EFFECTS OF THE 1997 FLOOD ON THE KLAMATH NATIONAL FOREST, NORTHERN CALIFORNIA: LESSONS LEARNED & IMPLICATIONS TO FUTURE FOREST MANAGEMENT

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Abstract: The Klamath National Forest occupies about 1.7 million acres (0.7 million hectares) in the Klamath Mountains of Northern California. This rugged terrain includes four arcuate belts of accreted oceanic terranes intruded by numerous plutons. Landsliding and debris flows are dominant slope processes, strongly influenced by the presence of steep slopes, abundance of older landslide deposits, and weathered and dissected granitic plutons. The storm of December 26, 1996 through January 1, 1997 delivered up to 17 inches of precipitation to parts of the study area. At the onset of the storm, the above average snowpack extended down to about 3,100 feet in elevation. The warm storm produced rain up to 7,500 feet in elevation. One station recorded 5 inches in the last 18 hours of December 31. Total precipitation for December ranged from 170% to 420% of normal for that month. Happy Camp, California received 28 inches of warm rain with about 3 inches per day coming on December 30th, 31st, and January 1st. Estimates of recurrence intervals for 1997 peak stream flows range from 9 to 37 years: (Scott River - 14 years; Salmon River - 37 years; Klamath River at Orleans - 18 years). Peak flows ranged from 51-84% of the 1964 flood (largest on record).

Landslides, debris flows, and altered channels were concentrated in a SW-NE band, about 20 miles wide by 40 miles long. Infrastructure damage (primarily to roads and bridges) exceeded $27 million. Effects were greatest in the Walker, Grider, Elk, Tompkins, Kelsey, Deep, and Ukonom Creek watersheds. Abundant debris flows were initiated by landslides at elevations over 3,800 feet. These flows scoured upper channel reaches, removed riparian vegetation, and deposited sediment and large logs in lower reaches. Air photo and field investigations identified a total of 1,543 landslides (including road-related landslides). Of these, 415 occurred on older landslide deposits, with 270 classed as debris slides, 97 deep-seated landslides, and 48 combinations. These 415 slides delivered about 1.3 million cubic yards of sediment to streams (34% of the total). Many of the 270 debris slides were associated with reactivation of deep landslides.

This event provided a unique opportunity to better understand the interactions between forest management practices and slope/channel processes. A model was developed which closely predicted the proportion of 1997 flood sediment (landslides) originating from undisturbed land, harvested or burned land, and road corridors. Similarly, it predicted the increase in landslide rates on disturbed land relative to undisturbed land. The model over-predicted total landslide sediment production several fold.

INTRODUCTION

The Klamath National Forest is located in northernmost California, adjacent to the border with Oregon (Figure 1). The flood of 1997 primarily affected the western portion of the Forest.

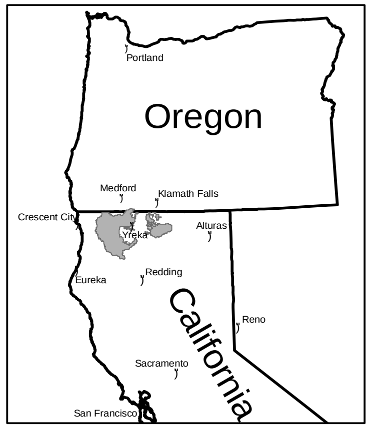

Figure 1 Location map of the Klamath National Forest.

