

IMPACTS OF LANDSLIDES ON AN ECOSYSTEM

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Summary:

A large debris flow was studied. The probable cause was the failure of a logging road. Most of the sediment was deposited at the tow of the flow, or in the channel below the flow. Mitigation has been instigated to reduce the impacts of the flow. The failure was predictable.

Keywords:

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Impacts of Landslides on an Ecosystem

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Introduction

Landslides are a common natural phenomena on the steep slopes in the Western U.S. and in similar topographic and climatic conditions worldwide. Landslides include debris avalanches (rapid events), debris flows down steep upland channels (rapid movement carrying large rocks), and hillslope block movements (Varnes, 1978). The risk of a landslide occurring is greater on weaker soils, often caused by saturation or even positive pore-water pressures. The presence of distinct changes in soil layers, or previous planes of failure can also increase the likelihood of failure. Landslides are more likely to occur during the spring of the year when soil water contents are high from snow melt and spring rainfall. Human Disturbances, including road construction and timber harvest can increase the likelihood of a landslide.

Slope failures can have adverse impacts on the ecosystem. Areas prone to natural instability can have trees with bowed bases, detracting from timber quality. A major failure generally results in a total loss of all of the forest products on the failure for a number of years. Roads may be blocked by landslides, or may initiate landslides. In either case, the road may be severely damaged. Sediment from landslides can significantly add to the sediment in rivers, adversely affecting the aquatic ecosystem and general geomorphological equilibrium (Reid, 1981). In some instances, the relatively coarse material in a landslide may add gravel to the stream bed enhancing the environment for some aquatic species. In two studies, two thirds of the sediment load in a stream came from landslides due to roads (Reid, 1981).

Although the subject of a number of general studies, specific analyses of the impacts of a given landslide on the environment are lacking. This paper presents an analysis of a specific landslide, and the fate of the sediment from that landslide. It also addresses the ability of current technology to predict such events.

Details of Site

The landslide occurred in the Clearwater National Forest in Northern Idaho (Figure 1) about 2 miles north of Elk River, in the Elk Creek Watershed. The soils consist of volcanic ash material directly over decomposed granitic material which has little soil development. Soil profiles are 1.5 m plus deep. The surface soil is volcanic ash 200 to 550 mm deep (silt loam), and subsurface soil is coarse textured with 10 to 40 percent rock fragments (sandy loam/loamy sand). The dominant vegetation series is the *Thuja plicata* (western red cedar). Elk Creek drains a 100 km² watershed which receives an average annual precipitation of 937 mm. Elevations range from 1775 m atop Elk Butte to 861 m in the nearby town of Elk River. The average discharge of Elk Creek ranges from 1.3 to 4.7 m³/s (46-166 cfs). Figure 2 shows the 1993 discharge hydrograph.

Figure 1. Location of the Clearwater National Forest in northern Idaho.



The Elk Creek slide originated either late April 17th or April 18th, 1993. The day before the slide received 7.5 inches of rainfall, and the five-day antecedent precipitation was less than 4 mm. There was only a trace of snow in Elk River at the time of the slide, but there was an estimated 600 mm of snow at the slide initiation point. The temperatures during the slide ranged from -1 to 15 degrees Celsius.

The landslide appeared to start on a large fill of a major system surfaced logging road that had originally supported a logging railroad in the early 1900s. A wooden "culvert" was installed in the bottom of the fill, but apparently, most of the timbers had rotted and collapsed some time ago. The fill failed, and initiated a debris flow approximately 1200 feet long down a waterway with a 50 percent slope, across a flood plain, and into Elk Creek (Figure 3). Figures 4, 5, and 6 contain the plan profile, and cross section of the railway embankment that is believed to have failed, initiating the landslide. There was considerable deposition of large boulders and sediment on the flood plain, and the remainder of the landslide material was carried into Elk Creek.

