STABILIZATION OF LANDSLIDES FOR THE IMPROVEMENT OF AQUATIC HABITAT [1]

Michael J. Furniss[2]

Abstract: Chronic surface and mass erosion from recent landslides often prevents the recovery of productive stream habitats following initial mass failure events. Low-cost methods that can accelerate recovery and stabilization processes have been employed on numerous failed slopes in the Six Rivers National Forest in the northwest corner of California, with notable success. Two treatment methods, toe erosion control and revegetation have wide applicability in situations where funding is scarce.

There is often an important relationship between the condition of the soils in a watershed and the productivity of its riparian areas and streams. The maintenance and improvement of productive riparian systems is largely a consequence of good soil management. In the steep and erodible basins or northern coastal California that means maintaining the stability of slopes and the productivity of their soils.

The production of anadromous fish is being emphasized in the coastal streams and rivers on public lands managed by the Forest Service in northern California. In planning the enhancement of fish habitats, it is appropriate to evaluate watershed conditions and identify the factors that limit fish production.

On the North Coast of California, landslides are the most common habitat-degrading watershed problem. Large inputs of sediment from landslides often severely degrade or eliminate downstream fish habitat, and create unproductive islands in otherwise productive stream and riparian systems.

Large mass failure events are often followed by years of continued surface erosion and secondary mass failures, with each process worsening the other. Chronic sedimentation from subsequent erosion of failed slopes can prevent the natural recovery of downstream channels and riparian systems. It is suggested that such chronic, long-term sediment inputs are much more damaging, volume-for-volume, than catastrophic sediment inputs from mass failure events.

The willingness of land managers to attempt any landslide stabilization is often lacking, chiefly because the size of the features creates a perception of futility of anything but extremely expensive, large-scale engineering solutions. However, the cost of corrective measures is not always prohibitive, and high value fish and wildlife habitat can often be reclaimed without great expense or effort.

Landslide stabilization measures have been applied extensively to road and real estate development, and are well developed. Because of the urgency and high values at risk in these situations, very expensive measures are readily justified and usually include detailed evaluation and engineering designs. Vehicular access is usually feasible.

Where wildland water quality or fish habitat are the values at risk, the options for landslide stabilization are usually more limited because of: (1) a lack of perceived urgency and risk - no human life, access or improvements are threatened, (2) small amounts of available funding, often with higher priority projects competing, and (3) lack of vehicular access. Despite these limitations cost-beneficial options often do exist and may be an essential step in the reclamation of a stream reach or riparian system.

Some General Principles

There is a great variety of landslides that can occur in nature resulting from many combinations of causative factors acting on a great variety of landforms. No standard methods of control are universally applicable, but some generalizations about approaches can be made:

1. Corrective measures must be designed to act on the driving forces causing the slide or secondary erosion, or on the resisting forces tending to keep the hillslope stable. The specific factors causing the movement or risk of movement must be identified.
2. Corrective measures will either decrease the destabilizing forces or increase the resistance of the soil or slope to erosion.
3. The consequences of erosional impacts should be evaluated on the basis of the value of the resources threatened. A risk-value versus cost analysis should be done for each possible erosional process and contemplated corrective treatment.

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[2] Hydrologist, Six Rivers National Forest, USDA Forest Service, Eureka, California.

The risk is the probability or potential for a particular erosional or hydrologic event to occur. The value is the perceived worth of the resource or beneficial use that would be lost if the event occurred. The combination of risk and value defines the problem (Huffman and Bedrossain, 1979).

Corrective treatments will modify the risk and the attendant potential change in value. Comparing risk-value under various corrective treatments with the cost of corrective treatments facilitates rational decisions as to what to do, and forms a basis for assigning priorities to various processes and treatments.

4 Long-term, self-sustaining treatments that do not require maintenance are preferable to short-term treatments that depend on maintenance for success, particularly in poor access areas.

Types of corrective treatments that apply somewhat generally to landslides include:

1. Relocate the affected resource (road, stream).
2. Unload the head of the slope.
3. Load the toe of the slope.
4. Remove water from the slope.
5. Restrain or divert materials.
6. Protect landslide toe from stream erosion.
7. Control gully erosion.
8. Protect erodible surfaces.

