

## MASS EROSION AND FOREST MANAGEMENT<sup>1</sup>

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In Japan, landslides are such a major national hazard that in 1958 the "Landslide Prevention Law" was passed and an extensive program for research, engineering, and control of landslides has developed. There is no comparable legislative mandate in the United States. Contrary to the situation in Japan where lives and property are jeopardized by landslides, in the U.S. the main concern for controlling landslides is to preserve water quality and timber site productivity. In late summer 1981, a team of six U.S. scientists spent two weeks in Japan under the auspices of the U.S./Japan Science and Technology Exchange Program. Three of the scientists, W. F. Megahan, D. A. Sangrey, and D. N. Swanston studied the Japanese work on landslide, groundwater, and erosion problems. These visiting U.S. scientists were very impressed with the quality and scale of work being conducted by Japanese scientists. In their technical report, they made specific recommendations for future U.S./Japan exchanges of individual scientists and engineers concerned with landsliding.

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<sup>1</sup>Presented at the Ninth Meeting, U.S./Japan cooperative Program in Natural Resources, Panel on Forestry, June 6-13, 1982, Tokyo, Japan.

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Forest land management in many areas of northwestern North America is complicated by a high potential for mass erosion. The problem is most pronounced along the Pacific rim from northern California to southeastern Alaska. Areas within the northern Rocky Mountain region have similar, but less frequent, problems with slope stability.

Reliable data on the total area classified as unstable, the value of the resources on these lands, and the increased cost of managing unstable lands is very limited. However, a U.S. Forest Service survey of the management problems associated with unstable areas in Oregon and Washington is applicable to much of the Pacific rim of North America. About 11 percent of the area was classed as unstable. Some of the most unstable areas are presently being developed or will be within the next 10 years. These unstable soils are among the most productive for timber growth in the region. Some of the most extensive unstable areas are found in watersheds with high value anadromous fisheries, and upstream from reservoirs. The cost of managing landslide-prone soils to ameliorate adverse impacts are significantly higher than managing stable soils. For example, road construction costs increase 100 to 200 percent; road maintenance costs increase 50 to 100 percent; and sale layout costs increase 20 to 40 percent.

An inventory of mass failures covered 5490 km in the northern Rocky Mountains (Megahan et al. 1978). About 0.1 percent of the productive forest land was lost each year to mass failures, 97 percent of which were related to land management. About 23 percent of all landslide material was delivered to active stream channels. Of this material, 40 percent was delivered directly to third-order streams or larger where fishery values are concentrated in the northern Rocky Mountains.

In undisturbed forested steeplands, mass erosion is the dominant mechanism by which soil is transported from hillslopes to stream channels. Land management activities can dramatically increase the probability of certain types of mass erosion, but influence other types only slightly (Swanston 1976).

Creep is the slow downslope movement of the soil mantle where the long-term gravitational shear stress is large enough to produce permanent deformation but too small to cause discrete failure. Creep is the most common and widespread mass erosion process in steeplands, but is the least understood and documented. It occurs at varying rates and depths in all sloping cohesive soils. Changes in the rate of creep of a given slope seem to be correlated with changes in the piezometric level in the slope (Swanston 1976). Measurements of borehole deformation in a variety of geologic materials in U.S. Pacific coastal forested areas suggest annual creep rates of less than 10 mm/yr. These rates vary widely with climatic stress even within the same geologic material (Swanson and Swanston 1977, Swanston 1981). The effect of timber cutting on creep rate is poorly documented. However, Swanston (1981) reported that data from one site in southwestern Oregon suggests an increase in creep rate beginning the second year after logging. Although the influence of timber harvest may be subtle, a small increase in creep rate may result in a large increase in the quantity of soil delivered to the stream channels because of the vast areas subjected to creep processes.

Slump-Earthflow can be considered accelerated creep where shear stress exceeds the strength of the soil mantle and results in discrete failures. These failures may range from less than a hectare in area and a meter in depth to several square kilometers in area and tens of meters in depth. The rate of movement of earthflows, as of creep, may be imperceptibly slow, but can exceed a meter per day (Kelsey 1980).

Creep and deep-seated earthflows may be affected little by timber cutting or road building unless the distribution of mass or water within the slide is changed substantially (Wilson 1970). The distribution of mass can be changed by excavations that undercut the toe of the earthflow, removing downslope support. Road fill can add mass to the head of an earthflow, adding to the gravitational forces contributing to slope failure. Roads can also modify the water relations within the earthflow. Road cuts can intercept subsurface flow. If this water or surface road drainage is diverted away from the earthflow, the slide below the road may become more stable. If water is diverted onto the slope, dormant earthflows may be reactivated. Timber cutting can also modify the internal water relations of the earthflow (Gray 1970, Rothacher 1971). Evapotranspiration by forests may deplete 50 to 75 cm of soil moisture per year (Ziemer 1981). In a Mediterranean-type climate having warm, dry summers, forest transpiration can reduce both piezometric head and the slide mass. Vegetated dormant landslides may therefore, be reactivated if the forest cover is removed.

