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ECOLOGICAL AND GEOMORPHOLOGICAL CONSEQUENCES OF MASS MOVEMENTS IN THE ALDER CREEK WATERSHED AND IMPLICATIONS FOR FOREST LAND MANAGEMENT

by

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INTRODUCTION

With increased demand of resources from our western forests the understanding of problems associated with the management of steep unstable forest land becomes more crucial. There is need for more interdisciplinary study of factors effecting mass soil movement and the subsequent longterm consequences of these events. This study, begun in April 1974, is an exploration of the ecological and geomorphological significance of mass movement processes in a small watershed in the Western Cascades Mountains of Oregon.

Two major classes of mass movement processes are operating in the low elevation Western Cascades. Slow deep-seated mass movements which generate a hummocky earth flow topography affect relatively large areas of some watersheds. As these encroach on stream channels, sediment is contributed due to shallow slumping along the toe and margins of the earthflow. The second class of mass movements includes shallow slumps, rapid earthflows, debris avalanches, debris slides, and debris torrents. Under forested conditions these events appear to occur infrequently and are often associated with the large deep seated failures. Forest fires which recur periodically in this region may also appear to accelerate mass soil movement. Once steep hillslopes have been altered by roadbuilding and clearcutting, shallow soil mass movement becomes an important erosional process and

contributes a significant amount of sediment to stream channels. The shallow soil mass movements (hereafter called landslides) usually create scars on the steep hillslopes which are then vulnerable to subsequent erosional forces. Revegetation of these landslide scars is slow and trees often appear stunted.

In this study I have documented the various mass movement phenomena operating in the Alder Creek watershed. Both natural and man induced landslides occurring over a 90 year period were mapped and measured in order to determine the impact of forest management activities on erosion rates in the watershed. Slow deep seated earthflows were mapped and efforts were made to determine whether they are active or presently stable. Other than measuring shallow mass movement scars associated with the slow earthflows, no attempt was made to measure the rate of movement or the amount of material transported by earthflow processes.

Stream channels scoured by debris torrents were mapped and measured in the study area. Debris jams composed of a tangle of logs, rocks, soil, and other debris were also mapped. The possible impact of these phenomena on stream ecosystems is briefly discussed.

Although studies similar to this have been carried out in the H.J. Andrews Experimental Forest, only 23 miles north east of the study area, there is need to establish a broader understanding to determine if the findings of those studies are representative of slope stability

conditions throughout the Western Cascades. Also I am interested in comparing the impact of management activities in a typical Forest Service management unit with the impact of closely supervised and highly regulated management activities occurring at the Experimental Forest.

In order to assess the long term impact of the landslides on forest productivity I have made observations of secondary erosional processes and revegetation on the landslide scars. Several techniques were experimented with in determining the rate of erosion due to surface run off, dry raveling and freeze-thaw activity. Plant succession was observed on a chronosequence of landslide scars varying from about 3 to 90 years in age. This information should be of use to forest managers in determining the impact of shallow soil mass movements on the timber growing base.

REVIEW OF PAST STUDIES

Mass movements in forested regions of the Pacific Northwest have been investigated by several authors. However no study has been published that discusses secondary erosional processes once landslides occur. Also there is only scant information about revegetation on landslide scars in the Pacific Northwest.

Early general work on landslide processes was done by Varnes (1958), Terzaghi (1936,1950), Terzaghi and Peck (1968) and others. These investigators layed the foundation for the classification of landslide events and the study of slope processes influencing stability.

Bishop and Stevens (1964) conducted the first extensive survey of landslide activity on steep forested land in the United States. In their southeastern Alaska study area they found that clearcut logging on steep slopes accelerated the occurence of debris avalanches during heavy rainstorms. They noted that certain hillslope localities were more prone to mass movements than others. The decline of tree rooting strength after logging was considered to be an important factor contributing to failure.

Subsequent work in Alaska by Swanston (1969, 1970, 1974) expanded on the earlier studies. Excessive pore water pressure during periods of high precipitation was concluded as the triggering factor for mass movement events. Soil cohesion and shear strength are again suggested to be

influenced by the presence of viable tree roots. Active soil creep was observed and suggested as a mechanism for stress buildup which increases slide susceptibility.

In Oregon, landslide phenomena on forested lands was first discussed by Fredriksen (1963) after a landslide originating at a logging road scoured out 3,000 feet of stream channel. Catastrophic storms in December 1964 and January 1965 produced a large number of landslides in the H.J. Andrews Experimental Forest which have been the topic of much subsequent investigation, (Fredriksen, 1965, 1970, and Dyrness 1967). These studies indicated that roadbuilding was a prime contributing factor to accelerated soil mass movement. The number of slides per unit area in clearcuts was nearly ten times that in the undisturbed forest.

Swanson and James (1975a, 1974b) and Swanson and Dyrness (in press) have further documented the mass movement history in the H.J. Andrews Forest. They have mapped landslides occurring over the last 25 years as well as deep - seated mass movements which have been active for many thousands of years. Geologic mapping of the area facilitiated in the conclusion that many slope stability problems originate below a contact zone where lava flows cap altered volcaniclastic rocks. Slow deep seated mass movements originating in this zone may travel over a mile in some instances and contribute a significant amount of sediment to drainageways along their margins.

Recent work by O'Loughlin (1972a, 1972b) in the forested coastal mountains of British Columbia indicates that although landslides are less frequent than in the Alaska and Oregon study areas, landslides still constitute the principal erosional process operating in that region. His study of tree rooting strength is particularly informative since it documents the speculation of many previous authors that rooting strength contributes significantly to soil strength.

Debris avalanche occurrence after forest fire in Washington was discussed by Helvey (1973). Several studies of landslides in forests in the Idaho Batholith discuss the relationship between stability and forest management activities (Craddock, 1967; Gonsior and Gardner, 1971; Megahan and Kidd, 1972).

Secondary erosional processes on landslide surfaces have not been investigated to the author's knowledge. Mersereau and Dyrness (1972) investigated dry ravel processes in clearcuts in the Western Cascades and this is directly applicable to the situation on landslides. Surface erosion in agricultural lands has been intensively investigated by numerous authors.

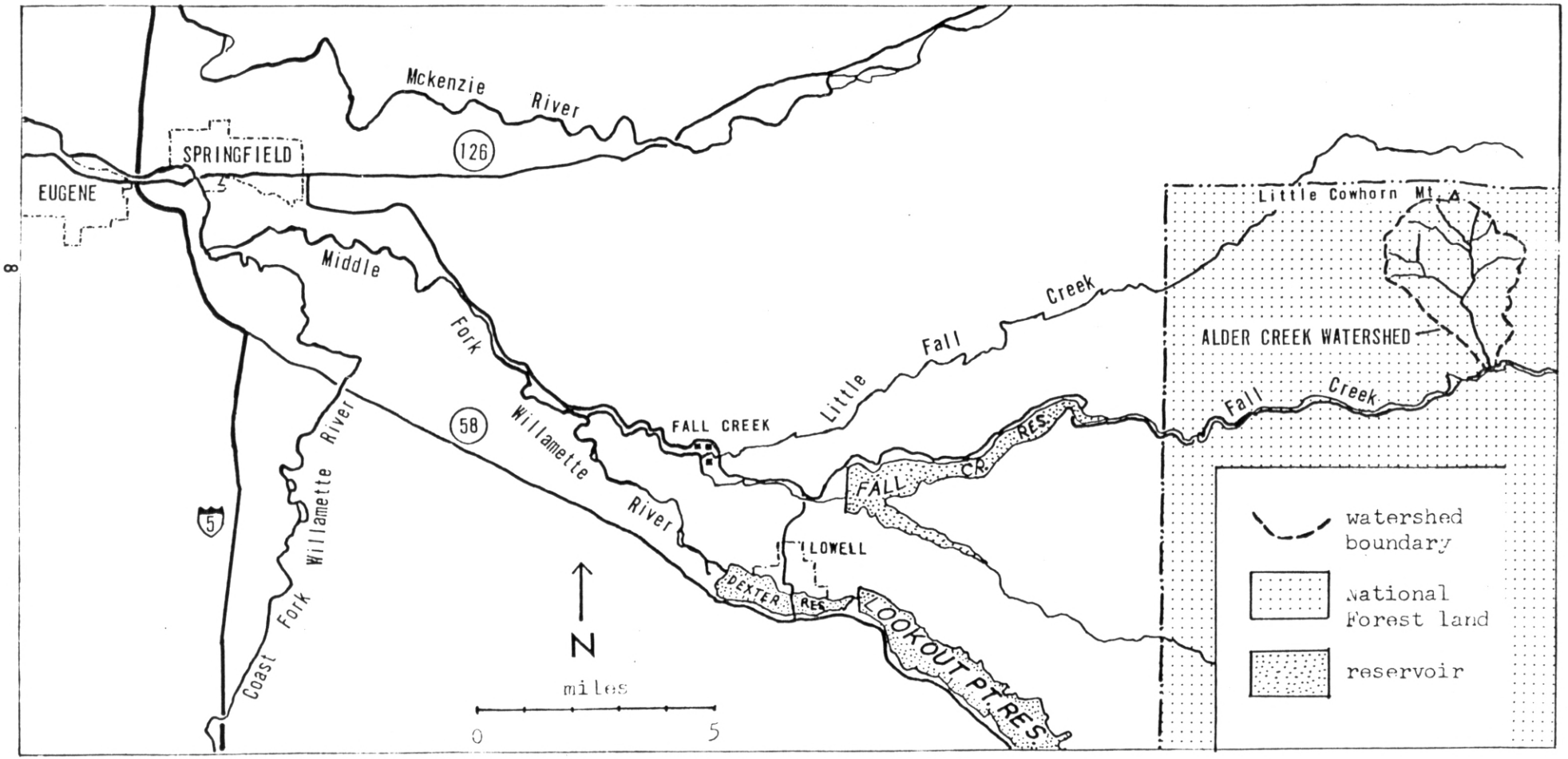
Plant succession on landslides was studied by Flaccus (1959) in the White Mountains of New Hampshire. His study was primarily restricted to landslide deposits but general observations of revegetation of landslide scars was included.