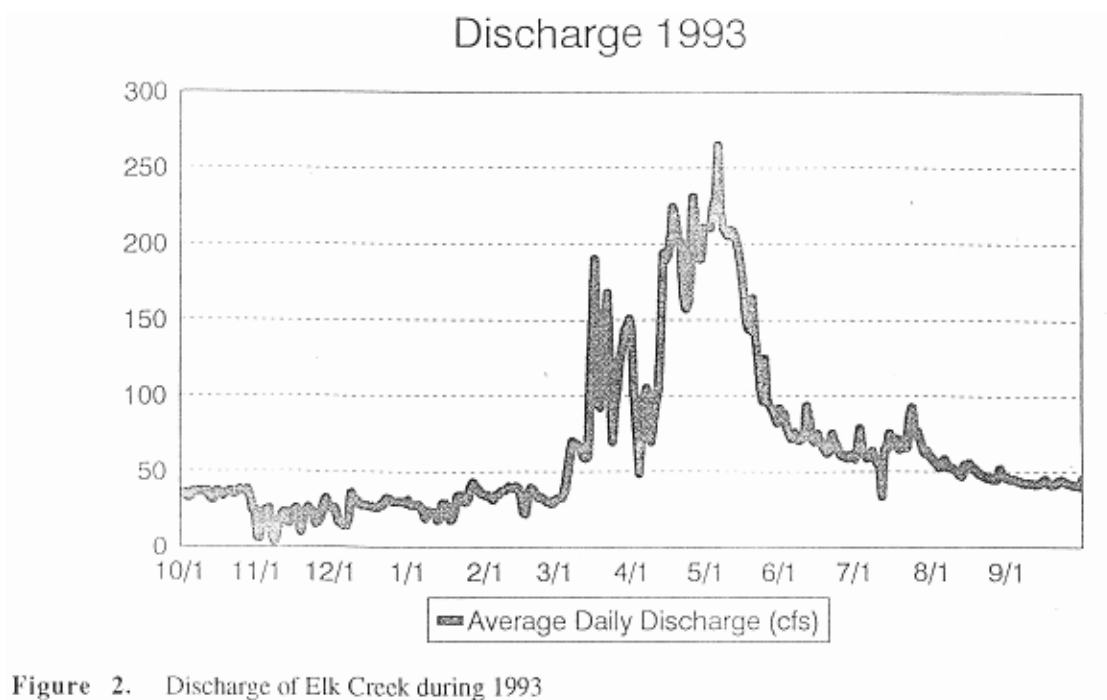


Figure 2. Discharge of Elk Creek during 1993

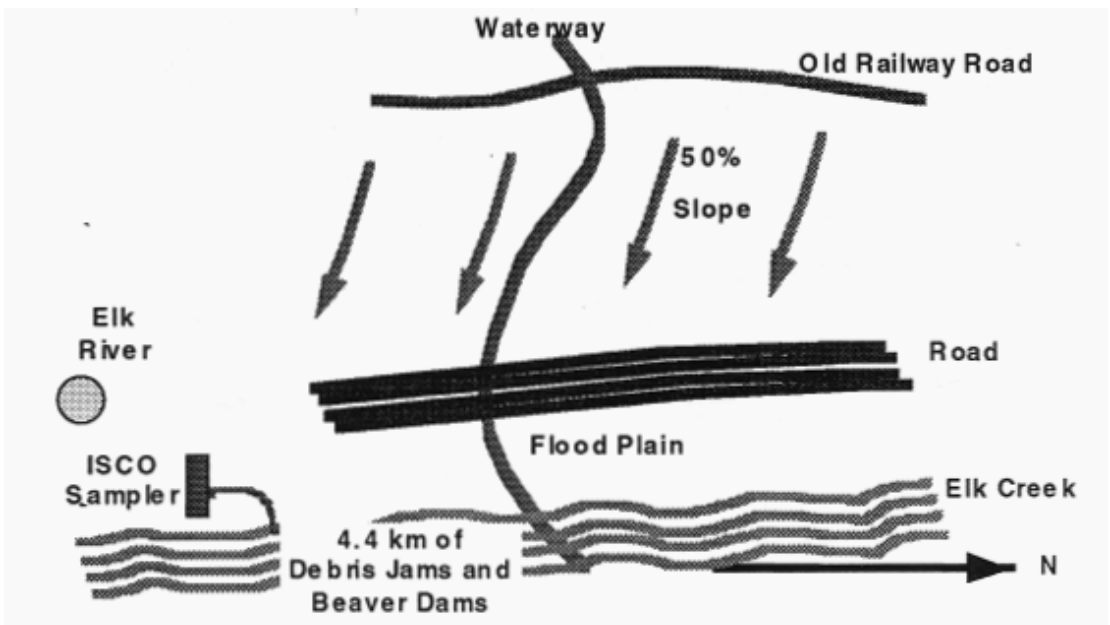


Figure 3. Relative locations of upper and lower roads, the town of Elk River, and Elk Creek, and waterway that routed the debris flow downslope.

