	7.0	11793.8	0.0	-	-	0.0	0.0	-	-	0.0	1.3	11940.5	23734.3	105.9
16	SL	Strong	5.10	8.90	10.0	969.0	5.0	26.0	4.8	565.3	0.0	-	-	0.0	5.0	36.0	5.8	947.8	3.5	33915.0	33532.5	149.6
17	SL	Moderate	0.80	6.80	40.0	208.6	39.0	42.4	6.8	12082.8	0.0	-	-	0.0	0.0	-	-	0.0	1.9	15855.5	27938.3	124.6
18	SL	Strong	4.20	5.10	22.0	393.0	25.0	38.0	3.6	3344.8	0.0	-	-	0.0	10.0	40.5	4.8	1717.0	1.0	8645.0	10272.8	45.8
19	L	Moderate	2.50	4.20	16.0	602.5	13.0	21.2	5.2	1258.0	0.0	-	-	0.0	3.0	28.3	8.0	854.3	1.3	12532.0	12935.8	57.7
20	L	Moderate	1.70	2.50	6.0	1595.0	7.0	45.7	3.3	909.5	0.0	-	-	0.0	4.0	27.5	3.5	284.7	-	-	624.8	2.8
21	SL	Strong	0.80	2.50	40.0	228.6	37.0	21.5	5.8	4955.5	0.0	-	-	0.0	2.0	30.0	4.0	51.0	1.3	11888.5	16793.0	74.9
22	L	Moderate	2.50	11.90	9.0	1073.3	9.0	36.7	5.1	1853.0	0.0	-	-	0.0	1.0	10.0	2.0	17.0	-	-	1836.0	8.2
23	SL	Moderate	1.30	9.30	6.0	1640.8	5.0	31.0	14.4	2048.5	0.0	-	-	0.0	0.0	-	-	0.0	5.4	53163.0	55211.5	246.3
24	SL	Moderate	1.30	10.20	26.0	356.5	22.0	33.2	5.8	4209.8	0.0	-	-	0.0	0.0	-	-	0.0	1.9	17613.0	21822.8	97.3
25	SL	Moderate	1.30	11.00	43.0	172.4	55.0	35.9	8.0	15560.1	1.0	80.0	66.0	4488.0	23.0	23.0	4.1	2057.0	2.5	18537.5	36528.6	163.0
26	L	Moderate	1.30	11.90	16.0	594.4	15.0	32.0	5.3	2129.2	0.0	-	-	0.0	1.0	10.0	2.5	21.3	1.3	12363.0	14471.0	64.6
27	L	Moderate	1.30	15.20	16.0	559.4	15.0	70.0	4.8	4717.5	0.0	-	-	0.0	0.0	-	-	0.0	3.8	34010.0	38727.5	172.8

Table 4 - Erosion data summarized by transect – number (num), width, depth, and cross-sectional area (Xsec) for inter-rills (IR), rills (R), gullies (G), re-deposition (D), and sheet (S) erosion features. Water repellency (W.Rep., WR) is averaged from multiple points per transect. Net_Xsec = combined erosion Xsec minus re-deposition Xsec, and is the primary analysis variable. All numbers are in cm or cm^2, except Sed_Prod. Sed_Prod is sediment production in tons/acre, strictly as a beta-conversion attempt for further analysis and scrutiny.

Transect	SurveyDate	GroundCoverPCT	AshColor	AshDepthMM	SoilStruct	RootAlt	InfiltMeth	W.Rep.	SBS_obs	Comment	Aspect	SlopePCT	SlopeLenFT	SlopePos	Texture	SurfRockPCT	SoilComment	PreFireVeg	PreVegDensity	VegComment
1	8/12/2013	20 - 50	Gray	20	DegradedPowdery	ModerateConsumption	WDPT	Weak	High		SW	55	1000	Mid	SL	50	sandy loam	Forest	High	
2	8/12/2013	20 - 50	Black	20	DegradedPowdery	ModerateConsumption	WDPT	Weak	High		SE	55	1000	Mid	SL	45	neuns	Forest	Low	d-fir
3	8/13/2013	20 - 50	Black	10	DegradedPowdery	ModerateConsumption	WDPT	Strong	High		S	55	1000	Mid	SL	45		Forest	High	
4	8/13/2013	20 - 50	Black	0	DegradedPowdery	ModerateConsumption	WDPT	Weak	Moderate		N	45	500	Upper	SL	40		Forest	High	
5	8/13/2013	20 - 50	Black	0	DegradedPowdery	ModerateConsumption	WDPT	Weak	Moderate		N	40	600	Upper	SL	30		Forest	High	
6	8/14/2013	20 - 50	Gray	20	DegradedPowdery	ModerateConsumption	WDPT	Weak	High		SW	55	1000	Mid	SL	35	Neuns sandy loam infiltration at 4 inches repelancy high	Forest	High	
7	8/14/2013	> 50	Black	0	DegradedPowdery	VeryFineConsumed	WDPT	Weak	Low	mostly live trees	E	25	900	Mid	SL	40		Forest	High	
8	8/14/2013	0 - 20	Black	15	DegradedPowdery	ModerateConsumption	WDPT	Moderate	High		NW	40	350	Upper	L	30		Forest	High	
9	8/14/2013	> 50	Gray	20	SlightlyAltered	ModerateConsumption	WDPT	Weak	Moderate		SW	45	800	Mid	SL	45	lots sheet erosion	Forest	High	mixed severity burn moderate
10	8/15/2013	20 - 50	Gray	30	SlightlyAltered	ModerateConsumption	WDPT	Strong	Moderate		W	25	300	Mid	SL	15		Forest	High	
11	8/15/2013	20 - 50	Gray	30	SlightlyAltered	ModerateConsumption	WDPT	Strong	Moderate	6mm pedestaling	S	30	600	Upper	SL	15		Forest	High	
12	8/15/2013	20 - 50	Black	10	SlightlyAltered	VeryFineConsumed	WDPT	Strong	Low	repellency 2-4"	N	45	1000	Mid	SL	40	Sheet erosion and pedestals in quantity soil sandy loam	Forest	High	
13	8/15/2013	20 - 50	Mixed	25	SlightlyAltered	VeryFineConsumed	WDPT	Strong	Low	wr 1 to 3	N	30	500	Mid	CSL	50	vg sl	Forest	High	knobcone/d-fir
14	8/15/2013	20 - 50	Black	1	DegradedPowdery	VeryFineConsumed	WDPT	Strong	Low		NW	30	1000	Mid	SL	45		Forest	High	
15	8/16/2013	0 - 20	Black	25	DegradedPowdery	VeryFineConsumed	WDPT	Strong	Moderate		NE	50	1000	Mid	SL	25	sandy loam neuns	Forest	High	
16	8/16/2013	20 - 50	Black	0	DegradedPowdery	ModerateConsumption	WDPT	Strong	Low		S	48	1000	Upper	SL	40	1-1/4 to 1.5 in pedi	Forest	High	mixed conif
17	8/16/2013	20 - 50	Black	2	DegradedPowdery	ModerateConsumption	WDPT	Moderate	Moderate	range camera 1456	E	27	1000	Mid	SL	45		Forest	High	
18	8/16/2013	20 - 50	Black	20	SlightlyAltered	VeryFineConsumed	WDPT	Strong	Moderate	wr 2-4"	SW	50	800	Mid	SL	50	vg-sl	Forest	High	d-fir/p-pine
19	8/16/2013	20 - 50	Black	1	SlightlyAltered	NoChange	WDPT	Moderate	Low		SE	54	500	Mid	L	30		Forest	High	
20	8/21/2013	20 - 50	Black	50	SlightlyAltered	VeryFineConsumed	WDPT	Moderate	Moderate	weak infiltration at 11"	NW	12	1000	Foot	L	10		Forest	High	
21	8/21/2013	20 - 50	Black	5	SlightlyAltered	VeryFineConsumed	WDPT	Strong	Moderate		SW	27	300	Upper	SL	20	.25-.75in pedestals	Forest	High	
22	8/21/2013	> 50	Black	0	SlightlyAltered	VeryFineConsumed	WDPT	Moderate	Low		NW	55	700	Mid	L	15		Forest	High	
23	9/11/2013	20 - 50	Black		sllightly altered	slight	WDPT	Moderate	Low		N	65	500	Mid	SL	25		Forest	High	
24	9/12/2013	20 - 50	Black		slightly degraded	low	WDPT	Moderate	Low		NE	70	1000	Mid	SL	25		Forest	High	
25	9/12/2013	20 - 50	Black		slightly degraded	slightly degraded	WDPT	Moderate	Low		W	85	1000	Mid	SL	25		Forest	High	
26	9/16/2013	20 - 50	Gray		powdery	low	WDPT	Moderate	Moderate	SBS patchy	SW	41	450	Mid	L	20		Forest	High	
27	9/16/2013	20 - 50	Gray			slight	WDPT	Moderate	Moderate		SW	37	1000	Mid	L	18		Forest	High	

Table 5 - Erosion data summarized by transect number. Results here are largely confined to "net cross-sectional area" of erosion features; average widths, depths, and groupings of erosion features have yet to be evaluated in depth

