HYDROLOGIC FACTORS AND ENVIRONMENTAL IMPACTS OF MASS SOIL MOVEMENTS IN THE OREGON COAST RANGE

by

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ABSTRACT

Mass soil movements of four types; debris avalanche, debris torrent, debris slide and bank slough, were field inventoried in the Oregon Coast Range. A total of 104 mass movements were located in 21 undisturbed watersheds and 13 clearcuts harvested in the last six years. Failures associated with roads and landings were not included in this inventory. Failure volume ranged from 2 yd^3 to 196 yd^3. The average volume of all failure types ten cubic yards or more in volume is 41 yd^3 in undisturbed watersheds and 47 yd^3 in clearcuts. Failures less than ten cubic yards are of little significance in terms of initial volume moved, but in undisturbed watersheds they account for over one-fourth of the channel impact by mechanical scour and deposition. The frequency of all failures is similar in clearcuts and undisturbed watersheds, one in 19 acres and one in 17 acres, respectively.

Mass failures travel 1.7 times farther in clearcuts than in undisturbed watersheds. Debris jams from failures in clearcuts contain 3.2 times more inorganic and 2.5 times more organic debris than debris fans from undisturbed watersheds. Eight percent of the Class III and IV stream length (U.S. Forest Service Classification) in forested drainages and ten percent of that within clearcuts is impacted by channel scour and deposition.

The erosion rate for all soil landtypes encountered in undisturbed watersheds is 0.11 yd^3/ac/yr. This rate increases by 3.5 times in clearcuts. Landtypes with very steep, highly dissected slopes show the largest increase in erosion rate from uncut to clearcut watersheds (10 times). Less than one percent of the forested or clearcut land area is affected by the mass soil movements.

Half of the failures in undisturbed drainages and nine-tenths of the failures in clearcuts occurred on slopes of 80 percent or greater. The average volume of failures is greatest on slopes of 80 to 100 percent. No apparent relation exists between failure frequency and aspect in this study.

The results are compared with other studies in the Pacific Northwest and the differences are discussed. Natural variation accounts for much of the differences. Guidelines are given for assessing the risk of damage by debris avalanche and torrent type failures in proposed timber harvest areas.

KEY WORDS: mass soil movements, debris avalanche, slope stability, debris jams, channel scour

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INTRODUCTION

Mass soil movements are common in steep, deeply incised landforms such as the Oregon Coast Range. In this geologically young landform, narrow V-shaped stream channels and narrow ridges provide an abundance of steep slopes on which slope processes can act. The sedimentary rocks that comprise most of the Coast Range are rapidly weathered when exposed in the mild, wet climate of the area. However, soils are generally shallow and poorly developed. Mass wasting processes, windthrow of large trees with massive root systems and activities of burrowing animals are continuously churning the soil mantle and moving it down the steep slopes to the stream channels. The debris avalanche, a rapid shallow-soil mass movement that disintegrates substantially while travelling along a narrow track, is a dominant erosion process in young landform evolution in humid climates.

When a debris avalanche enters a stream channel carrying storm runoff, the water and debris combine and move as a slurry or debris torrent, scouring the channel to bedrock. In very steep headwall channels, a torrent may initially gain kinetic energy from the force of gravity. The scouring and gouging of the stream channel expends the kinetic energy and eventually the torrent begins dropping debris and finally stops, typically in the lower gradient portion of the drainage. Deposition is often in the form of a debris jam.

Logging activities have recently encroached upon lands that were once avoided because of their unstable soils and steep slopes. The unstable nature of these areas has not changed, but technological advances and the demand for lumber has brought these areas under intensive management. In the Oregon Coast Range and Cascades, intensive forest management on steep, unstable slopes poses problems for land managers, including an increase in debris avalanche activity.

The impacts of large volumes of debris scouring a channel to bedrock have concerned fisheries people as well as others. The danger of causing serious damage to private property or of taking lives, and concern for the impact of these failures on the timber production base and fisheries resource has come to bear on managers as well as specialists. Enough concern was generated on the Mapleton Ranger District, Siuslaw National Forest, to cause management changes directed toward mitigating or preventing impacts on soil, water, fisheries, and wildlife resources, including specific actions to avoid debris avalanching.

Past slope stability research generally focused on events produced by extraordinarily large storms (75 to 100 year return intervals). In many areas of the world, the large storms produced a relatively small number of very large mass failures (over 1000 yd^3). In the Oregon Coast Range the pattern is different. Here relatively small mass soil movements (less than 500 yd^3) are produced in very large numbers by both the large infrequent storms and more frequent storms having short return intervals of only five to ten years. One example of this pattern of extensive mass movement is found on the Mapleton Ranger District. In late November and December, 1975, rains from a storm having a five-to-ten year return interval caused an estimated 246 mass failures on the Mapleton District alone (Gresswell, Heller, and Minor, 1976).

Mass failure of this extent poses substantial land management problems. Roads, structures and productive forest land were damaged by the mass movements. The full extent of the impacts on aquatic resources from channel scour and debris jams is unknown.

An aerial photo inventory was conducted on the Mapleton Ranger District to assess the damage from mass failures on roads, in clearcuts and in undisturbed forest areas (Gresswell, Heller, and Minor, 1976). Failures in clearcuts and along roads are easily detected on aerial photos, but the number of failures in the undisturbed forest may be greatly underestimated. Shadows caused by steep, narrow ridges and tall, dense forest vegetation make these failures difficult to identify on aerial photos. Thus the extent of mass movement activity before logging lacks adequate description and comparison with past-logging mass movement is tenuous.

This research project was structured to meet the following objectives:

a) to characterize site conditions where natural failures occur, including soil properties and geomorphic location, to aid land managers in planning projects in these areas;

b) to quantify the amount of land area affected by slope failures in mountain watersheds and determine the impact of these failures on stream channels by mechanical scour of channel materials and deposition of organic and inorganic debris in the form of debris jams;

c) to compare the findings in undisturbed watersheds with the same information collected on mass movements in clearcuts.

The Mapleton Ranger District, Siuslaw National Forest, was chosen for this study because it provided an abundance of mass movements on a wide variety of site conditions. Other portions of the Coast Range experience the same kinds of failures on similar landforms, but the large number of events recorded on the Mapleton District have not been documented elsewhere. However, the basic information in this report applies to other areas of the Coast Range as well.

LITERATURE REVIEW

The literature dealing with mass soil movements contains many accounts of large, destructive failures having occurred in the past throughout the world (Bishop and Stevens, 1964; Williams and Guy, 1971). Rapid forms of mass movement, such as debris avalanches and debris torrents have the potential to be catastrophic, because of their relative speed and great erosional power. Large storms may trigger a large number of mass movements and cause property damage and sometimes loss of life (Campbell, 1975) or create hazardous conditions and road damage in forested lands (Fredriksen, 1965, 1970).

Rapid, shallow-soil mass movements of the debris avalanche type are prominent mass wasting features of "youthful" slopes in humid climates but are not found in the "mature" stage of landform development (Sharpe, 1938). Swanston (1967a) identifies debris avalanches as the most frequent form of mass wasting in southeastern Alaska. Mass soil movements are considered to be western Oregon's most important erosional process (Brown, 1973).

Mass Failure Processes

Mass failure occurs when the internal friction forces within the soil mass or between the soil and some sliding surface, such as bedrock, do not balance or exceed the downslope force of gravity. The forces resisting downslope movement are defined as the soil shear strength. Shear stress is caused by the force of gravity acting on the soil mass and any objects on the soil mass. When shear stress equals or exceeds shear strength, failure results (Wu, 1976). Many factors are involved in determining the instantaneous shear stress and shear strength of a soil mass.

Soils involved in much of the debris avalanching in the coast ranges of the Pacific Northwest are, or are assumed to be, cohesionless (Harr and Yee, 1975; Bishop and Stevens, 1964; Swanston, 1970). The strength of cohesionless soils is expressed by:

$$S = \overline{\sigma}\tan\overline{\emptyset} \tag{1}$$

where S is the shear strength, σ is the effective normal stress, and $\emptyset$ is the internal angle of friction. The effective normal stress is the stress perpendicular to the failure plane and is the perpendicular component of the weight of the soil above a point, plus the weight of anything on the surface, such as vegetation, road fill material, buildings, etc., minus the pore water pressure. Pore water pressure will be discussed later. The angle of internal friction is a measure of the intergranular friction and interlocking of soil grains. Conditions that tend to decrease the effective normal stress and intergranular friction will decrease the shear strength while conditions favoring intergranular friction and increase effective normal stress will increase the shear strength.

Soil Water Effects on Slope Stability

Episodes of debris avalanching are most often reported during periods of high intensity rainfall or rain-on-snow events (Young, 1972; Corbett and Rice, 1966; Rapp, 1962; Williams and Guy, 1971; Bishop and Stevens, 1964; Patric and Swanston, 1968; Hack and Goodlett, 1960; Day and Megahan, 1975; Fredriksen, 1965; Tubbs, 1975; Campbell, 1975; Rice and Foggin, 1971; Rice and Krammes, 1970; Scott, 1972; O'Loughlin, 1973; Gresswell, Heller, and Minor, 1975). In undisturbed forested terrain, very little water runs off the soil surface during these storms (Harr and Yee, 1975; Swanston, 1967a). The forested soils of the Northwest have the capacity to transmit tremendous amounts of water to streams and groundwater storage.

The movement of water through the soil in response to potential gradients causes a force to be transferred to the soil grains, called the seepage pressure (Terzaghi and Peck, 1967). This force, pulling on the soil grains, increases the shear stress on the soil mass and can decrease the stability of a slope. However, seepage pressure in porous forest soils is probably of minor importance for slope stability when weighed against changes in effective normal stress from increasing pore water pressure.

Pore water pressure (u) is the product of the unit weight of water (γw) and the height of the free water surface above a point of interest (h_w) (Wu, 1976):

$$u = \gamma_w h_w \tag{2}$$

When a soil is relatively dry, water in the soil is held under tension in small pores by capillary forces. This tension pulls the soil grains together and increases the friction force and intergranular locking, promoting a fairly stable condition. Harr and Yee (1975) attribute apparent cohesion of cohesionless soils to capillary tension. As water enters the soil and fills the pores, capillary tension is reduced.

If the infiltration rate exceeds the rate at which the water is transmitted through the soil, saturation occurs and a free water surface (piezometric surface) develops. Pressure at the free water surface is zero (Hillel, 1971). If the saturated zone thickens, the pressure (pore water pressure) at a fixed point increases (equation 2). The pore water pressure forces soil grains apart, diminishing the effectiveness of intergranular friction and reducing the soil shear strength. According to Young (1972), the presence of water in a saturating soil does not reduce soil stability by lubricating the mass, but by increasing the pore water pressure through a rising water table, thus decreasing the shear strength.

Intense storms may cause a saturation zone to develop in soils on forested hillslopes. There has been some speculation as to the size of storm required to initiate mass soil movements, but too many factors deny its definition. The storm preceding Christmas 1964, in western Oregon produced 8.25 inches of rain in over two days and more than 13 inches in four days, plus an undetermined amount of snowmelt (Fredriksen, 1965). This was the largest storm in 104 years of record in the area. A rain-on-snow event in 1974 produced 214 landslides in central Idaho, of which debris avalanches and slumps were the most prevalent type (Day and Megahan, 1975). Torrential rains associated with hurricane Camille in August, 1969, ravaged central Virginia with 27 to 28 inches of rain in 8 hours (Williams and Guy, 1971). Localized serious mass wasting resulted from highly irregular rainfall intensity. Campbell (1975) and Scott (1971) estimate a 75 to 100 year return interval for the storm that caused extensive mass movement in southern California in January 1969. Campbell points out that the soil slips occurred early in the storm, before the 75 to 100 year amount of precipitation fell. The failures did occur during the most intense period of the storm, however. With the aid of a radar installation at a nearby airport, Campbell established that apparently no soil slips occurred at rainfall intensities less than 0.25 inches per hour (iph). The recurrence interval for 0.25 iph in the Santa Monica mountains is less than one year. O'Loughlin and Gage (1975) reported storms of two year return frequency were causing failures in New Zealand.

O'Loughlin (1973) measured a rise of the piezometric surface (water table) in soils of southwestern British Columbia during rainfall and snowmelt events. For daily rainfall exceeding 120 mm, complete saturation was observed in hillslope depressions. From piezometer measurements and rainfall records, Swanston (1967b) established a curvilinear relationship between rainfall and piezometric head, or pore water pressure. Patric and Swanston (1968) were able to document the development and persistence of a piezometric surface six to eleven inches above the unweathered till (common slip surface in southeastern Alaska) during simulated 0.70 iph rainfall. Two-thirds of the water applied moved directly to the stream channel through the soil. In the saturated zone, water moved to the channel through root holes, rock crevices and other macropores. Hammermeister (1977) also found saturated flow in pasture soils during both simulated and natural storms. The observed rapidity with which water traversed his plots could not be explained using theoretical flow models, including Darcy's Law. Large mole holes and other macropores apparently provided low resistance pathways for water and nutrient movement. Rice, Corbett and Bailey (1969) measured smaller hydraulic conductivities just below the slip surface than above, suggesting that a zone of saturation developed along the slip surface before failure. Harr and Yee (1975) observed only one, discontinuous, short-lived saturation zone during a wet winter in the Central Oregon Coast Range, and discounted it as a common occurrence. Saturation measurement may have been hampered by clays lining their piezometer holes and pervious bedrock conditions.

The idea that there is a threshold storm of a specific size and intensity required to initiate mass movements is not generally accepted because of the importance of events preceding the storm and antecedent site conditions (Harr and Yee, 1975). Patric and Swanston (1968), and others, suggested that rainfall is probably the main driving force determining when debris avalanches occur, but topographic, geologic and soil factors usually control where they occur. The importance of

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other factors in determining whether or not a mass will fail can be illustrated by the spotty nature of debris avalanche events. In three adjacent watersheds, two cut and one undisturbed, only one watershed showed mass movement during a large storm (Fredriksen, 1965). Heavy rainfall during the early part of the devastating storm of January 1969, in the Santa Monica mountains of California did not cause failures (Campbell, 1975). The lack of major slide activity until later in the storm was reportedly due to a "pre-conditioning period" requirement.

The pre-conditioning of a soil mass for failure may take place over a much longer period of time than elapses during the initial part of a storm, and involve more than wetting the soil and developing pore water pressure. Rice and Krammes (1970) emphasize the importance of factors with temporal variation that create inherent instability in a slope such that an extended period of rainfall will trigger failures. Among these "stage setting factors" are, antecedent soil moisture, chemical weathering of clay substrate, under-cutting of slopes by streams or roads, and channeling of runoff into cracks created by soil creep and shrinkage of clays. Swanston (1967a) and Gonsior and Gardner (1971) also identify these types of pre-conditioning factors and add that tree roots may be less effective in soil stabilization in over-mature forests because of their reduced growth rate and increasing decay rate. Tree roots that wedge into cracks in bedrock may dislodge blocks and decrease stability. These other factors affecting slope stability will now be discussed in more detail.

Topographic Factors

Steep slopes and debris avalanching seem closely related. Swanston (1973) used slope alone to indicate landslide potential in southeastern Alaska. Slopes greater than 36 degrees were classed as highly unstable and potentially unstable slopes were between 26 and 36 degrees. Table I summarizes the relationship of slope to debris avalanche occurrence as it is found in the literature. The greatest number of failures occur

Table I. Slope angles on which debris avalanches are most common.

Source	Location	Slope (°)
Campbell, 1975	Southern California	25 - 45
Corbett and Rice, 1966 and others	Southern California	30 - 40
Morrison, 1975	Central Oregon Cascades	37 - 42
Scott, 1972	Appalachian Blue Ridge Mtns.	30 - 35
Simonett, 1967	New Guinea	35 - 55
Williams and Guy, 1971	Central Virginia	16 - 39
Day and Megahan, 1975	Idaho	31 - 42
O'Loughlin and Gage, 1975	New Zealand	25 - 40
Bishop and Stevens, 1964	S.E. Alaska	34+
Dyrness, 1967	H.J. Andrews Experimental Forest, Oregon Cascades	24+

on slopes between 25 and 45 degrees. Failures do occur on gentler and steeper slopes, but the number of events is much smaller than on slopes of 25-45 degrees. Failures were found to occur on slopes down to 16 degrees in central Virginia (Williams and Guy, 1971). The storm that caused the failures in the inventory was the remnant of Hurricane Camille and is believed to have represented a 75 to 100 year event. Researchers in the brush conversion areas of southern California noted that above 45 degrees the soil mantle was discontinuous and not prone to debris avalanching. Dyrness (1967) and Corbett and Rice (1966) obtained a positive correlation between slope and slide frequency. Not all studies, however, report such a correlation. Williams and Guy (1971) obtained no consistent relationship between slope angle and slide frequency. Highly irregular rainfall intensity may have masked the effect of slope on failure occurrence. Simonett (1967) found slope angle to be of little significance in a multiple regression analysis. His results are difficult to interpret.

The influence of slope angle on slope stability can be seen by referring to the equation for calculating the factor of safety (FS) against sliding for a cohesionless soil on an infinite slope (Terzaghi and Peck, 1967):

$$FS = \frac{\tan\phi}{\tan\alpha} \tag{3}$$

This shows that when the slope angle α approaches the internal angle of friction ϕ, the factor of safety goes to 1.0 and theoretically the slope will fail. Typical values of ϕ are (Terzaghi and Peck, 1967):

dense silt-sand	$30-34^{\circ}$
dense angular sand	45°

Swanston (1970) calculated ϕ of 37 degrees for till soils of southeastern Alaska. Factors of safety using this value and soil properties were less than one, even for slopes that had not failed. O'Loughlin 1/ calculated slope angles at which the factor of safety would be 1.0 from elementary slope parameters. He obtained ϕ of 24 degrees for saturated conditions and 43 degrees for unsaturated conditions. Gray (1973) calculated FS's greater than 1.0 for dry soils, but at complete saturation, the FS's dropped below 1.0. Once again the importance of pore water pressure in saturated soils is illustrated.

Soil Properties

As noted earlier, the angle of internal friction is a measure of the frictional resistance within a soil mass, which depends heavily on the interlocking of soil grains. The particle size distribution and angularity of soil grains controls the amount and effectiveness of interlocking within a soil mass.

When the particle size distribution is narrow, most of the particles are about the same size. This results in either an open-packed or close-packed structure. The open-packed structure has the least

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1/ Informal seminar presented at Oregon State University, Department of Forest Engineering, October, 1976.

intergranular friction and the most large pores. The close-packed structure has greater interlocking but still has many large spaces between particles. This structure is stable when dry, but is subject to rapid water infiltration and saturation if overlying an impervious material. In both instances, the greater the angularity of the soil grains, the more resistance there is against sliding. With a wide range of particle sizes, smaller particles are able to fit into the gaps between larger grains and the degree of interlocking and intergranular friction enables the soil mass to be stable on steeper hillslopes. Greater pore water pressure is required to reduce the intergranular friction to a critical level. Harr and Yee (1975) obtained high angles of internal friction (40-41 degrees) for soils in the Central Oregon Coast Range. These soils contain a high proportion of stable soil aggregates.

Some investigators have looked at other properties of soil in relation to shear strength and mass movements. Chorley (1964) ran a multiple regression analysis of soil shearing resistance against six soil characteristics on well-sorted sands in England. The independent variables were: 1) median grain size, (2) range of grain sizes, (3) % silt and clay, (4) % moisture, (5) dry soil density, and (6) unit dry root weight. Unit dry root weight was the single most influential factor and the best-fit model included median grain size, dry soil density, and unit dry root weight. O'Loughlin (1973) found a relationship between bulk weight of soil and shear strength in tests on soils in the coast mountains of British Columbia. Scott (1972) found deep, fine textured soils prone to debris avalanching.

Bedrock

Some of the soil and topographic factors affecting slope stability have been discussed. Geologic conditions can also be very important. Parent material can both enhance and detract from the stability of a slope. In most studies where bedrock has been considered to influence mass movement, it has been identified as a source of instability. Bedding planes oriented parallel to the slope typically provide a smooth surface from which little support can be derived by the soil mantle (Scott, 1972; Swanston, 1969; Bishop and Stevens, 1964; Swanston and Dyrness, 1973). This smooth surface, parallel to the slope, often constitutes the failure surface. Bedding planes may create even more serious instability when they intercept water and concentrate it at some point (Swanston and Dyrness, 1973). The point of concentration may be some distance away and may be located across the ridge in a different drainage than where the water was intercepted (Hack and Goodlett, 1960).