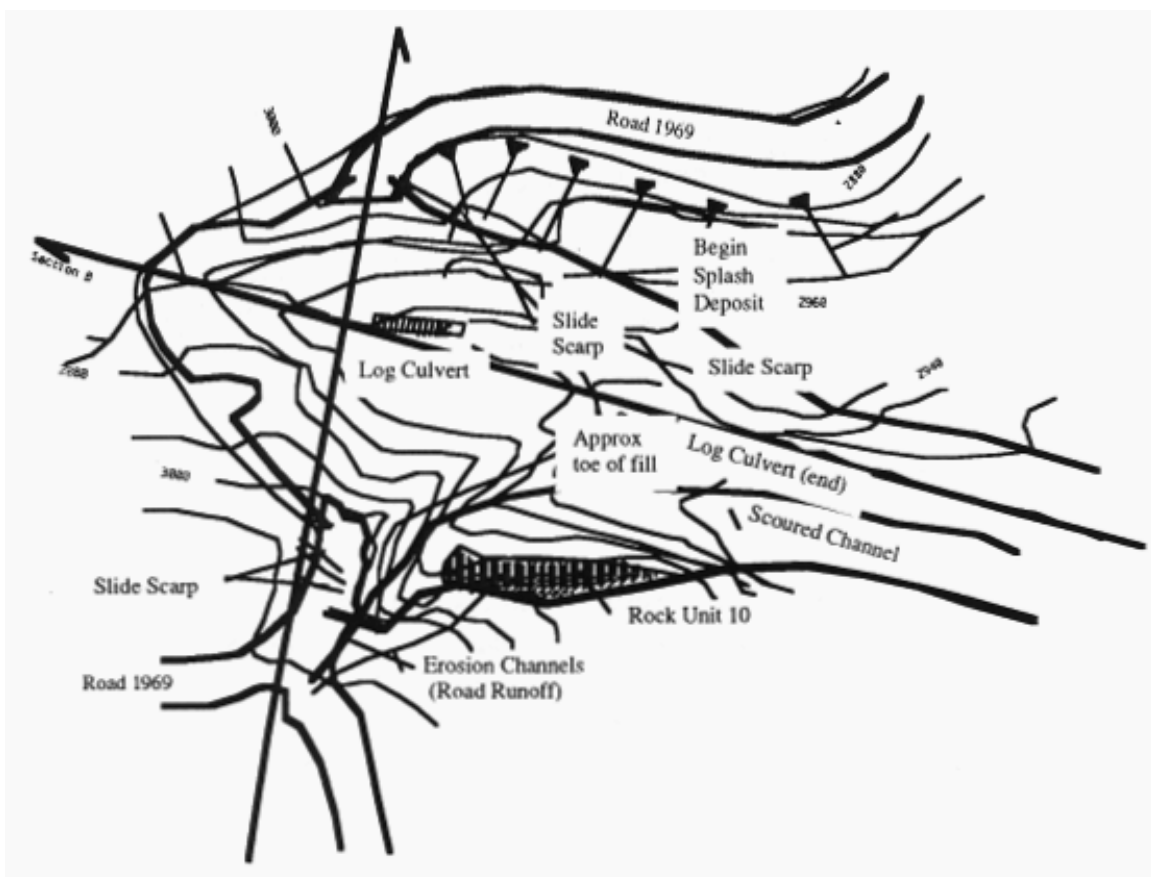


Figure 4. Plan of embankment that failed

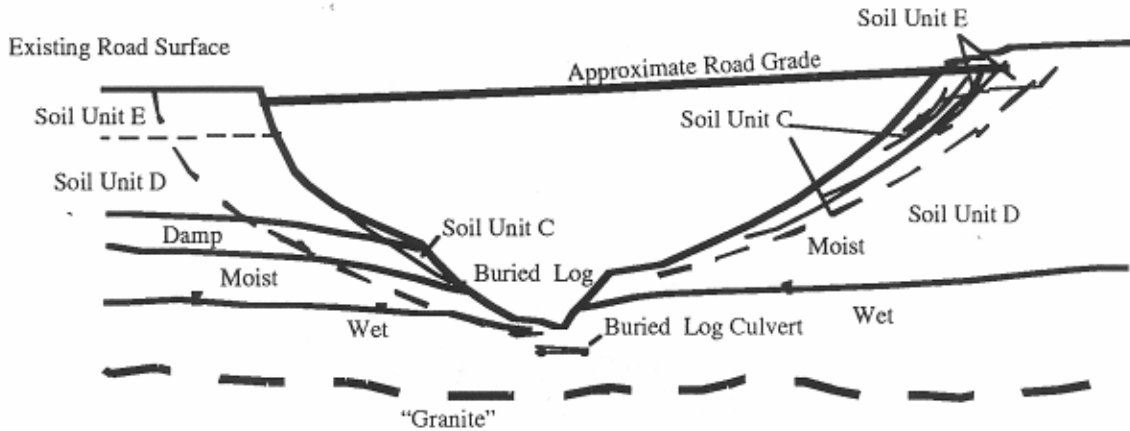


Figure 5. Profile of upper road embankment that failed.

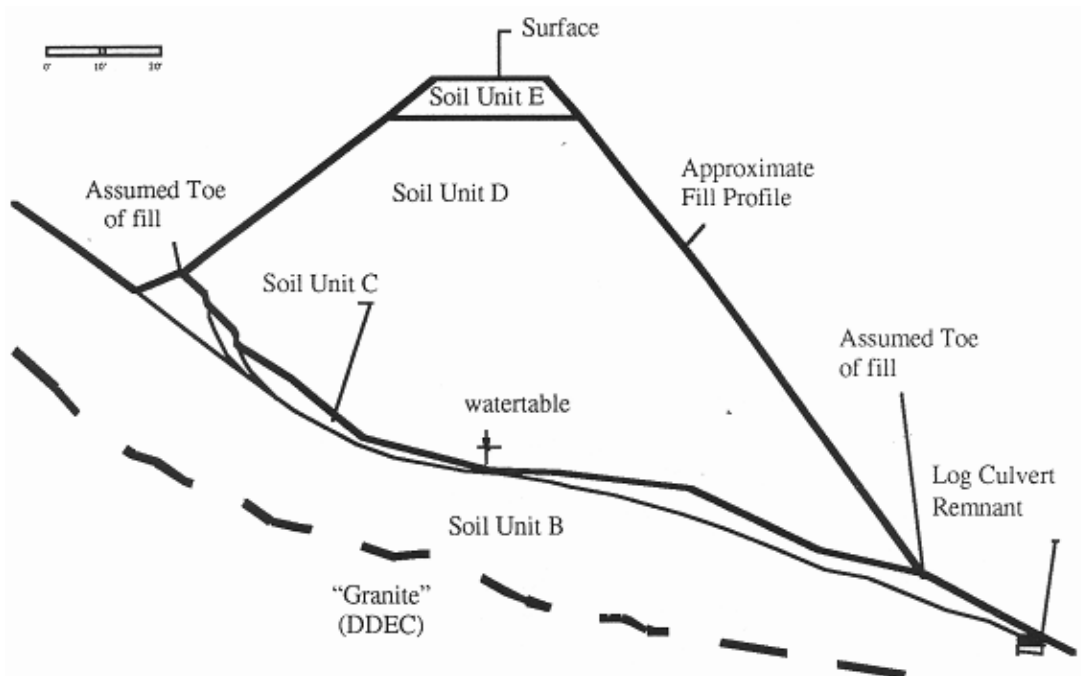


Figure 6. Cross section of road embankment that failed.

Field Observations

The slide length was about 1200 in. To measure the amount of sediment scoured out of the waterway, forty-one stations were surveyed, using the sag tape method, to determine the existing cross sectional area from scour mark to scour mark. Adjacent slopes were measured with a clinometer and extended into the center of the slide. These slopes, along with an assumed valley bottom width, were then used to estimate the pre-slide cross sectional area. An example transect is shown in Figure 7. The difference in cross sectional area was attributed to the slide.