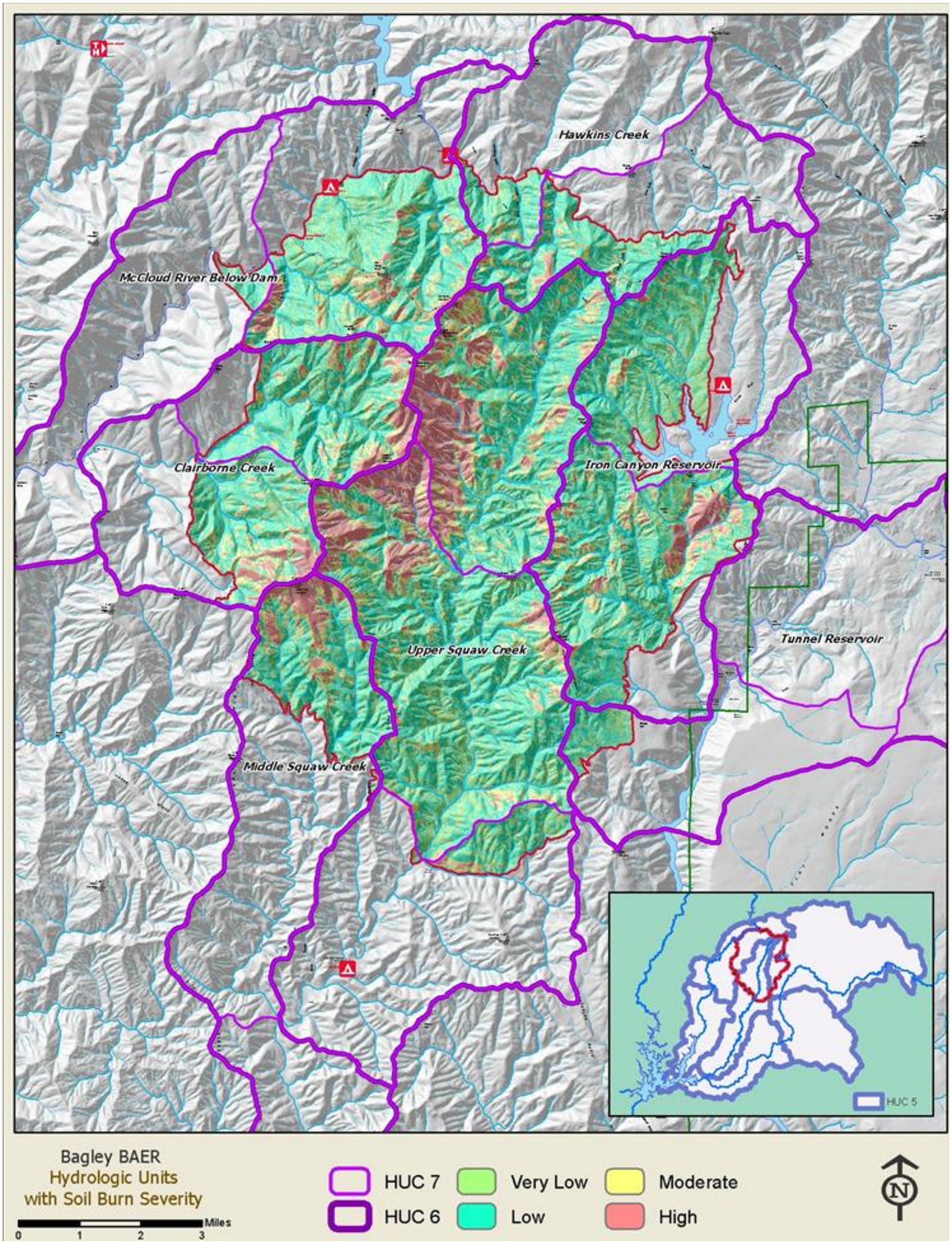

Figure 11 – Overview and Soil Burn Severity Map with Watersheds

Debris Flows and Altered Channels

Mapping on the 1:24,000 post-fire air photos showed, as expected, that altered channels, gullies and landslides are concentrated in areas of high and moderate soil burn severity. However, this may be partly due to better ground visibility in those areas on the air photos. Field inventories have identified other such features in areas of low and unburned severity. Field surveys combined with LiDAR data will be used to refine this mapping. The altered channel/gully map (Figure 12) does not show a pattern of high gully/altered channel density along NE/SW bands as suggested by the Doppler data. Rather, higher densities are closely associated with fire severity as stated previously. In fact, flood damage does not extend more than a few miles to the west, north, and east of the fire perimeter. However severe road damage and landslides are known to have occurred about 3 miles SE of the fire area, immediately west of the James B. Black Power House, on the east side of the Pit River (Bob Hutchins, personal communication, 2013).

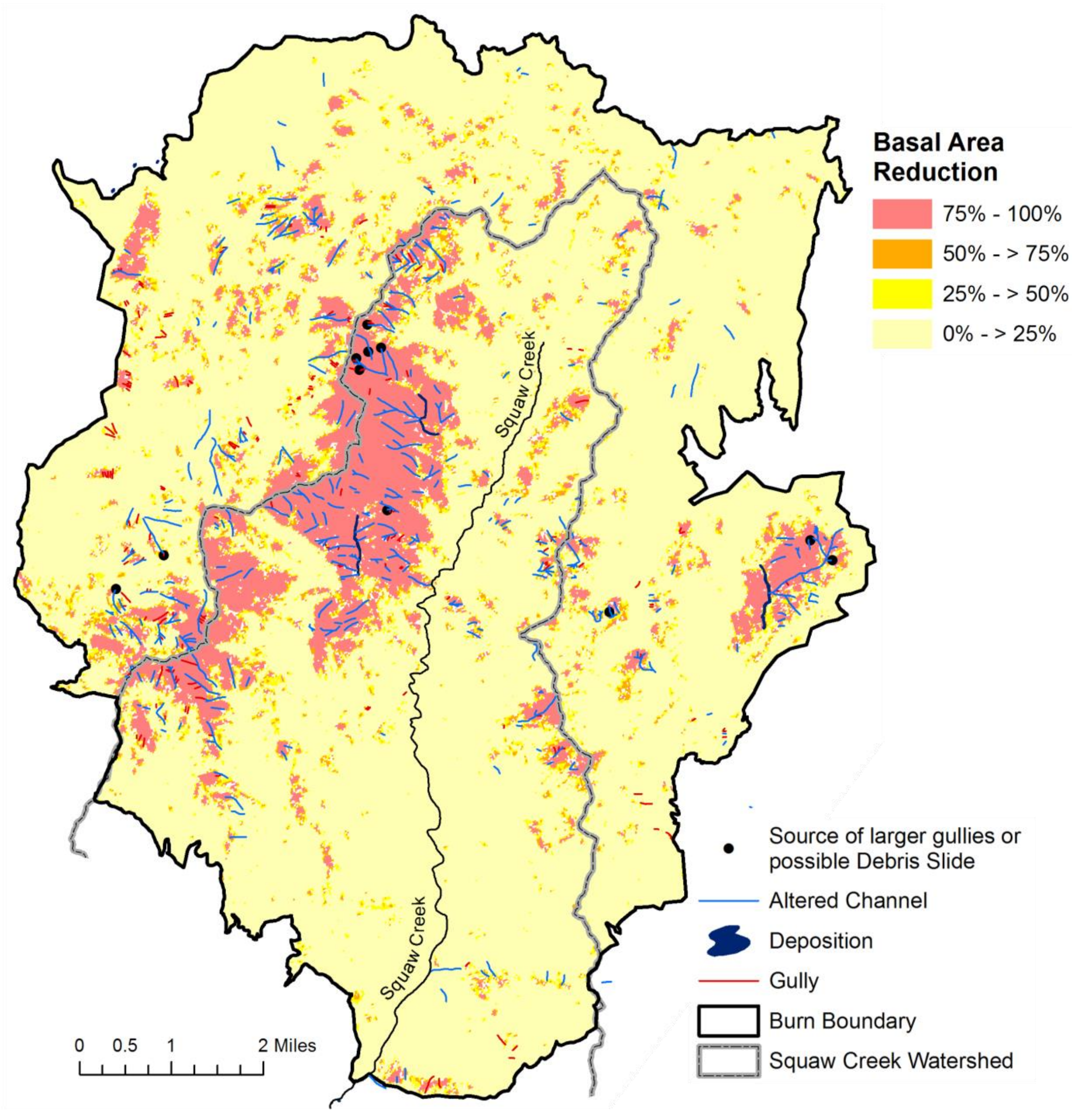

Figure 12- Altered Channels and Gullies Mapped using 1:24000 Color Infrared Air Photos. Depositional areas on smaller channels are rarely discernible at this scale. Refinements to this mapping will be made using LiDAR.

The scarcity of landslides in the fire area could be due to relatively low antecedent precipitation leading up to the big storms. Also, the widespread water repellency observed in the watershed could have greatly reduced the infiltration needed to saturate deeper parts of the regolith to the point where landslides would occur. Most channel altering events appear to have been sediment laden flows. This may partially be due to the lack of landslides capable of mobilizing bed material in headwater channels.


Photo 6 (#8736) - Fresh debris fan in tributary to Iron Canyon Creek 12-14-12 JdlF


Photo 7 (#4240) - Tributary to Iron Canyon Creek below PG&E penstock (downstream from Photo 6) 6-12-13 JdlF

Photo 8 (#8647) - Shallow debris slide (about 5 ft. of colluvium on bedrock) in a tributary to Iron Canyon Creek 12-14-12 JdlF

Photo 9 (#8508) - Gravel debris flow in a tributary to Iron Canyon Creek 12-14-12 JdlF

Channel Response and Sedimentation

Low gradient stream reaches < 2 % (i.e. response reaches) in Squaw Creek were aggraded with sand and gravel as a result of the 2012 flood. During the spring and summer of 2013 high levels of turbidity were sustained along the main stem. Turbidity is attributed to upland erosion and degradation of low-order channels that loaded higher-order streams with highly mobile fine sediments. Stream channel reconnaissance and subsequent channel monitoring surveys demonstrated significant loss of slow-water (pools and glides) habitat as a result of filling during the flood. However, filled pools and aggraded riffles are storing gravels that should provide increased spawning habitat post-flood.