He noted that revegetation was very slow on the scars and often herbaceous and shrubby vegetation predominated for over 30 years. Trees appeared chlorotic in many instances.

O'Loughlin (1972b) briefly discusses revegetation on landslides in British Columbia. He noted that Red alder (Alnus rubra) frequently colonizes landslide scars and that a stunted coniferous forest is found on old landslides.

Figure 1

LOCATION OF ALDER CREEK STUDY AREA



DESCRIPTION OF THE STUDY AREA

Geographical setting

The Alder Creek watershed which is part of the drainage area of the Middle Fork of the Willamette River, was chosen as the site for this investigation of the impact of mass movement processes on forest and water resources. It is characteristic of parts of the Western Cascades where erosion problems associated with road building and logging are severe. Alder Creek is a tributary of Big Fall Creek and lies eight miles upstream from Fall Creek Reservoir. The study area is approximately 45 road miles east of Eugene, Oregon.

Most of the study area lies below 3000 feet in elevation. Little Cowhorn Mountain rises to 4200 feet on the northern edge of the area and is the highest point. The confluence of Alder Creek with Big Fall Creek lies at about 1180 feet. The total area of the Alder Creek watershed is 6.73 square miles or 4,306 acres. (Figure 1)

The watershed is part of the Lowell Ranger District of the Willamette National Forest. Annual timber sales in the area provide employment and raw timber for residents and industries in the Eugene, Springfield, Jasper, and Lowell areas.

Climate

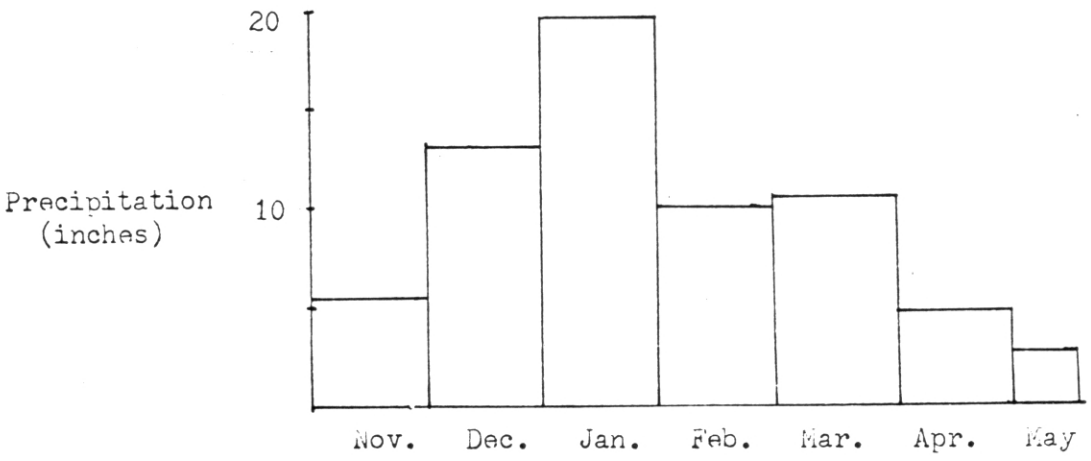
The climate of the study area is typical of the maritime conditions prevalent throughout the Western

Cascades. Winters are wet and mild, while summers are relatively dry and cool. In the winter long periods of moderate intensity rain result as moist warm air masses from the Pacific cool as they rise over the Cascades. Most of this precipitation falls between November and March. During cold weather snow showers are common. Snow levels vary throughout the winter, but above the 4,000 foot level most precipitation falls as snow during the winter. The zone between 3,000 feet and 1,500 feet is marked by periods of snow accumulation followed by periods of fairly rapid melting. Intense storms occur periodically. On December 18-20, 1957 12.51 inches of rain fell in three days in the H.J. Andrews Experimental Forest (Rothacher, Dyrness, and Frediksen, 1967). During December 1964 and January 1967 other intense storms occurred in this area. During these storms, warm rain and condensation melt accumulated snowpack and add additional water to the soil and to stream flow.

Alder Creek lies above the 80 inches of precipitation per year isohyetal line (Legard and Meyer, 1973). A rain gauge was maintained at 1,800 feet in a clearcut in the Alder Creek watershed. Between November 10,1974 and May 10 1975 67.7 inches of precipitation were recorded. A graph showing the monthly distribution of this precipitation follows (Figure 2).

Figure 2

Precipitation at Alder Creek, November 1974 through May 1975



Geology

No large scale geologic mapping is available for the Alder Creek watershed. In a reconnaissance map of the Western Cascades, Peck et al. (1964) portray the entire study area as underlain by tuff, lapilli tuff and less abundant domes and flows of andesite, dacite and rhyodacite of the Little Butte Volcanic Series. The Little Butte Formation originated from a widespread series of eruptions of Oligocene and early Miocene age as dated by Peck using paleobotanical evidence.

Personal observations reveal that the portion of the watershed under 3,000 feet appears to be underlain by greenish to reddish massive tuff-breccias with occasional zones of welded tuff and fine - grained waterlain tuff.

Above this elevation welded tuff and flows of basalt and andesite are common. These resistant rocks cap the easily eroded breccias and form the tops of the present ridges. Swanson and James (1975a) observed that this capping effect prevents the development of a stable slope profile. The underlying breccias are left in an oversteepened condition which is prone to deep seated mass movements and landslides.

Geomorphology

Most of the study area consists of steep, very dissected valley sides. Hill slopes average over 30° in the lower two thirds of the watershed. In the upper portion of the watershed moderately sloped and somewhat hummocky surfaces are also common. Deep-seated mass movements are responsible for the development of this landform. These deep-seated mass movements generally originate at a contact zone between hard capping flow rocks which form the ridges and weathered and plastic pyroclastic rocks. These mass movements are described in detail later in this paper.

Fluvial and mass wasting erosional processes have shaped the present topography. The presence of old landslides and stream scoured areas indicate that the areas not affected by the deep seated earthflows are incised by occasional landslides under undisturbed forested conditions. Although overland flow is seldom observed under forested conditions it probably contributes to considerable surface

erosion during periods of bare ground following forest fire.

Alder Creek is a fifth order stream in its lower reaches. The streams throughout the watershed generally occupy narrow "V" shaped channels and are actively downcutting. Alluvial terrace deposits are present along the lower portion of Alder Creek and it appears that the stream is reworking this material. Alluvial fan deposits occur where many tributary streams enter the main channel of Alder Creek. These appear to be formed by the accumulation of material from periodic debris torrents as well as bedload deposited during peak storm discharges (Swanson and James, 1975 b).

Vegetation

The major portion of the study area is in the Tsuga heterophylla zone of the Western Cascades. A small portion on the flanks of Little Cowhorn Mountain reaches into the Abies amablis zone. Many of the climax associations identified by Dyrness, Franklin and Moir (1974) are represented in the watershed.

Fire has periodically burned sections of the watershed. Seral stands where Pseudotsuga menziesii is dominant are common. Stand ages vary considerably. The oldest stands in the watershed are over 400 years old. These originated after a fire in 1560 AD (Willamette National Forest TRI System data).

Soils

There is considerable variability in the composition, structure, depth and stability of the soils in the watershed. A reconnaissance level soil - landtype map prepared by

Legard and Meyer (1973) covers the study area and this portion is reproduced in Figure 3. Descriptions of the soil types and erosional characteristics are included in an appendix to this report.