These same general methods also apply to the prevention of landslides.

Detailed discussion of landslide processes and corrective measures can be found in several of the references (Bell 1964; Bradshaw and Chadwick 1980; Transportation Research Board 1978; California Department of Public works 1970; Federal Highway Administration 1978).

Site-specific measures are best developed when imagination and judgement are applied and the physical processes involved are understood.

Experience With Three Large Debris Slides On The Six Rivers National Forest

The Six Rivers National Forest has treated many landslides that impact anadromous fish habitat. Treatment of three very large slides with common erosional processes and similar resources at risk are described here.

The landslides are known as the Horse Linto, Rib, and Bigtoe Debris Slides. The Rib Debris Slide was initiated, and the Bigtoe and Horse Linto Debris Slides were greatly enlarged by the flood of 1964. The Horse Linto Debris Slide is within the Trinity River watershed and the Rib and Bigtoe Debris Slides are within the Smith River watershed.

Each slide had a mass failure volume of several million cubic yards, and each had ongoing severe surface erosion from the barren failure surfaces. The toe of each slide was rapidly being eroded by stream flows. This was a major driving force for ongoing and potential erosion from the slides.

Stream gravel sampling above and below each landslide showed substantial increases in both spawning gravel embeddedness and the proportion of fine sediment downstream of each slide, relative to gravels just upstream. Each slide was believed to be adversely affecting high-value habitat for king salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salrno gairdneri gairdneri*).

Each slide was treated in the early 1980's to control toe erosion, and was revegetated to control surface erosion. The objectives were to reduce sediment delivery to affected habitat, hasten the recovery of productive channel conditions, and accelerate the recovery of the soil and ecosystem productivity on the failed slopes.

The treatments are being monitored by annual visits for qualitative evaluation, annual photo points, evaluation of the embeddedness of downstream spawning gravels, and survey lines to track slope movement.

Control of Toe Erosion

Three different methods were used to control erosion at the toe of the slides that were being chronically destabilized by erosive river and stream flows: placement of a large prism of rock rip rap; excavation of a new channel with explosives with emplacement of tetrahedron-retard training fences, and; widening of the channel with heavy equipment.

On the Horse Linto Debris Slide, an energetic fifth-order stream (Horse Linto Creek) with a narrow channel and steep sideslopes was impinging on the toe of the slide at a sharp meander bend. The stream undercut the slide and promoted its instability, and an active gully system developed on the failure surface.

Placement of a prism of rock to protect the toe of the slide was judged to be the best treatment given the circumstances. The channel could not be relocated or modified to reduce the energy of the stream. Access to the toe by heavy equipment was easy to develop, and sufficient funds were available.

This treatment has been in place for five years and has been completely effective. There has been no toe erosion since the treatment. However, this treatment was quite expensive and this amount of funding is not usually available for such projects.

On the Rib Debris Slide, a smaller third-order stream (Idelwild Creek) was eroding the toe of the slide and causing a threat of additional large mass movements as well as ongoing sediment input to the stream from the erosion itself. Vehicular access to the toe of the slide was impractical.

A new channel was blasted using serial explosive charges to relocate the stream away from the toe of the slide, and a "retard" was constructed using a line of steel-rail tetrahedrons with cyclone fencing wired to their stream-side faces. This acted as a flow-obstructing energy dissipator, to retard flow velocity in the original channel and cause sediment deposition.

This treatment was completely effective. Seven years later, the retard caused extensive sediment deposition and debris accumulation preventing reoccupation of the original channel by the stream. The new channel carries all the flow well away from the toe of the slide. No visible toe erosion has occurred since the treatment.

On the Bigtoe Debris Slide, the upper Main Fork of the Smith River (sixth order) was impinging on the toe of the slide, causing ongoing piecemeal mass erosion and promoting surface erosion by removing backed-up sediments. An old rock source development widened the channel somewhat, but riparian vegetation was restricting the effective width of the channel.

The River flows are very energetic and funding was quite limited. Placement of rock rip rap would have been appropriate, but was too expensive.