Joints and fractures in the bedrock also intercept and concentrate water. A later discussion will show that a certain amount of jointing and fracturing can contribute substantially to slope stability, by allowing plant roots to anchor themselves, and the soil mantle to bedrock. Irregularities or depressions on the slope also concentrate runoff and are common origins of debris avalanches (Hack and Goodlett, 1960; O'Loughlin, 1973; Scott, 1972).

The type of bedrock underlying slopes prone to debris avalanching is highly variable. Debris avalanches occur on slopes underlain by granitic and volcanic rocks as well as sandstone and shale in southern California (Campbell, 1975); igneous and metamorphic rocks in Virginia (Williams and Guy, 1971); tertiary sediments in Japan (Fujiwara, 1970); granite and diorite in Alaska (Swanston, 1969; Bishop and Stevens, 1964); basalt, andesite, and weathered volcaniclastic rocks in the Oregon Cascades (Morrison, 1975); and the Tyee Sandstone of the Coast Range of Oregon (Harr and Yee, 1975). Scott (1972) reported bedrock type to have little influence on failure occurrence. However, in some studies, failure frequency is strongly associated with the type of bedrock. Swanson and Dyrness (1975) found laval flow bedrock to underlie stable slopes and unstable slopes to be over volcaniclastic rocks in the western Cascades of Oregon. Debris avalanching was confined to interbedded sandstone and shale or mudstone in the Appalachians (Hack and Goodlett, 1960).

The structure of the bedrock, and the configuration of the material overlying the bedrock may be more important than the bedrock type itself. Rapp (1972) identifies four different sites in which slides were initiated in Norway:

> 1) shallow slides on glacially smoothed gneiss rockwall, 2) sheet slides from talus mantle 2-3 m thick, 3) thin slides from till over bedrock above the forest, 0.5 m or less in thickness, and 4) in the birch forest, the bottom of the podzolic layer over fine-grained, compacted till.

In southeastern Alaska, Bishop and Stevens (1964) and Swanston (1969) commonly observed the failure plane to be a smooth compacted till layer. Tubbs (1975) describes failures occurring along the contact between Lawton clay or pre-Vashon sediments and overlying Esperance sand in the Seattle, Washington area. The soil-bedrock interface is also a common failure surface (Williams and Guy, 1971; Swanston, 1969; Bishop and Stevens, 1964; O'Loughlin, 1973).

Vegetation

Vegetative factors have been added to the list of site conditions that control the occurrence and relative importance of mass erosion processes (Swanston and Swanson, 1976). Vegetation enhances the strength and stability of soil masses by soil moisture depletion (Gray, 1973) and through mechanical reinforcement by the root system (O'Loughlin, 1973; Swanston, 1976a; and others). Researchers in the San Dimas Experimental Forest in California report that any effect of bedrock was apparently masked by vegetation and topographic factors (Rice, Corbett, and Bailey, 1969). These observations were made on grass conversion sites where, as will be seen, vegetation manipulation can have a profound effect.

Soil moisture depletion by plants in reponse to evapotranspiration needs helps prevent or delay the build-up of pore water pressure in the soil. During the dry season, water uptake for the satisfaction of evapotranspiration demands, reduces the soil moisture content to below field capacity. Thus, it takes more moisture to re-wet a soil that has been dried by vegetation than a soil with little evapotranspirational requirements. If some of the most intense storms occur early in the rainy season, potentially unstable conditions due to high pore water pressure may not develop in a dried soil and an episode of mass movements may be avoided. Gray (1973) found the water content of soils in clearcuts to be higher than that in the adjacent forest. He found creep rates to be greater when the soil moisture was high, and creep rates in clearcuts exceeded those in the forest sites. This would indicate that soils over impervious substrates in clearcuts saturate sooner than similar soils in the undisturbed forest, assuming infiltration is not impaired.

It is thought that plant roots provide stability in shallow soils primarily by anchoring of the soil mass to bedrock (O'Loughlin, 1973; Swanston, 1976a; Swanston and Dyrness, 1973). Where joints, fractures, bedding planes, or rough surfaces allow roots to grip or wedge into the bedrock, considerable support is achieved. Plant roots also help bind masses of soil particles together and contribute to soil aggregation (Swanston and Dyrness, 1973). O'Loughlin (1973) notes that under saturated conditions, the soil strength is derived mainly from apparent cohesion as the result of tree roots. The stabilizing effect of tree roots has been suggested to be the reason cohesionless soils are maintained on slopes exceeding the angle of internal friction (Swanston, 1970).

Swanston and Dyrness (1973) observe that deterioration of root systems may be associated with increased mass movement activity. Bishop and Stevens (1964), Dyrness (1976), Fujiwara (1970), Gonsior and Gardner (1971), Takeda (1972), O'Loughlin (1973), Swanson and Dyrness (1975), Morrison (1975), and Swanston and Swanson (1976) all document increases in mass soil movement activity after logging. Decaying roots and the accompanying loss of cohesive strength and anchoring to bedrock are considered a major factor in explaining the increase. Other authors also indicate the probable importance of tree roots to slope stability (Rice and Foggin, 1971; Scott, 1972; Grottenthaler and Laatsch, 1973; Campbell, 1975).

On the California grass conversion sites, more soil failures have occurred in the areas converted to grass than areas left in brush (Campbell, 1975; Rice, Corbett and Bailey, 1969; Rice and Krammes, 1970). This may be because grass transpires less than brush (Rice and Krammes, 1970), leaving the soils wetter on the converted sites, or that the shallower root systems of grass do not provide as much structural reinforcement as the deeper rooted brush (Rice, Corbett and Bailey, 1969).

The loss of stability associated with rotting tree roots has been a source of controversy for several years. Fujiwara (1970) assumed the loss of root stabilizing effects were responsible for greater landslide frequency five to eight years after cutting. Swanson and Dyrness (1975) studied slide history in the Oregon Cascade Range and concluded the frequency of slide occurrence is reduced 10 to 20 years after deforestation and road construction. Re-invading trees and other vegetation would have sufficient time to develop root systems that could provide some support after this much time. On grass conversion sites in California, Rice and Krammes (1970) found mass movement erosional processes on the increase 30 years after logging. The shallow rooted grass vegetation is unable to provide as much structural reinforcement of the soil as the natural brush species.

Recent studies have dealt with the question of how fast roots lose their strength. O'Loughlin (1973) showed small roots lose half of their original tensile strength within three to five years after cutting. Burroughs and Thomas (1977) studied the decline in numbers and tensile strength of roots with time after felling, on Douglas-fir in western Oregon and in central Idaho. Numbers of roots per unit area of soil and tensile strength of individual roots were obtained to arrive at a value of total root tensile strength per unit soil area. Results differed between the two species in relation to how fast tensile strength declined, but both Coast Douglas-fir Pseudotsuga menziesii (Mirb) Franco, and Rocky Mountain Douglas-fir Pseudotsuga menziesii var. glauca (Beissn) Franco, lost strength rapidly after cutting. Thirty months after felling, roots one centimeter or smaller in diameter lost 82 percent of their original strength in Coast Douglas-fir, while Rocky Mountain Douglas-fir roots lost 64 percent of their strength. The authors concluded that the finer roots (0-1 cm) are the most effective in slope stability, and these have their greatest effect at the edges of a root mass. Burroughs and Thomas identify three main ways roots add to stability: 1) by anchoring to the bedrock, 2) by providing tensile reinforcement to the soil mass, and 3) by the co-occupation of a common soil volume by lateral edges of two or more neighboring root systems. They found that fine roots at the lateral edges of the soil-root mass of each tree are among the first to lose their stabilizing strength. Each tree becomes separated from others by this zone of weakness that increases in size with time.

Root strength dynamics are beginning to be understood but much needs to be done to incorporate this phenomenon into slope stability analyses. Though vegetation adds substantially to slope stability, slope failures also commonly occur in undisturbed timber. Vegetation cannot totally stabilize a slope and prevent all failures (Rapp, 1962; Williams and Guy, 1971).

Some authors have also noted the destabilizing effect of vegetation on slopes. The plant biomass adds a surcharge to the soil mantle, thus increasing the shear stress (Gray, 1973 and McNutt 2/). But at the same time this weight adds to the effective normal stress and probably more than offsets the surcharge effect by adding to the shear strength (Bishop and Stevens, 1964). The increase in normal stress is considered beneficial under saturated conditions (Gray, 1973). The relative importance of these two opposing stresses is small compared to the anchoring and soil binding by plant roots, and pore water pressure.

Soils underlying forest vegetation are subject to dynamic loading by uprooting forces during windstorms (Swanston, 1969; Gray, 1973).

2/ Effects of forest cover on slope stability: a review. Unpublished paper compiled for graduate research under D.N. Swanston, Forest Sciences Lab, Pac. N.W. For. and Range Exp't. Station, Corvallis, Oregon, 1974.

Windthrown trees disrupt large amounts of soil and may be involved in triggering some mass soil movements. The presence of tall trees may also cause the center of gravity of the soil-vegetation mass to rise, such that the potential shearing plane may move to a more unstable zone within the soil mantle.3/

Aspect

Williams and Guy (1971) consider aspect to play a significant part in debris avalanching. Morrison (1975) found landslides most frequent on north aspects, which comprised a small part of his study area. The average volume of slides on north aspects was about eight times that on south aspects. However, Rice and Foggin (1971) suggest that aspect only has minor influence on the occurrence of mass movements. The effect aspect does have on the occurrence of failures may be through the influence aspect has on other site factors such as rate of weathering and soil formation (Dyrness, 1967; Morrison, 1975), vegetation density (Corbett and Rice, 1966; Rice, Corbett and Bailey, 1969), soil moisture and alignment to storms (Williams and Guy, 1971) and geomorphology of north verses south slopes (Bishop and Stevens, 1964).

Environmental Impacts

Much of the literature cited thus far has dealt with the failure sites themselves, i.e. size, aspect, soil and bedrock type, factors contributing to failure, etc. Once the failure leaves the hillslope, that material has the potential to cause considerable damage. Lives were lost in debris avalanches in 1969 in California (Campbell, 1975). Damages caused by debris avalanches near or in populated areas can be extensive (Tubbs, 1975; Williams and Guy, 1971; Scott, 1971).

3/ Ibid.

Thankfully, most of the mass soil movements occur in more remote forested watersheds where debris avalanche material is deposited in drainages far from any structure that might be damaged. However, a large number of failures in managed forests do cause monetary damages through plugged culverts and washed-out roads. The impact of debris jams in small headwater streams or their tributaries is not well understood nor has it been the topic of much research.

Interest in the role of debris in streams in the Pacific Northwest has recently developed. Froehlich (1973) quantified the amounts of natural debris in several streams of the western Cascades. The amount of debris reported was surprisingly large. The average of all samples was 12 tons of organic debris per 100 feet of channel. Ninety-four percent of this was large material. Considerably less organic debris was found in channels that showed evidence of past scouring by debris torrents.

Stream systems in the Pacific Northwest have evolved with heavy organic debris loads, periodically flushed out by debris torrents (Swanson and Lienkaemper, 1977; Froehlich, 1973). Debris avalanches are identified as major contributors of organic material to undisturbed streams (Swanson and Dyrness, 1975; Swanson and Lienkaemper, 1977) and over 80 percent of debris torrents studied in the Cascades were triggered by debris avalanches from adjacent hillslopes.

Natural debris in streams has been determined to be highly beneficial for the stability of small, high gradient headwater streams (Swanson and Lienkaemper, 1977) and also in providing valuable habitat for invertebrate communities, which in turn are responsible for the breakdown of organic debris (Sedell and Triska, 1977). Wood-created aquatic habitat is formed when large organic debris causes relatively small amounts of sediment to accumulate. This reduces the water velocity at this point and fine organic matter in the water settles out and filters through the sediment. Aquatic organisms have a ready supply of fine organic matter stored for them and flourish in sediment accumulation areas behind debris jams (Sedell and Triska, 1977).

Unfilled portions of debris created sediment traps are available for sudden pulses of sediment from bank failures and debris avalanches. This allows a more uniform release of sediment to lower reaches, except when debris torrents carry even the sediment traps away (Swanson and Lienkaemper, 1977).

Large organic debris also influences the morphology of small mountain streams by deflecting the current around them and into the banks. This causes erosion of the toeslope and oversteepening of the hillslopes. Mass failure from oversteepened slopes delivers more debris to the channel and redirects the flow into another bank. When large debris jams form, as is typical from debris torrents and large debris avalanches entering stream channels, they can increase the difficulty of fish migration. This can be serious in terms of energy expenditure and maturation of salmonids. Complete blockage of a stream to fish migration by debris jams is relatively rare (Narver, 1970).

The above few paragraphs describe conditions that are common to undisturbed as well as disturbed watersheds. In undisturbed drainages, the flourishing aquatic organism populations in wood created habitat are thriving on natural levels of organic matter that do not create a biological oxygen demand (BOD) high enough to deplete the oxygen concentration in the water to levels harmful to fish. The deflection of flow by large organic debris probably progresses in a controlled manner, such that oversteepening of toeslopes is confined to small areas. Subsequent debris avalanching would thus be somewhat controlled.

However, management activities, particularly clearcutting and road construction, in the Pacific Northwest have been associated with an increase in mass movement activity. Swanson and Dyrness (1975) have shown that slide activity on the H.J. Andrews Experimental Forest increased about five times in unstable management zones relative to undisturbed forest areas over a 20 year period. Swanston and Swanson (1976) report that clearcutting in the Pacific Northwest commonly accelerates erosion by avalanche two to four times. Morrison (1975) and Swanson 4/ report increases in debris torrent activity of 8.8 and 4.5 times, respectively, after logging.

Understandable concern has been raised about the impact of this accelerated erosion on fisheries. Debris avalanches and debris torrents contribute large amounts of sediment to stream channels and bare hillslopes and streamside areas to surface erosion. The apparent increase in mass movement activity resulting from management operations increases the amount of sediment to be carried by the streams. Settling of sediment in pools fills intergravel pores. Filled pores results in reduced oxygen exchange, blocks fry emergence, and reduces cover for the juveniles (Hall and Lantz, 1969; Philips, 1970; Narver, 1970).

Deposits of sediment behind debris jams are not necessarily stable. Break-up of debris jams and the associated gravel shifting and downstream scour can cause embryo and alvin mortalities in pink and coho salmon by direct scour or jarring (Hall and Lantz, 1969; Narver, 1970). Insect production is also adversely affected by gravel bed movement.

Debris avalanching in the Pacific Northwest typically occurs during the winter rainy season from November to March. The timing of these coincides with spawning of coho salmon and cutthroat trout in coastal streams (November - February) (Hall and Lantz, 1969). If the movement enters an important spawning stream, the impact on fish can be substantial. Sedimentation following avalanching will progress during the time the fry begin emerging (February - May).

Both debris deposits and the scars on hillslopes left behind by the failures may take considerable time to heal. Little is known as to how rapidly the scars and debris fans heal. Hack and Goodlett (1960) note that avalanche chutes were fresh appearing six years after formation. Weathering had started breaking up exposed bedrock ledges. They speculate that falling rock and further mass movements eventually obliterate the original scar. At rare intervals the material is

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4/ Unpublished data, Oregon State University, School of Forestry, Corvallis, Oregon.

flushed out and the chute is deepened by heavy rainfall and avalanching debris. Fujiwara (1970) reports that scar recovery takes ten to fifteen years. These scars are large, encompassing up to 2500 m^2. Sigafoos and Hendricks (1969) studied several kinds of landform deposits around Mt. Rainier, Washington, to date the invasion of tree species. On a large debris flow deposit trees started growing from one to twelve years following the event. Trees invaded river floodplain deposits the following summer to one year after the winter floods occurred. Invasion of the smaller deposits and scars of debris avalanches in the Oregon Coast Range by vegetation would be expected to be as rapid. Morrison (1975) found the invasion of failure scars by vegetation to be highly variable. Revegetation was patchy and confined to the moist areas where some soil remained on all young landslides observed. More xeric portions of scars and bare bedrock were unvegetated after five years. Morrison found revegetation of scars ten years old also quite variable. Some scars were as much as 60 percent vegetated, while others had only 13 percent vegetative cover. Forty-five and ninety year old landslides were completely revegetated, but trees were stunted. Stunting was apparently the result of poor site conditions and insufficient soil over bedrock.

The large amount of information in the studies cited in this review has added greatly to our understanding of mass soil movements. Other studies now being completed and others still underway will help even more. But as yet we are unable to predict the occurrence of debris avalanching beyond giving some probability that failures will occur. Additional studies in soil mechanics and root decay dynamics may one day give a satisfactory predictive model.

THE STUDY AREA

The Mapleton District of the Siuslaw National Forest encompasses the western side of the Oregon Coast Range from approximately Heceta Head in the north to the Umpqua River in the south (Figure 1). The

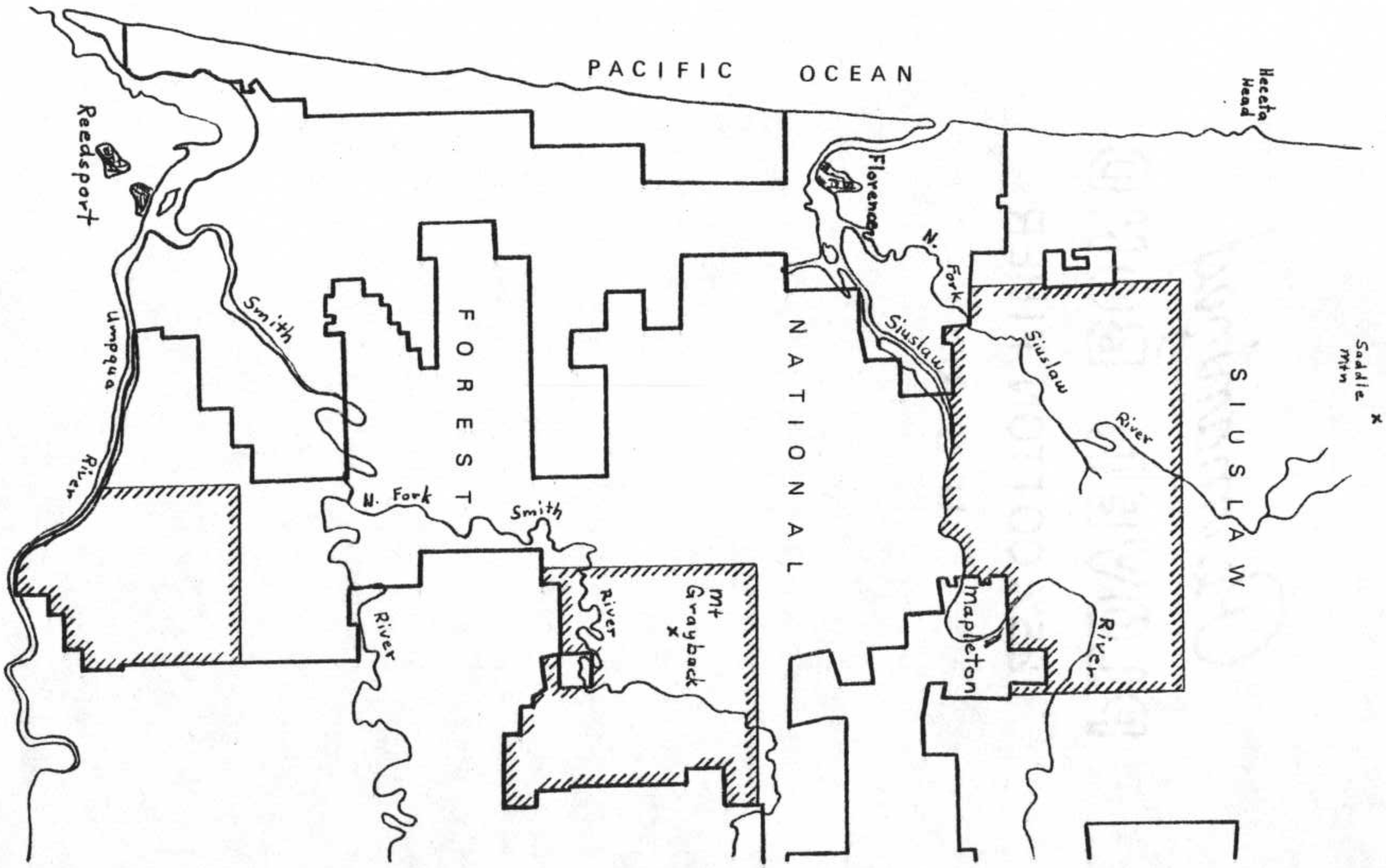

Figure 1. Mapleton District, Siuslaw National Forest

Study areas indicated by ▨

Siuslaw River conveniently divides the district into north and south portions. The area in the extreme south between the Smith and Umpqua Rivers is referred to as the Smith-Umpqua block.