Reach #	Reach Name	Survey Year	Length (m)	Gradient (%)	Particle Size (d50)	Pools/Glides (#)	Large Wood (#)	2012 Flood XSA[a] (ft^2)	2012 Flood Q[b] (cfs)
7	Modin Creek	2002	275	1.3	Small cobble	3	0		
		2012		1.3	Very large cobble	5	0		
		2013		1.4	Coarse gravel	0	12	750	5,300
1	Wheeler Ranch	2002	399	0.6	Medium cobble	1	0		
		2012		0.6	Small cobble	3	0		
		2013		0.7	Medium gravel	0	20	690	5,400
8	Madrone Campground	2002	613	0.5	Large cobble	4	0		
		2012		1.0	Very coarse gravel	5	1		
		2013		0.4	Coarse gravel	0	2	620	5,500

a--Preliminary flood XSA estimated based on high-water marks and the 2013 channel bed elevation.

b--Preliminary discharge estimate.

Table 6 - Summary of SCI survey data and preliminary 2012 flood discharge estimates for three Squaw Creek reaches.

Reach thalweg gradients appear mostly unchanged while bed texture was fined with gravel and sand as a result of the 2012 event. Limited slow-water habitat (pools and glides) was buried by the flood sediment and a minor amount of large wood conveyed to and stored in the reaches. Preliminary discharge estimates that do not increase appreciably between the Modin and Madrone survey reach are limited by approximated field data and initial computational methods.

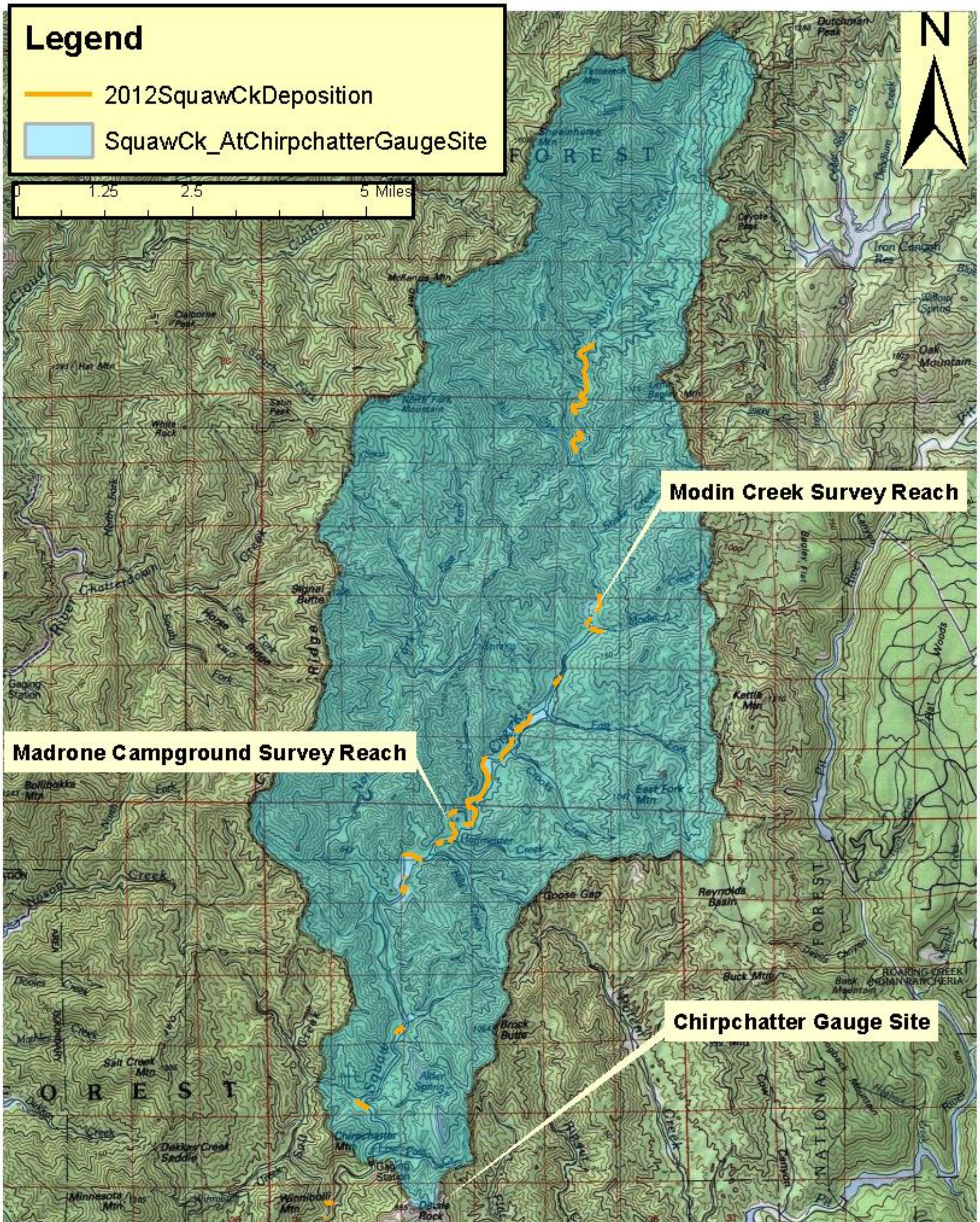

Figure 13 - 1:100,000 scale topo map of Squaw Creek catchment above the Chirpchatter gage site. Orange channel segments are areas of 2012 flood deposition mapped on 1:4,000 post-flood air photos. Approximately 30 depositional segments were mapped totaling about 6 miles in length. Upstream extent of flood deposition ends where photo interpretation was limited by a narrow valley and shaded channel. Depositional zones were seen in the field upstream of this mapping (B. Rust, Shasta-Trinity NF, personal communication). Wheeler Ranch survey reach not identified on map but just downstream of Modin Creek survey reach.

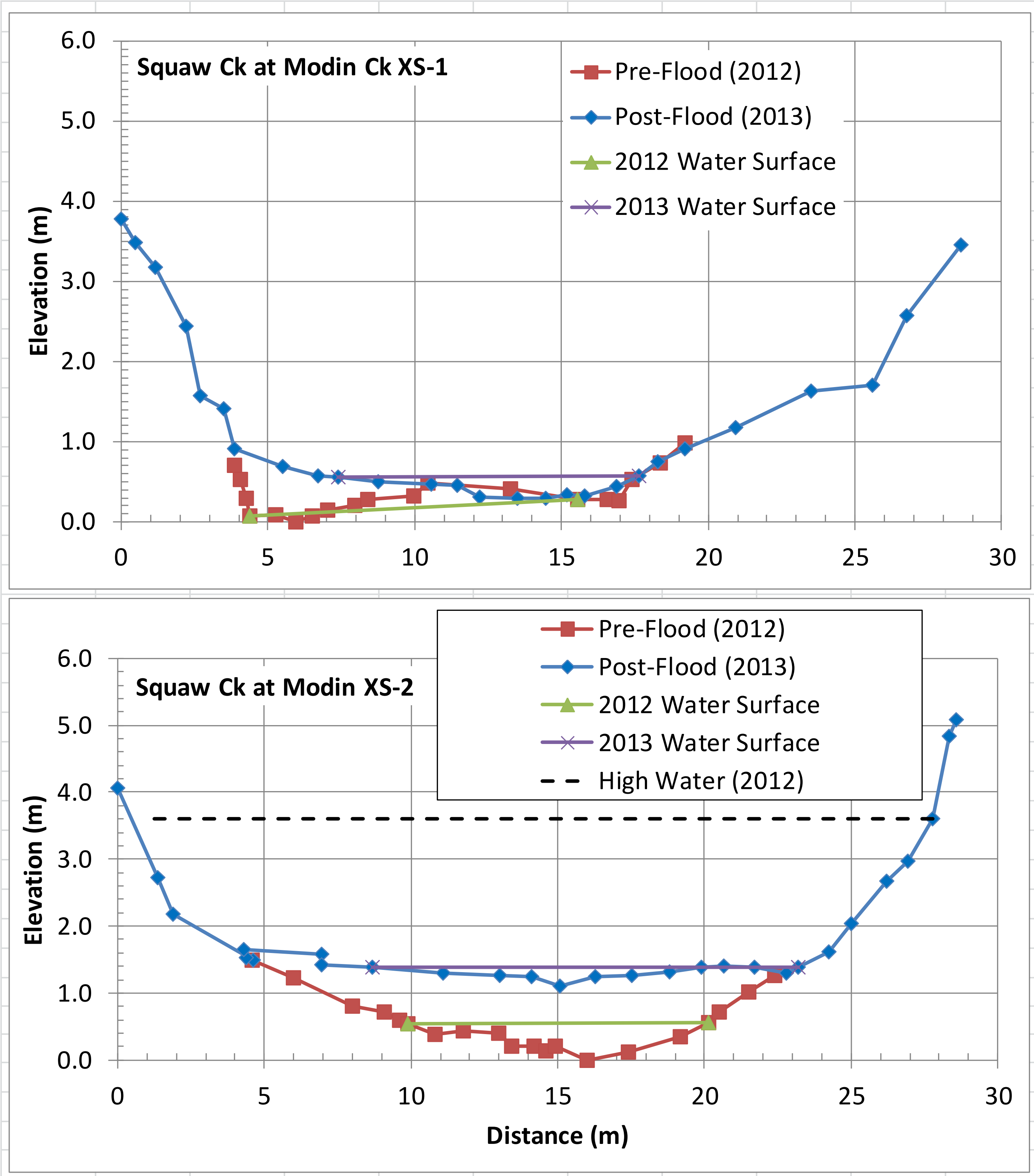

Figure 14 - Repeat channel X-section surveys from the Modin Creek reach of Squaw Creek. Repeat channel surveys were performed in August 2012 and July 2013 in three reaches of main stem Squaw Creek. These data when compared with one another documented channel change resulting from the 2012 flood. Data indicate an active channel width of 15 to 20 meters and channel filling of up to 1 meter by flood sediment. Horizontal and vertical scales are equal in both plots. 2012 X-section end pins were apparently set near the pre-flood bankfull elevation.