Simple widening of the channel and removal of densely growing willows by bulldozer was employed, with emplacement of a small tetrahedron retard along part of the toe. The widened channel is about three times wider than the pre-treatment channel. This spreads high flows, reducing the level of peak flows and effectively reducing their energy. The retards consist of six-foot steel-rail tetrahedrons cabled together. These have accumulated floating woody debris that has increased their effectiveness in dissipating the erosive power of high flows.

After two years, it appears that this treatment is effective in substantially reducing but not eliminating toe erosion. The low cost and partial success of this treatment suggests that it is cost-effective where funding is insufficient for rip rap protection and access for heavy equipment exists or is inexpensive to develop.

Revegetation

Bare slide surfaces usually are inhospitable to plant growth due to very low nutrient capital and unstable surfaces. They tend to revegetate very slowly. Surface erosion of failure surfaces often removes enormous volumes of sediment before revegetation can stabilize the surfaces. We can accelerate the revegetation and stabilization process through planting and fertilization treatment.

Planting and fertilization of slide surfaces, if feasible, is almost always cost-effective. In some situations the newly-established vegetation will simply accompany sediment to the stream or slide toe in mass erosion events. However, the cost of planting and fertilizing is quite low and the long-term benefits are high. The risk of losing the treated areas to additional mass erosion is usually warranted.

Many bare and eroding slide surfaces have been planted and otherwise treated for revegetation on the Six Rivers National Forest. The results have been favorable in most places. Vegetative cover, root permeation of unstable soils, and ecosystem productivity have been increased many-fold through simple and inexpensive treatments.

While not all slide surfaces are accessible for planting and not all treatments result in successful revegetation, the cost of these treatments and their apparent long-term effectiveness suggests that this can be a highly cost-effective type of treatment. However it is rarely employed, probably because most landslides are believed to be completely untreatable, except with very large amounts of money.

We have learned several things from our revegetation efforts on many slide surfaces:

1. Inoculated nitrogen-fixing species such as alder (*Alnus* sp.), black locust (*Robinia pseudoacacia*), and sweet clover (*Melilotus sp.*) should be used because the soils on bare slide faces have not hosted plants before and are therefore very low in nitrogen. Survival rates were not related to nitrogen-fixing, but overall growth and vigor was. Non-nitrogen-fixing species that were planted have not thrived, while those that do fix nitrogen have grown much more quickly and are providing more stabilizing effect.

   Nitrogen-fixing species will tend to build up nutrient capital in the site, greatly hastening the development of topsoil, plant succession, and ecosystem recovery.

2. Fertilization alone sometimes produces adequate revegetation, with native or local species. In the humid North Coast, seeds of pioneer species are abundant and ubiquitous. If the surface is at least temporarily stable, seedlings will become established each

spring. However, unless there are sufficient nutrients, root growth is too slow to keep up with the summer drought period and seedlings dessicate and die. A single treatment of an N-P-K fertilizer has often proven adequate to achieve revegetation.

3. Cuttings, such as willow (*Salix*) and coyote brush (*Baccaris pilularis*) seem inexpensive, but often have a low survival rate. Unless labor is free, cuttings are not inexpensive when the overall success rate of plantings is considered. Our experience is that rooted stock is much more likely to survive and is worth the extra initial cost, if suitable species can be obtained.

4. Vegetation needs no maintenance and gets more effective with time. Deep-rooted woody species require several years to become well-established and effective. Managers must be willing to wait for several years to see distinct beneficial effects.

Conclusions

In some situations, inexpensive measures for the protection of landslide toes from erosive streamflow can be effective. Channel realignment with flow obstructions to maintain new configurations can be as effective as more costly solutions such as rip rap.

Revegetation of bare, eroding slide faces is a cost-effective treatment almost anywhere it is feasible, and should be more widely used.

Where revegetation is to be employed, nitrogen-fixing species should be included to accelerate soil building. Fertilization can be a useful treatment alone or in combination with introduced vegetation.

Landslides that degrade fish habitat and riparian resources can sometimes be stabilized with relatively inexpensive treatments. Land managers should be willing to consider low-cost treatments before concluding that landslides cannot be stabilized.

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