Precipitation: The event which caused the flood was a warm tropical storm which occurred from December 26, 1996 through January 3, 1997, and traversed the forest in a northeasterly direction. This storm caused flooding from Idaho and Oregon to the Sierra Nevada Mountains (California Department of Water Resources, 1997). Prior to the beginning of this storm, precipitation was above normal for most recording stations on the Forest. November precipitation ranged from 90% to 170% of normal, while that for the water year from October 1, 1996 through January 3, 1997 was 150% to 220% of normal. December precipitation was about double the norm for the month of December, ranging from 170% to 420% of normal. Most of the early December precipitation accumulated during a storm which occurred from December 5-10. Another cold storm brought snow below 2,000 feet from December 21-23, and set the stage for the New Years storm and flood. From December 26 to January 3, a series of warm storms traversed the Pacific northwest in an E-NE direction, and brought rain above 7,000 feet in elevation on the Forest, and above 10,000 feet in the Sierra Nevada Mountains. Beginning December 30, rainfall intensified on the Forest.

Snow Melt: Snow pillow gages recorded intensities of 0.38-0.42 inches per hour at four stations over the last six hours of 1996, producing 6-hour totals of over 2 inches. During the last 18 hours of December 31, totals of four to over five inches were recorded at stations in Big Flat, Mumbo Basin, Scott Mountain, and Highland Lake. This intensity and duration of precipitation exceeds that identified in several studies as necessary for the initiation of debris slides (Cannon, 1985). The shallow debris slides which occurred in Deep Creek and in the granitic portion of Elk Creek were of this type. Data from the snow pillow recording stations suggest that snow melt may have contributed an additional 1-3 inches of water (or more) to the storm runoff at elevations below 6,000 to 6,500 feet. Since an average of ~10 inches of precipitation was recorded from December 30 through January 1 at these snow pillow stations, snow melt may have contributed an additional 20-30% (or more) to 3-day totals in the vicinity of the stations (de la Fuente and Elder, 1997). Intense precipitation came to an abrupt halt on January 3, and no significant storms occurred during the spring of 1997. Had more storms occurred that spring, it is likely that more large slumps, activated by the flood, would have failed catastrophically.

Figure 2 Slump South Fk Salmon River (left); Earthflow on road, Walker Creek (right).

Peak Stream Flows: Peak flows in rivers and streams on the Forest ranged from second to fifth highest on record. This compares to record flows in some rivers of the Sierra Nevada Mountains, and possibly on Sacramento River tributaries. Estimated recurrence intervals for these peaks ranged from 16 years at Indian Creek (near Happy Camp), to 37 years at Salmon River. The recurrence interval for the 1997 Flood was 14 years on Scott River, 32 years on the Shasta River, 15 years on the Klamath River at Seiad, and 18 years on the Klamath River at Orleans. These intervals were computed by the Federal Emergency Management Act (FEMA) method: Recurrence interval T= (period of record + 1)/ranking. In the case of the Salmon River, the computation is: (73+1)/2 = 37.

Management Effects: The effect of human activities on landslide rates is a key issue in the management of western forests. In the Klamath Mountains, sedimentation has been identified as a key issue relative to anadromous fish habitat, and landslides contribute up to 90% of the total (de la Fuente and Haessig, 1993).

METHODS

Landslide Inventories: A landslide inventory was done on color infrared air photos (1:40,000 scale) flown after the flood in May of 1997 (Figure 3). These photos allowed an area-wide assessment of landslides and altered channels. Altered channels are those where the beds had clearly experienced recent scour or deposition and loss of vegetation rendered them visible on the air photos. These were associated with either debris flows or simply high water flows. Landslides as small as 20 feet wide were visible under optimal conditions, such as in open areas where barren soil contrasted with vegetated slopes. Densely timbered areas obscured smaller landslides, and field inventories were conducted in sample watersheds to augment the air photo work. All roads were examined as part of the damage assessments done for the Emergency Relief Federally Owned program (ERFO). Lastly, the Forest also conducted comprehensive road inventories identifying potential problem sites, such as where culverts were at high risk of failure in the future. All visible landslides and altered channels were mapped and classified as natural, associated with roads, timber harvest, or fire, and then, the amount of sediment delivered to the stream system was estimated.

