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Erosion was not considered a serious problem in the early 1950's in the U.S. Logging operations were concentrated mainly in the better timber stands along beaches and in valley bottoms. In the mid-1950's, large-scale clearcutting began to include steeper slopes. Now areas having a high erosion hazard are being logged. One apparent consequence of large-scale logging is an increase in soil movement (Bishop & Stevens, 1964).

Natural soil-mass-movements on forested slopes in the western United States can be divided into two major groups of closely related landslide types. These include, in order of decreasing importance and regional frequency of occurrence: (1) debris slides, debris avalanches, debris flows, and derbis torrents; and (2) creep, slumps, and earth flows. Each type requires the presence of steep slopes, frequently in excess of the angle of soil stability. All characteristically occur under high soil moisture conditions and usually develop or are accelerated during periods of abnormally high rainfall. Further, all are encouraged or accelerated by destruction of the natural mechanical support on the slopes (Swanston, 1974).

Clearcutting, it should be pointed out, is a timber harvesting procedure in which all the vegetation (or mechanical support) is felled in a selected area. This is the usual logging practice in the redwoods of the north coast ranges of California and in vast tracts of Douglas fir in the Cascade Range of Oregon and Washington. Denudation is made more awesome and complete by burning the slash remaining after a logging or cutover operation. Controlled slash burning is justified by various arguments, the foremost being that it eliminates a potentially serious fire hazard later on (Gray, 1970). In a study by Croft & Adams (1950), they also concluded that the recent occurences of landslides were largely due to loss of mechanical support by root systems of trees and plants, chiefly by timber cutting and burning and, to some extent, by excessive livestock grazing (Bishop & Stevens, 1964).

Clearcut logging and slash burning in a steep 237-acre watershed in western Oregon resulted in increased rates of soil movement, especially on slopes unprotected by organic derbis. During the first growing season after burning, soil movement, which largely occurred as dry gravel, was most pronounced on 8 percent slopes (versus 60 percent), on south aspects (versus north), and in areas having little plant cover (versus well-vegetated areas). By the second growing season after burning, rapid invasion by vegetation essentially halted soil movement on all slopes except extremely stony talus areas (Mersereau & Dyrness, 1972).

It becomes apparent that vegetative cover is a major factor in soil stability. Kawaguchie (1956, 1959) and his co-workers in Japan placed great value on a well-rooted forest cover as a means of minimizing landslide activity. They noted that landslides were far more prevalent in shrublands and grasslands than in forested areas. They also observed that the effectiveness of the forest cover in preventing landslides increased with the age or maturity of the forest. Bernardini (1957) studied the occurrence of landslides in the mountains in northern Italy and recommended forestation as a principal control technique. In another article by Cappuccini and Bernardini (1957) on the causes, classification, and prevention of landslides, the authors stated that an insufficient cover of vegetation is one of the most important causes If landslides (Gray, 1970).

Without vegetative cover, surface erosion will undoubtedly occur. Surface erosion can be defined as the movement of individual soil particles along the surface of the ground. Three factors control the rate of surface erosion. They are detachability, forces applied and surface erosion. Estimated effects can be found in Table 1 for the period immediately after logging.

Detachability is the ease with which soil particles can be detached and transported; it is an inherent soil characteristic. Soil aggregation has been used by many as a detachability index. Cutting and skidding tend to disrupt the soil surface to some degree, and hence might have a small effect. Roads remove all surface soil, exposing material that possesses very little aggregation; we would expect a moderate-to-great effect.

Forces applied are simply the forces available for transport, including raindrops, wind, surface flow and gravity. Raindrops and wind will have a greater influence on the logged area than an unlogged area, but the biggest increase will be the surface flow on roads. A large increase in surface flow on roads is likely primarily because of reduced infiltrating, interception, and interruption of subsurface flows by the road cuts (Megahan, 1972).

Since logging and road cutting began in 1950 on the H. J. Andrews Experimental Forest in Oregon, only two small road-related slides have taken place in the designated stable zone, occurring at elevations above 900 to 1000 m. in terrain underlain by lava-flow bedrock. The unstable zone, located at elevations below 1000 m. and underlain by latered volcaniclastic rock, has been the site of 139 slides during the same period.

Slide erosion from clearcut areas in the unstable zone of H. J. Andrews Forest has totaled 6.0 m^3/km^2, or 2.8 times the level of activity in forested areas of the unstable zone. Along road rights-of-way, slide erosion has been 30 times greater than on forested sites in the unstable zone; however, only about 8 percent of a typical area of deforested land in the unstable zone is in road right-of-way. At comparable levels of development (8 percent roads, 92 percent clearcut), road right-of-way and clear-cut areas contribute about equally to the total impact of management activity on erosion by land slides in the unstable zone. The combined management impacts in the unstable zone (assuming 8 percent road right-of-way and 92 percent clear-cut) appear to have increased slide activity on road and clear-cut sites by about 5 times relative to forested areas over a period of about 20 years (Swanson & Dyrness, 1975).