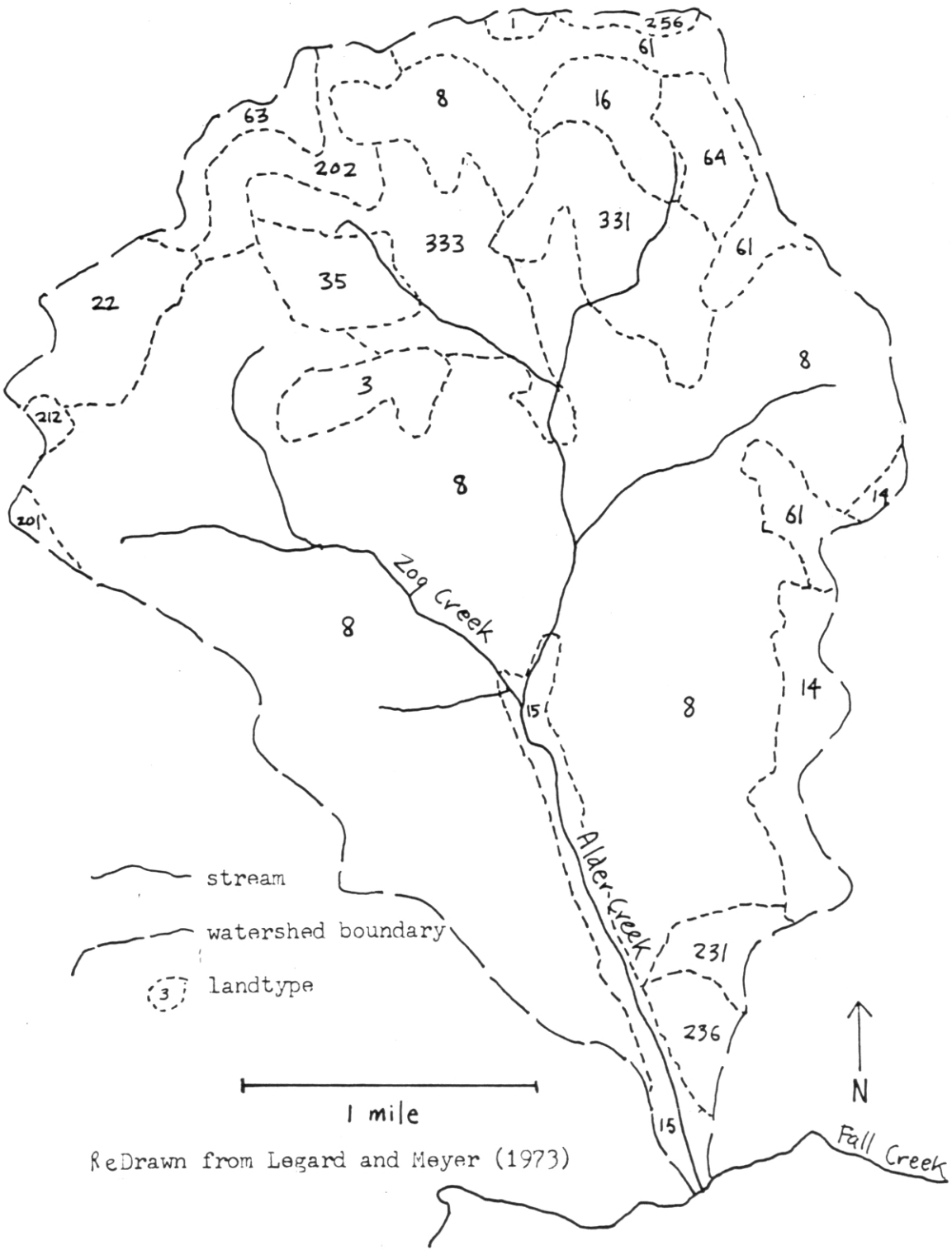
Soil - landtype 8 occupies a major portion of the watershed where residual soils occupy steep, dissected hillslopes composed of weathered pyroclastic rocks. The actual soil composition is highly variable; therefore Legard and Meyer make no attempt to describe it in their report. This area is the most susceptible to landslide activity in the watershed. A description of a sample of this soil taken in T. 18 S., R.3 E. Sec. 18 is included below. It is representative of the structure and composition of this soil type in most of the watershed but depth of various horizons varies greatly from one locality to another.

0 - 2.5 inches	Litter, decomposed litter, angular pebbles up to 3". Roots abundant.
2.5 - 5 inches	Clay loam, fine granular structure, some small pebbles and iron nodules, roots and mold common.
5 - 13 inches	Clay with some pebbles up to 2", fine subangular blocky structure, roots.
13 - 25 inches	Clay with some sand and pebbles, fine subangular to angular blocky structure, roots.
25 - 31 inches	Clay with mottles of yellow and red, fine subangular to angular blocky structure, roots.
Below 31 inches	Weathered volcanic breccia, clay in seams in upper portion.

Soils in the rest of the watershed occupy more gentle slopes. Much of the upper portion is composed of slightly

Figure 3

LANDTYPE MAP ALDER CREEK WATERSHED



ReDrawn from Legard and Meyer (1973)

plastic to plastic landforms on hummocky sideslopes and benches. These soils are formed from green breccias but fragments of other rocks are not uncommon in the profile. Clay loam to clay subsoils predominate. Some steep areas of rock and talus are found below the ridgetops.

Deep-seated mass movements play an important role in forming the soils in the upper part of the watershed. Considerable churning is evident in the soil profile. The depth of the soils on the steep side slopes in the lower portion of the watershed appears to be controlled to a great degree by aspect which controls weathering rates. Soils on north aspects are often much deeper than soils on south aspect slopes.

History of Forest Managment Activities

The study area remained in an undisturbed condition until 1950 when high lead logging began in unit G14B1 and P25C2 below Gibralter Mountain. Previous to this a lookout station had been maintained on Little Cowhorn Mountain and was serviced by trails. Road building during the 1950's was confined to the perimeter of the watershed and very few roads extended into the study area. These roads were all confined to ridgetops.

In the early 1960's Roads 1857 and 1814A were constructed on west and east sides of the watershed. Both roads are midslope roads traversing generally long, steep, unbroken

hillslopes. High lead logging of various clearcut units commenced before these roads were completed and continued throughout the 1960's. An active logging operation is presently underway on Road 1814A.

During the 1960's Road 1806 was completed around the top of the watershed and several units were logged. Later in 1970 a connecting road to Road 1814A was built across hillslopes in the upper portion of the watershed. Several spur roads were also built. High lead logging of various clearcut units began in the early 1970's along these roads and is still active today.

Most of the clearcut units were broadcast burned after logging ceased. All but the most recent units have been artificially replanted with Douglas-fir seedlings. Growth and survival of the planted Douglas-fir varies. Many areas have adequate stocking whereas other areas are dominated by Ceanothus velutinus and Acer circinatum.

As of December 1974, 16.85 miles of roads had been constructed within the study area. This was determined by tracing road mileage off a 1:15,840 scale map. Presumably these were constructed to Forest Service standards for all-weather roads. Assuming 8 acres per mile of road, which is an average used in the H.J. Andrews Experimental Forest (Swanson, personal communication), 134.8 acres in the study area are in road right-of-way. In a study by Fredriksen (1970) of a small patch-cut watershed in the Andrews Forest 9.45 acres of road right-of-way were associated with each mile

of road. Using this figure, 159.3 acres or 3.7 %of the Alder Creek watershed are in road right-of-way. For purposes of this study 150 acres or 3.5% of the area will be considered in road right-of-way.

As of December 1974, there were 26 high lead clearcut units in the study area. Generally these were arranged so that alternate units of forest were left uncut. At that time 1119 acres had been clearcut (Forest Service records). This comprises 26% of the total study area.

A map of all clearcuts and roads in the watershed is provided in Plate 2 .

AREAS OF INVESTIGATION

AN ANALYSIS OF MASS MOVEMENTS IN THE ALDER CREEK WATERSHED: THEIR HISTORY AND RELATIONSHIP TO LAND USE AND OTHER ENVIRONMENTAL FACTORS.

Methods

The mass movements in the study area are grouped into two major classes, shallow soil mass movements and slow, deep-seated mass movements. The locations of all mass movements were plotted on two 1:15,840 topographic maps [Plate 1 and Plate 3] . Forest Service air photos taken in the summers of 1946,1959, 1967 and 1972 aided in the identification and approximate dating of the landslides. Specifications of these photos are included in Table 1. Extensive field work verified these observations and revealed a significant number of small events which were not visible on the air photos.

Table 1

Specifications of Aerial Photography

YEAR	FLIGHT NAME	FLIGHT DATES	SCALE	FILM TYPE	COVERAGE
1972	F16 41043	7-15-72 7-27-72	1:15,840	color	complete
1967	ESF	7-4-67 7-10-67 8-19-67	1:15,840	black and white panchromatic	complete
1959	EGI	5-30-59 6-2-59 6-8-59	1:12,800	"	"
1946	DEK	9-12-46	1:24,000	"	southern 7 of study a

The shallow soil mass movements were classified into a variety of types based on descriptions of landslides by Varnes (1958), Dyrness (1967) and Swanson and James (1975a). These types include slumps, rapid earthflows, debris slides, debris avalanches, road washouts and debris torrents causing channel scour.