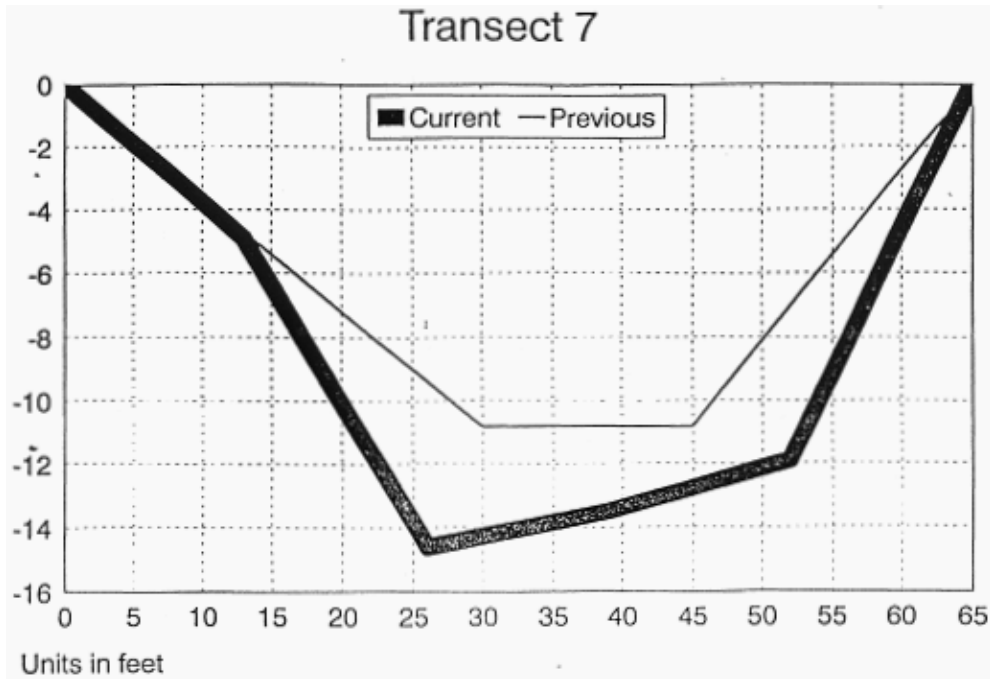


Figure 7. Typical transect of waterway that was scoured by the debris flow

The depth of sediment deposition on the flood plain was surveyed with a level and rod. To estimate in-stream deposition, 103 stations were surveyed using probes to determine deposition depth. A rod was inserted until the original stream bed was contacted (determined by a change in stream bed density). At least three depths were measured at each station. The survey extended for 1520 m downstream from the site of the landslide.

An ISCO water sampler was located 4.42 km downstream of the landslide site. Suspended sediment was determined from the continuous sediment sampler which was running before, during, and after the slide. The sedimentation concentration before the slide was known, so the increase in concentration during the slide was attributed to the slide event. All concentrations were considered impacted until the concentration fell to pre-event levels. The hydrograph for water year 1993 was analyzed and the suspended sediment data were divided into two period: (1) the rising limb, peak, and falling limb, and (2) the low flow/base portion. Using these periods and the impacted days, a graph of sediment transported per day was developed. Background sediment concentrations were assumed to be the average for the spring time period, and this was subtracted from the total daily sediment yield. The mass per day was converted to volume assuming a density of 1.65 for decomposed granite.

A detailed survey was carried out on the road fill site that was believed to have initiated the failure. It was determined that the log culvert had failed, and that the till had been near saturation several meters from the bottom. The results of the field survey were analyzed using XSTABL, a slope stability program developed by the Forest Service to assist in site specific analysis (Prellwitz, 1994).