Climate and Vegetation

The climate of the area is controlled by the marine air masses that move in from the Pacific Ocean in response to the prevailing westerly winds. During the winter, winds from the south and southwest force moist air masses up over the Coast Range where they release much of their moisture. Most of the annual precipitation falls as rain during the winter months (October - March). Periods of snow and heavy freezing are rare. The annual rainfall varies from 60 inches along the coast to 120 inches in the coastal mountains. Summers are cool and dry with winds shifting to the north and northwest. Moist marine air masses forced inland may often cause a narrow coastal fog belt during the warmer months.

Most of the forest on the district is dominated by Douglas-fir, *Pseudotsuga menziesii* (Mirb) Franco. Western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and western red cedar, *Thuja plicata* Donn., are present in most stands, and common in others, particularly along stream channels. Red alder *Alnus rubra* Bong., is another very common tree species, most generally occupying headwalls and lower slopes, but also scattered about the hillsides with the Douglas-fir. Big leaf maple, *Acer macrophyllum* Pursh., is locally common. Understory vegetation is predominantly sword fern, *Polystichum munitum* (Kaulf) Presl., vine maple, *Acer circinatum* Pursh., and evergreen huckleberry, *Vaccinium ovatum* Pursh., on the slopes; rhododendron, *Rhododendron marcophyllum* G. Don., salal, *Gaultheria shallon* Pursh., and vine maple on the ridges. Salmonberry, *Rubus spectabilis* Pursh., and stink currant, *Ribes bracteosum* Dougl. are confined to the channel bottoms and lower slopes, and may occur in some headwalls. Other moist and wet site species are common locally.

Geology and Topography

The Oregon Coast Range is composed mainly of older Cenozoic marine and estuarine sedimentary rocks with areas of intrusive igneous rocks. The rocks (sediments and volcanic flows) were laid down during the early Cenozoic era (65 million years ago) when the Coast Range and Willamette Valley were covered by a shallow sea. In the middle Eocene (40-50 million years ago), uplift of the Klamath mountains to the south brought an influx of sand into the basin. These spread out in large density currents giving rise to graded beds with coarse material at the bottom grading into fine sediments on top. Later uplift of this material formed the Coast Range (Baldwin, 1976).

During the Pleistocene Ice Age (2-3 million to 11,000 years ago), sea level dropped several hundred feet, allowing rivers to cut deeply into the Coast Range, laying bare the igneous sills and dikes that now cover nearly every peak in the range (Baldwin, 1976).

The central Coast Range, until recently, was thought to be mainly underlain by the Tyee sandstone formation. Recent mapping has traced the Tyee formation only as far north as the Smith River in the south end of the Mapleton district. Baldwin (1976) believes that the sandstone beds to the north belong to the Flournoy formation. The Tyee lies unconformably on the Flournoy and the distinction between the two is based on regional dips and apparent greater drainage densities in the Flournoy formation than the Tyee.

Both the Tyee and Flournoy formations were composed of rhythmically bedded micaceous sandstone beds grading upward into siltstone. Distinction between the two is difficult without a detailed investigation and the contact is only approximately mapped between the Smith and Siuslaw rivers.

Downcutting of coastal streams during the Pleistocene has created deeply incised stream channels with steep hillslopes. The major rivers in this area of the Coast Range have cut to below present sea level along the coast. Many of the streams are probably still downcutting in the upper portions of the drainages in order to re-achieve the dynamic equilibrium they had prior to glaciation. This preserves the very steep slopes and contributes to instability. Elevations over 2000 feet, within 15 miles of the coast line, are present on the Mapleton district. Saddle Mountain in the northwest corner is the highest point, at 2297 feet. Mt. Grayback, in the central portion of the district is 2255 feet in elevation.

Soils

Most of the soils in the Coast Range are shallow, poorly developed gravelly soils derived from residuum and colluvium. Evidence of past movement of the soil mantle is displayed by an occasional buried organic horizon, but generally the horizons are not well differentiated in a soil profile. The Siuslaw National Forest has completed reconnaissance soils mapping based on soil, landform geology, and vegetation characteristics (Badura, Legard and Meyer, 1974). Mapping units in the Soil Resource Inventory (SRI) are general and used mainly for resource planning. SRI mapping units contain a dominant landtype which accounts for at least 70 percent of the landtype delineation. In this report, mapping units are referred to as SRI landtypes. The SRI landtypes encountered in this study are described in Table II. The soils are all derived from interbedded sandstone and siltstone bedrock except for landtypes 52, 52F, 61 and 62, which are over volcanic rocks. Landtypes 44 and 44F are differentiated on the basis of elevation which manifests itself through differences in site class and the dominant tree species present. Landtypes 52 and 52F are also distinguished in this way. For complete descriptions of the landtypes, see Badura, Legard and Meyer (1974).

Table II. Soils descriptions from Soils Resource Inventory (SRI).

SRI Landtype	Texture* Surface	Texture* Subsoil	Bedrock Depth (ft.)	Slope %	Landform
26	1	sil	<2 soft to mod. hard siltstone w/ minor amts of sandstone	0-30	smooth gently sloping benches and ridgetops
41	sl,1	1,cl	<3 mod. hard to hard massive sandstone w/ thin siltstone interbeds	50+	smooth to mod. dissected sideslopes and ridges
42	1,sil	1,cl,sicl	2-6 " " "	30-50	smooth slopes and ridges
44,44F	gsl,1	1,gl	<3 " " "	50+	mod. to highly dissected slopes w/ generally rounded interfluves
47	gsl,1	gl	<3 " " "	50+	highly to extremely dissected slopes w/ angular shapes
43	1	cl,sicl	4-10 soft to med. hard massive sandstone w/ thin siltstone interbeds	0-30	smooth hummocky sideslopes, toe-slopes, terraces, gently sloping ridgetops
52,52F	1,sil,cl	cl,sicl,c	2-6 soft to mod. hard volcanic sediments, pillow lavas, breccias	30-50	smooth to mod. dissected sideslopes
61	1	1,sil	<3 hard basalt, andesite syenite, diorite	50+	smooth to mod. dissected slopes and ridges
62	1,gl	gl,sl,sil	1-4 " " "	30-50	smooth slopes and ridges

Table II. (cont.)

SRI	Complexes
421	60 percent unit 42 and 40 percent unit 41
411	70 percent unit 41 and 30 percent unit 61
414	50 percent unit 41 and 50 percent unit 44
417	50 percent unit 41 and 50 percent unit 47
443	60 percent unit 42 and 40 percent unit 43
462	65 percent unit 42 and 35 percent unit 62

*l = loam; sil = silt loam; sl = sandy loam; cl = clay loam; sicl = silty clay loam; gl = gravelly loam; gsl = gravelly sandy loam; c = clay.

METHODS

Site Selection

Three broad areas within the Mapleton Ranger District were chosen for this study (Figure 1). These areas were selected because they are in less intensively managed sections of the district and provide a wide range of site conditions. The three areas were subdivided by construction of a numbered grid on the district map. Randomly selected subdivisions were viewed on aerial photographs. For each subdivision a small drainage (100 acres or less) that originated within the subdivision boundaries was chosen for study. To be acceptable for field reconnaissance, the drainage must have appeared undisturbed by management activities and be reasonably accessible. Each drainage meeting these criteria was then investigated in the field. Many of the drainages selected had a mainline or spur logging road along the ridge. This meant that each must be field inspected for disturbance of the headwall due to road sidecast material, right-of-way trees felled into the headwall, or road fill failures. Road drainage ditches emptying into the headwall were also inspected to see if excess water was being concentrated in the headwall by this means. Any unnatural disturbance of the headwall was noted, and if the disturbance was considered great enough to adversely affect the stability of the drainage as a whole, the drainage was not inventoried.

Clearcuts were also selected for the inventory of mass soil movements. Using the Mapleton District reforestation records, clearcuts that were harvested in the last six years were chosen from the same three broad areas within the district as were the undisturbed drainages.

Mass Movement Inventory

All drainages selected for the mass movement inventory were inspected by walking along one side of the drainage about mid-slope, and visually inspecting the opposite side for mass failures. When visibility was poor due to dense underbrush or fog, both sides were traversed. Each headwall was carefully inspected. If a failure was discovered to have entered the channel, unless conditions became too hazardous, the entire channel length was walked to the confluence of another significant tributary. If no failures entered the channel, only spot checks of the channel were made.

Each inventoried failure was designated as one of the following failure types:

Debris avalanche: rapid, shallow-soil mass movement that involves the soil mantle and possibly some rock fragments. The moving mass disintegrates substantially while travelling along a narrow track.

Debris torrent: rapid movement of water-charged debris down a stream channel. Debris torrents may often be triggered by debris avalanches entering swollen streams during storm events.

Debris slide: similar to the debris avalanche except the mass does not disintegrate or travel far, but generally remains intact just below the failure scar.

Bank slough: small mass movements involving soil material directly adjacent to a stream channel.

When a failure was discovered, the failure type and geomorphic setting was recorded. Measurements were taken for failure volume determination and hillslope and aspect were recorded. The sample debris avalanche inventory field form (Appendix A) shows other site factors noted. The debris track was measured for travel distance and if a discrete debris fan and/or jam was present, this too was measured for volume calculations.

Travel distance was related to Stream Class in order to better assess the impacts of the failure on stream channels. The Stream Classes are defined in the USFS Manual, March 1974, R-6 Supplement No. 2 as follows:

Class I: Perennial or intermittent streams or segments thereof that have one or more of the following characteristics:

— Direct source of water for domestic use (cities, recreation sites, etc.).

— Used by large numbers of fish for spawning, rearing or migration.

— Flowing enough water to have a major influence on water quality of a Class I stream.

Class II: Perennial or intermittent streams or segments thereof that have one or both of the following characteristics:

— Used by moderate, though significant numbers of fish for spawning, rearing or migration.

— Flow enough water to have only a moderate and not clearly identifiable influence on downstream quality of a Class I stream, or have a major influence on a Class II stream.

Class III: All other perennial streams or segments thereof not meeting higher class criteria.

Class IV: All other intermittent streams or segments thereof not meeting higher class criteria.

The clearcut drainages were approached the same way that the undisturbed drainages were. Failures related to roads and landings were not tallied in the inventory. Aerial photographs were used to aid in locating failures that occurred before cutting took place. If such failures were identified on aerial photos, they were deleted from the inventory. Failures existing before harvest were difficult to identify in the field.

Measurement of the size of the failures required considerable judgement because the boundary where the failure ended and the avalanche or torrent began was not always distinct. Average length, width, and depth were measured with a tape measure in all cases. Hillslope was measured at the failure site but any changes in slope above the failure were also noted. Slope of the failure plane was measured when bedrock was exposed in the failure surface. The type of bedrock was recorded and notes made as to its appearance. Soils were described by texture and depth and any unusual features. Soil Resource Inventory (SRI) landtypes were taken from the Siuslaw National Forest SRI maps (Badura, Legard, and Meyer, 1974).

Failure age determination also required judgement. Several approaches were taken on each slide to date it as accurately as possible:

1. General appearance of the failure scar. Was it being reinvaded by vegetation? If perennial vegetation was present, it was used as an index of age.
2. Tree ring analysis of surrounding trees to determine if release had occurred in trees adjacent to the failure. If surrounding trees tilted, borings were examined for the occurrence of reaction wood.
3. Sprouts and upturned branches of vegetation damaged by the failure and plants growing on the debris fans were also examined and used as possible age indices.

On some of the failures, the evidence of age was conflicting and some uncertainties exist. Aerial photos were used to help date older movements, but were seldomly helpful because of difficulty in identifying movements on aerial photos.

Debris Measurement

Determining the volume of material in debris fans required the same type of judgement as in measuring the failures. Average length, width, and depth was measured for inorganic debris. Large end diameter, small end diameter, and length were measured on individual pieces of organic debris. Organic debris volumes represent only relative amounts, as only large material on the surface and in the toe of the jam was measured. Logs engulfed in, but protruding from the inorganic debris were measured only to where they disappeared into the fan material. Organic volumes were calculated using the following formula:

$$V = \frac{\frac{\pi(d_1/2)^2}{144} + \frac{\pi(d_2/2)^2}{144}}{2} (L) \qquad (4)$$

where d_1 and d_2 are the small and large end diameters and L is the length of the piece.

Acreages of the drainages included in the inventory were digitized from two-inch-per-mile maps using the HP9830 computer. Three measurements of area were taken and averaged. Acreages of clearcut units came from the Mapleton District reforestation records.

Channel Cross Sections

Four drainages were selected to monitor changes in failure scars, debris tracks, and debris fans over one winter's rainy season. Two of these had experienced recent mass movements, and two were relatively undisturbed. Transects at selected locations were established in the fall of 1976. These transects were placed perpendicular to the direction of the movement and of sufficient width to include the entire disturbed cross section, whether it be on the hillside or in the channel. A cloth tape was stretched between two leveled stakes, and vertical measurements were taken using a leveling rod. These cross sections were to be measured again the following fall, but due to an extremely dry winter of 1976-1977, only the two drainages with recent failures were remeasured.

Soil Sampling and Analysis

Three failures were selected for intensive soil sampling. The purpose of this sampling was three-fold: 1) to determine if a significant texture change existed in the soil column and/or laterally away from the failure site; 2) describe the sizes of material involved in this mass transport process; 3) determine bedrock depths. Three sampling lines running laterally away from the failure were used; one on each flank of the failure and one above the failure scarp. Along each line, three locations were selected for augering. The first point was at the failure edge, the other two being at approximately 20 foot intervals. A 1¼ inch auger was used to drill the holes and retrieve soil samples. Samples were collected from the two-foot depth and at the five-foot depth or bedrock interface, if bedrock was less than five feet below the ground surface. Several holes were drilled at each location to obtain adequate samples and to try to avoid mistaking a large rock for bedrock. Samples from within several other failure scars were taken to add to the data on particle size distributions of the soils. The soil samples were dry sieved and the fines (<2mm) analyzed with a standard hydrometer technique. The soils were dispersed with sodium pyrophosphate after organic matter digestion using hydrogen peroxide, and agitated overnight.

RESULTS

A total of 104 mass soil failures were located in uncut and logged watersheds. These failures range in size from two cubic yards to 196 cubic yards. The data have been separated into two groups; those ten cubic yards or greater in volume and all failures, including those less than ten cubic yards. This is done so that the data can be compared with other studies limited to failures greater than ten cubic yards and to assess the relative importance of smaller failures.

A tabulation of the data collected on each failure and definitions of terms can be found in Appendix B and Appendix C.

Natural Failures

This inventory of natural mass movements includes a total of 21 small uncut drainages. These cover 1076 acres on which 65 mass movements were found. Thirty-eight (58 percent) of the 65 natural failures are ten cubic yards or greater, and average 41 yd^3 in volume. Including those less than ten cubic yards reduces the average volume to 26 yd^3. A total of 1715 yd^3 of soil material moved from the slopes in these failures (Table III). Approximately 3569 yd^3 of material is incorporated in debris jams in the stream channels below these failures. This added volume is due to material being scoured from the bed and banks of ephemeral and first order streams.

Table III. Volume and travel distance for failures from undisturbed watersheds.

Failure Type	No.	Total Volume (yd^3)	Average Volume (yd^3)	Total Travel Distance (ft.)	Average Travel Distance (ft.)
All sizes					
Debris avalanche	39	1174	30	6889	191 (36 failures)
Debris torrent	7	314	45	3445	492
Debris slide	11	150	14	198	18
Bank slough	8	77	10	345	49 (7 failures)
	65	1715	26	10877	178 (61 failures)
$\geq 10yd^3$					
Debris avalanche	25	1091	44	3917	170 (23 failures)
Debris torrent	7	314	45	3445	492
Debris slide	4	112	28	75	19
Bank slough	2	41	21	17	17 (1 failure)
	38	1558	41	7454	213 (35 failures)

Debris avalanche and debris torrent type failures have nearly the same average volume for failures greater than ten cubic yards. As no debris torrents are smaller than ten cubic yards, the average volume of all debris torrents is higher than the average volume of all debris avalanches. Debris avalanches are most common, comprising 60 percent of the inventoried events, and 68 percent of the total volume. Debris torrents are much less common, but contribute the next highest total volume (18 percent of the total). Twenty-nine percent of the failures are of the debris slide and bank slough types, but together they represent only 13 percent of the total volume. The discussion to follow will concentrate on debris torrents and avalanches.

Travel Distance and Stream Impact

Total and average travel distance for natural failures is also shown in Table III. Failures greater than ten cubic yards account for just over two-thirds of the total travel distance of 10,877 ft. (2.06 mi.). The average debris torrent travels over 2.5 times as far as the average debris avalanche. Debris slides, by definition, do not travel far, and bank sloughing typically does not travel far under its own energy. Bank sloughing may be incorporated in the stream flow at the time of failure which may cause a small debris torrent, or be slowly washed away by the stream.

Total travel distances listed in Table III are lengths measured along the debris track from the origin of the failure to the toe of the debris jam. Channel impact, the actual scour and deposition of debris in a stream channel, is not accurately described by total travel distance. Not all failures end in a distinct debris jam, while some failures form several small ones. A newly formed debris jam in a channel often causes some scour and deposition in the vicinity of the jam. Channel impact by mechanical scour and deposition is tabulated in Table IV. The distances given are channel lengths only and do not include distances traveled on the hillslopes. Where the same length of stream channel is impacted by two or more failures, the length is added only

Table IV. Channel impact from mechanical scour and deposition by natural failures.

Failure Type	Scour: Class IV	Scour: Class III	Deposition: Class IV	Deposition: Class III
All sizes				
Debris avalanche	4739		1123	50
Debris torrent	3027	50	509	320
Debris slide			45	
Bank slough	128		98	
	7894	50	1775	370
				= 10089
$\geq 10yd^3$				
Debris avalanche	2637		761	50
Debris torrent	3027	50	509	320
Debris slide				
Bank slough			10	
	5664	50	1280	370
				= 7364

Channel length (ft) affected by: Scour / Deposition once. The total channel length directly impacted by mass movements in this study is 10,089 feet, of which 7364 feet (73 percent) is from failures ten cubic yards or more in volume. Ninety-six percent of the impact (9669 feet) is confined to Class IV streams. Scour and deposition affect 420 feet of Class III streams including 370 feet of deposition. Debris avalanching from Class IV channels that enter lower gradient Class III channels at a sharp angle, usually do not have enough energy to turn the corner, so most of the Class III channel impact is from debris jams at the junction of small tributaries.

Six out of ten natural failures ten cubic yards or more in volume, result in distinct debris fans. Nine of 24 inventoried fans are accompanied by significant debris jams containing 300 ft^3 of woody debris or more. Table V shows the amount of organic and inorganic debris in these jams by failure type. The six debris jams resulting from debris torrents are by far the largest and involve more inorganic material and nearly as much organic debris as the other 18 jams together. It is these jams from torrents that account for most of the 1775 feet of Class IV stream channel deposition. All jams from debris torrents are located in channel reaches at 20 percent or less gradient. Debris accumulations for other types of failures may be on steep slopes (60-70 percent) if they did not enter the channel, but the steepest gradient of an in-channel debris jam is 40 percent.

Failure Age

All failures in the natural mass movement inventory were dated at less than 15 years old. Some grouping of the failure ages occurs. Nearly one-third of the failures (32 percent) are recent and probably occurred during the November - December, 1975 storm. Twenty percent may be the result of a January 1974 storm that deposited 7.84 inches of rain in four days in the Florence area. Another one-third of the failures are dated between 1970 and 1973. These may be related to heavy but not unusual rains in January 1970, 1971 and 1972. The older

Table V. Organic and inorganic debris volumes in debris jams of natural failures.

Failure Type	No. of Jams	Inorganic debris volume (yd^3) Total	Inorganic debris volume (yd^3) Average	Organic debris volume (ft^3) Total	Organic debris volume (ft^3) Average
All sizes					
Debris avalanche	19	1116	59	6463	340
Debris torrent	6	2292	382	6531	1089
Debris slide	7	104	15	20	3
Bank slough	6	57	10	216	36
	38	3569	94	13230	348
$\geq 10yd^3$					
Debris avalanche	15	1032	69	6443	430
Debris torrent	6	2292	382	6531	1089
Debris slide	3	87	29	0	0
Bank slough	1	5	5	0	0
	24	3416	142	12974	541

failures may be remnants of the Christmas storm of 1964 or heavy rains in November, 1966 (U.S. Weather Bureau, 1961-1975).