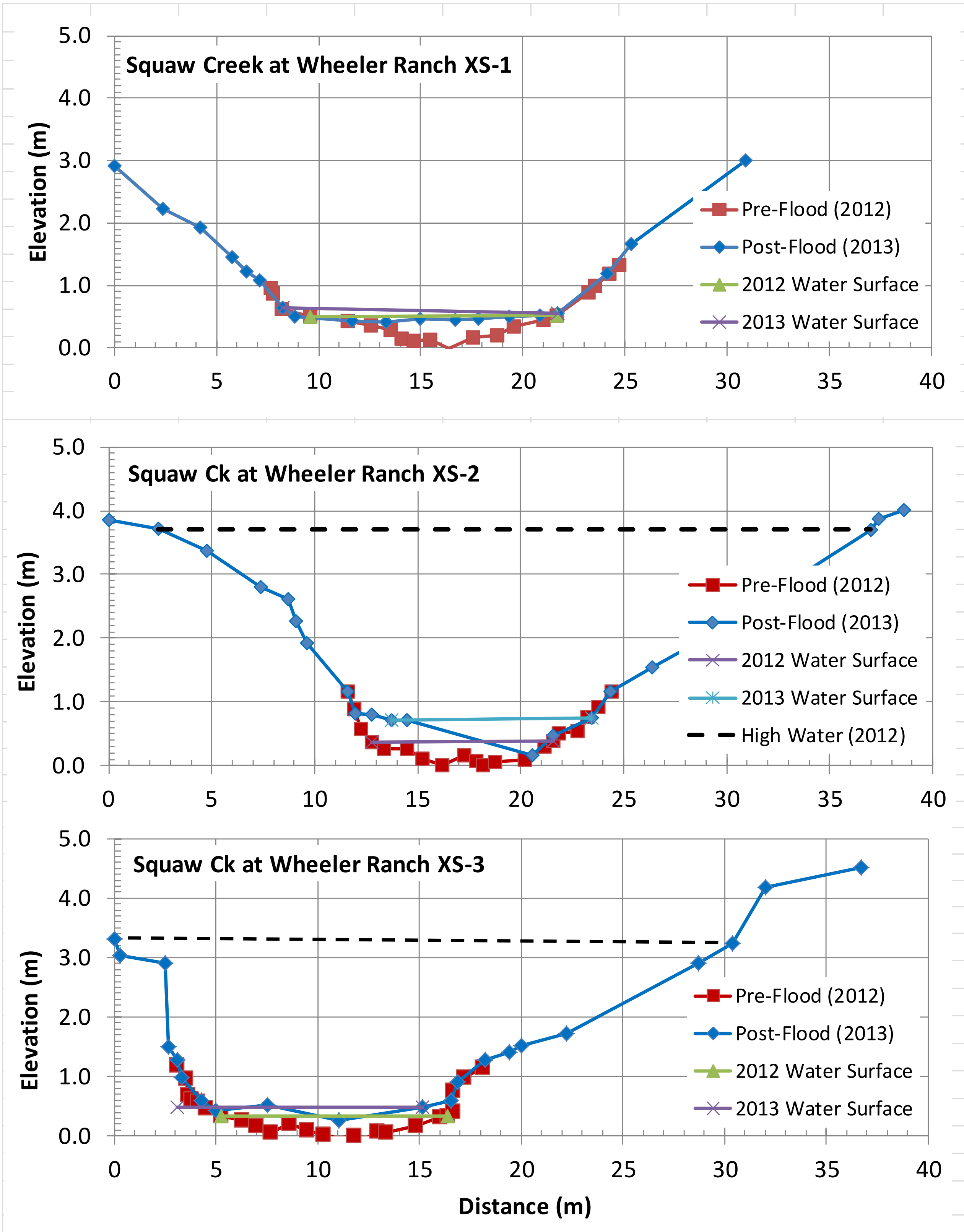

Figure 15 - Repeat channel X-section surveys from the Wheeler Ranch reach of Squaw Creek. Channel widths are similar to those in the Modin Creek reach but the channel bed only filled to a depth of approximately 0.5 meters. Black dashed lines denote surveyed high-water marks. 2012 cross section end pins were apparently set near the pre-flood bankfull elevation. Horizontal and vertical scales are equal in all plots.

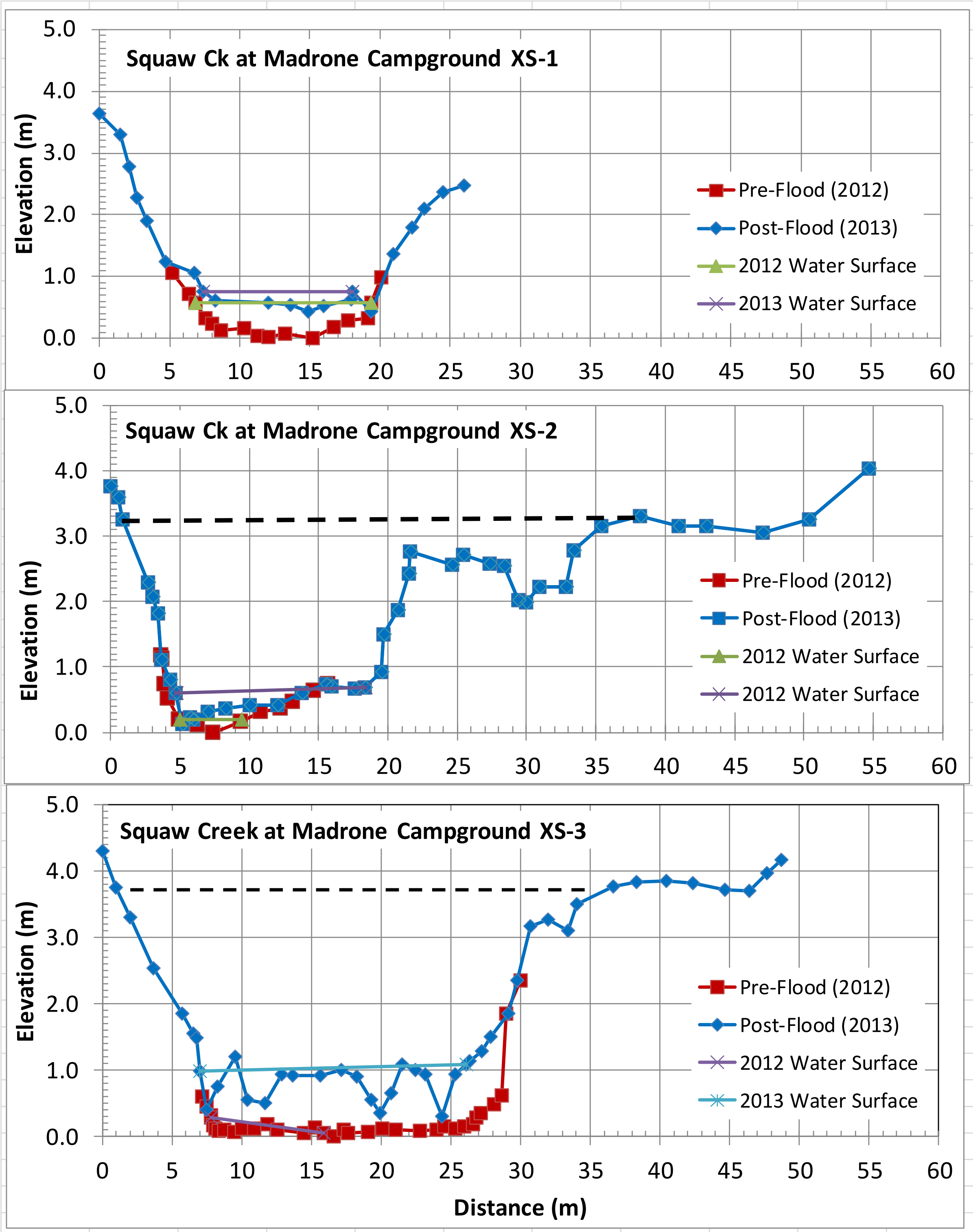

Figure 16 - Repeat channel X-section surveys from the Madrone Campground reach of Squaw Creek. The channel is wider in this reach and bed filling ranged up to approximately 1 meter (XS-3). 2012 X-section end pins were apparently set near the pre-flood bankfull elevation. Horizontal and vertical scales are equal in all plots.