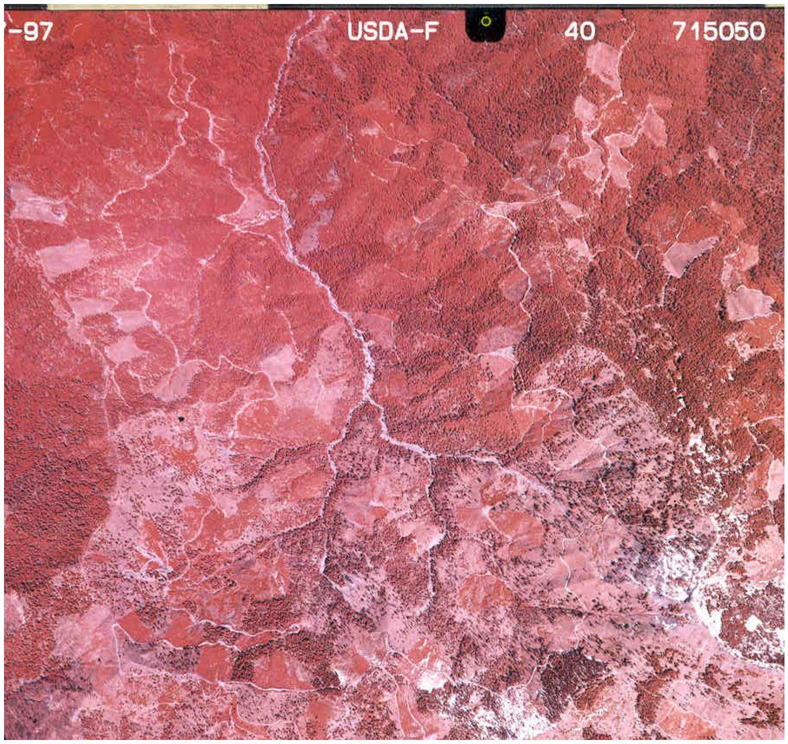

Figure 3 Color infrared air photo (1:40,000 scale) of Walker Creek, May, 1997.

GIS Coverage: A GIS coverage with all identified landslides and altered channels was created and linked to a data base with information on management association, volume of sediment delivered to the stream system, etc.

Geomorphic Terranes: The landscape was stratified into 12 geomorphic terranes (Figure 4) on the basis of geomorphic type, bedrock, and slope gradient. Polygon size ranged from a few acres for active landslides, to several thousand acres for other terranes such as granitic and non-granitic mountain slopes.

Predicting Landslide Sediment Production: An empirical model was used to estimate the amount of sediment landslides would deliver to the stream system on the west side of the Forest. A landslide production rate was assigned to each geomorphic terrane for undisturbed, harvested or burned, and roaded conditions. These rates were based on air photo/field inventories of landslides which occurred in the Salmon River basin, a 751 square mile tributary to the Klamath River, from 1965-1975 (de la Fuente and Haessig, 1993).

Landslide Coefficients for the 1997 Flood: A GIS was used to overlay the new active landslide inventory with other GIS coverages such as roads, timber harvest, and fire. This was done to measure the amount of landslide sediment delivered to the stream system by each geomorphic terrane by disturbance class (natural, fire/harvest, road) during the 1997 Flood. Coefficients were then developed for each terrane.