Failures greater than ten years old were often difficult to identify, depending on their size and the degree of impact they had on the hillslope and stream channel. Some of the larger failures that were deep or exposed considerable bedrock, could easily be identified and generally lacked a continuous vegetative cover. Other old failures were well covered with sword fern or forbs and salmonberry. Only where there is still a distinct scarp surface can these be identified. In a few cases an old, well-vegetated debris fan was located, but no failure could be found in the drainage above. Only debris fans with traceable failures were inventoried.

SRI Landtypes

Thirteen different SRI landtypes were encountered during the natural failure inventory. Thirty-four percent of the failures are on the moderately steep to steep, smooth to moderately dissected slopes of landtypes 421 and 42. Thirty-two percent of the failures are from the very steep, highly dissected slopes of landtype 47. These three landtypes combined, produced two-thirds of the failures on 57 percent of the acreage inventoried. SRI landtype 421 comprises only 17 percent of the total acreage, but produced nearly one-third of the failures (32 percent). Landtype 421 produced 42 percent of the failures ten cubic yards or greater in volume. Another 29 percent of the larger failures are on SRI landtype 47. Eight percent of all the failures originated on the very steep, highly dissected slopes of landtype 417, although the acreage inventoried in landtype 417 is only 2.5 percent of the total acreage. Table VI lists the landtypes encountered and the acreage and number of failures in each.

Erosion Rates

Using volume, age, and landtype information, erosion rates, in

Table VI. SRI landtypes from undisturbed watersheds.

Landtype	47	421	42	41	44	414	417
Acres	416	185	11	108	59	45	27
No. of failures							
$\geq 10yd^3$	11	16	1	3	0	2	4
$<10yd^3$	10	5	0	8	1	0	1

Landtype	43	443	26	52	44F	52F
Acres	22	76	93	11	15	8
No. of failures						
$\geq 10yd^3$	0	0	0	0	1	0
$<10yd^3$	0	1	0	0	1	0

yd^3/ac/yr, from rapid, shallow-soil mass movements can be estimated. Table VII shows calculated erosion rates for various landtypes and groups of SRI landtypes, as well as relative volume and frequency information. Some SRI landtypes are grouped together for comparison with in-unit erosion rates and other studies. Those that are grouped have similar characteristics. SRI type 417 has the highest frequency and erosion rate. However, the area inventoried in type 417 is small and the rate needs verification by further inventory of type 417. SRI types 421 and 42 have the next highest natural failure frequency and erosion rate. The erosion rate is 4.3 times that of type 47 and 3.75 times that of the group of all other types that produced failures. The average volume of failures in types 421 and 42 is also larger than the other types. The two largest mass movements inventoried are on type 421. They are both recent (1975) failures and consequently combine to give an inflated erosion rate of 1.38 yd^3/ac/yr for the 0-2 year age class. Failure frequencies and erosion rates diminish as the time period is increased. This is due to the difficulty of identifying failures as they age. Also, it should be expected that the actual rate of failures varies greatly from year to year. The erosion rate for all types incorporates the acreages in landtypes that have not produced detectable failures, as well as those that are active.

Inclusion of the smaller failures (less than ten cubic yards) increases the overall erosion rate by only nine percent. SRI landtype 47 has the highest proportion of small failures, and the addition of failures under ten cubic yards results in a 14 percent increase in erosion rate from 0.07 yd^3/ac/yr to 0.08 yd^3/ac/yr.

Erosion continues after the passage of the initial failure, because the soil mantle is bared of vegetation and the subsoil is exposed to surface erosion. The land area involved in the initial failure scars from the inventoried mass movements is approximately 0.6 acres. An additional 0.51 acres is estimated as disturbed hillslope below failures before they reached a channel and for those not affecting a channel. For the seven debris torrents, channel scour typically might affect a 20-foot wide strip along the channel. If these additional

Table VII. Failure frequency and erosion rate in undisturbed watersheds.

SRI Landtypes	Acres	No. of Failures by age (yrs.)			Ave. Volume (yd^3) by age (yrs.)			Frequency (slide/acres)			Erosion Rate $yd^3/ac/yr$		
		0-2	0-9	0-15	0-2	0-9	0-15	0-2	0-9	0-15	0-2	0-9	0-15
<u>All failures</u>													
47	416	6	20	21	19	20	20	1/69	1/21	1/20	0.14	0.11	0.07
417	27	0	5	5		32	32		1/5	1/5		0.66	0.40
421,42	196	9	19	22	60	38	41	1/22	1/10	1/9	1.38	0.41	0.30
41,44,414	212	5	14	14	11	16	16	1/42	1/15	1/15	0.13	0.11	0.07
41,417,44F 44,414,443	330	6	21	22	11	19	18	1/55	1/16	1/15	0.10	0.13	0.08
All types	1076			65			27			1/17			0.11
<u>$\geq 10yd^3$</u>													
47	416	2	10	11	46	33	33	1/208	1/42	1/38	0.11	0.09	0.06
417	27	0	4	4		39	39		1/7	1/7		0.64	0.39
421,42	196	7	14	17	76	49	51	1/28	1/14	1/12	1.35	0.39	0.29
41,44,414	212	2	5	5	20	35	35	1/206	1/42	1/42	0.09	0.09	0.06
41,417,44F 44,414,443	330	3	10	10	17	34	34	1/110	1/33	1/33	0.04	0.11	0.07
All types	1076			38			41			1/28			0.10

land areas are included, approximately 2.9 acres or 0.27 percent of the sampled forest area are at least temporarily rendered unproductive and vulnerable to erosion.

Slope

All natural failures occurred on slopes between 53 and 110 percent (28 and 48 degrees), with three-fourths of them between 60 and 99 percent. Figure 2 shows the distribution of natural failures by slope category. The average volume of failures in each slope class is indicated on the graph. The volume of failures on slopes of 80 to 99 percent is larger, on the average, than failures on steeper and gentler slopes. The two largest failures encountered are in these groups, and if they are omitted from the average volume calculation, the average volume of failures in the 80 to 89 percent and 90 to 99 percent slope classes reduce to 21 yd^3 and 28 yd^3, respectively. This eliminates any relationship between slope and failure volume, except that failures on very steep slopes (100 percent or more) are smaller on the average than the others. The frequency of movements increases with slope to 60 percent slopes, and then remains high. The frequency of failures on 100 percent slopes is somewhat less. The distribution of natural failures ten cubic yards or more in volume is bi-modal, with the largest numbers occurring in the 60 to 69 percent and 90 to 99 percent slope classes. This may be the result of the small sample size.

No failures classed as debris torrents originated on slopes of 100 percent or more, but four of the seven were initiated on slopes of 60 to 69 percent. Seventy-six percent of the debris avalanches occurred on slopes between 60 and 90 percent. Half of the debris avalanches from slopes over 100 percent are less than ten cubic yards in volume.

Minor changes in slope at or immediately above a failure were difficult to detect with the inventory procedure. Several of the larger, incipient channel failures have unbroken terrain above them. The hill-slope has only a slight depression with no discernable channel. But immediately below the failure is a well incised gully, indicating that

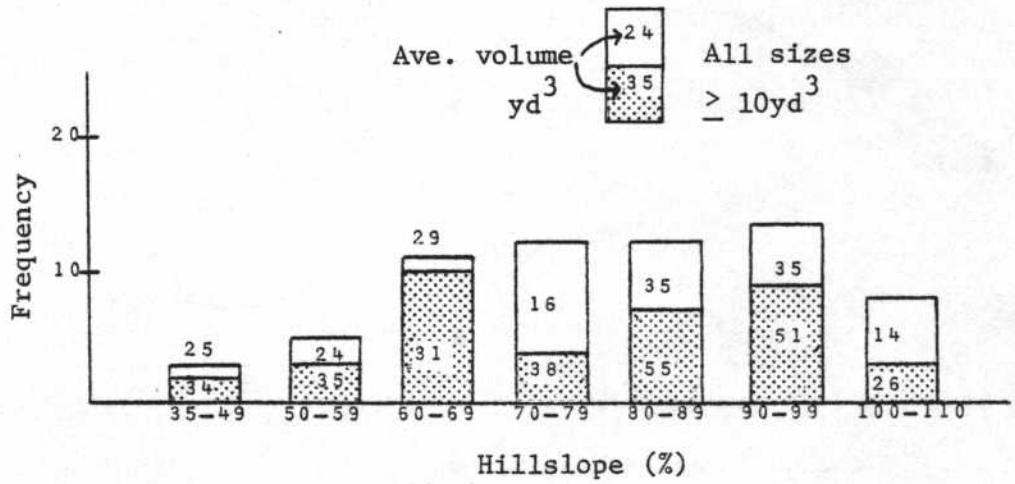

Figure 2. Slope distribution of natural failures.

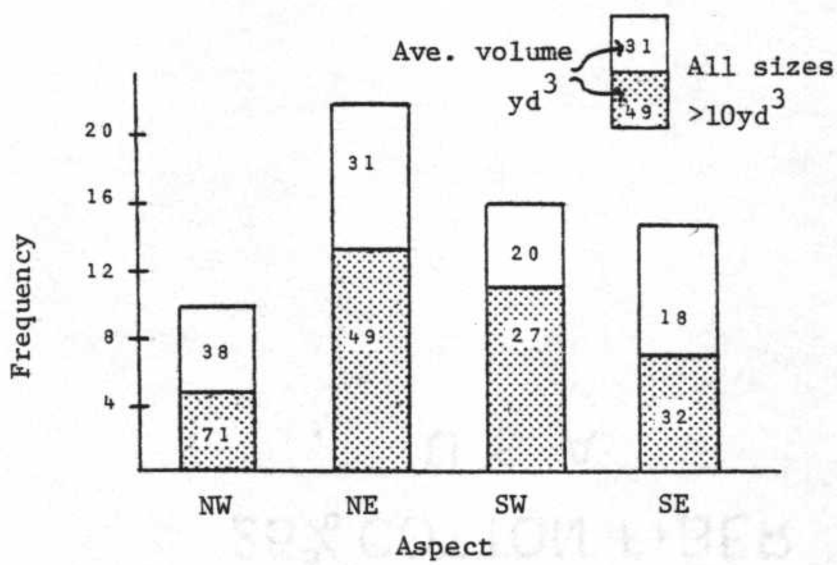

Figure 3. Aspect distribution of natural failures.

an abrupt change in the character of the slope occurred at the point of failure. These failures are likely features of the headward erosion of gullies.

Bedrock

The bedrock surface, if exposed in the failure scar, is generally inclined steeper than the adjacent hillslope. However, the bedrock is also inclined less than the hillslope in about one-third of the failure scars. Eighty-two percent of the failures exposed bedrock in at least part of the scar. All exposed bedrock is sandstone or interbedded sandstone and siltstone of the Tyee and/or Flournoy formations. The beds have a general southwest dip north of the Siuslaw River and on the western part of the Smith-Umpqua block. The dip is mostly east in the eastern part of the Smith-Umpqua block. From rough measurements during the inventory, there is considerable local variation. In some cases the bedrock seemed to dip away from the failure, and in others it dipped toward the failure. The bedrock dip is mostly less than 15 degrees. The bedrock surface varies from hard, smooth and bowl-shaped, to soft, fractured and broken.

Aspect

Thirty-four percent of all failures occurred on northeast aspects. Over half of the failures came from both NW and NE aspects (Figure 3). Even when the two largest failures are deleted from these two aspects, the average volume is still higher for failures greater than ten cubic yards; 41 yd^3 and 42 yd^3, respectively, than the southern aspects. Debris avalanches are well distributed among all aspects, but debris torrents are concentrated on NE aspects and absent on SW aspects. This may be due to the small number of debris torrents inventoried, the majority of which are from one active drainage (10-N), with a large proportion of NE aspects.

Geomorphic Location

Ten natural failures (15 percent) originated within the channel bottom and another 17 (26 percent) involved material from hillslope depressions and draws. Five failures originated in the major headwall portion of drainages (IC-H). Most of the failures (46 percent) originated on the lower or toeslope portion of hillslopes. The remaining three failures were found on the mid- to upper portion (Figure 4).

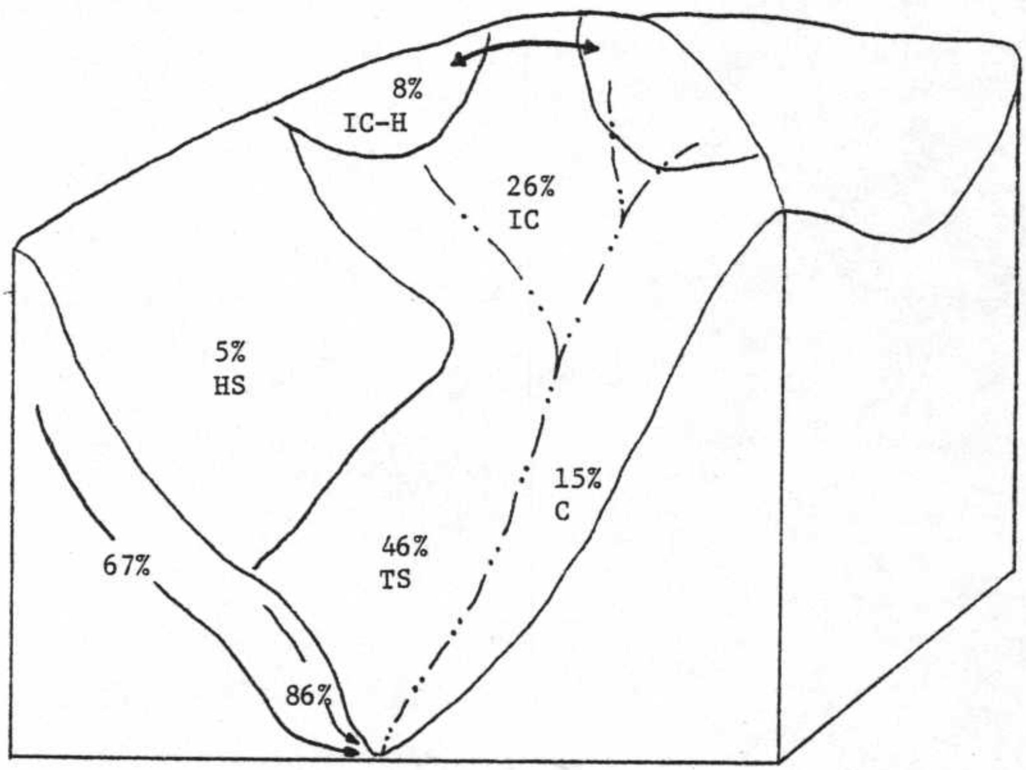

Figure 4. The proportion of natural failures in each geomorphic location. The percentage of hillslope and toeslope failures entering a channel is shown by the arrows.

All debris torrents originated from headwall, channel, or incipient channel positions. Half of all the failure sites were wet or had water running across exposed bedrock or seeping from subsoil in the scar.

This was the case even in late summer during which the inventory was conducted. Water was found in many of the failures even during the second summer, after the extremely dry winter of 1976-1977. In many cases water was observed seeping or flowing from cracks or bedding planes of the bedrock at the failure site.

Nearly all (88 percent) of the natural failures deposited some debris into a stream course. Only four of the 29 toeslope failures did not enter a channel. Two of the three hillslope failures traveled all the way to a channel (Figure 4).

Soils

All soils at the failure locations are less than ten feet deep to bedrock. Most failures (82 percent) originated in soils three feet or less in depth. Most of the deeper soils are on northerly aspects. In some cases, the depth to bedrock decreases away from the failure site, but in others it increases or remains the same.

The hydrometer analysis revealed that the sampled soils are all gravelly sandy loams or loamy sands. All but two samples had less than ten percent clay (<0.002 mm). A representative sample is 13.6 percent gravel (25.4-4.75 mm); 62.4 percent sand (4.75-0.05 mm); 20.0 percent silt (0.05-0.002 mm); and 4.0 percent clay, by weight (Figure 5). Reproducibility of the hydrometer analysis was poor, due to the small amount of fine particles. Coarse materials greater than 2.0 mm typically account for less than 50 percent of the sample by weight. The median grain size varies from 0.2 mm to 3.5 mm and many of the soils are well graded. As much as 25 to 30 percent of the soil material is less than 0.1 mm in diameter.

Samples from the two-foot depth and at five feet or the bedrock interface were paired to determine if the texture changes with depth. Five of the fourteen paired samples show a slight increase in clay (<5.0 percent) with depth. Only three of these are likely to be measurable differences; three to five percent change. Most of the other

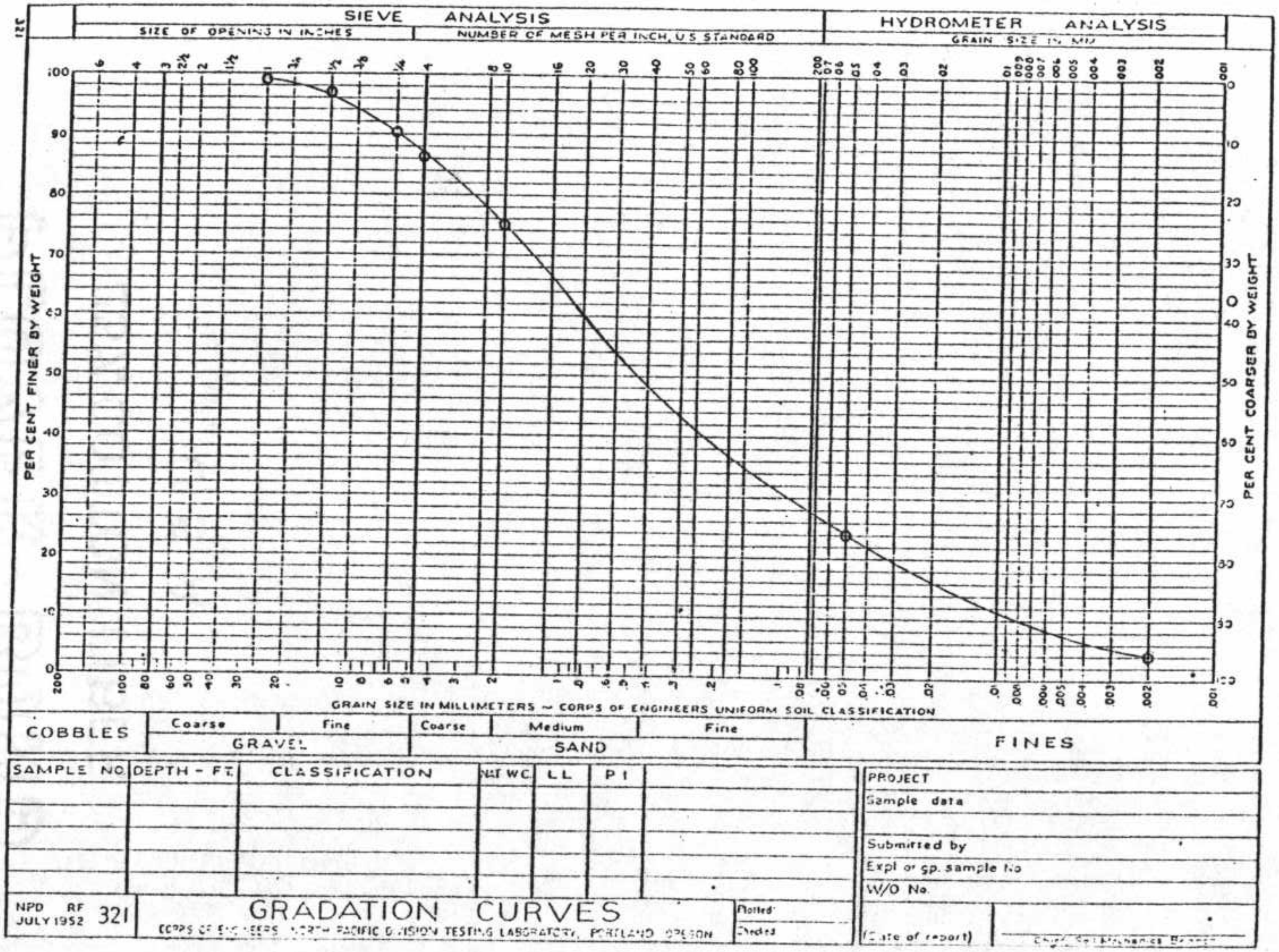

Figure 5. Composite particle size curve (24 samples).

samples show a small decrease in clay content with depth, accompanied by a decrease in silt and an increase in sand of a few percent. Therefore no significant increase in clay content at the failure plane was detected in this study. No textural trends were detected moving laterally away from the failure scars.