The shallow landslides were measured with a Toko Duo-Sight range-height finder. One landslide was measured with a tape measure, stadia rod and hand level and checked against the range finder measurements. Volume estimates for most landslides were obtained by measuring the overall length and the width of a number of cross sections. A number of vertical depths were measured along each cross section with the range finder. These were later converted to the depth perpendicular to the slope of the original land surface by multiplying by the cosine of the slope.

In most cases a uniformly planar hillslope was presumed as the original surface before failure. In cases where the landslide occured in a depression or drainageway the local topography was taken into consideration in estimating the depth of the failure. Small cutbank failures and fillslope failures were often approximated as parabolic or elliptical sections and depth estimated by eye. This necessitated taking fewer measurements with the range-finder. Only landslides with a volume greater than 100 cubic yards were included in the tabulated results. A computer program was developed to

process the great volume of data generated by this measurement proceedure.

In addition to dimensional characteristics of the landslides, note was made of the slope angle, aspect, landuse setting, geomorphological setting, bedrock, revegetation status, surface erosion features, elevation and probable date of occurrence. The landslides were roughly dated using the available aerial photography. Many of the larger landslides were dated by dendrochronological methods. Scars due to impact of landslide debris on living trees provided the most accurate dates. In some instances growth release of small trees adjacent to the scar or growth suppression of trees whose roots were sheared or exposed provided an accurate date. Other landslides were dated by the oldest plant growing on the scar. Two years were added to this date as this was generally the minimum lag time for tree regeneration on accurately dated scars. The age of some landslides was estimated by comparing revegetation with that of dated landslides.

Canopy breaks in undisturbed timber were identified as possible landslide sites on aerial photographs and then visited on the ground. Many of such sites turned out to be rocky openings and cliff scarps. Because it was not possible to traverse the entire undisturbed portion of the watershed it is quite possible that some small landslides have been left out of the survey. The volume attributed to those small slides which occurred in the undisturbed forest but were not identified on air photos or ground traverses appears to be

insignificant relative to the volume of material moved by the landslides which were measured.

Slow deep-seated mass movements were identified on air photographs and on the ground by broken canopy, active tension cracks, poorly drained depressions, active headwall scarps, highly unstable streamside areas, tilted , bowed and eccentric trees, and by their characteristic hummocky and somewhat subdued topography. The general boundaries of these mass movements are delineated on Plate 3.

Resolution of Mass Movement Events and Mass Movement Volumes through the Time Period of the Study.

Resolution in the identification of mass movement at Alder Creek was determined by scale and quality of the aerial photographic record, by the extensiveness of ground surveys and by the age of events studied. Twelve landslides were surveyed that occurred in a sixty-five year period (1885-1950) prior to any logging and road construction in the drainage. An additional eight landslides were surveyed that occurred in the undisturbed forest between 1950 and 1975. Since forest canopy tends to obscure small landslides rendering them invisible on air photos and complete ground survey of the study area was impossible, it is highly likely that only a fraction of the smaller landslides occurring in the undisturbed forest. were included in the inventory.

As plant cover develops on landslide scars they become increasingly difficult to distinguish from the surrounding forest. This factor plus the lack of quality and partial coverage of the 1946 air photos makes it difficult to distinguish some landslides occurring prior to 1950. Resolution in the identification of landslides therefore diminishes with increasing age. It is useful to estimate the minimum resolution for different time periods in the study.

Over the last 25 years (1975-1950) it is estimated that a minimum of 80% of the landslides over 100 cubic yards occurring in undisturbed forest were included in the inventory.

This estimate is based on the excellent air photo record during this time period and observations of revegetation of landslide scars. Revegetation on most landslides 10 to 25 years old does not appear to be sufficient to render them unrecognizable on the ground or on air photos. Generally they remain partially unvegetated or covered with low stunted vegetation through this period. It is also estimated that 90% of the volume moved by landslides occurring in undisturbed conditions during this time period can be attributed to the landslides included in the inventory. This estimate is due to the fact that landslides with large volumes are easily identified on air photographs.

Estimates of the resolution of landslide observation during other time periods are presented in Table 1. Observation of plant succession on landslides indicated that herbaceous and shrubby vegetation is still predominant on landslides 30 to 50 years old. Therefore it is estimated that at least 60 % of the landslides occurring in undisturbed forest can be discerned on the air photos.

Over a ninety year period resolution in the identification of landslides diminishes. Several landslides 60 years or more in age were identified and two landslides about 90 years old were found. On the 90 year old landslide scars a stunted coniferous forest had developed which is distinguishable from the surrounding forest canopy on 1972 color air photos. But due to the difficulty in distinguishing such landslides

TABLE 1

ESTIMATED RESOLUTION OF LANDSLIDE OBSERVATIONS IN UNDISTURBED FOREST THROUGH TIME.

Period	1975-1950	1975-1915	1975-1875
Length of period (years)	25	60	100
% of number of slides surveyed occurring in undisturbed forest	80%	60%	40%
% of volume of slides surveyed occurring in undisturbed forest	90%	65%	45%

it is estimated that over the last 100 years only 40% of all landslides occurring in undisturbed forest were included in the inventory. These landslides probably include at least 45% of the volume moved by landslides in that period.

In 1950 roadbuilding and logging commenced in the study area. Landslides larger than 100 cubic yards which subsequently occurred in clearcuts and at roads were easily discerned on air photographs and by field observation. Therefore nearly 100% of all landslides associated with roads and clearcuts were included in the inventory.

Results

During the study 114 shallow soil mass movement scars and 15 scoured stream channel areas were identified, measured and described on the ground. A total volume of 255,240 cubic yards of soil and rock debris were moved by these

events. Of this total, 102 landslides and eleven scoured stream channel areas accounting for a total volume of 214,500 cubic yards of transported material occurred during the last 25 years. The total volume moved by individual landslides ranged from the minimum volume of cubic yards to 18,900 cubic yards. Landslides under 800 cubic yards in volume were the most common, comprising 56% of those measured. Landslide frequency decreased as volume per slide increased (Figure 4).

Although the small landslides were the most frequent, they constitute only a small fraction of the total volume of material transported. The cumulative volume moved by landslides less than 800 cubic yards in volume is less than 10% of the total volume moved by landslides. A histogram of the cumulative volume of landslides of different size classes indicates that landslides in the volume range between 6,400 and 12,800 cubic yards account for the greatest percentage of the volume (Figure 5).

All the landslides and stream scours are plotted on a scale of 1:15,840 [Plate 1] . Descriptive data on each landslide, including type of slide, land use setting, slope, aspect, area, volume, elevation and age are included in Table 2. Data on the stream scoured areas are included in Table 3.

Landslide types varied considerably, and it was often difficult to distinguish from the landslide scar and deposit the

Table 2
LANDSLIDE DATA

LANDSLIDE	TYPE OF SLIDE	LAND USE	SLOPE (°)	ASPECT	AREA ft²	VOLUME yd³	ELEVATION ft.	AGE yrs.
1	D AV	RF	40.00	N	37720.00	4509.11	1700	10
2	D AV	RF	38.00	N	35250.00	4166.69	1850	8 -10
3	D AV	RF	38.00	NE	44587.99	5502.67	1850	8 -10
4	D AV	RF	37.00	N	54840.00	9611.64	1850	10 -13
5	D SL	RF	42.00	N	9750.00	509.19	1850	8 -13
6	D AV	RF	43.00	NW	17566.66	1958.58	2000	10
7	D AV	RF	42.00	N	19333.33	2454.44	2000	8 -13
8	D AV	RF	42.00	N	9815.00	1258.38	2000	8 -13
9	D AV	RF	42.00	SE	6825.00	637.50	1920	8 -13
10	D SL	RF	40.00	E	10925.00	1246.59	1920	8 -13
11	D AV	RF	35.00	N	22050.00	3657.05	2000	8 -13
12	D AV	RF	38.00	N	31793.33	4232.50	2000	8 -13
13	SLMP	RC	39.00	E	1399.96	155.55	2300	8 -13
14	D SL	RF	42.00	E	22165.00	1954.15	2100	3 -8
15	D AV	RF	41.00	N	67857.94	14706.87	2200	10
16	D AV	RF	40.00	NE	49455.00	9180.38	2200	10
17	D AV	RF	38.00	N	66843.75	15164.69	2200	10
17	D AV	RF	36.00	N	9000.00	942.74	2200	10
18	D AV	RF	39.00	NE	87228.19	18939.51	2200	10
19a	D AV	RF	45.00	N	68604.13	11795.16	2240	8 -13
19b	D AV	RF	39.00	NE	11500.00	1357.12	2240	8 -13
20	D AV	RF	44.00	N	64487.50	7408.59	2240	8 -13
21	D AV	RF	36.00	NE	3703.33	324.25	2300	8 -13
22	D AV	RF	39.00	N	7130.00	1270.73	2300	8 -13
23	D SL	RF	39.00	E	5595.97	310.89	2300	8 -10
24	SLMP	RC	38.00	NE	8482.32	1256.64	2300	8 -13
25	D AV	RF	40.00	SE	15000.00	709.30	2850	3 -8
26	D SL	RF	39.00	N	4993.87	185.18	2300	8 -13
27	SLMP	RC	38.00	N	11666.37	2592.53	2300	8 -13
28	SLMP	RC	38.00	N	1599.96	177.77	2300	8 -13
29	D AV	RF	37.00	SW	1003.31	111.48	2500	3 -8
30	RO M	RF	15.00	SW	600.00	279.04	2500	6
31	D AV	RF	26.00	W	35200.00	6508.08	3440	8 -13
32	D AV	RF	22.00	W	15840.00	1626.90	3440	8 -13
33	SLMP	RC	41.00	N	6333.17	1407.37	2300	8 -13
34	D AV	CC	41.00	NE	5610.00	496.57	2380	8 -13
35	D AV	CC	35.00	NW	6902.00	1054.50	2000	3 -8
36	D AV	CC	37.00	NW	10208.00	1704.69	1850	3 -8
40	D AV	RF	38.00	NW	3800.00	665.43	1950	8 -13
41	SLMP	RC	49.00	N	1633.29	725.91	2000	8 -13
42	D SL	RF	41.00	N	2133.28	316.04	2300	8 -13
43	D AV	RF	38.00	NW	43000.00	10094.71	2000	3
45	D AV	RF	40.00	NW	19840.00	2004.65	1850	3 - 8
46	D AV	RF	46.00	NW	9435.00	1191.41	1700	3 - 8
47	D SL	RF	39.00	SW	6720.00	696.93	2200	8-10
48	SLMP	CC	42.00	S	1335.18	148.35	1600	8-13
50	D AV	CC	44.00	NE	4250.00	567.53	1550	3-8
52	SLMP	CC	40.00	S	3000.00	170.23	2450	6-7
53	D AV	RF	36.00	SW	1335.18	296.71	2240	3-8
54	SLMP	RC	40.00	W	3061.06	680.68	2350	3-8
55	D AV	RF	39.00	NW	19525.00	2366.18	2300	3-8
56	D SL	RF	39.00	W	3825.00	495.34	2300	3-8
57a	CPLX	FRST	40.00	W	10367.50	1689.37	3040	60+ ACT
57b	CPLX	FRST	40.00	W	1237.00	229.07	3040	60+ ACT
58	SLMP	CC	42.00	S	8400.00	462.40	2560	16-?
59	SLMP	RC	42.00	S	15199.61	1688.85	3300	8-13