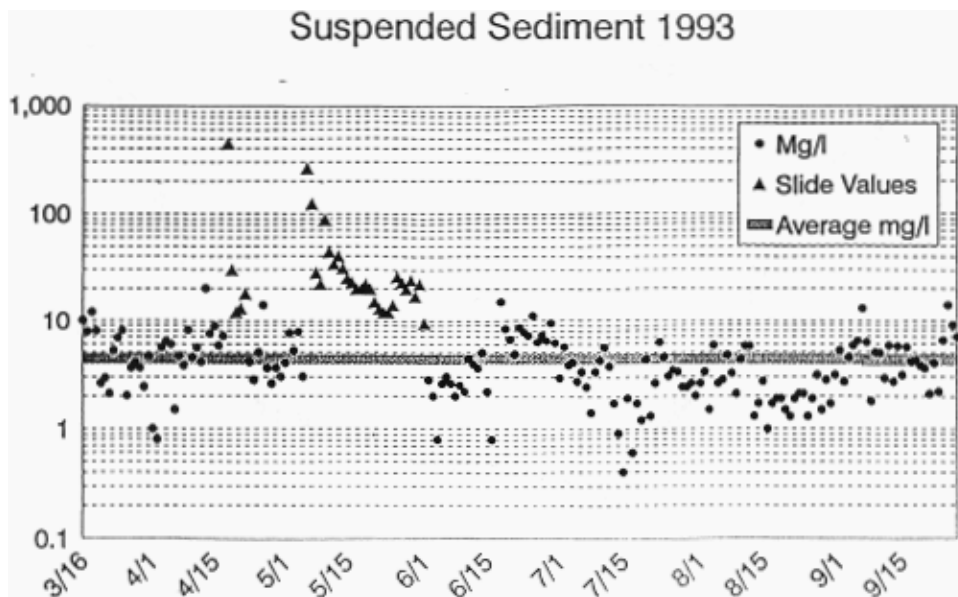


Figure 8. Observed suspended sediment loads during 1993

Results and Discussion

Figure 8 shows the suspended sediment amounts during 1993. The increase in the values observed from April 19 until about June 1 are attributed to the landslide. The observed sediment concentrations during 1993 were higher than had been observed in some years, but Figure 9 shows that there have been several recent years when sediment concentrations were even higher than observed during 1993. There were no records of any major landslides during the years with high values of suspended sediment, 1984, 1986, and 1991. 1984 was the wettest year in the 41 years of record (EarthInfo 1992), which would result in greater channel flows, and may have accounted for the increased sediment concentration (Yang, 1976). There was an ongoing timber sale with logging truck traffic in the watershed from 1983 until about 1986, and the suspended sediment may have come from eroding native surface roads in the watershed. Table 1 contains the ten highest daily concentrations recorded by the sampler from 1982 until 1993, and only two of the days following this landslide are included in that list. The source of the higher sediment amounts in 1986 may have been due to a logging operation, but the 1991 source of sediment is not known. The 1993 values may have been lower than some of the earlier years because the reach of channel between the slide and the sampler had three debris jams that resulted from the slide, as well as beaver activity which would increase rates of channel sedimentation. Because of the coarseness of the debris, there would be less fine sediment in suspension from a debris flow than may have been the case with sediments that eroded from roads in the early 1980s.

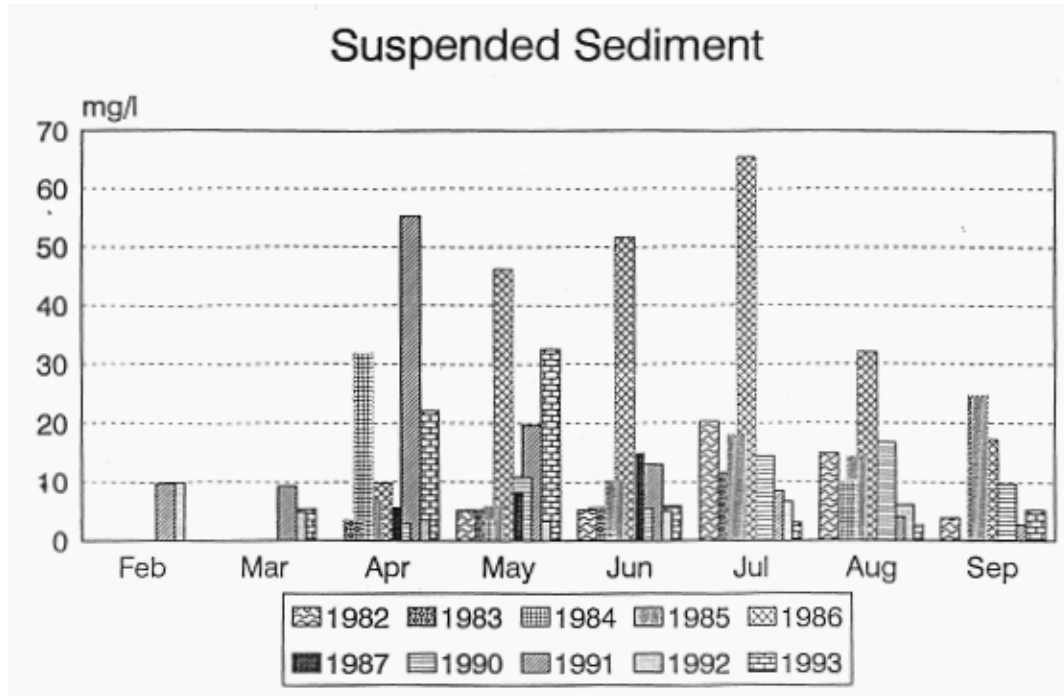


Figure 9. Sediment concentrations observed on Elk Creek from 1982 until 1993

Table 1. Ten highest daily suspended sediment concentrations on Elk Creek from 1982 until 1993.