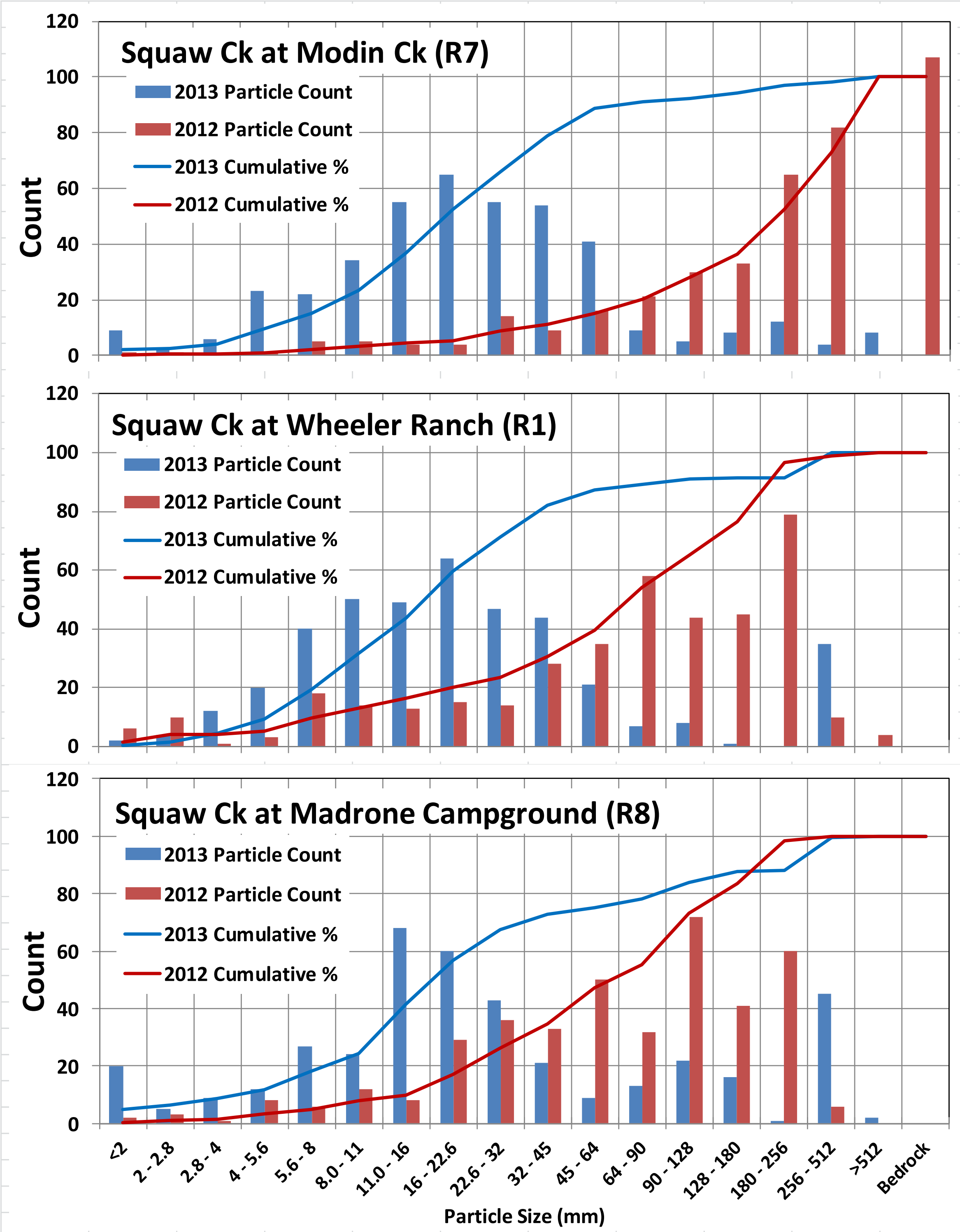

Figure 17- Pre- and post-flood riffle pebble counts from three Squaw Creek survey reaches. The Modin Creek reach (top plot) is furthest upstream and the Madrone Campground reach (bottom plot) is furthest downstream. Particles (N ≈ 400) were sampled in four riffles in each reach per the Stream Condition Inventory Technical Guide protocol (Frazier et al., 2005). All three reaches were characterized by cobble substrate prior to the 2012 flood event, and each experienced bar formation, bed filling, and bed fining by sands and gravels. Pebble counts were also done in 2002 in these reaches but the protocol was sufficiently different so as to not allow display on these plots.

Estimate of 2012 Flood Channel-Stored Sediment

Approximately 11,000 meters of channel were mapped as depositional as a result of the 2012 flood event. Physical surveys in three depositional reaches document mean active channel widths of 15 to 20 meters and mean flood aggradation of perhaps 0.5 meters. Multiplying the length, width, and depth results in a preliminary estimate of 2012 channel-stored flood sediment of 110,000 cubic meters.

Large Wood and Debris

Photo 10: View upstream of the Squaw Creek arm of Shasta Lake and log boom system filled with flood debris.

The 2012 flood transported significant volumes of woody debris to Shasta Lake from both Squaw Creek and the McCloud River, and field personnel observed large volumes of floating woody debris in the lake (Photo 10). In-channel surveys and interpretation of 1:4,000 post-flood air photos indicated that minor large wood volume was stored along Squaw Creek after the 2012 flood.

Fish Populations

Electroshocking surveys were conducted in Squaw Creek in the summer of 2013, and are currently being analyzed. No findings were available for presentation when this report was completed. They will be presented in the final report.

Reservoir Effects

We were unable to locate any previous bathymetric surveys of the Squaw arm of Shasta Lake, and as a result, have not definitively identified the extent of the delta in the reservoir associated with 2012 storms. The minimum and maximum reservoir elevations during the storm events are the locations where fine sediments are evident. The actual depth and extent could not be determined, given the lack of pre-storm bathymetric data. Field observations were made on 9-26-13, at a time when Shasta Lake water levels were receding rapidly, and extensive channel cutting through the reservoir deposits was observed. Stream banks were eroding so rapidly that large sections of stream bank 3-4 feet long / 8-18 inches deep were collapsing every few minutes. Field observations in various parts of the reservoir floor revealed a general pattern of stratified sand deposits adjacent to the channel of Squaw Creek which appeared to be of multiple ages (Photos 11 & 12).

Photo 11 (#7542) - New sediments (foreground, dark brown) in the Squaw Creek Arm Shasta Lake SW of Madison Gulch 9-26-13 JdlF


Photo 12 (#7519) - Older reservoir sediments in the Squaw Creek Arm Shasta Lake immediately SW of Madison Gulch 9-26-13. Materials (likely organic) that were in a reducing environment are now oxidizing, and staining underlying sand orange, as Squaw Creek cuts through deposits JdlF

These sandy deposits were up to 10 feet thick near the mouth of Fowler Gulch. Dark brown silt which appeared to contain fine charcoal and organic material buried the flatter terrace areas, and in places, draped over the sands adjacent to the active channel. These deposits ranged from inches in thickness in the upper parts of the reservoir to 5 feet or more at lower elevations in flatter areas where they were less subject to wave erosion. Observations on 7-1-13, midway between the mouths of Fowler Gulch and Dark Canyon revealed that 2012 deposits were only 1 or 2 inches in thickness at an elevation of about 20 vertical feet above the reservoir level that day (1004 feet).

It is likely that the largest pulses of sediment into the reservoir occurred from November 29 through December 2, 2012 and perhaps a few days beyond that while high flows persisted. The relationship between reservoir level and timing of sediment introduction is critical because the reservoir level dictates how deposition will occur, and where. If in fact the bulk of the sediment was delivered between November 28 and December 5, then most fine sediment would have been deposited below the 1000' contour. Since reservoir levels have rapidly receded some of this sediment has likely eroded and would then be depositing further into the Shasta Lake reservoir. This would create a new prograding delta front of strata with even more ambiguous origins.