D AV = debris avalanche
D SL = debris slide
SLMP = slump
CPLX = complex failure associated with deep-seated mass movement

RF = road fillslope
RC = road cutslope
CC = clearcut
FRST = forest

Table 2 (continued)
LANDSLIDE DATA

60	SLMP	RC	43.00	S	4476.78	497.42	3300	8-13
61a	D AV	CC	40.00	SW	12510.00	1575.17	3040	6
61b	D AV	CC	40.00	SW	1146.64	42.47	3040	6
62	D AV	CC	40.00	S	3680.00	247.97	3400	8-13
64	D SL	RF	37.00	SW	1472.62	109.08	2500	3-8
67	D SL	RF	40.00	E	3015.94	223.40	2800	3-8
68	D SL	RF	40.00	SE	2120.58	157.08	2680	3-8
69	D SL	RF	39.00	SE	2159.85	239.98	2880	3-8
70	D AV	RF	39.00	SE	20481.25	2096.11	2900	5
71	D AV	RF	42.00	NE	10845.50	1021.23	1700	8-10
72	SLMP	RC	41.00	N	5999.85	1555.52	2200	8-13
73	SLMP	RC	45.00	NE	3999.90	592.58	2200	8-13
74	SLMP	RC	50.00	NE	17612.00	2381.77	2150	8-13
75	D SL	RF	41.00	NE	9800.00	1260.64	2080	8-13
77	CPLX	FRST	30.00	SE	23125.00	3167.20	2750	10
78	D AV	CC	38.00	SE	2340.00	260.53	2150	3
79	D AV	CC	40.00	NE	1599.96	177.77	2500	3-8
80	D AV	FRST	43.00	N	15750.00	2179.06	1650	16-29
81	CPLX	FRST	39.00	SE	37125.00	4841.56	3360	10ACT
81	CPLX	FRST	39.00	SE	41250.00	6332.29	3360	38+ ACT
82a	D AV	FRST	45.00	E	35201.25	4394.81	2240	45
82b	D AV	FRST	45.00	E	3920.00	555.28	2240	10
82c	D AV	FRST	45.00	E	6000.00	502.83	2240	45 ?
82d	D AV	FRST	40.00	E	1133.30	83.95	2240	10
83	SLMP	CC	37.00	SE	1633.29	120.98	1850	1-3
84	SLMP	CC	44.00	SE	3180.87	353.43	1900	1
85	D SL	RF	40.00	NW	15000.00	547.17	2000	3-8
86	D SL	RF	40.00	N	13125.00	372.38	2000	3-8
89	SLMP	RC	46.00	NE	1253.30	139.26	2250	8-13
91	SLMP	RC	43.00	NE	2816.59	417.27	2000	3-10
93	D AV	RF	43.00	SE	8100.00	670.41	1920	3-10
94	SLMP	RC	44.00	E	1546.63	171.85	2080	3-10
95	SLMP	RC	43.00	N	1679.96	373.32	2250	3-10
100	SLMP	RC	47.00	NW	3033.26	337.03	1760	3-13
101	D AV	CC	35.00	S	1649.34	244.35	2000	3-8
102	D SL	RF	38.00	N	1866.62	207.40	1950	3-8
103	D SL	RF	45.00	SW	1334.00	104.81	3150	1
104	SLMP	RC	40.00	E	4433.22	656.77	2880	3-8
106	D AV	CC	40.00	N	1884.96	349.07	1850	1-2
107	D AV	RF	45.00	NE	11312.50	1015.21	2700	1
108	SLMP	CC	38.00	S	959.98	106.66	2500	1
110	SLMP	CC	45.00	NE	1399.96	103.70	2350	1
111	CPLX	FRST	50.00	NW	8639.39	3199.78	2720	50-100
111	CPLX	FRST	25.00	N	1178.10	436.33	2720	50-100
112	SLMP	FRST	38.00	S	6400.00	560.36	2800	3-5
113	SLMP	RC	45.00	SE	1906.62	211.85	2900	3-8
120	RD W	RF	15.00	S	700.00	250.43	2900	3-8
121	D AV	FRST	39.00	SW	2968.81	659.74	3400	26-30
122	D AV	CC	42.00	SW	4199.89	311.10	3150	3-8
123	SLMP	RC	45.00	NW	6715.16	497.42	2080	3-10
124	SLMP	RC	44.00	N	1943.86	107.99	2080	3-10
125	D AV	FRST	38.00	NE	115200.00	10751.94	2400	90
126	D AV	FRST	40.00	NE	11780.99	3054.33	2400	90
128	SLMP	RC	41.00	NE	2999.92	555.54	1750	10
129	SLMP	FRST	40.00	SW	6597.36	1466.08	2240	31-35
130	SLMP	FRST	41.00	SE	1159.97	128.89	2100	8-10
131	SLMP	FRST	42.00	W	2356.20	261.80	2560	10
132	SLMP	FRST	40.00	E	785.40	130.90	2300	20+

TABLE 3

DEBRIS TORRENTS CAUSING STREAM CHANNEL SCOUR

Stream Scour No.	Associated Landslide No.	Land Use at Initiation Point	Age (Years)	Length (Feet)	Area (Square feet)	Volume (Cubic Yards)
#1	LS #1	Road	10	310	6200	115
#2	LS #2,3,4.	Road	10	930	37,200	982
#3	LS # 15,16, 17,18	Road	10	2950	118,000	3523
#4	LS # 19,20	Road	10	1170	35,100	1813
#5	LS # 82	Forest	45 and 10	1310	39,300	3599
#6	LS # 38	Clearcut	3 - 8	220	4,400	348
#7	LS # 43	Road	3	1210	48,400	2223
#8	LS # 77	Forest	10	3470	86,750	5785
#9	LS # 61	Clearcut	6	2600	52,000	965
#10	-	Clearcut	3 - 8	400	8,000	595
#11	?	Forest	29	7475	149,500	2765
#12	LS# 125,126	Forest	90	3180	63,600	1254
#13	?	Forest	16-29	2120	42,400	785
#14	?	Forest	29+	750	15,000	280
#15	LS # 107	Road	1	650	19,500	778
TOTAL				28,745 ft. (5.4 miles)	725,350 sq ft (16.7 acres)	25,815 cubic yds.