Rank	Date	Concentration mg/l	Comment
1	4/08/91	584	
2	4/18/93	448	Slide
3	7/05/86	383	
4	5/27/86	299	
5	5/06/93	263	Slide
6	4/09/91	250	
7	7/04/86	230	
8	5/26/86	167	
9	6/10/86	136	
10	5/28/86	132	

Figure 10 shows the sediment transport rate calculated from the flow rate and suspended sediment concentration. Generally, spring values are greater because of the greater flow rates (Figure 2), and the impact of the landslide during the high flow season increased the sediment transport rate from April 19 until about June 1.

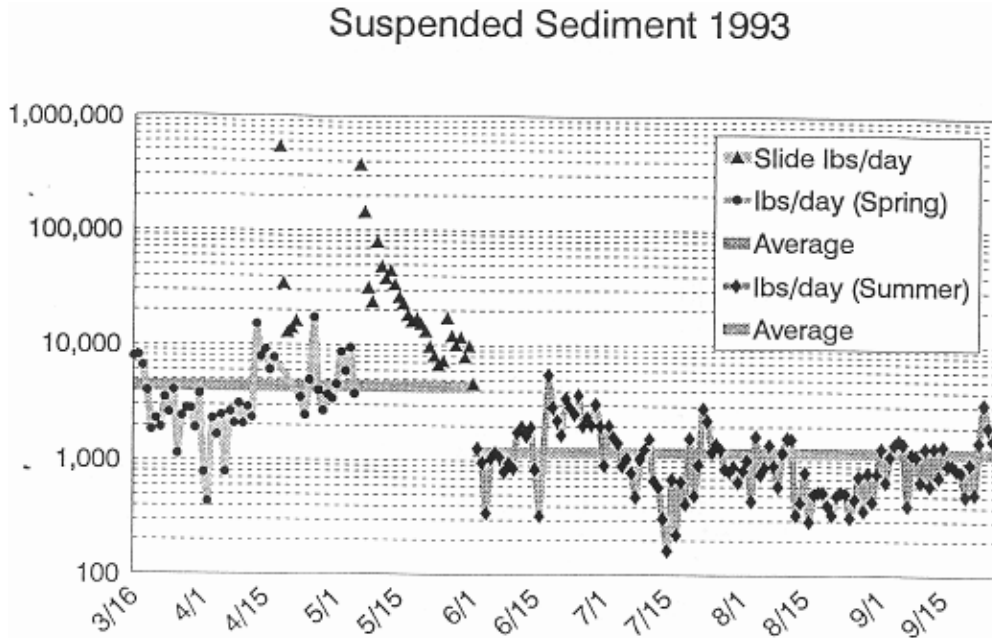


Figure 10. Transport rate of suspended sediment in Elk Creek in 1993.

Table 2. Source and Fate of Sediment in Elk Creek Landslide

Location	Volume of Material cubic meters	Percent of Total
Scoured from Waterway	17,211.20	100
Flood Plain Deposition	10,362.55	60.2
In Stream Deposition	5443.80	31.6
Suspended Sediment	444.01	2.6
Unexplained Sediment	960.84	5.6

The results of the analysis of the source and fate of sediment are presented in Table 2. We theorize that the unexplained sediment represents material deposited on the slopes adjacent to the slide (sediment was found splashed up to 10 m high on trees adjacent to the slide), and on the flood plain of Elk Creek. The largest portion of the unexplained sediment was probably deposited within the substrate of Elk Creek, where the cobbles have been embedded by sediments, and could not be measured.

The stability analysis carried out with XSTABL predicted that under dry conditions, the embankment that failed would have been stable. On successive iterations with the model, it was found that only a small increase in the pore pressure at the base of the embankment was necessary to reduce the Factor of Safety to under 1.0. This result confirmed the field observations that an increased pore pressure in the base of the fill, perhaps aggravated by the collapsed log culvert, led to the failure.