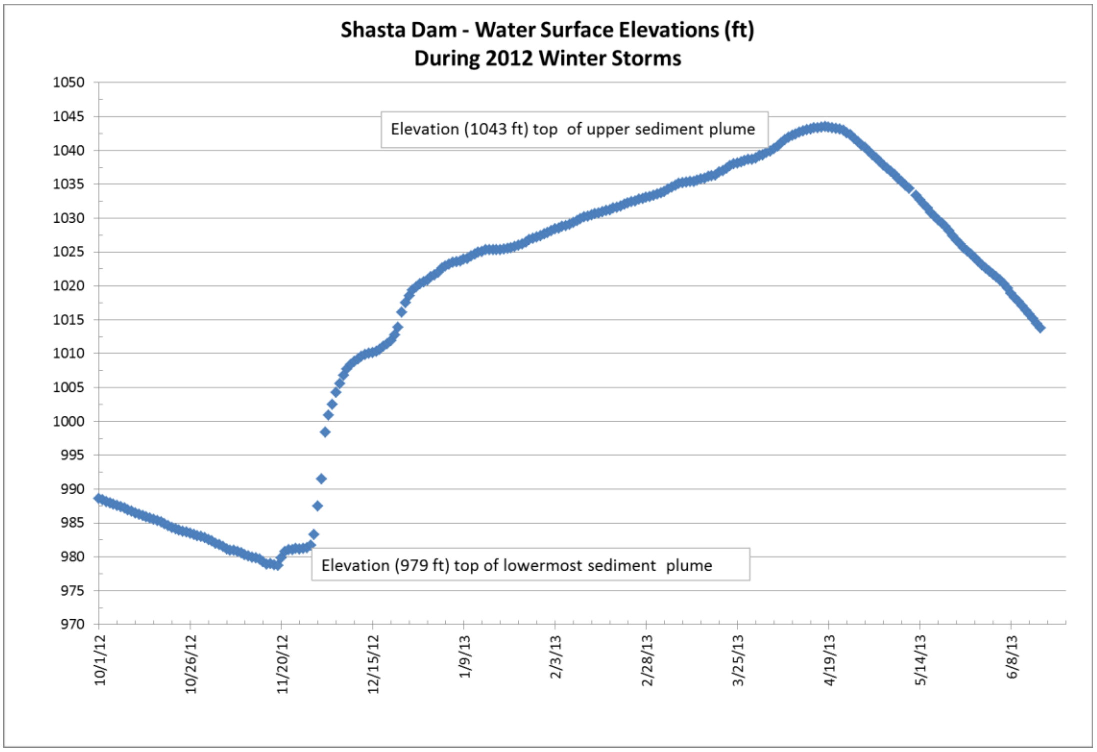

Figure 18- Shasta Lake Water Levels in 2012-2013

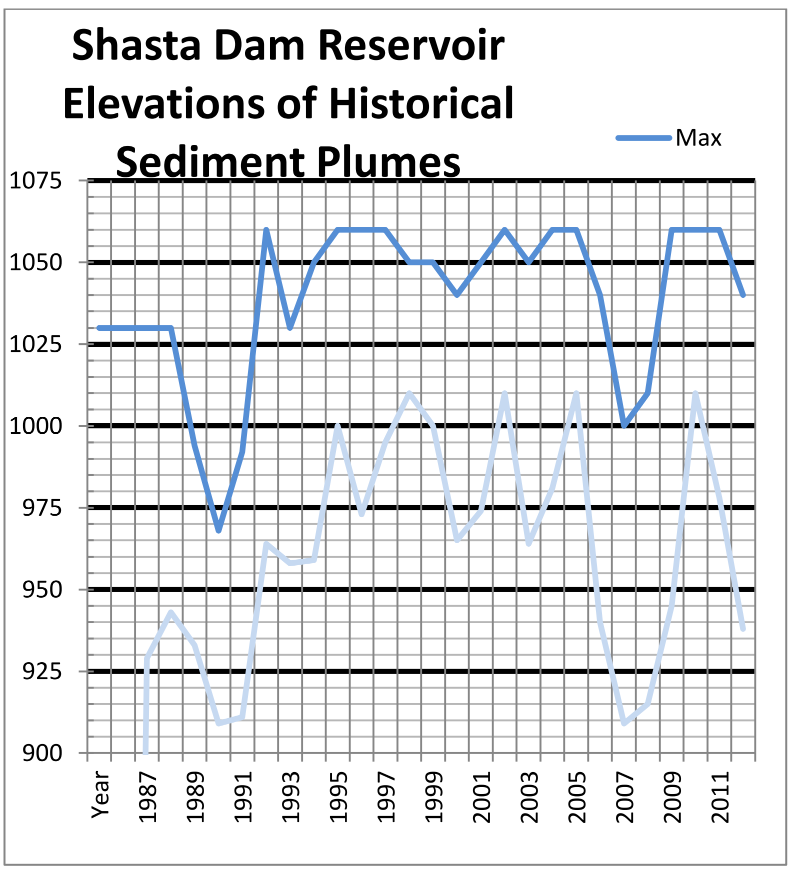

Figure 19 - Shasta Lake Water Level History

Figure 19 shows historic reservoir levels back to 1987. The lake elevation at the time of large flood events should control formation of flood deposits in the reservoir. For example, lake levels were higher during the 1997 flood than the 2012 flood and as such we would expect non-eroded, well protected 1997 deposits to be higher in elevation, and non-eroded 2012 deposits to perhaps be inset within them. Unfortunately many of the large flood events are outside of this data set (prior to 1987). In order to further pursue this question, a relationship can be developed to estimate the water levels prior to 1987elevations based on reservoir not-readily available storage values.

Sediment Budget

Insufficient data were available at the time of this Interim Report to calculate a sediment budget, but this will be done for the final Report. Newly acquired LiDAR data will be used to measure gully and landslide volumes, and where possible, channel scour and deposition. It will also be used to estimate reservoir deposition in areas which were above the water level when the LiDAR was flown.

Infrastructure (Roads)

The purpose of the roads part of this investigation was to document the effects of the 2012 storms, describe some of the subsequent repair measures, and to recommend road maintenance measures which should be applied in the fire area in the future. Figure 20 displays road damage sites identified soon after the late 2012 storms. Many, if not most, stream crossing culverts failed in high severity burn areas. In some cases, this resulted in deposition of debris on the road bed and in the channel upstream. In others cases erosion of part of the fill occurred. Roads also disrupted the downslope transport of soil by rill processes. As a result, many road segments were buried by small sediment fans up to a meter thick. Roads diverted flows in many locations, resulting in gullies downslope of where the water exited the road. In general, most of the road damage consisted of shoulder erosion, rilling, sediment deposits in culverts and on road beds. Some of the roads most heavily damaged by the 2012 post-fire storms were: Claiborne - 37N95; Gable - 37N68; Mckenzie Mtn -37N51Y; Squaw Creek - 35N07; 37N86; and Fender Ferry - 34N17; Van Sicklin - 37N48.

BAER Actions

No BAER road work was done in 2012 due to lateness of fire and difficulty getting contracts through and awarded. Fire suppression repair work was accomplished and seemed to help mitigate further damage to some extent.

Photo 13 (#2981) - Road Fill Failure Hawkins Creek Watershed 5-17-13 JdlF

Future Road Restoration Opportunities

Roads 38N60, 37N91Y and 37N88 did not receive any work during the post-fire rehab and BAER restoration and could be considered for future restoration work. However these roads are overgrown and to some extent have naturally stabilized. Opening them up to allow restoration work would involve soil disturbances, and could have some short term adverse effects which would need to be evaluated in terms of the longer term benefits. These roads have minor washouts and some partially blocked drainage structures.

Future Road Management Guidelines

The roads in the Bagley area are all maintenance level 1 and 2. Due to the work done by Sierra Pacific Industries and BAER work accomplished in 2013, most of the roads are at or above recommended condition requirements for level 1 and 2 roads. The main recommendation for these roads would be to keep up with general maintenance, especially to drainage structures. Major road/channel crossing should have critical dips or low water crossings installed.

Recommendations for more detailed maintenance practices will be developed for the Final Report.

Road #	Map Point	Type of Damage
34N17	1-2	fill slope/shoulder erosion
34N17	3	fill slope slide
34N17	4	Cut slope slough onto road-
34N17	5	plugged culvert
34N17	6	Road washout/gully
34N17	7	plugged culvert
34N17	8	plugged culvert
35N07	14	low water crossing washed
35N07	15	Road washed out
35N07	16	low water crossing washed
37N78	17	slough/mudslide
35N56	18	fill slope/shoulder erosion
35N18	19	fill slope/shoulder erosion
35N20	21	fill slope/shoulder erosion
35N04	23	root wad and small slide.
35N46	26	erosion of road bed
35N07	42	water running under pipe
35N07	43	18" pipe
35N07	44	Need construct rocked ford
35N07	45-46	stream crossing
35N07	47	wet stream crossing
35N07	48	sedimentation on roadway traffic rerouted around
36N83	49-52	erosion of road bed
37N43	63	erosion of road bed
37N68	64	Plugged Culvert
37N68	65	Road creek crossing wash-out
37N95	66	Road creek crossing wash-out
37N95	67-71	erosion of road bed
37N86	72-79	Road creek crossing wash-
36N85	80	erosion of road bed
36N85	81	plugged culvert
36N85	82	erosion of road bed
37N48	83	Road creek crossing wash-
37N48	84	Road washout/gully
37N48	85	fill slope slide
37N48	86	Cut slope slough onto road-
37N95	53-62	These are on cost share in SPI sections and it appears already done by SPI

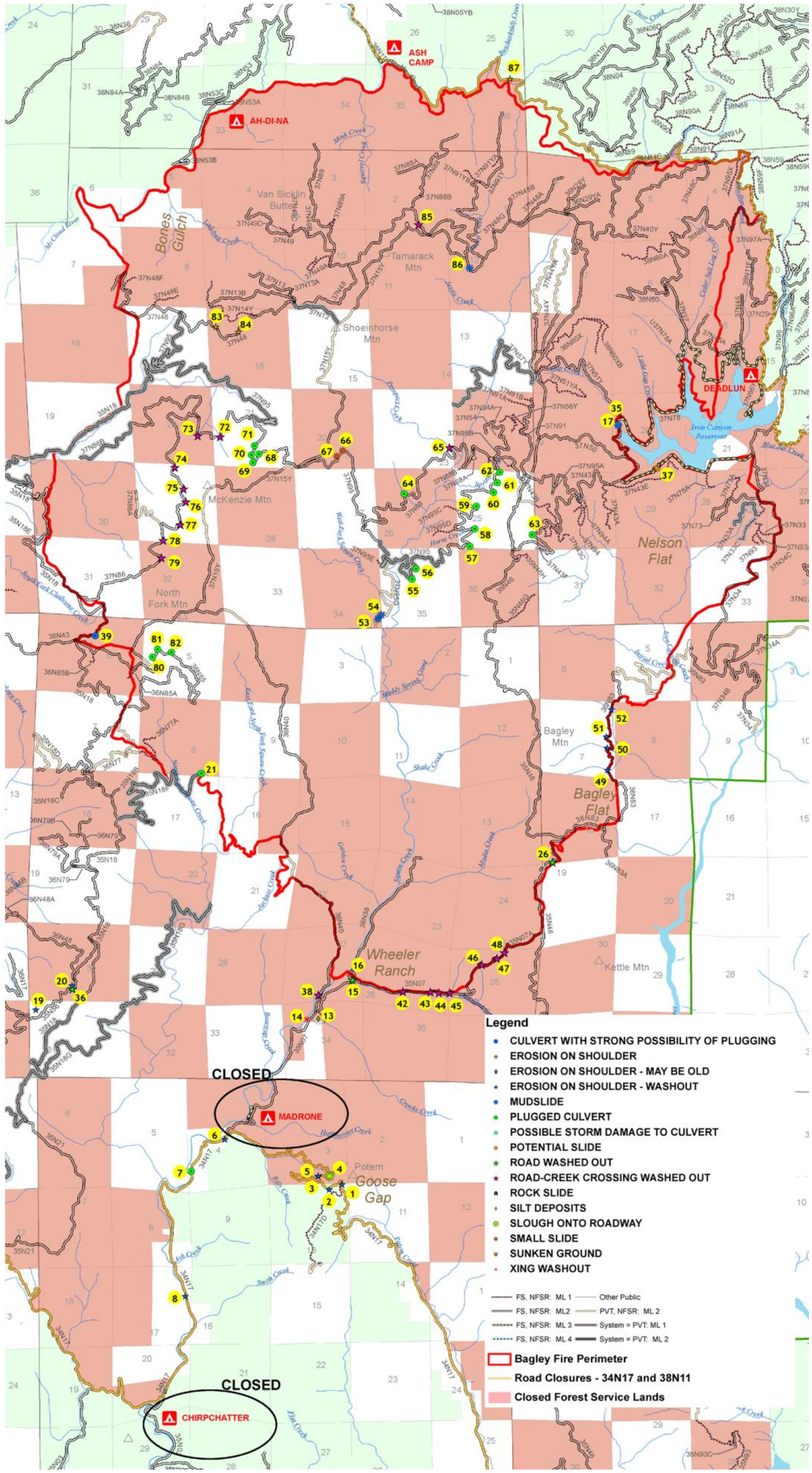

Figure 20 - April 10, 2013 Preliminary Road Damage Assessment by Engineering. Original map modified to fit this report. Some locations listed in the table may be clipped out of the map.