Channel Cross Sections

Very little change in the appearance of the failure scars and debris fans was noticed during the period of the study. The winter of 1976-1977 was extremely dry in the Pacific Northwest and lacked major storms. Coastal streams did not experience large freshets or runoff events, and most of the runoff filtered through the gravels of debris fans, doing little erosion. Channel cross sections remeasured in the fall of 1977 show no significant downcutting of debris fans. A few cross sections show a minor amount of deposition along one side and scour around the toe of a large debris jam (Figure 6). Some minor subsequent sloughing of the undermined soil mantle along debris torrent tracks was observed. Failure scars became covered with a greasy film of decomposing leaves from the previous fall. This litter remained in place all winter because no storms caused surface runoff large enough to remove it.

Where severe scour and deposition from mass failures completely removed vegetation and soil to bedrock, or deeply buried vegetation, no re-invasion of plants was detected over the one year period of the study. However, where the mass movement merely skimmed off the vegetation and a few inches of soil, root systems, particularly of salmonberry and stink currant, rapidly sprouted the following summer (15 months after failure). Where this occurred, small brush thickets, four feet high, were formed by the second fall season after failure.

Vegetation

Headwall vegetation of the natural drainages that were inventoried

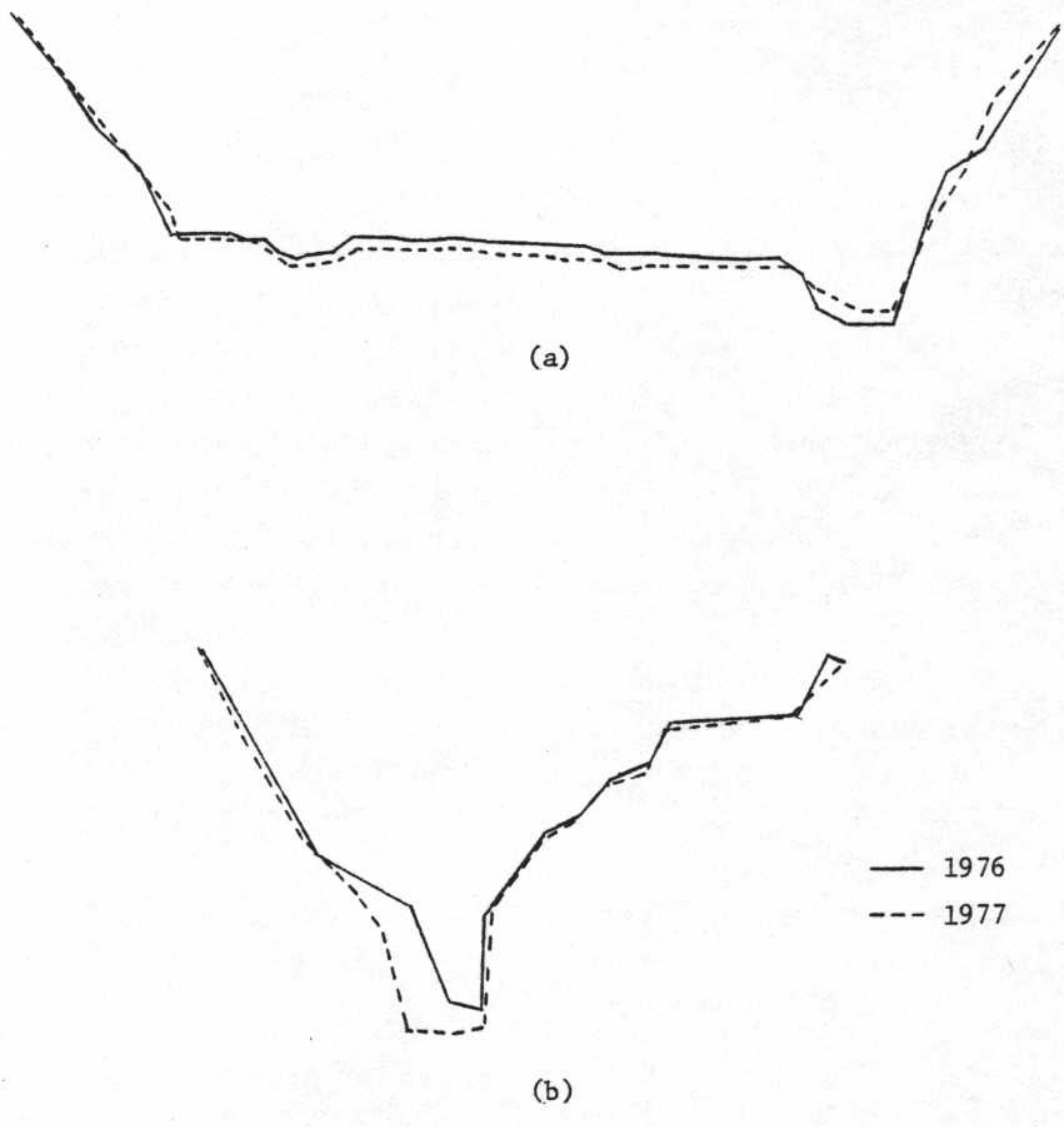

Figure 6. Cross sections of a debris jam in the undisturbed forest. Some deposition occurred to one side of fan (a) and scour around the toe of the jam (b).

was of two general types. In the northern part of the district, hardwoods typically dominated the headwalls. Alder was most common, with a few conifers, and a thick understory of mainly salmonberry with sword fern and vine maple. Salmonberry and stink currant dominate along the drainage bottom and 50 to 60 feet up the slopes on each side. Rarely are there coniferous trees next to the channel. In the southern part of the district, dominated by SRI landtype 47, headwalls commonly had a vigorous stand of young Douglas-fir and western red cedar. The understory was mainly sword fern. Big leaf maple and alder were often scattered among the conifers as was vine maple in the understory. Sword fern dominated the bottom of the headwall until a well defined channel formed, and then salmonberry and stink currant began to take over in the channel bottom. The lower slopes supported sword fern, vine maple, and huckleberry, and a few coniferous and hardwood trees.

Nearly all of these plant species are common or dominant on wet sites. Locations on a slope where water concentration may be occurring cannot be identified using vegetative indicators because of the rather uniform wet site species present.

Mountain beaver were particularly abundant on sword fern dominated slopes. Their tunneling activities were often so intense that loose debris covered much of the slope. This debris would ravel downslope and collect in the channel or channel depression. Runoff from winter storms is apparently great enough to move some of this debris and some channels showed scour below these slopes. Fresh scour was traced back to the diggings of mountain beaver in several cases. Mountain beaver burrows are common in and around failure scarps and they may be a source of instability, if not a direct cause of some mass movements. Water was observed flowing in a few mountain beaver tunnels, even during the dry summers of this study. It is probable that considerable interception and concentration of soil water occurs in these tunnels during winter storms when soils are at or near saturation.

Some failures appeared to be related to fallen logs and windthrow. Fourteen percent of the natural failures appeared related to windthrown trees, where uprooting forces disturbed the soil mantle enough for the surrounding soil to fail. Eight percent seem to have been triggered by logs sliding down the slope. Another nine percent may have resulted when a tree fell across the slope and the shock dislodged some of the soil mantle. If a cause-effect relationship exists in the above instances, nearly a third of the natural failures may be related to windthrow of trees.

Failures in Clearcuts

Thirteen clearcuts were investigated, covering 722 acres. A total of 39 failures were inventoried with an average volume of 41 yd^3. Clearcut mass movements ten cubic yards or greater in volume average 47 yd^3 and account for 99 percent of the 1605 yd^3 of soil material involved. Debris torrents make up only 26 percent of the failures in clearcuts, but produced 59 percent of the volume (Table VIII). On the average, debris torrents are 4.0 times larger than debris avalanches in clearcuts and travel 8.6 times farther. Debris slides and bank sloughs contribute only nine percent of the total volume and one percent of the travel distance.

Travel Distance and Channel Impact

Clearcut failures traveled a total of 10,885 feet (2.06 mi.). The total channel length directly impacted by mechanical scour and deposition from the 39 failures in clearcuts is 9773 feet (1.85 mi.), 99.8 percent as the result of failures ten cubic yards or more in volume (Table VIII). Not one of the seven debris slides entered a stream channel. Debris torrents caused 86 percent of the total direct impact by scour and deposition. Class IV streams were scoured 7483 feet (1.42 mi.) and had deposits along 1379 feet (0.26 mi.). This amounts to 91 percent of the mechanically impacted channel length.

Debris fans associated with mass movements in clearcuts contain an estimated 6380 yd^3 of inorganic debris, nearly four times that estimated at the initial failure sites. Debris fans resulting from debris

Table VIII: Volume, travel distance and channel length impacted by failures from clearcuts.

Failure Type	No.	Total Volume (yd^3)	Average Volume (yd^3)	Total Travel Distance (ft.)	Average Travel Distance (ft.)
All sizes					
Debris avalanche	21	510	24	1931	102 (19 failures)
Debris torrent	10	950	95	8799	880
Debris slide	7	99	14	125	18
Bank slough	1	46	46	30	30
	39	1605	41	10885	294 (37 failures)
$\geq 10yd^3$					
Debris avalanche	18	495	28	1841	108 (17 failures)
Debris torrent	10	950	95	8799	880
Debris slide	5	94	19	110	22
Bank slough	1	46	46	30	30
	34	1585	47	10780	327 (33 failures)

Channel length (ft.) affected by:

Failure Type	Scour Class IV	Scour Class III	Deposition Class IV	Deposition Class III
Debris avalanche	1110		277	
Debris torrent	6373	400	1082	511
Bank slough			20	
	7483	400	1379	511 = 9773 ft.

torrents are three times larger than those associated with debris avalanches (Table IX). Nine debris torrents formed fans with 2.5 times more inorganic and 4.8 times more organic debris than the 11 debris avalanches. All in-channel debris accumulations are at channel gradients less than 45 percent.

Soil Types and Geomorphic Location

Failures in clearcuts originated on three SRI soil landtypes that represent 73 percent of the total clearcut acreage inventoried. Table X lists the SRI landtypes encountered and the acreage and number of failures in each. The very steep, highly dissected slopes of landtype 47 represent 37 percent of the clearcut acreage and produced 72 percent of the failures. Soil depth exceeding five feet was not observed at failure sites in clearcuts. Over one-third of the failures are in soil one foot or less in depth. Many of the deeper failures originated in channel depressions and headwalls. Headwall failures make up 26 percent of the total; channel and incipient channel failures, 31 percent. Twenty-six percent of the failures came from toeslopes and 17 percent from hillslope positions where the soil is shallow.

One-third of the failures in clearcuts did not transport debris to a stream channel. Seven of the thirteen not reaching a stream channel were initiated on upper hillslopes.

Erosion Rates

Erosion rates of mass movements in clearcuts are based on a six year period. This corresponds to the oldest clearcut inventoried. Type 47 has the greatest erosion rate (Table XI). It is 2.2 times greater than the erosion rate for types 41 and 44, despite the fact that failures from type 47 are nine percent smaller than those on types 41 and 44. The only difference between landtype 47 and types 41 and 44 is that landtype 47 has more angular, highly dissected slopes than do landtypes 41 and 44. Landtypes 41 and 44 can have very steep slopes,

Table IX: Organic and inorganic volumes of debris jams from failures in clearcuts.

Failure Type	No. of Jams	Inorganic debris volume (yd^3) Total	Average	Organic debris volume (ft^3) Total	Average
All sizes					
Debris avalanche	11	1827	166	3050	277
Debris torrent	9	4512	501	14682	1468
Bank slough	1	41	41	0	0
	21	6380	304	17732	887 (20 failures)
$\geq 10yd^3$					
Debris avalanche	10	1823	182	3050	305
Debris torrent	9	4512	501	14682	1468
Bank slough	1	41	41	0	0
	20	6376	319	17732	933 (19 failures)

Table X: SRI landtypes from clearcuts

Landtype	47	41	411	417	44	42	443	462
Acres	267	167	57	60	91	35	42	3
No. of failures								
$\geq 10yd^3$	24	7	0	0	3	0	0	0
$<10yd^3$	4	1	0	0	0	0	0	0

Table XI. Failure frequency and erosion rate in clearcuts (6 year period).

SRI Landtypes	Acres	No. of Failures	Average Volume (yd^3)	Frequency (slide/acres)	Erosion Rate (yd^3/ac/yr)
All failures					
41,44	258	11	44	1/23	0.32
47	267	28	40	1/10	0.70
All types	722	39	41	1/19	0.38
$\geq 10 yd^3$					
41,44	258	10	48	1/26	0.31
47	267	24	46	1/11	0.69
All types	722	34	47	1/21	0.37

but generally type 47 has steeper slopes. Failures less than ten cubic yards do not add significantly to the erosion rate in clearcuts.

The 39 failures in clearcuts exposed approximately 0.7 acres of land to surface erosion. Forty percent of the exposed land resulted from ten debris torrents. Including the area disturbed by avalanche and torrent tracks, the exposed land surface becomes 6.7 acres or 0.93 percent of the sampled area.

Slope

No failures in clearcuts were found on slopes under 60 percent. Two-thirds of the failures are on slopes between 80 and 99 percent. Twenty-three percent occurred on slopes of 100-110 percent (Figure 7). The majority of failures on 100-110 percent slopes in clearcuts are of the debris avalanche type. All debris slides in clearcuts occurred on 80 to 90 percent slopes. The large average volume of failures on 70-79 percent slopes is the result of two of the three failures being 100 yd^3 and 196 yd^3 in volume. Two other failures are over 100 yd^3 and are on slopes of 82 and 110 percent. No trend of increasing or decreasing volume in relation to slope is observed from failures in clearcuts.

Aspect

Forty-one percent of the failures in clearcuts are on NW aspects with another 26 percent on SE aspects (Figure 8). Half of the debris torrents and one-third of the debris avalanches originated on NW aspects. On the average, failures from SE aspects are larger, but they are only 11 percent larger than failures from NW and NE aspects in clearcuts. Southwest aspect failures average 26 percent less in volume than failures from SE aspects.

Bedrock

Nearly three-fourths (74 percent) of the failures in clearcuts

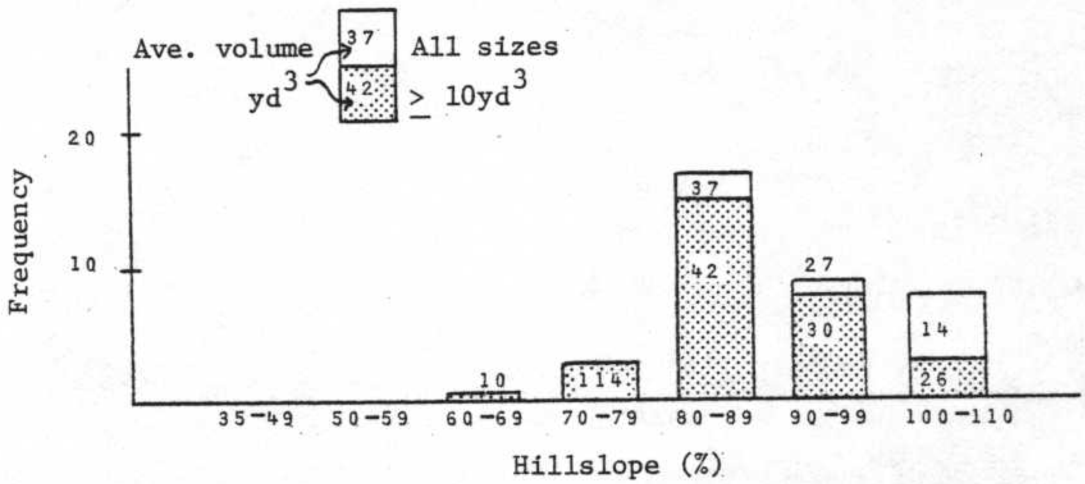

Figure 7. Slope distribution of failures in clearcuts.

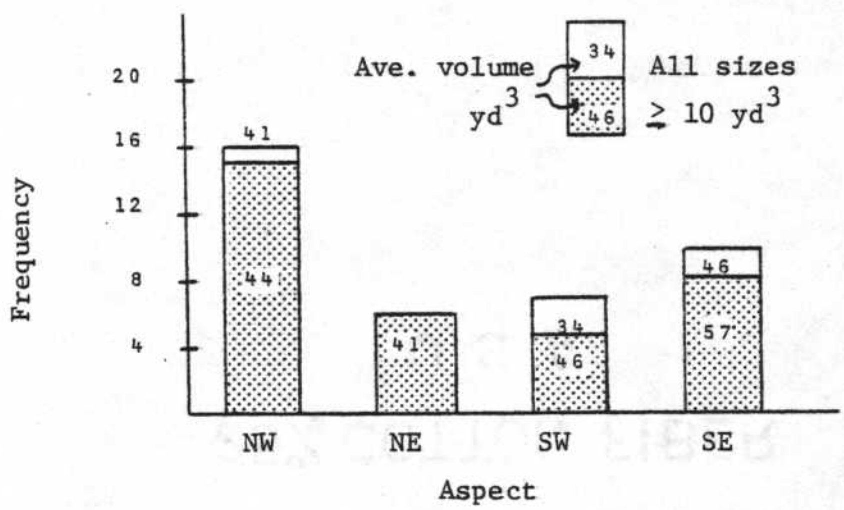

Figure 8. Aspect distribution of failures in clearcuts

exposed solid sandstone or sandstone and siltstone in the failure scar. The surface of the bedrock is inclined steeper than the hillslope in half the scars in which it is exposed. In 31 percent of the scars, the bedrock surface is less steeply inclined than the immediate hillslope. Nearly all of the failure scars in clearcuts were dry when inventoried. Only five failures were damp or wet.

DISCUSSION

The sample size of failures from undisturbed watersheds and clearcuts, and particularly of some landtypes, is small and the few large events recorded greatly influence the data. However, general characteristics and approximate erosion rate information can be useful. The significance of some of the results and trends in the data will be discussed in this section. Comparisons will also be made with other studies in this area.

Failure Volume

The average volume of all four failure types ten cubic yards or greater from the undisturbed watersheds and from clearcuts is similar (Table XII). However, when failures less than ten cubic yards are included, failures in clearcuts average 1.6 times greater than failures in undisturbed watersheds. A greater proportion of the failures in undisturbed watersheds are less than ten cubic yards than in clearcuts. This may be due to an underestimate of small failures in clearcuts. Logging operations cause some scarring of the hillside where logs dig into high spots in the terrain. This is particularly common to the highlead system. Where soil is thin, bedrock may be exposed. If disturbance of this nature in a clearcut was identified on aerial photographs, small bare zones in that portion of the clearcut were excluded from the inventory. Because of the difficulty in distinguishing between small scars left by the logging operation and scars from small

Table XII. Comparison of failures from the undisturbed forest and clearcuts.

Item	Forest $\geq 10yd^3$	Forest all	Clearcut $\geq 10yd^3$	Clearcut all
Ave. vol. (yd^3)				
DA	44	30	28	24
DT	45	45	95	95
all	41	26	47	41
Ave. travel dist. (ft)				
DA	170	191	108	102
DT	492	492	880	880
all	213	178	327	294
Debris jam vol.				
Inorganic (yd^3)				
DA	69	59	182	166
DT	382	382	501	501
all	142	94	319	304
Organic (ft^3)				
DA	430	340	305	277
DT	1089	1089	1468	1468
all	541	348	933	887
Erosion rates (yd^3/ac/yr)				
SRI Type				
47	0.06	0.07	0.69	0.70
41,44(414)	0.06	0.07	0.31	0.32
421,42	0.29	0.30		
all types	0.10	0.11	0.37	0.38
Frequency (slide/acres)				
all types	1/28	1/17	1/21	1/19

subsequent mass movements unrelated to the yarding of logs, small mass movements in clearcuts may have been overlooked. However, failures less than ten cubic yards in forested areas may also be underestimated. Small failures are difficult to see in the thick underbrush common in the Coast Range. Small failures in forested terrain also heal very rapidly and are not easily detected a few years after failure. However, I believe few failures of any size were missed in this inventory.

The similarity in failure volume of all types of failures in clearcuts and undisturbed watersheds does not hold when considering debris avalanches and debris torrents separately (Table XII). Debris torrents in clearcuts are 2.1 times larger than debris torrents in forested watersheds. Larger debris torrents in clearcuts than in undisturbed watersheds may be the result of headward progression of failure scars such that the volume measured at the time of this inventory overestimates the initial failure volume. Headwall failures in clearcuts have a characteristic broad, fan shape as if they progressed headward up the channel and laterally across the headwall during or after failure was initiated. Headward migration is impossible to identify with certainty after the fact, but probably occurs frequently on steep slopes in clearcuts. Headward migration of failure scars has been observed in the months following a large storm event that initiated an abundance of failures (Heller, pers. comm. 5/). Failures in headwalls might undermine a focal point of stability for much of the soil material above. This material may fail at the time of the initial failure or it may slough off at some later time. All debris torrents in clearcuts occurred in headwalls or incipient channels where headward progression is likely. Headwalls produced all failures over 100 yd^3 in clearcuts. Measurement of the total volume of a failure that may have progressed in size provides a true estimate of erosion rates, so this error in determining the initial failure size is not considered a problem.