Implications of Study

Elk Creek has a water quality objective of “High Fish” with an indicator species of Brook trout. The High Fish Forest Plan Standard requires the “Maximum short term reduction of water quality that is still likely to maintain a fish habitat potential that can support an excellent fishery relative to the stream system’s

natural potential, and that will provide capability for essentially full habitat recover over time, and maximum short-term sediment loading that is not likely to cause more than a 20% reduction from full biological potential of the habitat for the appropriate fish indicator species.” Threshold levels should not be exceeded for more than 10 of 30 years. The approximate maximum sediment loading that generally supports this criteria for a Brook trout, channel type is 55 percent over natural (30 Mg/sq km/yr). Therefore, in order to meet Forest Plan Standards, sediment production can not exceed 30 Mg/sq km/yr in any given year. This landslide delivered 614 Mg/sq km (3200 percent over natural) or 20 times the maximum sediment loading for a High Fish standard. This landslide also pushed the stream beyond its geomorphic threshold, estimated at 256 percent. An estimated 9739 Mg of sediment actually reached the creek. The impacted reach has become energy limited (as evidenced by dramatic channel aggradation from pre to post slide and the reduce shear stress monitored from 1993 to 1994). The aggradation has resulted in pool filling, reducing both summer and winter fish rearing habitat, and has also smother gravel spawning beds needed by trout. Any additional sediment will cause further aggradation.

There are many kilometers of little-used or disused roads in the National Forest System. There will be numerous fill sections, similar to the one that initiated this debris flow. If all of these fill slopes are removed, then the chances of this sort of event occurring would be eliminated. With scarce financial resources, however, forests must determine the best way to maximize the benefits of such activities. The application of XSTABL to disused roads can aid in determining which fills are in most danger of failure, and resources targeted on those fills.

Mitigation

Two sediment traps were installed during the summer of 1993 to prevent any further sediment from reaching Elk Creek from this tributary. The first is an 8.4 m³ trap which completely filled twice during the year. It was located where the scoured waterway entered the flood plain. A second trap on the flood plain is estimated to have 172 m³, and has trapped an estimated 15 in³ during the first season. A channel was constructed to route runoff from the waterway through the sediment traps. Brook trout have been observed to utilize the larger trap, while fish and other aquatic species can be found in the second trap.

Other mitigation measures included the aerial application of 160 kg of grass seed, 600 kg of fertilizer, and 1200 bales of straw. To stabilize the center of the debris flow, 56 debris steps were installed. These steps will add structure, dissipate stream energy, slow the routing of fine sediment, store fine organic matter, and help to reestablish the formation of a flood plain. In addition, approximately 150 trees were felled into the waterway. These trees will serve the same functions as above, plus trap sediment before it enters Elk Creek. In 1994, 2500 trees were planted in both the waterway and in Elk Creek's flood plain to stabilize soil and provide a source of future woody debris and shading to enhance the fish habitat.

Monitoring

We will continue to operate the sampler and flow station, as well as make riffle stability transects. Two riffle stability monitoring sites were installed in 1993, one in the slide impact zone, and one at the sampler site. These stations are monitoring surface fines and channel stability (aggradation/degradation). It is clear from data obtained during the past two seasons that fine sediment is still moving downstream. At the sampler site, three pebble counts had increases in percent fines from 50 to over 60, 32 to over 40, and 27 to over 48. At the slide impact zone, one station stayed the same, one decreased from 30 to under 25, and one slightly increased. At all cross sections, channel aggradation has occurred since the debris flow.

Fifteen bank erosion pins (600 mm long steel stakes) were installed to monitor bank erosion in the center of the debris flow. Thirteen of those were completely lost over the first winter/spring, while the remaining two were lost during the 1994 spring/summer season. This reflects the highly unstable condition of the waterway, and the need for the sediment traps on the flood plain to collect the eroded sediments from the waterway.

Summary

A large debris flow was studied in the Clearwater National Forest. The probable cause of the flow was the failure of an old railway fill that was serving as a road. Most of the sediment was deposited at the tow of the flow, or in the channel immediately below the flow. Mitigation measures have been instigated to reduce the impacts of the flow. This failure could have been predicted with current modeling technology.

Conclusions

Landslides can substantially alter sections of forest streams, and it is possible to quantify many of the impacts of such disturbances. Current computer technology can assist in predicting susceptibility of old road fills to failure.

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