Debris avalanches are rapid, shallow hillslope failures generally found in shallow noncohesive soils on steep slopes where subsurface water concentrates. These failures are the type most frequently linked to timber harvest. Plant roots can reduce the occurrence of these shallow failures. Roots can anchor through the soil mass into fractures in bedrock. They can also develop lateral support by crossing zones of weakness to more stable soil as well as providing long fibrous binders within a weak soil mass (Gray 1970, O'Loughlin 1972, Wu 1976, Waldron 1977). In deeper soils, root-anchoring to bedrock becomes negligible, but the lateral support by roots remains. In marginally stable areas, debris avalanche frequency may increase after trees

are cut, as their root systems progressively decay (O'Loughlin 1974, Burroughs and Thomas 1977, Ziemer 1981).

Although many studies have documented increased debris avalanche erosion after logging, road building appears to increase the frequency of debris avalanches much more than does timber cutting (Swanston 1976, Swanson et al. 1981, Gray and Megahan 1981). In addition to profoundly affecting the soil water regime, road cuts can intersect and undercut the shallow failure surface. And road fills can add a substantial mass surcharge to the slope. These effects become, relatively less important as the depth to the failure surface increases.

Debris torrents are the failure and rapid movement of water-saturated soil, rock, and organic debris in small, steep stream channels. Debris torrents might be considered a transitional link between mass erosion caused by a debris avalanche, and channel erosion. They typically occur during periods of high precipitation and streamflow. They may be started by a debris avalanche that enters the channel, or they may result from an initial failure of accumulated debris within the channel (Swanston and Swanson 1976). They recur whenever there is enough noncohesive debris accumulated in the steep channel and sufficient water to mobilize that debris (Takahashi 1978). Typically, as debris from the initial failure moves downslope, it entrains large quantities of additional material obtained from the channel banks and bed. The channel may be scoured to bedrock for a great distance until the channel gradient lessens and deposition occurs (Costa and Jarrett 1981).

Land management activities may increase the frequency of debris torrents. Material from management-accelerated hillslope erosion can increase the amount of debris accumulated in channels. Road fills at stream crossings place a

large mass of rock and soil in channels. Road culverts in small steep stream channels often are commonly plugged with soil and organic debris, resulting in saturation and failure of the road fill. Failure of road crossings is an important cause of accelerated channel erosion and debris torrents in many forested steepland areas. Also, channel flow can be dramatically changed by roads intercepting subsurface flow, rerouting of microdrainage networks, and the concentrating of surface runoff from compacted road or tractor trails.

Management activities can modify the stability of debris within the channel. The local gradient of a steepland channel, as well as its stability, is often controlled by bedrock. However, large woody debris, a natural component of forested steepland channels, can also control channel gradient (Keller and Swanson 1979). The residence time of large decay-resistant logs, such as redwood, in a channel may approach a geologic time scale—up to 500 years. Large logs of Douglas-fir may remain in a channel up to 200 years (Swanson and Lienkaemper 1978). When this organic debris decays, accumulated material is subject to channel erosion and, further, is available for rapid mobilization into a debris torrent.

Land management activities can influence both short and long-term stability of debris deposits within channels. Mechanical removal of naturally accumulated large organic debris can release stored sediment within a short time, whereas decay allows intermittent releases over a longer time while new deposits simultaneously form behind recently fallen trees. Logging residue can greatly add to the organic loading of a channel, thus providing additional opportunities for debris deposits. These additional deposits can increase the risk of debris torrents in steep channels or predispose channels to increased erosion many years after logging as organic components eventually decay and

release accumulated deposits, if channel stability is controlled by the long-term supply of large organic debris, and large trees adjacent to channels are eliminated by continued forest management, active channel erosion may follow the decay of existing logs because new large logs are no longer available for replacement (Swanson and Lienkaemper 1978). In intermittent channels, live roots from surrounding trees provide substantial strength and reinforcement to the channel bed. If these trees are cut, the strength of the debris composing the bed will progressively weaken as the roots decay. This condition may result in accelerated channel erosion or increased risk of a debris torrent.

Often land management economic decisions in the U.S. are dominated by cost-benefit analyses limited to short-term factors of monetary outlay and income. The consequences of erosion are often considered only when road maintenance or other direct costs are anticipated. But, mass erosion may follow land treatment by many years or even decades. Factors such as effects on fish habitat, soil productivity, and long-term slope stability, being difficult to quantify either physically or economically, are usually not adequately considered. Nonetheless, these must be considered in the decision process.

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