GEO Mass-wasting model **1997 FLOOD**		[Values represent model-estimated sediment delivery in cubic yards / **DECADE**]			
Code	**Description**	**Background (undisturbed)**	**Roads**	**High impact fire or harvest 1/**	**Moderate impact fire or harvest 2/**
0	unknown				
1	Active Landslides	27.75	506.25	33.91	30.83
2	Toe Zone of Dormant Slides	1.01	84.06	8.65	4.83
3	Dormant Landslides	1.01	84.06	8.65	4.83
4	Granitic Mtn. Slopes, Steep Slopes (>65%)	0.30	165.32	8.88	4.59
5	Granitic Mtn. Slopes, Low to Moderate Slopes (<65%)	0.47	32.72	4.10	2.29
6	Non-Granitic Mtn. Slopes, Steep Slopes (>65%)	0.32	230.88	0.98	0.65
8	Non-Granitic Mtn. Slopes, Low to Moderate Slopes (<65%)	0.15	17.38	1.91	1.03
9	Inner Gorge on Unconsoildated Deposits	6.85	174.40	24.56	15.70
10	Inner Gorge on Granitic Slopes	4.44	197.61	37.10	20.77
11	Other Inner Gorge	0.99	51.82	3.96	2.48
12	Debris Basins	0.66	0.00	0.41	0.54
13	Surficial deposits (e.g., glacial moraines, terraces and fan deposits)	0.04	4.25	3.57	1.81
1/	Includes clear-cuts and equivalent silvicultural prescriptions and high/moderate burn intensity wildfire				
2/	Includes partial cuts and other moderate impact silvicultural prescriptions				

Figure 4: Landslide production coefficients for Geomorphic Terranes (1997 Flood data)

FINDINGS

General Findings: Figure 5 shows the distribution of landslides and altered channels across the west side of the Forest. Landslides were concentrated at elevations of 4000-6000 feet above sealevel, and in the north central part of the Forest. Debris slides (shallow rapid landslides) were abundant, but many deep slow moving landslides were also activated.

1. **Sensitive Lands-** Certain geomorphic terranes displayed particularly high landslide and debris flow rates under flood conditions, particularly inner gorges, previously active landslides, and older landslide deposits (Figure 7a). The influence of older landslide deposits has been reported for other storm events elsewhere (Nilsen 1975);
2. **Roads-** Roads exhibited the largest directly observable effects on flood processes (Figure 7b);
3. **De-vegetation-** Watersheds devegetated by a combination of wildfire and timber harvest experienced high rates of landslides and debris flows, particularly on devegetated sensitive geomorphic terranes (Figure 7b).

Predictive Ability of the Landslide Model: It was found that undisturbed land produced 34% of the landslide sediment volume in 1997 (Figure 6) compared to a model prediction of 39%. For