Figure 4
Volume Distribution of Landslides

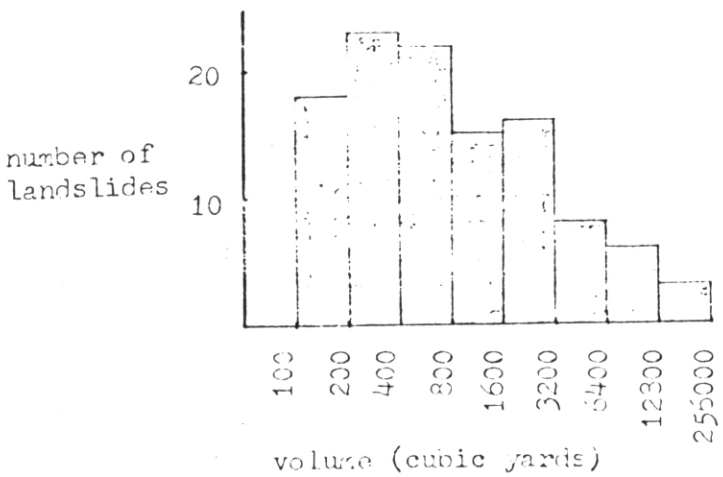
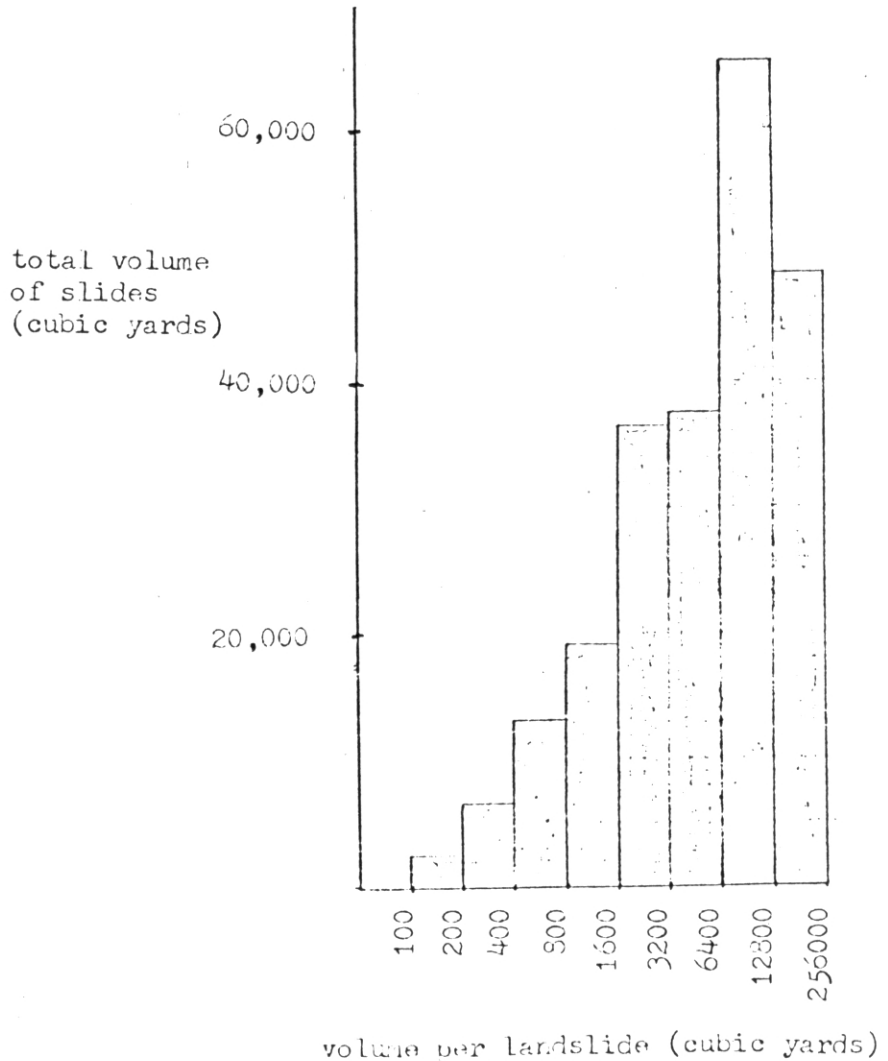


Figure 5
Cumulative Volume by Volume Size Classes



type of mass movement which occurred. The classification scheme used follows Varnes (1958) as modified for the Pacific Northwest by Dyrness (1967) and Swanston(1970). Debris avalanches were the most common type of mass movement event (Figures 9 and 10). Many of the landslides listed as debris avalanches in Table 2 had some rapid earth-flow characteristics and might have been classified as earthflows by some observers. Slumps were common along roadcuts and streamsides; commonly the toe became cohesionless and adopted flow characteristics. Debris slides which involved the movement of a shallow layer of road fill were also common. Complex landslides occurred at the headwall or toe of large deep-seated failures and often involved periodic renewed activity. This is denoted by the letters "ACT" in the age column of Table 2. Two road washouts, where the entire roadbed was removed when a culvert was plugged by debris, were included in the inventory.

The slope of the landslides was quite constant, usually ranging from 37° to 42° (Figure 6). The average slope for all the landslides was 39.8°. There were several landslides outside the normal range. Excluding road washouts (15°slope) all landslides fell within a range of 25°to 50°.

Aspect has a pronounced influence on the distribution of landslides. The distribution of slope aspects in the watershed was determined by sampling the aspect at 100 points distributed over the entire watershed in a square grid over a topographic map. The watershed faces south, and the distribution of aspects of the points sampled reflects this

TABLE 4

RELATIONSHIP BETWEEN LANDSLIDE DISTRIBUTION AND ASPECT

Aspect	NW	N	NE	E	SE	S	SW	W
% of watershed	7	4	8	15	19	17	11	19
area of land with certain aspect (acres)	301	172	344	646	818	732	474	818
number of landslides	12	28	20	11	14	10	10	7
% of slides	10.7	25.0	17.9	9.8	12.5	8.9	8.9	6.3
landslide volume per acre of land with particular aspect (cubic yards/acre)	85	538	171	16	24	6	12	14
average volume per slide (cubic yards)	2140	3310	2952	944	1423	437	565	1670