5/ Dave Heller, Fisheries Biologist, Mapleton Ranger District, Siuslaw National Forest, Mapleton, Oregon.

I suspect that headward progression of failure scars is relatively rare in forested terrain, at least in a time frame of weeks and months. In a few instances, headward migration of failure scars had occurred, but appeared to be a year or more after the initial movements. These were measured as separate events.

Debris avalanches of all sizes in forested watersheds are 1.25 times larger than debris avalanches in clearcuts. This increases to 1.57 times for failures ten cubic yards or more in volume. A large proportion of the debris avalanches in clearcuts occurred on convex or linear hillslope segments whereas over a third of the debris avalanches in undisturbed watersheds originated in incipient channels and headwalls. Soils tend to be deeper in headwalls and incipient channels than on convex slopes. Also all debris avalanches in clearcuts are on SRI landtypes 47, 44 and 41; the soils of which are typically less than three feet deep. Forty percent of the debris avalanches in forested watersheds are on landtypes 421 and 42, that generally have soil two to six feet deep. Deeper soils were sites of the larger failures.

Vegetation seemed to be a major factor in limiting the areal extent of natural failure scars. Several natural failure scars had slump blocks along the sides or above the failure scarp. The movement of these blocks of soil appears to be checked by vegetative root systems. Failure scars in the undisturbed forest often had roots protruding from the scarp surface. The roots were flexible and there was a significant number of small roots (10 mm or less). Breakage occurred as a clean snap perpendicular to the root as from tension forces. This is in contrast to the few roots showing in scars of failures in clearcuts. Those present were larger roots appearing obviously dead and were often splintered and torn, suggesting that they did not give, but were brittle and broke in shear as the mass began to move. Few fine roots were observed in clearcut failure scars.

The healthy, vigorous root systems in the undisturbed forest appear to help confine failures in these watersheds to narrow tracks and support the adjacent slopes. The scoured track in forested drainages is typically 15-25 feet wide for larger debris torrents. Failure of the toeslope is common, but typically confined to small movements of the immediate soil material. In clearcuts, many of the incipient channel and headwall failures appear to have initially been narrow, but later additional material sloughed off, leaving the characteristic fan-shaped failure scars and wider debris tracks (25-35 feet). Simultaneous or subsequent toeslope failures are frequent and may be of considerable size. Many slopes in clearcuts appear to have failed in large sheets during or shortly after passage of the main torrent. Loss of root reinforcement of the soil by healthy root systems might account for the sheeting action. Once the toe is undermined, little else supports the soil mass.

Since most debris torrents appear to be triggered by debris avalanches, the failure volume for both types is expected to be similar on the average. For failures ten cubic yards or more in forested watersheds, the average volume of the two types is similar, but in clearcuts debris torrents average 3.4 times larger than debris avalanches (Table XII). This may be due to the geomorphic location of debris avalanches and debris torrents in clearcuts. Forty-three percent of the debris avalanches in clearcuts originated on hillslope and toeslope areas whereas debris torrents were initiated in incipient channels and headwalls. As noted earlier, depressions in headwalls and incipient channels typically have deeper soils and are more prone to headward migration than hillslope areas. Incipient channels and headwalls are areas where pore water pressures develop most during storms. This may cause larger failures also.

Failures less than ten cubic yards in volume were included in the inventory to determine whether they are a significant part of the debris avalanche problem. While these failures represent 42 percent of the number of natural failures, they contribute only nine percent of the total soil volume moved. In clearcut units, failures less than ten cubic yards are even fewer in number and represent just over one percent of the total volume avalanching from clearcut slopes. Nevertheless, small failures do contribute significantly to the total stream impact in forested watersheds. Failures less than ten cubic yards in volume caused 28 percent of the total scour and 23 percent of the total deposition by failures from undisturbed watersheds in this study. By comparison, failures less than ten cubic yards in clearcuts add a negligible amount of stream impact.

Erosion Rates

Erosion rates calculated in this study for the different SRI landtypes for undisturbed forest and clearcut failures vary between soil types and between clearcut and undisturbed forest (Table XII). The Siuslaw National Forest categorizes landtypes 421 and 42 as moderately stable. Yet the erosion rate calculated in this study for landtypes 421 and 42 in undisturbed watersheds is over four times greater than that estimated for landtype 47, which is categorized as unstable to very unstable. Landtypes 41, 44 and 414 are classed as moderately stable to unstable by the Siuslaw National Forest, and have an erosion rate equal to that of type 47.

Erosion rates on comparable soil landtypes in clearcuts in this study vary substantially from the rates in undisturbed watersheds. The very steep, highly dissected, angular slopes of landtype 47 have an erosion rate in clearcuts ten times greater than in the undisturbed forest (Table XII). The erosion rate of landtypes 41 and 44 in clearcuts is 4.6 times greater than that of landtypes 41, 44 and 414 in undisturbed drainages. For all SRI landtypes in the inventory, the increase is 3.5 times from forest to clearcut, for the first six years after cutting.

The discussion in the above two paragraphs suggests that a landtype classed as highly unstable by the Siuslaw National Forest, such as type 47, may have a lower erosion rate when undisturbed, than landtypes classed as moderately stable (type 421). But logging activities that reduce slope stability cause a greater proportionate increase in erosion rate on the landtype classed as unstable than on the one classed as moderately stable.

The erosion rates derived from the present study are considered to be conservative estimates of total hillslope erosion by debris avalanching. Natural erosion rates are conservative for three reasons. First, not every square foot of the natural drainages could be walked and it is possible a few failures were missed. Second, only initial failure volumes are used in erosion rate calculations. Neither the material incorporated in the failure track nor that from subsequent failures caused by undercutting the toeslopes by a debris torrent are used. And third, only failures exhibiting no relation to roads or road drainage water were inventoried. Erosion rates in clearcuts do not include failures from roads or landings. Small slides off bedrock that appear related to the yarding operations are omitted from the inventory.

The apparent erosion rate increase in clearcuts may be exaggerated. An attempt was made to identify failures that occurred before timber harvesting and omit these from the inventory of clearcut failures. Very few such failures could thus be identified, although from studies of natural drainages there must have certainly been several failures that existed prior to harvesting. If the erosion rate for natural failures is subtracted from the rates calculated for clearcuts, the remainder should be the accelerated erosion due to timber harvesting. For example, landtype 47 has a natural erosion rate for all failures of 0.07 yd^3/ac/yr and a rate in clearcuts of 0.38 yd^3/ac/yr. This means that 0.31 yd^3/ac/yr is accelerated erosion on type 47 due to management activities. It should again be emphasized that these rates do not include road and landing failures.

If the volume of material in debris jams is substituted for initial failure volumes in erosion rate calculations, the overall rates become 0.22 yd^3/ac/yr and 1.5 yd^3/ac/yr for natural and clearcut failures, respectively. This may better approximate the short term erosion rate for these kinds of mass movements but it may also exaggerate the magnitude of change in these erosion rates between undisturbed and clearcut watersheds. A higher proportion of the debris jams that resulted from natural failures were not located compared to those from failures originating in clearcuts. Total volume estimates for debris jams from natural failures are made conservative because: 1) some debris tracks had several small deposits scattered along them that were not measured, 2) the debris jams of some of the natural failures were apparently eroded away by the stream and could not be identified, and 3) in a few cases, channel conditions were too hazardous to follow a debris track to the debris jam. Failures from clearcuts almost always terminated in a single distinct debris jam.

As shown in Table VII, the frequency and erosion rate varies substantially depending on the time period being considered. Frequencies and erosion rates based on short time periods are very susceptible to error. A short period of time may encompass a very unusual year or two that greatly alters the results from the true frequency of occurrence and erosion rate of mass movements experienced over a long time period. Longer time periods average out the extreme years. The 15 years estimated for the natural failures in the present study are sufficiently large to include some years experiencing unusually large storms and some dry, uneventful years. However, extending the period means that more failures of the earlier years will not be located because of regrowth obliterating the scars. The six year interval for failures in clearcuts is quite short. The data may be overly influenced by the recent episode of mass movement in 1975.

Slope

Harr and Yee (1975) obtained values of 40-41 degrees for the angle of internal friction (Ø) in cohesionless soils from their Coast Range study site. Using a value of 40 degrees, the factor of safety against sliding is 1.0 for a slope angle of 84 percent. Half of the natural failures and nine-tenths of the failures from clearcuts in the present study are from slopes of 80 percent or greater. The large proportion of natural failures on slopes under 80 percent suggests that other factors besides slope angle are important. These are the "stage setting" factors described by Rice and Krammes (1970) and others. Pore water pressure build up during storms may also be of great importance. No failures in clearcuts were inventoried on slopes under 68 percent. If removing the timber causes slope instability and increased incidence of mass failures, more failures would be expected on intermediate slopes that are stable in undisturbed conditions but lose stability after cutting. The data do not support this conclusion. The clearcuts inventoried had a small number of slopes under 70 percent. Those that did have gentler slopes did so because there is a large topographic bench in the clearcut. These benches are usually the result of old, deep-seated landslides and result in gentle slopes (<50 percent) except along the remnant escarpment and along the toe of the movement. Clearcuts are designed to take advantage of these benches so these clearcuts had mainly gentle slopes and a few very steep slopes. These clearcuts have few slopes between 60 and 80 percent. Debris avalanching is rare on these landforms except along the perimeter of active movements.

The volume of failures is greatest on slopes of 80 and 90 percent. Thinner soil on steeper slopes causes a drop in average failure volume in undisturbed watersheds. Reduced slope stability in clearcuts probably accounts for the large volumes maintained on slopes of 100 percent in clearcuts.

Aspect

No significant trends are shown by the relationship of aspect to failure frequency. Any effect aspect has, may be masked by several other factors. Many of the undisturbed drainages selected have a high proportion of NE and SW aspects, particularly in the Smith-Umpqua block. These are the aspects on which over half of the natural failures occurred. Over half of the clearcuts inventoried have a NW orientation, and the largest number (41 percent) of the failures in clearcuts have NW aspects. Volume averages by aspect show that the largest natural failures occur on NW aspects. The average volume for these aspects is strongly influenced by a 191 yd^3 failure. Excluding this failure reduces the average from 38 to 21 cubic yards. The two largest natural failures are from northerly aspects where conditions may be wetter and favor deeper soil development. Most of the deeper soils are on N aspects. However, the influence of aspect on microsite conditions of bedrock weathering, soil depth and vegetation type, are not well exhibited in the Coast Range. The wet climate seems to overshadow any microsite changes due to aspect. In clearcuts, as many large failures occur on southern aspects as north aspects. Failure scars on south aspects in clearcuts sometimes are baked by the sun such that the soil becomes hard and dry. Invasion of vegetation on these scars is slower than on north slopes.

Areal Impacts

The inventoried mass movements affect an insignificant amount of productive forest land. Including the land area of the intial failures and an estimated 20 foot wide debris torrent track, the total disrupted land is 2.9 acres in undisturbed watersheds and 6.7 acres in clearcuts. This amounts to 0.3 percent and 0.9 percent of the inventoried acreage in undisturbed and clearcut drainages, respectively. Clearcutting apparently triples the percentage of land immediately affected by mass movements although it amounts to only a six-tenths of one percent increase over undisturbed drainages.

Channel Impacts

Even though mass movements in both undisturbed and clearcut watersheds affect a relatively small amount of productive forest land, they have the potential to cause considerable damage to the aquatic ecosystems in waters draining forested lands. Failures from undisturbed drainages mechanically scoured or deposited debris along 1.94 miles of Class III and IV streams. Another 0.08 miles of channel is undergoing aggradation between debris jams in a few drainages. Together, this is eight percent of the Class III and IV stream length within the boundaries of the undisturbed drainages inventoried (26.42 mi.). Failures from clearcuts similarly impacted 1.85 miles of Class III and IV streams, or ten percent of the 18.2 miles of the streams within or along clearcut boundaries.

Thirty-seven percent of the channel scour in undisturbed drainages and 87 percent of the channel scour in clearcuts is from debris torrents, even though they are a small fraction of the total number of failures in each case. Debris torrents, because they are water-charged, travel considerably longer distances than the less fluid debris avalanches. On the average, debris torrents traveled 2.6 and 8.6 times farther than debris avalanches in forested and clearcut drainages, respectively (Table XII). A greater proportion of the total number of failures are debris torrents in clearcuts than in undisturbed watersheds.

Debris torrent travel distance in clearcuts averages 1.8 times farther than debris torrents in undisturbed watersheds. Vegetation may play a major role in explaining this difference. In forested watersheds, channel bottoms are well vegetated, and if debris torrents are not too frequent, considerable down timber criss-crosses the channel. Large logs that slide into the channel may extend a considerable distance up the slope. These logs resist being carried downstream because they are supported by vegetation on the side slopes. A debris torrent scouring down an undisturbed channel has to uproot and move in-channel vegetation, plus break or flow around, under, or over large logs stabilized by toeslope vegetation. This expends much of the torrent's energy.

Drainages within clearcuts also contain large amounts of debris. But much of this debris is smaller material left behind from the logging operation. Large old logs that were well stabilized before logging occurred tend to get disturbed during logging activities and supporting vegetation is logged or killed by subsequent burning. Rooting strength of stumps declines and slope stability decreases. When a debris torrent starts down a channel in a clearcut, it meets less resistance in the form of vegetation and stable large organic debris than the typical debris torrent in an undisturbed drainage. Once moving, the large amount of logging debris being carried along with the initial wave, grinds and scrapes the channel as it goes. Debris torrent tracks in clearcuts rarely have any debris remaining behind that could not be transported. The channel is usually scraped to bedrock until deposition occurs in a large debris jam. In contrast, debris torrent tracks in forested drainages are often strewn with large logs that were not moved far. These may catch other debris behind them as the torrent passes.

The data indicate that debris avalanches in undisturbed watersheds cause more channel impacts than do debris avalanches in clearcuts (Table XII). Debris avalanches in forested watersheds have an average slope plus channel travel distance of 191 feet and debris avalanches in clearcuts have an average travel distance of 102 feet. One reason for this is that 92 percent of the debris avalanches in undisturbed watersheds involved stream channels and only 71 percent of the debris avalanches in clearcuts entered stream channels. Also, it is likely that more of the debris avalanches reaching the channel in clearcuts resulted in debris torrents than under undisturbed conditions. This results in the channel impacts of torrent-causing debris avalanches to be accounted for under debris torrents and the debris avalanche impact in clearcuts remains low in comparison.

Ninety-six percent of stream impact in undisturbed drainages and 91 percent of the stream impact in clearcuts is in Class IV streams. Most of the Class IV stream channels are too steep for gravels to accumulate and provide spawning areas for fish. So most of the mass movements inventoried did not directly affect fish habitat. However, the remainder of the failures terminated in large debris jams in Class III streams. These channels are at lower gradients and may contain deep deposits of sediment, if not good spawning gravels.

Debris jams trapping large sediment accumulations produced 88 percent of the Class III stream impacts by natural failures and 56 percent of the Class III stream impacts from failures in clearcuts. Under undisturbed conditions, the debris jams are relatively small most of the time.

Seventy-seven percent of the measured debris fans in undisturbed drainages contain less than 100 yd^3 of inorganic debris. Only one is over 300 yd^3 (1692 yd^3). Not one natural fan that formed at the confluence of a higher order channel completely blocked the flow of that channel. The flow may have been shifted, but little cutting is required to reestablish the original gradient. These relatively small debris fans are fairly easily and rapidly reworked by the stream and stabilized by vegetation. The streams in the Coast Range have developed in response to these pulses of sediment and the formation of debris jams.

In clearcuts, however, only 21 percent of the debris fans are less than 100 yd^3 in volume. Fifteen percent contain over 500 yd^3 of inorganic debris. These larger fans create more of an anomaly for the stream system than the smaller fans from natural failures. Many of the fans completely block Class III or IV channels, creating a very high drop at the toe of the fan. The stream plunges over the toe and scours down if the streambed is gravel or sideways if it has a bedrock bottom.

The average debris fan from failures in clearcuts has 2.5 times more measurable organic debris than debris fans formed by failures in undisturbed watersheds. The source of organic debris transported to these streams is the Class IV channels and drainage depressions high in the watersheds. These are the areas normally excluded from stream cleanup requirements following logging. The increase in the amount of organic debris in fans from failures in clearcuts may be due to one or more of the following: 1) an increase in the amount of loose logs (slash) in clearcut headwalls, 2) greater mobility of material in clearcut channels, and 3) longer travel distances in clearcuts provide more opportunity to entrain debris.

Debris fans typically form at channel confluences where the gradient decreases and a corner must be negotiated, on large flat spots along the channel, or at channel constrictions where debris (logs) might be trapped. Debris fans are generally in channels of less than 15 percent gradient.

What happens to the sediment in these fans is not well documented. An initial high pulse of suspended sediment must move down the channel at the time the debris fan is formed. Swanston and Swanson (1976) report sediment research in Coyote Creek near Tiller, Oregon, that linked surges of heavy sediment depositions in weir basins to debris avalanches and slumps during storm events. Particle size analyses of the soil material involved in debris avalanching in the present study show that up to 25 to 30 percent of the material is less than 0.1 mm in diameter. As a general rule, particles less than 0.1 mm in diameter will move as suspended sediment in streams. Particles between 1.0 and 0.1 mm may move as bedload or in suspension. Roughly half of the soil material is less than one millimeter. Although the small size of the auger used to collect soil samples excluded the larger particles, the analyses do indicate that a large portion of the material can be transported downstream in suspension. Much of the rock debris in the failure scars and torrent tracks is highly weathered, friable sandstone. This material is likely to break down into smaller fragments from the churning and scouring of a debris torrent such that the material in debris fans may contain a high proportion of fine particles. Subsequent erosion of the raw debris accumulation will provide a large source of sediment until stabilization occurs.

Comparison With Other Studies

The average volume of natural failures greater than ten cubic yards in this study is 41 yd^3. Few very large (>100 yd^3) natural failures are found in the central Coast Range. However, in other areas of the Pacific Northwest, failures tend to be quite large. Swanston and Swanson (1976) report an average volume for debris avalanches in forested areas of 1450 - 4600 m^3 (1897 - 6017 yd^3). This contrasts with a later report that failures on uncut watersheds of the Mapleton district averaged 80 yd^3 in volume (Swanson and Swanson, 1977). Two failures exceeding 320 yd^3 in volume each strongly influence this average. Only two natural failures greater than 100 yd^3 were documented in the present study. My data show that less than three percent of the slides in this part of the Coast Range exceed a few hundred cubic yards in volume.

Table XIII. Debris avalanche erosion in forest and clearcut (From Swanston and Swanson, 1976 and Swanson and Swanson, 1977).

Site	Period of Record (yr)	Area (%)	Area (mi^2)	Number of Failures	Erosion Rate yd^3/ac/yr.	Erosion Rate Relative to Forested Areas
Stequaleho Creek, Olympic Peninsula (Fiksdal, 1974)						
Forest	84	79	7.5	25	0.38	x 1.0
Clearcut	6	18	1.7	0	0	x 0
Alder Creek, Western Cascade Range, Oregon (Morrison, 1975)						
Forest	25	70.5	4.7	7	0.24	x 1.0
Clearcut	15	26.0	1.7	18	0.62	x 2.6
Selected Drainages, Coast Mountains, S.W. British Columbia (O'Loughlin, 1972, and pers. comm.)						
Forest	32	88.9	95.0	29	0.06	x 1.0
Clearcut	32	9.5	10.2	18	0.13	x 2.2
H.J. Andrews Experimental Forest, Western Cascade Range, Oregon (Swanson and Dyrness, 1975)						
Forest	25	77.5	19.2	31	0.19	x 1.0
Clearcut	25	19.3	4.8	30	0.70	x 3.7
Mapleton Ranger District, Central Oregon Coast Range (Swanson and Swanson, 1977)						
Forest	15		2.0	42	0.17	x 1.0
Clearcut	10		22.0	317	0.33	x 1.9
Mapleton Ranger District, Central Oregon Coast Range (this study)						
Forest	15		1.8	38	0.10	x 1.0
Clearcut	6		1.1	34	0.37	x 3.7

The absolute volume moved by a failure is difficult to obtain and the differences in average size of failures between this study and Swanson and Swanson's may be due, in part, to differences in judging the average length, width and depth of failure scars. All data used in this present study are based on measurements made on the ground and are assumed to be reasonably accurate.