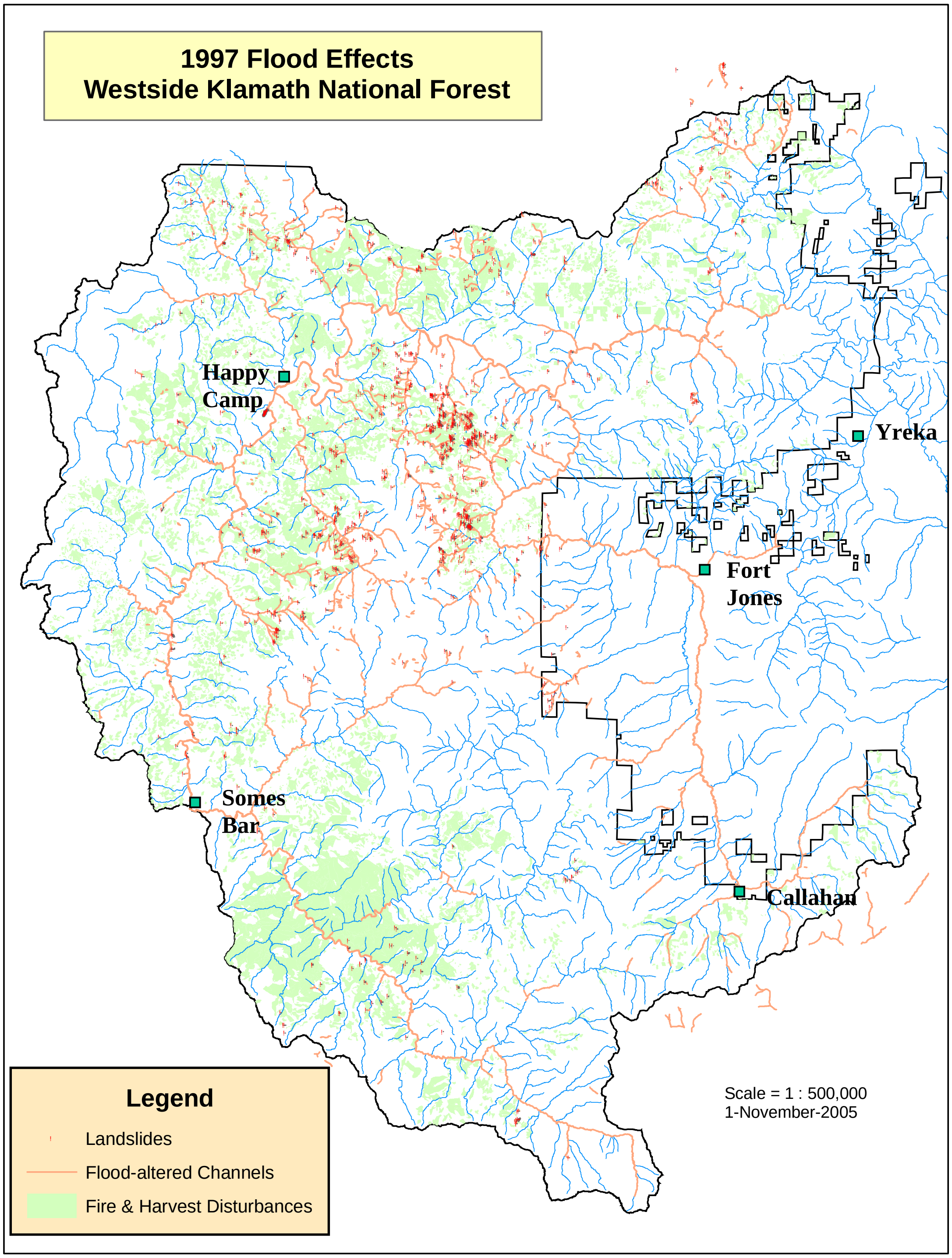

Figure 5 Active landslides and altered channels mapped following the 1997 flood event

road corridors, it was 40% versus the model prediction of 39%, and for harvested or burned lands, it was 27%, versus 21%. Similarly, the increases in sedimentation rate for harvested and roaded areas over undisturbed rates measured after the 1997 flood were very similar to those predicted by the model. For example, data from 1997 revealed an increase of 4.5 times for harvested or burned land over undisturbed rates, while the model predicted 3.6 times. For road corridors, the increase was 62.7 times, compared to 58.3 predicted by the model. Landslide sediment delivery rates (cubic yards/acre/year) measured from 1997 data. This was based on the assumption that the 1997 event had a return interval of roughly 10 years return (measured sediment volumes were divided by 10). The result for undisturbed land was 0.09, 0.39 for harvested or burned land, and 5.39 for road corridors. This compares to 0.28, 1.01, and 16.33 respectively for modeled values. Thus, the modeled rates were 3.3, 2.6, and3.0 times higher for these categories respectively, than the rates measured following the 1997 flood.

Some subwatersheds in the southern part of the study area produced no measurable landslide sediment (Figure 5). The lack of landslides in these watersheds was verified by intensive field-based road inventories in these watersheds. This could have been due to local high intensity storm cells, differences in geomorphic characteristics, roading or logging practices. We were not able to resolve this question.