Figure 6

Distribution of Landslides with Respect to Slope

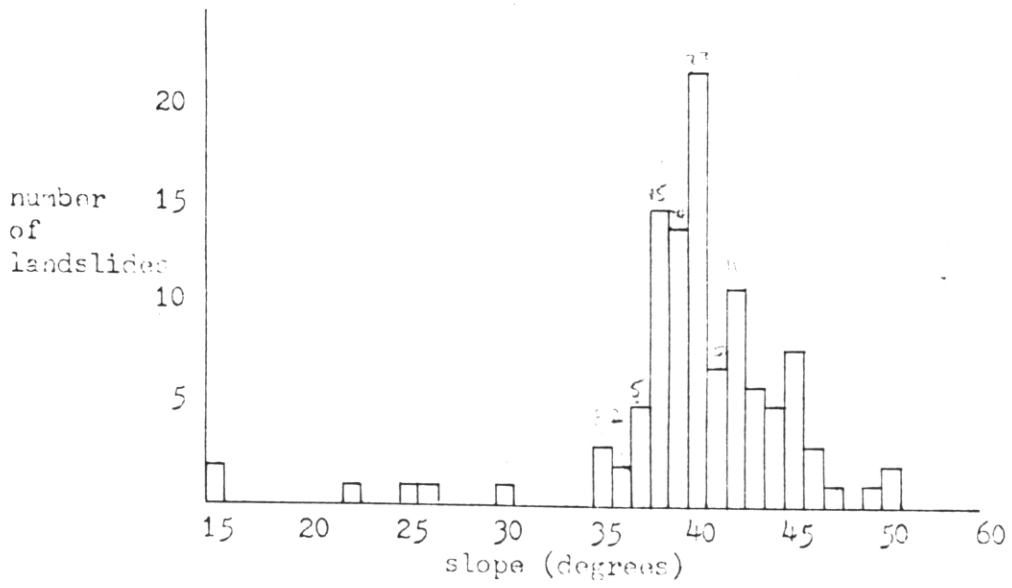


Figure 7

Aspect of the Study Area

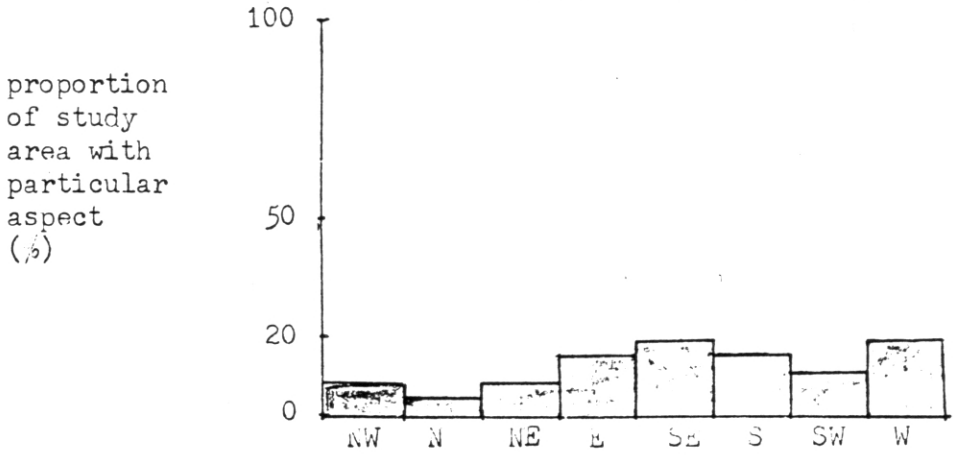
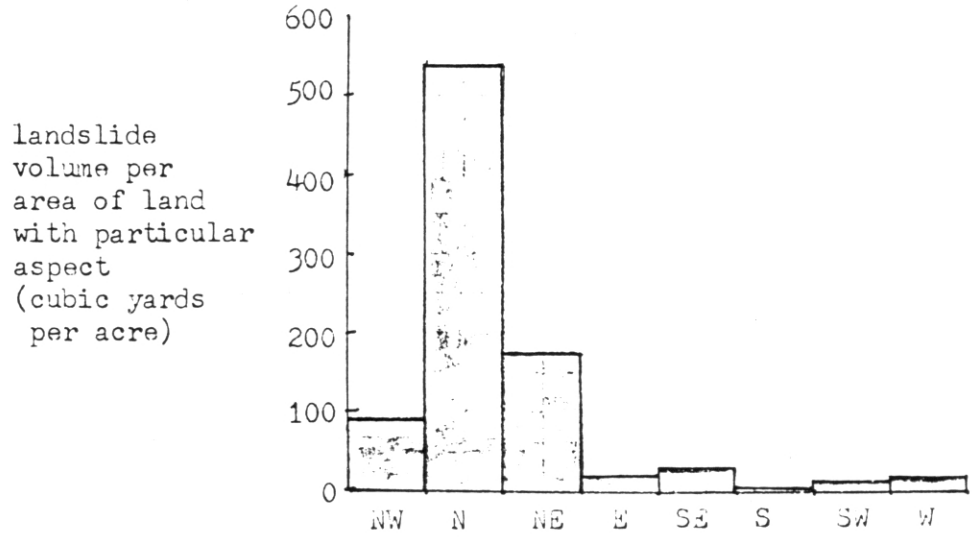


Figure 8

Volume Distrubution of Landslides with Respect to Aspect



orientation (Figure 7). Landslide activity was most frequent on north aspects which comprise a relatively small proportion of the watershed (Table 4, Figures 7 and 8). Nearly 100 times more landslide erosion occurred on north aspect land within the study area than from south aspect sites. It is also interesting to note that the average volume per slide on north aspects was nearly eight times the average volume per slide on south aspects (Table 4).

Bedrock characteristics strongly influenced landslide frequency. Most landslides occurred where the soil mantle was underlain by deeply weathered green breccias. Landslides in undisturbed areas were most common near contact zones of basalt and andesitic flows and weathered volcaniclastic rocks.

Landslide activity was affected greatly by forest management activities. Over a 25-year period (1950 to 1975), landslides and debris torrents in undisturbed forest moved 6.1 cubic yards per acre of forest. In the same time period landslides and associated debris torrents in clear cut areas moved 9.3 cubic yards per acre. Landslides associated with roads moved 1237 cubic yards per acre of road right-of-way.

Assuming 90% resolution of landslide volume occurring in undisturbed forests over the 25-year period, landslide activity in clearcut areas was 1.4 times that in undisturbed forest. Since over 95% of the management activities in the watershed have taken place in the fifteen-year period begin-

ning in 1960, it is useful to look at the relative rates of landslide activity per acre affected by various activities over this time period (Table 5). Such an analysis gives a more accurate indication of the impact of these activities on landslide erosion rates. Using this method of analysis landslide rates (cubic yards/acre/year) were 2.3 times higher for clearcuts than forested areas (Table 6). Road related landslides accounted for 66 % of all landslides surveyed. Over the last 25 years landslide erosion by road related landslides was 203 times that in forested areas. Since road mileage was minimal in the watershed prior to 1960 it is also useful to compare erosion rates per unit time that various activities were present in the study area. This analysis indicates that road related landslide erosion per year was 309 times that occurring in undisturbed forest.

Table 7 illustrates the relationships between various sites of road related failures. Fill slope failures over 100 cubic yards were the most frequent and accounted for the bulk of the volume attributed to road related landslides. However, small cutslope failures under 100 cubic yards were very common, although they were not included in the inventory. Along a 2.5 mile section of Road 1857 over 160 small cutslope failures were counted. Many were less than 30 cubic yards and therefore do not add a significant volume to the total. Two sections of road bed were washed out when culverts became obstructed by debris. It is possible that similar events occurred but were not included in the inventory since roads



Figure 9

Landslide #15 below
Road 1857 looking up



Figure 10

Landslide #15
looking down to
tributary of
Log Creek

TABLE 5

RELATIONSHIP BETWEEN LANDSLIDE ACTIVITY AND LAND USE OVER A 25 YEAR PERIOD

Total watershed area = 4,306 acres
Total # of landslides = 102
of landslides/area of study = 0.023 slides/acre
Total volume moved by landslides and debris torrents = 214,497 cubic yards
Volume/area of watershed = 50 cubic yards/acre

LAND USE

	Undisturbed Forest	Clearcut	Road right-of-way
Area affected (acres)	3,037	1119	150
Total number of landslides	7	18	75
# of landslides per acre	.002	.016	.5
Total volume of material moved by landslides and debris torrents (cubic yards)	18,552	10,385	185,560
Volume/area affected (cubic yards/acre)	6.1	9.3	1237
Volume per year over time period of management activity (cubic yards/acre/year)	(25 year period) .24	(15 year period) .62	(15 year period) 82.4

TABLE 6

COMPARISON OF EFFECTS OF FOREST MANAGEMENT ACTIVITIES TO UNDISTURBED CONDITIONS

	clearcut / forest (volume/acre)	clearcut / forest (volume/acre/year)	road / forest (volume/acre)	road / forest (volume/acre/year)
Landslide erosion relative to undisturbed forest conditions assuming 100% resolution of slide vol. in undisturbed forest	X 1.5	X 2.6	X 203	X 344
Assuming 90% resolution	X 1.4	X 2.3	X 183	X 309

were reconstructed after the major storms.

TABLE 7

Relationships between Various Sites of Road Related Landslides

	% of total number of road related slides	% of total volume of road related slides
Fillslope	68	90.0
Cutslope	29	9.7
Washout	3	0.3

Twelve landslides and four debris torrents were identified which occurred over a 65-year period prior to 1950. These events moved an estimated 34,200 cubic yards of soil and rock and debris. Volume estimates were difficult to make in some cases due to modification of the scar by secondary erosional processes and revegetation. Only a fraction of the landslides that occurred during this time interval were identified and measured; therefore it is difficult to extrapolate long-term erosion rates from these figures.

A very large (approximately 50,000 cubic yards) landslide occurred immediately north of Gibralter Mountain 60 to 180 years ago. This landslide was not included in the inventory. The mud, rock and debris torrent which resulted from this failure scoured over a mile of stream channel and deposited levees six feet high in some places. This landslide was initiated in an area of slow, deep-seated mass movement and

probably resulted from stress buildup by deep-seated failure. It is difficult to reconstruct the history of this landslide without extensive fieldwork, but it is an indication that large landslides occasionally occur under natural conditions.

Debris torrents scoured at least 5.4 miles of stream channel in the watershed over the past ninety years. Debris torrents recurred at various times along several segments of stream channel. Along many scoured channel segments subsequent small scale slumping was initiated due to undercutting of the hillslopes by the debris torrents. Scoured stream banks often remain bare or sparsely vegetated for many years and are easily identified on air photos and on the ground (Figures 11 and 12). Extensive areas of alluvial and debris deposits are scattered along the length of the scoured channels (Figure 13). They are generally found upstream of log and debris jams which can be up to fifty feet in height. Trees growing along the stream sides are usually entrained by the debris torrents and solar insolation of the stream channel is increased by removal of shading vegetation. All these factors combine to bring about great modifications in the stream habitat which have adverse effects on most aquatic life.