The erosion rates from this study can be compared to several studies summarized by Swanston and Swanson (1976), and a recent report by Swanson and Swanson (1977) (Table XIII). The overall natural erosion rate from the present study, 0.11 yd^3/ac/yr, is lower than all but the study in the Coast Mountains of British Columbia. It is close to that estimated by Swanson and Dyrness in the Oregon Cascades and by Swanson and Swanson working on the Mapleton district. The increases they documented in clearcuts ranged from 1.9 to 3.7 times that in undisturbed forests compared to 3.7 times in this study for failures ten cubic yards or more in volume. These results show that conditions encountered in individual studies, can result in large differences between studies, which in part may be due to differences in measurement techniques. This is expected for studies in different landforms, such as the Cascades, the Olympic Mountains and the Coast Range. But significant differences also exist between studies in the same landform. In particular, Swanson and Swanson (1977) conducted their studies on the Mapleton District in close proximity to the present study. Yet their erosion rate for natural failures greater than ten cubic yards is 1.7 times greater than the 0.10 yd^3/ac/yr calculated from this study (Table XIV).

Most of the discrepancy in erosion rate between this study and that by Swanson and Swanson is in landtype 47. The rate in the present study is 2.5 times less than that calculated by Swanson and Swanson. Part of the difference is a product of where the inventory of landtype 47 was conducted. Swanson and Swanson carried theirs out entirely north of the Smith River. Half of the acreage in landtype 47 in the present study is south of the Smith River in the Smith-Umpqua block. This area is characterized by very steep, highly dissected slopes with shallow soils and frequent outcrops of large sandstone ledges. Natural

Table XIV. Comparison of this study with the study by Swanson and Swanson (1977).

	This Study	Swanson and Swanson (1977)
Ave. volume (yd^3) $\geq 10 yd^3$		
Forest	41	80
Clearcut	47	145
Erosion rate ($yd^3/ac/yr$)		
Forest		
47	0.06	0.15
All except 47	0.15	0.28
All	0.10	0.17
Clearcut		
47	0.69	0.60
All	0.37	0.33
Frequency (slide/acres)		
Forest		
47	1/38	1/31
All	1/28	1/31
Clearcut		
47	1/11	1/24
All	1/21	1/44

mass failures in the drainages inventoried in the Smith-Umpqua block are shallow, small and scattered. The erosion rate for landtype 47 in the Smith-Umpqua block from this study is 0.01 yd^3/ac/yr. In comparison, the rate for landtype 47 north of the Smith River in the present study is 0.10 yd^3/ac/yr. This is still less than the 0.15 yd^3/ac/yr estimated by Swanson and Swanson, but the difference can now probably be explained by chance selection of study sites and failure incidence.

The results of this study and that of Swanson and Swanson (1977) show fairly comparable erosion rates in clearcuts (Table XIV). These can also be compared with other studies reported by Swanston and Swanson (1976) (Table XIII). Again, large differences may result among studies in various landforms.

Failure frequencies in undisturbed watersheds obtained by Swanson and Swanson (1977) agree well with those obtained in this study (Table XIV). But the frequency in clearcuts obtained in this study is much higher than that reported by Swanson and Swanson. This can be traced to the technique used in deriving the respective frequencies. The failure frequency obtained in this study is calculated from field inventoried failures. Swanson and Swanson obtained failure frequencies in clearcuts from aerial photos. Small failures could easily be overlooked, using aerial photos. Failure frequencies obtained from aerial photos by Mapleton District personnel (Greswell, Heller, and Minor, 1976) are 1/36 and 1/54 for "in-unit" and "other" failures, respectively. Only failures entering stream channels were included in their inventory, so it is expected that the frequency obtained in the present study is much higher.

Natural Variability

Many of the differences among various studies of mass failures is due to the natural variability of these phenomenon and the small sample sizes involved. The large change caused by one or two unusually large failures with small sample sizes is demonstrated by both this study and that by Swanson and Swanson (1977). Swanson and Swanson discuss the influence a slide of 450 yd^3 has on the overall erosion rate. The erosion rate with this failure included in the calculations is 0.28 yd^3/ac/yr. This reduces to 0.16 yd^3/ac/yr when the larger failure is excluded. This becomes very close to the 0.15 yd^3/ac/yr calculated in the present study for all failure-producing landtypes except type 47.

Natural variability in the present study is displayed in both undisturbed and clearcut watersheds. Undisturbed drainage 10-N, SRI landtype 421, produced eleven failures and has an erosion rate of 0.60 yd^3/ac/yr. Drainage 7-N, also undisturbed and landtype 421 has an erosion rate of 0.16 yd^3/ac/yr. Two clearcuts in this study in landtype 47 have the same aspect orientation and are only one mile apart, yet the erosion rates vary by a factor of 2.75. Other authors have noted the extreme variability of mass failure events (Fredriksen, 1965; Williams and Guy, 1971).

MANAGEMENT IMPLICATIONS

The information gathered in this study can be utilized in planning timber harvesting in similar terrain throughout the Coast Range. After clearcutting, the frequency of mass movements ten cubic yards or more in volume will increase on steep, dissected hillslopes. The very steep, highly dissected hillslopes, on which much of the remaining old and second growth cutting will take place is particularly sensitive to timber harvesting. The frequency of failures may more than double and the erosion rate increase by ten times on these unstable slopes.

During the course of this study, it became evident that the land taken out of production by these failures usually supports very small amounts of valuable sawtimber. Headwalls and incipient channels in which channel failures are often found have a large percentage of hardwoods and brush with scattered commercial coniferous trees. These areas may be old failure sites that have revegetated with brush and alder. Channel bottoms are dominated with salmonberry or other brush species

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with only an occasional tree on the banks. In undisturbed drainages, most debris torrents do not damage valuable timber. However, in clear-cuts, headward migration and toeslope failures do pose a threat to the re-establishment of a productive forest on undermined slopes.

Individual cutting units have different potentials for mass movement. Conditions most favoring debris avalanches at any one location include the following:

1. Headwalls and incipient channel depressions on hillslopes of 60 percent or more. These are areas where soil water accumulates and pore water pressure is greatest. An abrupt change in an incipient channel depression to deep incision may be a likely location for future failures.
2. Slopes of 80 percent or greater. In particular the lower portions of long rectilinear slopes. Pore water pressure will be high here also.
3. The presence of sandstone outcroppings. Small slips off these ledges can be expected after cutting.
4. Drainage channels that are steep, very deeply incised, with mostly bedrock bottoms. These generally have banks that jut up from a narrow channel (4 - 5 feet wide) at 90 percent slope or more for 20 to 30 feet before a slope change occurs. The channel bottom may have a thin layer of gravel, but it is shallow and discontinuous. These characteristics suggest that the channel, though bedrock controlled, is actively downcutting, producing oversteepend slopes that have a high probability of failure by debris avalanche. It is these failures that probably cause most of the downcutting in the bedrock channel.

The above characteristics are all common to landtypes 44, 47, 417 and 414. Other conditions that when present with any of the above may help identify probable failure sites are listed below.

1. Vegetation: Channel depressions and headwalls that are mostly occupied by brush species (salmonberry, vine maple, etc.) with a few coniferous or hardwood trees in the overstory may indicate a history of failures. However, failures do occur from heavily

timbered slopes as well. Jackstrawed trees in conjunction with broken topped trees indicated probable large, deep-seated mass movement.

2. Channel conditions may provide clues to past failure. Debris fans are the most obvious. The absence of tangled vegetation and large trees criss-crossing the channel may indicate recent scouring by a debris torrent. The presence of thick vegetation and tangled logs may indicate a stable watershed, or it may mean that the stage is set for failure.
3. The presence of mountain beaver activities. Mountain beaver tunnels loosen soil structure and intercept and concentrate soil water. These act to reduce stability.

Once the most probable failure sites are located for a proposed cutting unit, the degree of stream impact should be evaluated. This step will determine if special measures should be incorporated into the logging plan to minimize the impact of probable mass movements. If the cutting unit has relatively short steep Class IV channels feeding directly into lower gradient Class IV channels and there are several direction changes where a debris torrent may be stopped, no special measures may be warranted. However, if the probable failure has a fairly short, uninterrupted run to a Class I, II or III stream, or lands under other ownership, special measures will be warranted. The worst case is a clearcut with critically unstable headwalls feeding directly into steep, straight channels that enter a Class I spawning stream or a valley bottom where private residences or meadows may be threatened. One very important consideration in this regard is the probable streamflow in any channel that the avalanching debris may enter. The larger the flow, the more likely the debris will develop into a torrent and the more easily it will flow around corners. In any case, the stream channels should be inspected for conditions that might tend to stop a debris torrent or prevent an avalanche from becoming a destructive torrent.

The above discussion deals entirely with factors requiring a subjective decision. Familiarity with the area and with the debris avalanche problem, and a good system for maintaining records will be essential for good decision making. Identification of critical slope locations should be followed up with regular inspection of these sites to see how they are reacting.

No list of special measures that effectively reduce mass movement problems is available. Progress has been made in road construction techniques to reduce road-related failures. Leaving critical headwall vegetation intact may create some logging logistic problems and requires special burning procedures, but may prove to be a worthwhile and practical tool. It is particularly practical when headwall vegetation is mainly non-commercial species.

RESEARCH NEEDS

Questions still remain as to what effect large debris jams in the channels have on stream ecosystems. Cal Baker 6/ is characterizing the sediment accumulations behind debris jams and is observing the erosion and stabilization of the sediment behind debris jams after their removal. Further study is needed to determine where the sediment goes, how long high sediment yields last, and how and to what extent the debris affects the aquatic ecosystem downstream. Platts and Megahan (1975) studied the sediment composition of spawning areas in the South Fork of the Salmon River, Idaho. Logging and road construction have been connected with increased sediment yields of this river. They studied the surface composition of spawning beds for eight years since the implementation of a logging and road construction moratorium and watershed rehabilitation project has reduced sediment yields. From the eight years of sampling, they conclude that the river is capable of flushing fine sediment from the gravel if the sediment source is reduced. They found a slight decrease in the amount of fines and boulders on the riverbed surface. They did not determine if this is

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6/ Research Assistant, Dept. of Fisheries and Wildlife, Oregon State University. Ph.D. Thesis. pers. comm.

just a surface phenomenon or whether fines are also being flushed out of the gravels below the surface as well.

Some research is now underway that will help answer some of these questions. Robert Beschta 7/ is characterizing bedload movement in an undisturbed stream in the Oregon Coast Range and studying the mechanism of fine sediment entrainment in streambed gravels. The entrainment of fine organic debris in stream gravels after timber harvesting is also the topic of proposed research at Oregon State University.8/ The stabilization of debris jams not removed from the channel should also be studied. Debris jams in undisturbed watersheds in this study seem to be quite stable, but large jams in clearcuts did not.

Further inventory of failures is needed on certain landtypes to better describe debris avalanche erosion on different sites. No acreage in the moderately steep to steep, smooth to moderately dissected landtypes of 421 and 42 was inventoried in clearcuts in this study. Because these landtypes have a high erosion rate in undisturbed watersheds, data from clearcuts needs to be collected for a comparison to be made. Only minor area in some landtypes was covered in this study. Further inventory of these landtypes is warranted.

SUMMARY

Debris avalanches and debris torrents are common mass erosion features in the shallow soils and steep, dissected terrain of the Oregon Coast Range. The frequency of failures and erosion rates in undisturbed watersheds vary substantially from site to site, but are the greatest on moderately steep, moderately smooth hillslopes. Failure frequency and erosion rate decrease in undisturbed watersheds on steep, highly dissected slopes. However, timber harvesting increases the frequency and erosion

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7/ Associate professor, Oregon State University, Corvallis, pers. comm.

8/ Arne Skaugset, Research Assistant, Oregon State University, Dept. of Forest Engineering. Proposed MS Thesis.

rate dramatically on the steep, highly dissected slopes. The frequency may double and the erosion rate increase by ten times that in undisturbed watersheds. On less steep and moderately dissected hillslopes in this study, clearcutting increases the erosion rate by 4.6 times over that in forested drainages.

Debris avalanches in the Coast Range are small in size, averaging 41 yd^3 in undisturbed watersheds and 47 yd^3 in clearcuts, but occur frequently; one in less than 30 acres every few decades. Less than one percent of the land base is affected by debris avalanches in both undisturbed and clearcut watersheds.

Eight percent of the Class III and IV stream channels inventoried in undisturbed watersheds and ten percent of the Class III and IV streams in clearcuts are impacted by mechanical scour and deposition. Failures in clearcuts travel 1.7 times farther than failures in undisturbed watersheds. Debris jams from failures in clearcuts contain 3.2 times more inorganic and 2.5 times more organic debris on the average than debris jams from failures in undisturbed watersheds. At least a third of the inorganic material in debris jams is small enough to be transported in suspension by the streams (<0.1 mm).

Failures occurred on slopes from 35 percent (19 degrees) to 110 percent (48 degrees) in forested watersheds and from 68 percent (34 degrees) to 110 percent in clearcuts. Failure frequency in undisturbed watersheds increases as slope increases up to slopes of 60 percent. The frequency remains high on slopes from 60 to 100 percent and then decreases. The very shallow soils on the steeper slopes is apparently not prone to failure in undisturbed watersheds. In clearcuts the frequency of failures is highest on slopes of 80 - 89 percent, and somewhat less on slopes of 90 percent or more.

Climatic factors and the poor distribution of aspects encountered in the inventory mask any influence aspect has on failure frequency.

Clearcutting aggravates the natural erosion by debris avalanches and debris torrents. In unstable undisturbed drainages, a debris avalanche may enter the stream channel once every five or ten years, depending on stage setting factors and the occurrence of a major storm event. But shortly after clearcutting, a moderatley large storm may send several debris avalanches into the stream from one cutover area. The probability of these failures becoming debris torrents is greater in clearcuts than in undisturbed watersheds and more scoured stream channel results.

In the drainages inventoried, stream impact by scour and deposition was confined to Class III and IV channels and thus direct impact on fisheries is minimal. However, little is known about the indirect impact of these debris accumulations on the downstream ecosystem. In order to maintain the high water quality of streams flowing from forested lands, which is protected by law, land managers must consider the possibility of damage to fisheries from increased mass failure erosion in clearcuts.

LITERATURE CITED

Badura, G.J., H.A. Legard, and L.C. Meyer. 1974. Siuslaw National Forest soil resource inventory. U.S. Forest Service, Pacific Northwest Region. 139 p.

Baldwin, E.M. 1976. Geology of Oregon, revised edition. Kendall/Hunt Publishing Co., Dubuque, Iowa. 147 p.

Bishop, D.M. and M.E. Stevens. 1964. Landslides on logged areas in southeast Alaska. USDA For. Serv. Northern For. and Range Expt. Sta. Res. paper, NOR-1, 18 p.

Brown, G.W. 1973. The impact of timber harvest on soil and water resources. Oregon State University, Corvallis, Extension Bull. 827, 17 p.

Burroughs, E.R., Jr. and B.R. Thomas. 1977. Declining root strength in Douglas-fir after felling as a factor in slope stability. USDA For. Serv., Intermountain For. and Range Expt. Sta. Res. Paper INT-190, 27 p.

Campbell, R.H. 1975. Soil slips, debris flows and rainstorms in the Santa Monica Mtns. and vicinity, southern California. USGS. Prof. Paper 851, 51 p.

Chorley, R.J. 1964. Geomorphological evaluation of factors controlling shearing resistance of surface soils in sandstone. Journal of Geophysical Res., 69, p. 1507-16.

Corbett, E.S. and R.M. Rice. 1966. Soil slippage increased by brush conversion. USDA For. Serv. Pac. Southwest For. and Range Expt. Sta. Res. Note, PSW-128, 8 p.

Day, N.F. and W.F. Megahan. 1975. Landslide occurrence on the Clearwater National Forest. Geological Soc. of Am. Abstracts with programs, V. 7, No. 5, p. 602-603.

Dyrness, C.T. 1967. Mass soil movements in the H.J. Andrews Experimental Forest. USDA For. Serv. Pac. Northwest For. and Range Expt. Sta. Res. Paper, PNW-42, 12 p.

Fredriksen, R.L. 1965. Christmas 1964 storm damage on the H.J. Andrews Expt'l Forest. USDA For. Serv. Pac. Northwest For. and Range Expt. Sta. Res. Paper, PNW-29, 11 p.

Fredriksen, R.L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. USDA For. Serv. Pac. Northwest For. and Range Expt. Sta. PNW-104, 15 p.

Froehlich, H.A. 1973. Natural and man-caused slash in headwater streams. Loggers Handbook, V. 33, 8 p. (reprint).

Fujiwara, Koichiro. 1970. A study on landslides by aerial photographs. Res. Bull. Exp. For., Hakkaido Univ. 27(2)297-345.

Gonsior, M.J. and R.B. Gardner. 1971. Investigation of slope failures in the Idaho Batholith. USDA For. Service Intermountain For. and Range Expt. Sta. Res. Paper, INT-97, 34 p.

Gray, D.H. 1973. Effects of forest clearcutting on the stability of natural slopes: results of field studies. Dept. of Civil Eng., Univ. of Michigan, Ann Arbor, Michigan. Natl. Science Foundation Grant No. GK-24747, Wash. D.C. 131 p.

Gresswell, S., D. Heller, and D. Minor, 1976. A summary of slide inventory data, Mapleton Ranger District. U.S. Forest Serv. 18 p.

Grottenthaler, Von W. and W. Laatsch. 1973. Erosion of the slopes of the valley of the Lain near Benediktbeuern. Forstwissenschaffliches Centralblatt. 92(1) p. 1-19 (English summary).

Hack, J.T. and J.C. Goodlett. 1960. Geomorphology and forest ecology of a mountain region in the central Appalachians. USGS Prof. Paper 347, 64 p.

Hall, J.D. and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. IN: A Symposium on Salmon and Trout in Streams. T.G. Northcote, ed. Univ. of British Columbia, p. 353-375.

Hammermeister, Dale. 1977. Water and anion movement in selected soils of western Oregon. Ph.D. Thesis, Oregon State University, Corvallis.

Harr, R.D. and C.S. Yee. 1975. Soil and hydrologic factors affecting the stability of natural slopes in the Oregon Coast Range. Oregon State University, Corvallis, Water Resources Res. Inst. Report, WRRI-33, 204 p.

Hillel, Daniel. 1971. Soil and water: physical principles and processes. Academic Press, New York. 288 p.

Morrison, P.H. 1975. Ecological and geomorphological consequences of mass movements in the Alder Creek watershed and implications for forest land management. BA Thesis, University of Oregon, Eugene. 102 p.

Narver, D.W. 1970. Effects of logging debris on fish populations. Proc. Symp. Forest Land Use and Stream Environ., Oregon State University, Corvallis. p. 100-111.

O'Loughlin, C.L. 1973. An investigation of the stability of the steepland forest soils in the coast mountains, southwest British Columbia. Diss. Abstr. Int. V. 34, pt. 4, p. 2395B (Abstract).

O'Loughlin, C.L. and M. Gage. 1975. A report on the status of slope erosion on selected steep areas, West Coast Beech Project Area. New Zealand Forest Service (FRI) Report. 83 p.

Patric, J.H. and D.N. Swanston. 1968. Hydrology of slide prone glacial till soil in southeast Alaska. J. Forestry. 66:62-66.

Phillips, R.W. 1970. Effects of sediment on the gravel environment and fish production. Proc. Symp. Forest Land Use and Stream Environ., Oregon State University, Corvallis. p.64-74.

Platts, W.S. and W.F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Transactions of 40th North Am. Wildlife and Natural Resources Conf., Wildlife Management Institute, Wash., D.C. p. 229-239.

Rapp, Anders. 1962. The debris slides at Ulvadal, western Norway: An example of catastrophic slope processes in Scandinavia. IN: Slope Morphology. S.A. Schumm and M.P. Mosley, ed. Dowden, Hutchinson and Ross, Inc. Strandsburg, Penn. p. 364-383.

Rice, R.M., E.S. Corbett, and R.G. Bailey. 1969. Soil slips related to vegetation, topography and soil in southern California. Water Resources Research. V. 5, p. 647-659.

Rice, R.M., and G.T. Foggin. 1971. Effect of high intensity storms on soil slippage on mountainous watersheds in southern California. Water Resources Research. V. 7, p. 1485-1496.