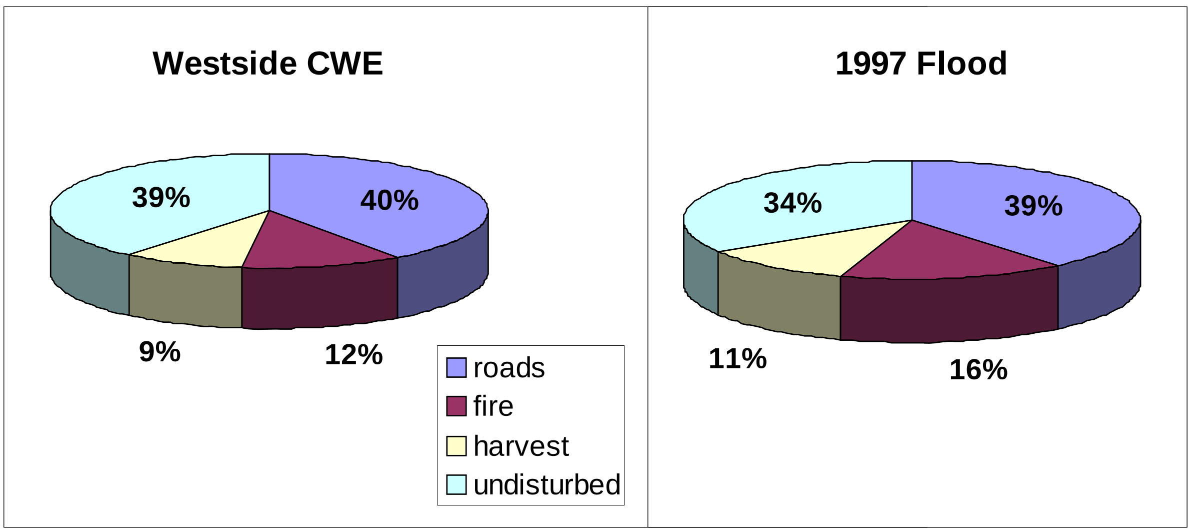

Figure 6 Comparison of sediment sources: CWE model, and 1997 Flood assessment

CONCLUSIONS

1. A model based on geomorphic terranes reasonably predicted the proportion of landslide sediment delivery to streams during the 1997 Flood associated with roads and devegetation.
2. The landslide model over-predicted landslide sediment delivery rate (cubic yards per acre per year) by a factor of 2 or 3, suggesting that it may not be suitable for predicting actual effects of future storms.
3. Knowing the relative contribution of undisturbed, harvested/burned, and roaded lands to the total sediment budget provides a sound foundation for prioritizing restoration activities to maximize efficiency in reducing the management-related contribution to the sediment budget.
4. The concentration of landslides in certain geographic areas lacking unique characteristics suggests that there were sharp local variations in storm intensity.

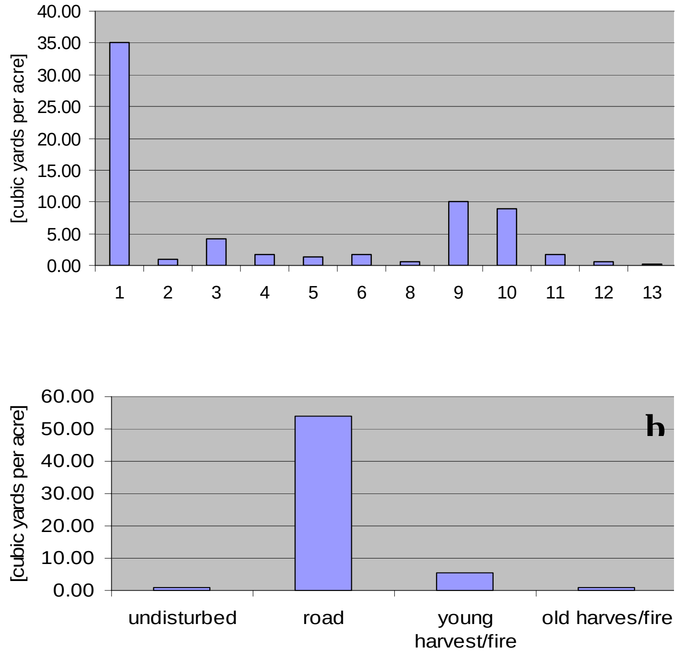

Figure 7 Landslide delivery rate by geomorphic terrane (a) and disturbance class (b)

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