Infrastructure (Developed Recreation Sites)

Developed Recreation Sites have not been evaluated.

Cultural Resources

The Squaw Creek drainage has been the focus of numerous archaeological investigations throughout the past 40 years and appears to be exceptionally rich in prehistoric cultural resources. The drainage encompasses an area of roughly 100 square miles and is bounded by ridgelines on its north, west, and east sides. Squaw Creek flows southward into Shasta Lake, where it turns into the Squaw Creek arm of Shasta Lake. Several tributary streams flow into Squaw Creek including Prospect Creek, Jessie Creek, West Fork Squaw Creek, East Fork Squaw Creek, and Modin Creek. The focus of field investigation has been sites located adjacent to Squaw Creek within the Bagley Fire area. Further investigation is recommended to determine the effects to sites in the lower Squaw Creek area, south of the Bagley Fire perimeter.

Photo 14 - Modin Creek Meadow Post-Bagley Fire 9-12-2012

Photo 15 - Modin Creek North Bank Erosion 9-25-2013

Photo 16 - Wheeler Ranch Road Wash-out 12-14-2012

Cultural resources within the Bagley Fire area include prehistoric sites such as lithic scatters, habitation areas, and one resource procurement area; and historic sites such as cabins, corrals, trails and a guard station. A majority of the prehistoric sites are located on flat creek terraces or gently sloping terraces near water, and a few are located on ridge tops. An extensive trail system that was constructed by the Forest

Service in the early 1900s is also located in the drainage. The trail system may be associated with pre-contact Native American travel routes.

A total of eight known cultural resources (sites) are located adjacent to Squaw Creek, on Forest Service property, and within the Bagley Fire perimeter. In addition, twenty nine sites are located along Squaw Creek south of the Bagley Fire perimeter. These lower gradient sites may have been adversely affected by increased water and sediment flow as a result of the storms. Monitoring of these sites should occur to determine effects from water/sediment flow.

Effects on Cultural Resources

The Squaw Creek drainage experienced a significant amount of moderate to high severity burning as a result of the Bagley Fire. The Bagley Burned Area Emergency Response (BAER) report predicted that within the next 3-5 years, a heavy precipitation event or high rainfall year would likely result in increased flows, erosion, rilling and potential for debris flows. Monitoring of sites along Squaw Creek during spring flows was recommended in the BAER report. Unfortunately, no short-term emergency action was taken under BAER to protect cultural resources, and the heavy precipitation event occurred within one month of the fire.

Eight known sites are located on Forest Service System lands, within the Bagley Fire perimeter, and adjacent to Squaw Creek or its tributaries (Table 7). At the time of this report, only five of the sites have been field assessed for post-storm impacts. A brief summary of effects for each of these sites is below:

Table 7 - Sites adjacent to Squaw Creek within the Bagley Fire Perimeter

Site Number	Site Name	Site Type[1]	Effects	Recommendations
05-14-58-255 CA-SHA-1598	Squaw/Prospect Scatter	PRE	Minimal. Site is located on a secondary terrace and appears unaffected by the higher creek flows. Lower terrace was impacted- unknown if it contained cultural materials	Continue to monitor
05-14-58-184 CA-SHA-862	Squaw Creek Anemia	PRE	Unknown at this time	Site visit
05-14-58-252 CA-SHA-1602	Squaw Creek Mano Site	PRE	Unknown at this time	Site visit
05-14-58-379	Trail Crossing Scatter	PRE	Unknown at this time	Site visit
05-14-58-147 CA-SHA-876	Modin Creek Site	PRE	Flooding of Modin creek created braided channels and severe erosion in the north cut bank, adjacent to the cultural deposit.	Stabilize cut bank adjacent to site and continue to monitor

05-14-58-201 CA-SHA-864	Wheeler Ranch	MUL	East fork squaw creek escaped its main channel and eroded a road that goes through a portion of the site. Severity of impacts needs to be determined.	Continue to monitor and assess impacts from erosion
05-14-58-378	Wheeler Ranch West	MUL	Minor disturbance of concrete bridge footings	Continue to monitor and assess impacts to site
05-14-58-431	Squaw Creek Trail	HIS	No effects noted	Full site recording/assessment

1- PRE= Prehistoric
MUL= Multi-component
HIS= Historic

Note: Additional information is available in a stand-alone Archaeological Report prepared by Peter Schmidt for this project (Infra Number R2013051400013).

Invasive Plants

Non-native invasive plants are always of concern following a major disturbance event like the Bagley fire. These events open up a large amount of potential habitat, inviting the spread of the plants into the new areas. Investigation of how these weeds go about spreading and colonizing the different disturbances, such as sediment deposits, eroded areas, road edges, fire lines, openings in vegetation, etc., can be of value in managing or mitigating their spread after future events.

The Bagley fire occurred in a largely remote area. As a result of that remoteness, there was virtually no information about invasive plant occurrences in most of the fire area. According to the Natural Resource Information System (NRIS) database, two exceptions occur around the developed areas of Iron Canyon Reservoir and Ah-di-nah campground. In addition, Botanists with Sierra Pacific Industries (2013) noted the following non-native species in the summer of 2013 at the given locations:

- **Lactuca serriola and Star Thistle -** T. 37N, R. 02W, Sections 25, 36
- **Torilis arvensis, Bromus tectorum, Cynosurus echinatus -** T. 37N, R. 02W, Sections 17, 18, 19
- **Torilis arvensis -** T. 36N R. 02W, Sections 09, 16, 17

Overall, there is very little information available about the pre-event conditions. Without that information, it becomes difficult to evaluate changes or effects of the fire with regard to the invasive plants

Post-fire weed surveys were conducted on the dozer lines constructed to fight the fire. No surveys were done on roads, open burned areas, or water courses. Preliminary observations from the surveys that were done indicate very little spread of weeds into most of the dozer lines. When the final data becomes available, it will probably bear that out. However, it must be kept in mind that those were first year surveys. During the summer of 2013, watershed personnel observed star thistle growing in a tributary to Iron Canyon Creek, on 2012 flood deposits, more than a mile downstream from the nearest road. Follow up surveys have been recommended and, if carried out, they may provide more accurate information on the spread of invasive weeds due to the fire and storm events. Effort also needs to be made to obtain information on the areas that were not surveyed.

In summary, without the baseline information, one cannot draw any real conclusions about the movement of invasive plants, as a result of the fire and storms, through the channel network, along roads, or fire lines. The Bagley fire provides the opportunity and motivation to obtain current information for future use.

Salt Creek Fire

The Salt Creek Fire had a similar response in that most channels experienced scouring flows, but not to the degree that would strip larger vegetation from the channel or floodplain.

Hillslope Impacts and Channel Resiliency in the Fire Area

This study presented a unique opportunity for the Forest Service to evaluate how recently burned watersheds in the Eastern Klamath Mountains responded to two large rain-dominated precipitation events that followed a large wildfire (potentially a worst case scenario for hillslope erosion and downstream impacts to aquatic systems). Stream channels in the Squaw Creek and Lower McCloud Watersheds are generally considered to be resilient to disturbance events such as fires and floods because they have exhibited rapid recovery from past disturbance events (i.e. fires and floods). However, these watersheds had not seen fire activity on the scale of 2012 in over 100 years, and the magnitude of the 2012 storms was also unusual. In contrast to affected stream channels in the study, we hypothesize that uplands do not exhibit the same level of resiliency and may have a very different trajectory of recovery.

Although large fires have historically occurred in close proximity to the Bagley Fire, fires larger than 100 acres have been notably absent from the Squaw Creek and Lower McCloud in the last 70 years. The Shasta-Trinity National Forest fire history data documents only three historic fires of considerable size intersecting the Bagley Fire area (USDA Forest Service, 2012) over the past 90 years. Newspaper accounts from the late 1800's document several large fires that burned throughout the Squaw Creek area that consumed all vegetation with the exception of wetter, riparian areas located in valley bottoms. With the onset of fire suppression very few large fires have occurred in the watershed since 1920 allowing for extensive recovery of vegetation throughout the affected watersheds.

The absence of fire as a disturbance process in the Squaw Creek and Lower McCloud Watersheds over the past 90 years is documented by stream inventory data and watershed assessments. Stream surveys in Squaw Creek indicated that aquatic and riparian habitats were properly functioning prior to the Bagley Fire. A total of 54 channels were surveyed in 1994 along ephemeral, intermittent, and perennial reaches, and all of these surveys documented healthy and functioning aquatic and riparian habitats (USDA Forest Service, 1999). The Lower McCloud Watershed Analysis also noted that channel conditions were similar to Squaw Creek prior to the Bagley Fire (USDA Forest Service, 2011). Additional stream condition inventory (SCI) surveys were performed in three reaches of Squaw Creek in 2002 and 2012 (immediately prior to the Bagley Fire), and no signs of degradation in aquatic or riparian habitats were noted during these surveys.