Rice, R.M. and J.S. Krammes. 1970. Mass wasting processes in watershed management. Proceedings of Symposium on Interdisciplinary Aspects of Watershed Management. Montana State University, Bozeman. p. 131-247. (Reprint)

Scott, K.M. 1971. Origin and sedimentology of 1969 debris flows near Glendora, California. IN: Geological Survey Research 1971:USGS Prof. Paper 750-C. p. 242-247.

Scott, R.C., Jr. 1972. The geomorphic significance of debris avalanching in the Appalachian Blue Ridge Mountains. Univ. of Georgia. Diss. Abstr. Int. V. 33, pt. 6, p. 4335 B. (Abstract).

Sedell, J.R. and F.J. Triska. 1977. Biological consequences of large organic debris in northwest streams. Proc. Symposium on Logging Debris in Streams II. Oregon State University, Corvallis. 10 p.

Sharpe, C.F. Stewart. 1938. Landslides and related phenomenon: A study of mass movements of soil and rock. Columbia Univ. Press. 137 p.

Sigafoos, R.H. and E.L. Hendricks. 1969. The time interval between stabilization of alpine glacial deposits and establishment of tree seedlings. USGS Prof. Paper 650-B. p. B89-B93.

Simonett, D.S. 1967. Landslide distribution and earthquakes in the Bewani and Torricelli Mountains, New Guinea: A statistical analysis. IN: Jennings, J.N. and J.A. Mabbutt. Landform studies from Australia and New Guinea. Cambridge Univ. Press. p. 64-84.

Swanson, F.J. and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geol. 3:393-396.

Swanson, F.J. and G.W. Lienkaemper. 1977. Physical consequences of large organic debris in northwest streams. Proc. Symposium on Logging Debris in Streams II, Oregon State University, Corvallis. 14 p.

Swanson, F.J. and M.M. Swanson. 1977. Inventory of mass erosion in the Mapleton Ranger District, Siuslaw National Forest. Forest Sciences Laboratory, Corvallis, Oregon. 41 p.

Swanston, D.N. 1967a. Debris avalanching from thin soils derived from bedrock. USDA Forest Service, Pac. NW For. and Range Expt. Sta. Res. Note, PNW-64, 7 p.

____________. 1967b. Soil-water piezometry in a SE Alaska landslide area. USDA Forest Service, Pac. NW For. and Range Expt. Sta. Res. Note PNW-68, 17 p.

____________. 1969. Mass wasting in coastal Alaska. USDA Forest Service, Pac. NW Forest and Range Expt. Sta. Res. Paper PNW-83, 15 p.

____________. 1970. Mechanics of debris avalanching in shallow till soils of southeastern Alaska. USDA Forest Service, Pac. NW For. and Range Expt. Sta. Res. Paper PNW-103, 17 p.

____________. 1973. Judging landslide potential in glaciated valleys of southeastern Alaska. Explorers Journal. Vol. 51, No. 4, p. 214-217.

____________, and C.T. Dyrness. 1973. Stability of steep land. J. Forestry. V. 71, p. 264-269.

____________, and F.J. Swanson. 1976. Timber harvesting, mass erosion and steepland forest geomorphology in the Pacific Northwest. IN: Geomorphology and Engineering, Donald R. Coates, ed. Dowden, Hutchinson and Ross, Inc. Stroudsburg, Penn. p. 199-219.

Takeda, Yasuo. 1972. A study on the foreknowledge of the dangerous regions through the transition of landslides in the mountain. J. of Japanese For. Soc. 54(4):126-134.

Terzaghi, K. and R.B. Peck. 1967. Soil mechanics in engineering practice. New York, John Wiley and Sons, 2nd ed. 729 p.

Tubbs, D.W. 1975. Causes, mechanics and prediction of landsliding in Seattle. Diss. Abstr. Int. V. 37, pt. 1, p. 664B. (Abstract).

U.S. Weather Bureau. 1964-1975 Climatological Data, Oregon Section. V. 70-81.

Williams, G.P. and H.P. Guy. 1971. Debris avalanches - a geomorphic hazard. IN: Environmental Geomorphology, Proceedings of 1st Annual Geomorphology Symposia series held at Binghamton, New York. State Univ. of New York at Binghamton, Publications in Geomorphology. p. 25-46.

Wu, T.H. 1976. Soil Mechanics. Allyn and Bacon, Inc. Boston, Mass. 2nd edition. 440 p.

Young, Anthony. 1972. Slopes: geomorphology text 3. Oliver and Boyd, Edinburgh, Great Britain. 288 p.

APPENDICES

APPENDIX A

Field Form

Debris Avalance Inventory

Date:

Identification and location ____

Failure size:

width ______ Est. vol. _____

length _____ Travel dist. ______

depth ______

Failure plane slope _____________

Bedrock description ____

Approx. age of failure _____

Hillside slope _______ Aspect _______ Elevation _______

Soil description ____

Depth ________ USFS soil-landform type __________

Principle debris jam vol. _______________ length _____

width at widest point __________

organic debris vol. est. _____

Remarks:

APPENDIX B

Data Summary

Drainage	Type	Failure Area (ft^2)	Failure Vol. (yd^3)	Aspect	SRI Landtype	Hillslope (%)	Travel Dist (ft)	Soil Depth (ft)	Year of Failure 19__	Principle Debris Jam Volume Inorganic (yd^3)	Principle Debris Jam Volume Organic (ft^3)	Entered Stream Channel?	Geomorphic Setting	Water in Scar?	Other
Undisturbed															
1-N	DT	1000	68	SE	41	60	414	2	74-75	37	50	yes	C	yes	
1-N	BS	150	9	NE	41	55	0	-	76	9	0	yes	C	no	FT
1-N	BS	40	4	NE	41	57	120	2-3	75	2	0	yes	C	yes	
1-N	DA	100	10	NE	41	55	20		76	9	0	yes	IC	no	
3-N	DA	72	4	SE	41	75	16	0.8	75-76	2	0	no	IC	yes	FT
3-N	DS	170	6	SE	41	85	10	1	72	6	0	no	TS	no	LS
3-N	DA	580	32	SE	41	97	(400)	1-2	72	-	-	yes	TS	yes	LS
4-N	DS	132	5	SW	421	100	11	1	72-74	5	0	no	HS	yes	FT
4-N	DA	972	191	NW	421	80	96	5+	76	201	198	yes	TS	yes	
5-N	DA	252	11	SW	44F	55	285	1	76	56	488	yes	TS	yes	
5-N	BS	100	6	SE	44F	60	10	1.5	74	6	0	yes	TS	no	
7-N	DS	288	11	SW	421	40	15	1	75-76	10	0	no	IC	yes	
7-N	DA	294	11	SW	421	60	17	1	74	10	0	yes	TS	yes	
7-N	DA	204	9	SE	421	75	14	1.2	74	5	0	yes	TS	no	FT
7-N	DS	100	7	SW	421	75	10	2	74	5	0	yes	TS	no	
7-N	DA	440	33	SW	421	70	20+	2	72	-	-	yes	TS	no	
7-N	BS	400	15	SW	421	72	-	1	73-74	-	-	yes	TS	no	FT
8-N	DA	1100	61	SW	42	70	55	2	67	36	318	yes	TS	yes	
8-N	DA	1102	41	SW	417	75	(492)	0.5	71-73	-	-	yes	TS	no	
8-N	DS	828	46	SE	417	90	12	1-2	-71	46	0	no	TS	no	MB
8-N	DS	840	31	SW	417	90	28	1	70-72	31	0	yes	TS	no	FT-MB
9-N	BS	96	7	SW	443	40	12	2+	74	-	-	yes	C	yes	slump
10-N	BS	120	5	NE	421	85	150	1-2	76	36	216	yes	C	no	
10-N	DT	340	38	NE	421	65	687	3-5	76	1692	2986	yes	IC-H	yes	
10-N	DS	110	8	SW	421	90	32	2	75	-	-	yes	TS	no	
10-N	DT	483	54	NE	421	92	219	3+	66	292	1495	yes	C	yes	MB
10-N	DT	500	56	NE	421	35	279	-	-66	same fan		yes	IC	yes	WT
10-N	DA	361	40	NE	421	60	90	6	74-75	120	151	yes	IC	no	MB
10-N	DT	341	51	NE	421	60	90	6	76	40	0	yes	IC	no	MB
10-N	DA	240	17	NE	421	85	180	1	73	53	1137	yes	IC	yes	MB
10-N	DA	702	130	NE	421	90	150	4-5	76	220	2495	yes	IC-H	yes	MB
10-N	BS	238	26	E	421	60	17	-	76	5	0	yes	C	no	MB
10-N	DA	575	21	SW	421	60	60	2	71	27	0	yes	TS	yes	FT
10-N	DA	280	21	SE	421	80	33	1-2	74-75	36	0	yes	TS	no	
10-N	DA	380	84	NE	421	50	140	7	75-76	-	-	yes	TC	yes	
11-N	DA	360	33	SW	414	90	35	3	66-71	-	-	no	HS	yes	MB
13-N	DT	258	30	SE	414	85	756	4-6	75	231	2000	yes	IC-H	yes	MB

APPENDIX B (cont.)

Drainage	Type	Failure Area (ft^2)	Failure Vol. (yd^3)	Aspect	SRI Landtype	Hillslope (%)	Travel Dist (ft)	Soil Depth (ft)	Year of Failure 19__	Principle Debris Jam Volume Inorganic (yd^3)	Principle Debris Jam Volume Organic (ft^3)	Entered Stream Channel?	Geomorphic Setting	Water in Scar?	Other
Undisturbed															
1-SU	DA	190	7	NE	44	78	383	3+	72-74	20	-	yes	IC	yes	MB
2-SU	DA	160	9	NE	47	100	200+	2	72-74	-	-	yes	IC	yes	LS
3-SU	DS	180	6	NW	41	97	50	1	74-75	2	0	yes	TS	yes	WT
3-SU	DA	104	5	NW	41	70	(1467)	1-2	67-72	same ledge		yes	C	yes	
4-SU	DA	90	2	NE	47	102	20	2	75-76	2	0	yes	TS	no	DT
4-SU	DA	224	21	NE	47	94	150+	2-3	67-72	-	-	yes	IC	no	WT-MB
4-SU	DT	300	17	NW	47	65	1000+	1.5	67-72	178	?	yes	IC-H	yes	
1-B	DS	252	9	NE	47	100	14	1-2	74-75	4	20	yes	IC	yes	LS
1-B	BS	80	3	NE	47	70	8	-	75	3	0	yes	C	no	WT-MB
1-B	DA	230	9	SE	47	100	77	2	74-75	33	0	yes	TS	no	FT
1-B	DA	307	12	SE	47	63	-	1	-72	diffuse		yes	TS	no	LS-MB
1-B	DA	315	30	NE	47	64	34	3+	62-65	21	0	yes	TS	no	WT
1-B	DA	2300	43	NW	47	100	(600)	1-2	68	diffuse		yes	HS	no	WT
1-B	DA	480	18	NE	47	100	180	1	72	18	0	yes	TS	yes	MB
1-B	BS	140	8	SE	47	80	38	6	76	2	0	yes	C	no	
1-B	DA	171	10	SE	47	85	-	2-3	75-76	-	-	yes	TS	yes	
1-B	DA	158	9	NE	47	90	20	3	76	5	20	yes	TS	no	MB
1-B	DA	624	81	NE	47	80	450	5-6	75-76	181	1350	yes	IC-H	no	
1-B	DA	2300	85	NW	47	92	300+	1	70-72	34	306	yes	TS	no	WT-MB
1-B	DA	440	8	NW	47	80	300+	1	70-72	same fan		yes	IC	no	MB
3-B	DS	816	24	SW	47	90	20	1	70-72	-	-	no	TS	no	
4-B	DA	40	3	SW	41	70	410	2-3	74-75	31	0	yes	IC	no	WT
4-B	DA	180	2	SE	41	-	-	1	-	-	-	yes	IC	no	ledge
5-B	DA	240	4	NW	47	80	20	1	72-74	-	-	yes	TS	yes	seep
5-B	DA	450	17	NW	47	110	90	1-2	chronic	-	-	yes	IC	yes	seep
5-B	DA	225	8	NW	47	90	25+	1	70-74	-	-	yes	IC	yes	seep
6-B	DA	238	4	SE	417	98	20	1	68-71	3	0	no	TS	no	
6-B	DA	680	38	E	417	80	40	2	67-70	10	0	yes	TS	no	
Clearcuts															
1-SU	DT	600	89	SE	47	100	990+	5		-	-	yes	IC	yes	
1-B	DA	600	11	SW	47	86	50	1		11	0	no	IC-H	no	
1-B	DS	102	3	SE	47	85	7	0.8		3	0	no	TS	no	
1-B	DA	472	35	SW	47	82	110	2+		20	0	no	HS	no	
1-B	DA	300	7	SE	47	104	60	0.5		diffuse in slash		yes	TS	no	LS
1-B	DT	260	14	NW	47	85	484	1.5		337	2293	yes	IC	yes	

APPENDIX B (cont.)

Drainage	Type	Failure Area (ft^2)	Failure Vol. (yd^3)	Aspect	SRI Landtype	Hillslope (%)	Travel Dist (ft)	Soil Depth (ft)	Year of Failure 19__	Principle Debris Jam Volume Inorganic (yd^3)	Principle Debris Jam Volume Organic (ft^3)	Entered Stream Channel?	Geomorphic Setting	Water in scar?	Other
Clearcuts															
1-B	DA	600	31	SE	47	80	94	2-3		13	0	yes	IC	no	
1-B	DT	2750	122	NE	47	110	500	2-3		(900)	(2000)	yes	IC-H	no	
2-B	DA	1148	34	SE	47	90	43	1		-	-	yes	IC	no	
2-B	DS	272	10	NW	47	85	10	1		-	-	no	TS	no	
2-B	BS	357	46	SE	47	76	30	4-5		41	0	yes	TS	no	
2-B	DS	128	2	NW	47	90	8	1		2	0	no	HS	no	
2-B	DS	1200	36	NE	47	90	15	1-2		-	-	no	TS	no	
2-B	DA	247	11	NW	47	84	50	1-2		10	0	yes	C	no	
2-B	DS	408	15	NW	47	84	15	1		-	-	no	HS	no	
2-B	DA	3855	81	NW	47	104	500	1		750	(3000)	yes	TS	no	
2-B	DA	96	4	SW	47	-	-	-		-	-	yes	IC	no	
2-B	DT	1300	48	NW	47	80	860	1-2		560	(3000)	yes	IC	no	
2-B	DT	1050	78	NW	47	80	641	2		47	242	yes	IC-H	no	
2-B	DT	696	64	SW	47	88	802	4-5		550	824	yes	IC-H	no	
2-B	DT	2146	183	NW	47	82	552	4		233	405	yes	IC-H	no	
3-B	DA	451	22	NW	41	84	31	2		-	-	no	HS	yes	seep
5-B	DA	1200	36	SE	47	100	200+	0.8		-	-	yes	TS	no	MB
5-B	DA	700	10	SE	47	68	100	1		diffuse		no	HS	no	
5-B	DS	480	11	NW	47	98	50	1		diffuse		no	HS	no	felling
5-B	DA	1220	23	NW	47	90	100	1		-	-	yes	TS	no	
5-B	DA	480	27	NW	47	84	88+	2-3		-	-	yes	IC	no	
6-B	DS	594	22	SW	47	90	20	1-2		22	0	no	HS	no	
6-B	DA	494	64	NW	47	84	150	4-5		diffuse		no	IC	no	
53C3	DT	903	100	SW	41	70	1370	4-5		750	2767	yes	IC-H	yes	
53C3	DA	100	4	SW	41	100	30	1+		4	0	yes	TS	no	
53C3	DT	760	56	NW	41	94	1150	3-4		150	2651	yes	IC-H	no	
59A1	DA	360	11	NW	44	81	25	1-2		10	0	no	TS	no	
19C3	DA	200	11	SE	44	-	40	2		-	-	yes	IC-H	no	
19C3	DA	712	19	NE	44	100	100	1-2		55	0	yes	C	yes	
3B5	DA	676	25	NE	41	90	300	1		480	0	yes	IC-H	no	
3B5	DA	550	11	NE	41	100	90	0.5		74	0	yes	IC	no	
3B5	DA	550	33	NE	41	90	270	1.5		400	0	yes	C	yes	
3B5	DT	1760	196	SE	41	73	1450	3+		985	500	yes	IC-H	no	

APPENDIX C

Definitions of Table Notation

Failure Type

Debris avalanche (DA): rapid shallow-soil mass movement involving the soil mantle and some rock fragments. Debris avalanches are usually triggered by intense storms, when the soil mantle approaches or becomes saturated. The mass disintegrates during movement down a typically narrow track or chute.

Debris slide (DS): these are similar to debris avalanches, but the mass does not disintegrate substantially and/or move far. These are common as soil slips off bedrock ledges.

Debris torrent (DT): rapid movement of water-charged debris down a stream channel. The slurry of debris often scours the channel to bedrock for several hundred feet or more. Debris torrents may often be triggered by debris avalanches entering stream channels during storm events.

Bank slough (BS): small mass movements involving soil material directly adjacent to a stream channel. These are often the result of undercutting by the stream channel and may often be related to high pore water pressure at the base of hillslopes. When these extend 20 feet or so up the bank, they are classed as a DA from the toeslope.

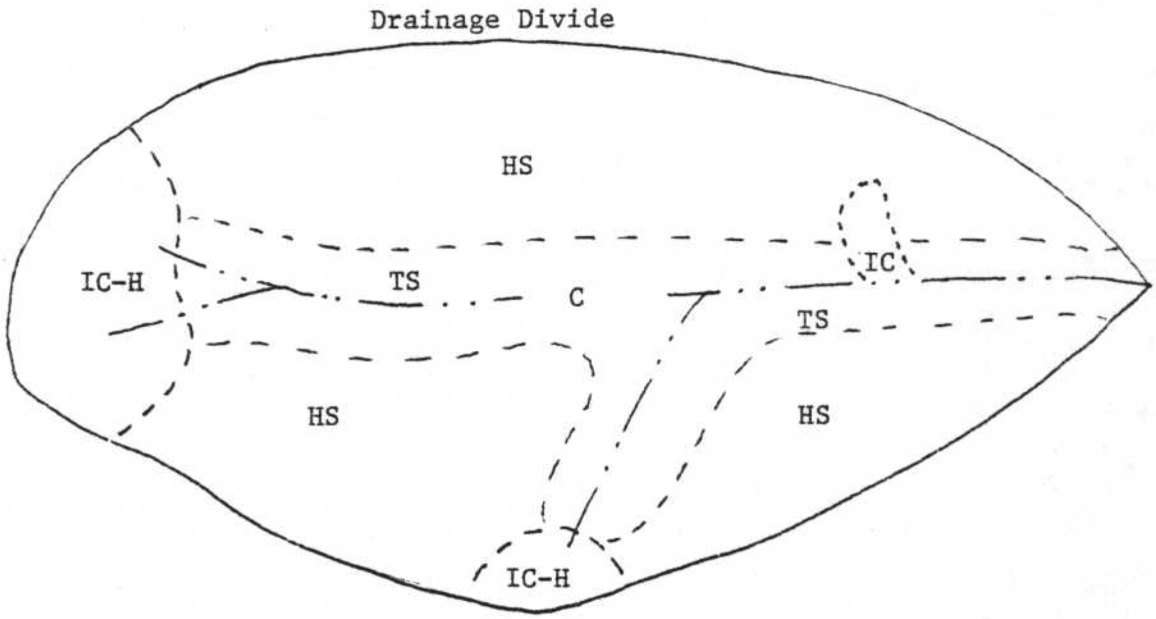
Geomorphic Setting

Channel (C): failures involving bank and bed materials of a well-defined stream channel are designated C.

Incipient channel (IC): failures originating in hillslope depressions in which no definite channel had formed. When located in headwall depressions, the failure is designated IC-H.

Toeslope (TS): failures involving the lower hillslope and/or upper bank material. A change in slope 100 feet or so above many channels was used to distinguish toeslope failures from;

Hillslope (HS): failures originating on the upper slopes.



<u>Other</u>

WT - windthrow: failures that appeared to have been triggered by uprooting forces during windthrow of a tree(s).

FT - fallen tree: impact of the bole of a large tree on the slope may have triggered some slides. This includes WT but is not related to upheaval by the root system.

LS - log slide: large logs sliding down a slope may dislodge varying amounts of the soil mantle.

MB - mountain beaver: tunneling in and around failure scars was common.