Surface cover refers to the materials (e.g., natural litter, logging debris, mulches, surface rock) that protect the soil from erosion forces. Protection might actually increase on some cutover areas, but usually decreased protection is expected on roads owing to the absence of plant cover or litter. Considering all three factors, the overall erosion hazard ratings show a small increase for cutting plus skidding and a moderate to large increase for roads. Roads have a much greater effect per unit area of disturbance than do cutting and skidding (Megahan, 1972).

It has been shown that soil erosion is related to clearcutting and road construction. Another disturbance caused by road construction is the soil water-holding capacity. Excessive slope gradient and pore-water stress in glacial till soils of Karta series are primary factors in derbis avalanche and flow occurrence in recently logged areas of southeast Alaska. Initial field investigations have indicated that during months of low rainfall, lateral movement of seepage water in these soils is limited to a zone 2 to 6 inches thick, directly above an impermeable, unweathered till surface. Seepage occurs along interconnected soil voids and partings produced by downslope growth of rootlets above this surface (Bishop & Stevens, 1964).

During high rainfall periods, the soil becomes saturated, and the seepage zone thickens with substantial increases in flow. The increasing volume of water, moving laterally through the soil as saturated flow, causes a rise in the piezometric surface, with two important consequences: (1) increasing shear stress along potential sliding surfaces caused by rising seepage pressures and increasing unit weight of soil materials, and (2) decreasing shear resistance resulting from increased pore-water pressure in the soil (Swanston, 1970).

Studies from three Oregon watersheds indicate that timber harvest operations involving high-lead cable yarding to a system of logging roads may increase sediment in streams draining these areas by two to 150 times the amount from undisturbed watersheds in any other year. These increases may average more than 100 times the undisturbed condition over a period of years.

By far, the greatest soil loss was associated with landslides and the scouring action of high-velocity mudflows which often pass down the stream channels following a landslide. Landslides associated with forest roads move the largest volume of soil. These landslides occur most often where roads intersect stream channels (Fredrikson, 1970).

Current research on the effect of forest operations on soil stability is directed toward: (a) anticipation of hazardous sites, (b) avoidance of disturbances systematically damaging to slope stability and (c) reduction of landslide incidence after disturbance.

The ability to identify hazardous sites is probably the most useful and economical management tool available. In the northern California Coast Ranges, aerial photos are being used extensively to identify, delineate, measure, and interpret topographic features related to deep-seated creep and sliding. The interpretations are supplemented by geologic maps compiled from surface outcrops and drill cuttings which aid in the interpretation and extrapolation of observed creep patterns. Vertical color-infrared photographs are being used to identify slope areas of high soil moisture content.

TABLE 1.* Estimated Effects of Cutting Plus Skidding and of Roads on Factors Influencing Surface Erosion

Erosion factor	Effect relative to undisturbed lands[1] Cutting + Skidding	Roads
Detachability	None to small +	Mod. + to large +
Forces applied		
A. Raindrops	None to mod. +	None to mod. +
B. Wind	Small + to mod. +	Small + to mod. +
C. Surface Flow	None to small +	Large +
D. Gravity	None	Small + to large +
Surface cover	Small + to mod. −	Large −
Overall erosion hazard	Small +	Mod. + to large +

[1]Comparison made immediately after logging
*Megahan, 1972

Avoiding activities that are systematically damaging to slope stability will keep slope disturbance to a minimum during forest operations. These include restricting forest road construction on potentially unstable slopes and preventing damage to the slopes by timber harvesting equipment and methods. A number of promising new timber harvesting methods are also being investigated or are undergoing limited practical trials. These include balloon logging and helicopter transport, both of which have a tremendous potential for reducing ground damage, but are of extreme expense at the present time.

Most direct methods of stabilization and control of disturbed areas are expensive and difficult. There have been some limited attempts to stabilize disturbed areas by vegetation planting. This has been done with some success in the Western States with grass and legumes on road cut and sidecast slopes to reduce surface soil erosion (Wollum, 1962; Bethlahmy & Kidd, 1966; Dyrness, 1967b; as cited in Swanston, 1974). The United States Forest Service is currently experimenting with hand seeding of debris avalanches tracks with older in southeast Alaska also (Swanston, 1974).

It is fair to conclude from an analysis of published literature on this subject that there exists a definite cause and effect relationship between forest clear-cutting and mass-soil movement. Studies carried out in many different parts of the world appear to support this conclusion.

A forest cover appears to affect the deep-seated stability of a slope in two principal ways, via, by modification of the hydrologic regime in the soil mantle and by mechanical reinforcement from the root system. The former is likely to be important only in the first year following clear-cutting and burning, i.e., before invading vegetation has had a chance to take hold. Evidence in the literature suggests that the effect of the root system is far more important and that gradual deterioration of a tree root system leads to progressively greater slope instability with time (Gray, 1970).

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