The characterization of channels in good condition documented in pre-2013 surveys supports the concept of the Squaw Creek and Lower McCloud River watersheds being resilient to disturbance. These surveys indicate that aquatic and riparian habitats appeared to have fully recovered from past disturbances including large fires in the late 1800s and floods in the 1900s. During the "New Year's Day" 1997 Flood Squaw Creek conveyed flows of similar magnitude to those of the 2012 flood, but stream channels did not manifest changes like those observed after the 2012 event. Some pool filling was noted during the first summer following the 1997 Flood, but these effects did not persist through the following winter. In addition, sustained turbidity as seen in 2013 was not documented in Squaw Creek following the 1997 Flood.

The ability of stream channels in the Squaw Creek and Lower McCloud Watersheds to recover from or withstand disturbance (i.e. channel resiliency) is attributed to channel slope and stream power. Winter storms are usually rain-dominated and often result in multiple large flow events during the winter season. The larger flows are capable of mobilizing and conveying large volumes quantities of sediment and debris through the channel network. Stream channels in these watersheds also exhibit stable morphological characteristics that withstand disturbance and recover rapidly (e.g. bedrock dominated reaches that can be aggraded but not eroded and densely vegetated stream banks and floodplains that resist erosion).

The storm scenario that developed in 2012 shortly after the Bagley Fire was viewed as a potential worst case scenario with respect to shallow erosion processes. The November and December storms were large that even in the absence of a recent large wildfire they would have likely impacted roads and hillslopes throughout the area. This observation is supported by the numerous stream crossing failures that occurred in unburned drainages in lower Squaw Creek and the lower Pit River during the storms.

The combination of the Bagley Fire and 2012 storms resulted in impacts to the channel network that had not been observed previously in the Squaw Creek or Lower McCloud Watersheds and have tested the notion that these channels are resilient to large disturbance events. Not only were the storm impacts readily observable as in the case of the volume of sediment deposited in response reaches on Squaw Creek and the McCloud River below Claiborne Creek, but some impacts have persisted into the summer and fall of 2013. Most notably, stream turbidity remained high for months following the November and December storms and also responded to summer precipitation events. Turbidity had decreased in Squaw Creek by June but increased again in late-June in response to an unusual summer storm that produced 4 inches of precipitation over a 4 day period at the Oak Mountain RAWS station. Turbidity in Squaw Creek remained high for over 1 week. Field observations indicate that fine sediment stored in the response reaches produced this turbidity.

The lack of late-winter pulse flows is apparent in the McCloud River below the Claiborne Creek confluence. Large deposits of sediment generated from the burned drainages in Claiborne Creek have partially filled pools in a 1 mile reach of the McCloud River below the Claiborne Creek confluence. These deposits would likely have been mobilized and redistributed over a larger extent of the McCloud River if rainfall and runoff were normal from January-March in 2013. Several more winters will be necessary in order to determine the resiliency, or how quickly, the response reaches in both Squaw Creek and the McCloud River recover from the Bagley Fire and early winter storms of 2012. Additional time will likely be needed to evaluate hillslope recovery rates for sheet erosion, rills, gullies, and headwater channels.

Implications for Land Management

The hillslope and channel impacts resulting from the Bagley Fire and subsequent storms are unprecedented in the past 100 years and have provided us with a rare opportunity to characterize impacts to hillslopes and channels and monitor post-fire and post-flood recovery. Future replication of data collected in this study will allow the Forest Service to assess channel and hillslope recovery rates. For example, stream surveys can be repeated to determine if the channel network displays the same resiliency to a very large disturbance event as it has to smaller disturbances that have occurred in the past such (e.g. 1997 Flood). In the case of the channel network, watershed resiliency can be expressed as the rate at which channel habitats recover to pre-fire conditions. Indicators of recovery include evacuation of accumulated sediments from response reaches and decreased turbidity durations following winter storms. The data collected for this assessment (e.g. photo-points, cross-section profiles, pebble counts, turbidity observations) can be replicated to document recovery rates for aquatic habitats. A similar approach can be taken to monitor recovery of erosional features on hillslopes (e.g. replication of lidar imagery). Hillslope recovery of storm created erosion features such as rills and gullies as well as steep upland channels is expected to take longer than the recovery of the larger downstream response reaches on Squaw Creek and the McCloud River.

Information on how watersheds like the McCloud River and Squaw Creek respond to, and recover from large-scale, episodic disturbance should be useful to land managers seeking to assess potential risks to hillslopes and channels from fuels management projects that employ prescribed fire or other mechanical treatments in similar watersheds in the Eastern Klamath Mountains. The data from the Bagley study will document channel and hillslope recovery rates following a large fire and subsequent flood event. Monitoring of hillslope erosion processes and channel processes following future projects that employ prescribed fire and other fuels reduction practices will allow land managers to demonstrate how properly applied fuels management activities can result in greatly reduced impacts to hillslope and channels when compared to larger disturbance events or conditions similar to the 2012 Bagley Fire.

Next Steps for this Investigation

The following items will be accomplished, and findings incorporated into the final report which will be completed in the spring of 2014:

1. **Storm Events -** Rainfall will be monitored in winter 2013-2014, and addressed in the final report.
2. **Streamflow -** Stream flows will be monitored in winter 2013-2014, and addressed in the final report. High water marks in Squaw Creek will also be identified and evaluated.
3. **Surface Erosion -** Soil transect data will be further analyzed and compared to LiDAR volume computations of gully volumes. The apparent lack of correlation between transect measured erosion to burn severity will be further analyzed. Erosion events in 2013-2014 will be closely monitored.
4. **Landslides, Debris Flows and Altered Channels -** LiDAR terrain data in conjunction with air photo data and field observations (2012-2014) will be used to refine mapping and volume estimates for landslides, large gullies and altered channels. Erosion events in 2013-2014 will be closely monitored.
5. **Channel Response and Sedimentation -** High flow events in 2013-2014 will be closely monitored, and changes in stream bed levels in Squaw Creek evaluated.

6. **Water Quality/Turbidity -** Temperature data will be analyzed and incorporated into the final report, and high flow events in 2013-2014 will be closely monitored for turbidity.
7. **Reservoir Effects -** New LiDAR terrain data and air photos (2013), along with bathymetry (2013), and field observations (2012-2014) will be used better identify and quantify 2012-2014 sedimentation in the Squaw Creek Arm of Shasta Lake. Depositional and erosional events in the reservoir in 2013-2014 will be closely monitored.
8. **Sediment Budget -** All data will be compiled, and a sediment budget developed, quantifying: a) Surface erosion; b) Gully erosion; c) Landslide erosion; d) Channel scour; e) Channel deposition; f) Reservoir deposition. Erosional and depositional events in 2013-2014 will be closely monitored.
9. **Effects on Other Resources -** Effects of winter 2012-2013 and 2013-2014 on other resources will be examined. Plans are to a) Evaluate effects of storms on cultural sites not visited in 2013; and b) Monitor impacts to aquatic habitats and fish populations as well as invasive plant species. Erosional and depositional events near or at sites in 2013-2014 will be closely monitored.
10. **Hydro-Geomorphic Regime -** The Hydro-geomorphic regime for the Bagley Fire area will be fully analyzed and interpreted.
11. **BAER Predictions and Treatments -** BAER predictions and treatments will be evaluated, including the effectiveness of road repairs made after winter 2013-2014. Guidelines for future road maintenance in the area will be developed.
12. **Forest Staff Professional Development -** Opportunities for hands-on experience in evaluating and monitoring post-fire watershed response with state-of-the-art tools, including LiDAR data interpretation will be provided to Forest staff.
13. **Adaptive Management -** Findings from this study will be used to identify adaptive management opportunities relative to interactions between current Forest management practices, wildfire, and post-fire watershed response. This will allow reinforcement of practices which are sound, and modification of those which are not.
14. **Proposal for Repairing Road Damage -** A proposal for repairing high risk sites along roads in the fire area will be developed contingent on getting funding in the future. It will focus on the more highly used roads, and will include site specific information.

Recommendations for Further Work in 2014

The following additional work items are recommended for 2014, but would require additional funding to complete. These actions would refine our understanding of the effects of the fire, and form the basis for a longer term monitoring plan.

1. **Stream Channel Inventories (SCI) -** Reoccupy SCI cross sections in Squaw Creek, repeat pebble counts, and repeat temperature measurements.
2. **Fisheries Inventory -** Repeat electroshocking surveys at Squaw Creek.
3. **Hillslope Erosion Monitoring and Inventory -** Conduct a fire-wide field reconnaissance in summer 2014 to identify any new erosion or deposition sites; Validate LiDAR estimates of landslide and gully volumes at sample sites; Install more soil erosion transects to refine estimates of sheet, rill and gully erosion.

4. **Turbidity Inventory -** Continue informal monitoring of turbidity in Squaw Creek, McCloud River, and in Shasta Lake on an opportunistic basis.
5. **Reservoir Sedimentation Inventory -** Repeat the bathymetric cross sections done in 2013, and conduct a more thorough evaluation of 2012 sediment volumes in the field.
6. **Cultural Resources Inventory -** Conduct field evaluations of sites not visited in 2013, but which could have been affected by the fire and subsequent flooding.
7. **Invasive Plant Inventory -** Continue invasive plant monitoring initiated in the BAER process.
8. **LiDAR -** Re-fly the Squaw Arm of Shasta Lake with LiDAR in 2014 at low reservoir levels to map more of the reservoir's exposed shores and bottom.

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