Slow, deep-seated earthflows are active in the upper portion of the watershed and in other isolated localities. These were investigated at a reconnaisance level and mapped on a 1:15,840 scale map [Plate 3]. Although it is difficult

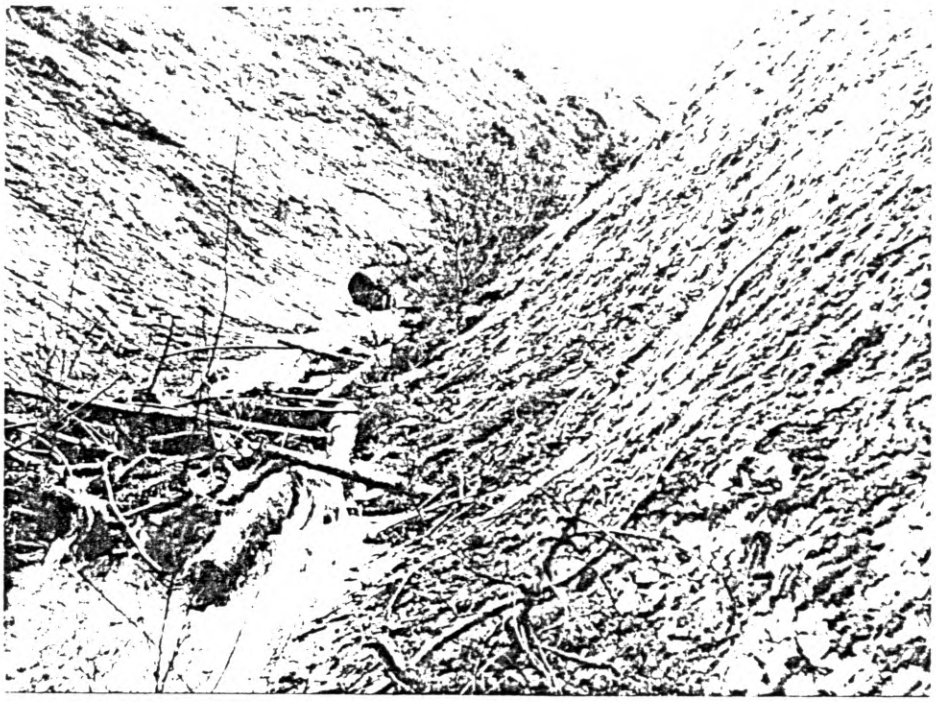


Figure 11

Scoured Stream Banks below Landslide #20
(tributary to Zog Creek).



Figure 12

Stream Scoured Area
below Landslide #43
(tributary to Alder Cr.)

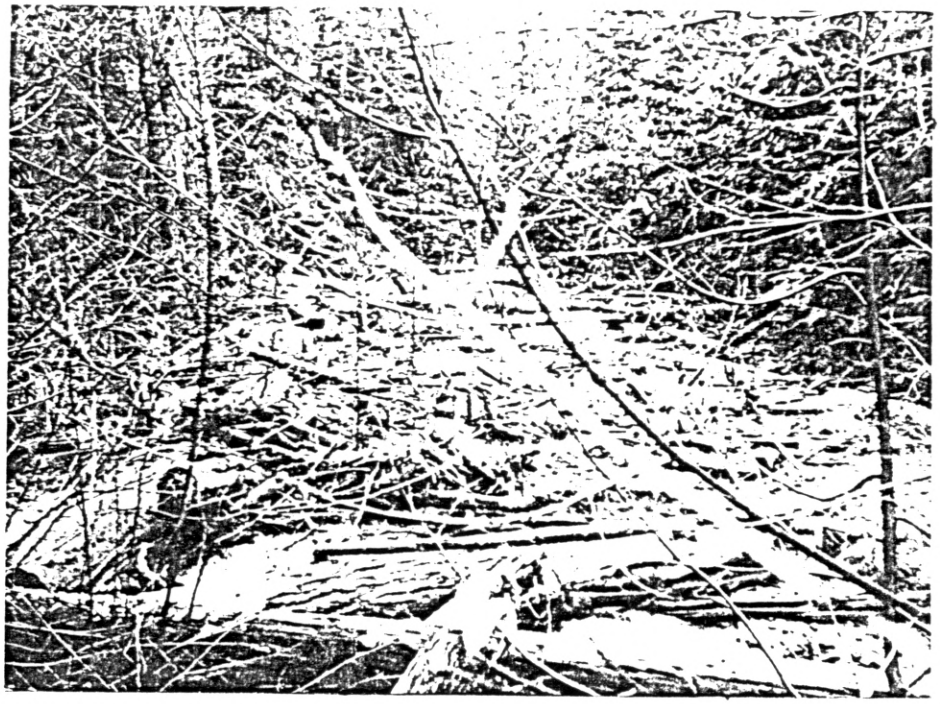


Figure 13

Debris jam and alluvial deposit at bottom of Stream Scour SS_4 (tributary to Zog Creek).

to determine the boundaries of these areas, at least 12% (500 acres)of the watershed is presently undergoing active slow earthflow. Where deep-seated earthflows impinge on stream channels along their lower margins, small slumps are common. It is apparent that annual movement of these earthflows may contribute substantial volumes of sediment to stream channels. Except for measurement of tension cracks in roadbeds no attempt was made to quantify the rate of movement or the amount of sediment contributed by these processes.

Discussion

Erosion by shallow soil mass movements in the study area was controlled by slope, aspect, bedrock geology and land use. Aspect and bedrock geology influences soil mineralogy and depth which directly influences slope stability (Paeth et al, 1971 and Dyrness, 1967). Although much of the study area is classed as stable to moderately stable under disturbed conditions (Legard and Meyer, 1973), man's activities may disrupt the tenuous equilibrium that exists between gravitational forces tending to drive downslope movement and frictional and cohesive forces tending to stabilize the soil mass.

Most of the study area is typified by slopes ranging from 30° to 45°. In this slope range the soil mantle is particularly susceptible to landslides following any disturbance which interrupts the natural stabilizing forces.

Hillslopes in the study area under 30° are generally stable with respect to landslides. However deep-seated earthflow associated landslides are often active at slopes less than 20°. Hillslopes over 45° are generally associated with cliff faces and rock outcrops. Although periodic rock falls occur on slopes greater than 45°, landslides are uncommon. The slope angle distribution of landslides is similar to results of other studies in the Pacific Northwest (Dyrness, 1967; Swanston,1970; Swanson and Dyrness; in press).

The marked aspect control over landslides observed in the watershed is primarily due to the great variability in depth of soil on the steep hillslopes which predominate in the area. Soil depth is usually much greater on northerly aspect hillslopes than on southerly aspects. Southerly aspect slopes are typically mantled with very thin soils. In the Andrews Experimental Forest, Dyrness (1967) noted an absence of landslides on south aspects while landslides on north or west aspects were predominant. He attributed this to the slow rock weathering and soil formation processes associated with the dry south facing sites. The results from the Alder Creek study area show even greater aspect control.

Aspect control was also noted by O'Loughlin (1972b). In his British Columbia study area landslides were most common on southeast aspect hillslopes and least common on north aspect slopes. This is attributed to the general north to south flow of Pleistocene ice sheets over this region which left north slopes broken and rocky while south slopes were

left relatively smooth and uniform with a deep till substratum. The broken rocky slopes are not susceptible to landslide activity while the smooth slopes with deep till deposits are prone to instability.

Although aspect is often an important factor in determining the occurrence of landslides, it is apparent that regions differ considerably in this respect and that results from one area may not apply to another area with a different geomorphic history. Geomorphologically, the Alder Creek drainage is most similar to the Andrews Forest area.

As mentioned previously, bedrock geology is important in determining slope stability in the watershed. Altered volcaniclastic rocks, particularly green breccias, are common throughout the study area. The observations that most landslides in the area were associated with these rocks is similar to conclusions of others working in the Western Cascades (Dyrness, 1967; Paeth,1970; Swanson and James, 1975a; Swanson and Dyrness, in press).

Landslide occurrence was greatly influenced by forest management activities. The relationship between clearcutting and landslide activity is similar to that documented by Dyrness (1967) and Swanson and Dyrness (in press). It is interesting to note that most landslides in clearcut areas occurred three to six years after logging. This is possibly due to a decline in soil cohesive strength due to the decomposition of tree roots during this period. However,

shortness of the record and the infrequent nature of major, landslide triggering storms prevent detailed analysis of slide history with respect to management activities.

Landslide activity in road rights-of-way was substantially higher than that reported by other authors (Dyrness, 1967; Swanson and Dyrness, in press). Several factors influence this result. Road design, placement and construction at Alder Creek appears to have been substantially inferior to that in the H.J. Andrews Experimental Forest. A higher proportion of roads in the study area were constructed on steep hillslopes than in the Experimental Forest. These factors lead to higher levels of instability in road right-of-way areas.

The geologic and geomorphologic character of the Alder Creek watershed was also responsible for the great increase in road related landslide activity compared to that in undisturbed forests. Soil-landtype #8 of Legard and Meyer (1973) occupies over 50% of the study area. Legard and Meyer regard this landtype as stable to moderately stable under undisturbed conditions but state that mass movement hazard is greatly increased by forest management activities. It is one of the few landtypes in the Soil Survey in which mass movement hazard is increased so dramatically by roadbuilding. When Alder Creek is compared to the H.J. Andrews Experimental Forest on Legard and Meyer's soil survey maps, it is noted that the instability of most of the landtypes in the Experimental Forest is unchanged or moderately increased by forest

management activities. Only a few small pockets of Landtype # 8 are found in the Experimental Forest. This difference between the two areas may partially account for the order of magnitude difference observed in the increase in landslide activity related to roads compared to undisturbed forest.

The quantitative relationship between landslide activity and roadbuilding cannot reliably be used to predict erosion consequences of future management activities. Siting of roads and construction methods on the Willamette National Forest have improved since most of the roads were constructed in the study area. An effort is being made to utilize the soil information provided by Legard and Meyer (1973) and to minimize mileage of midslope roads. Excess material excavated from cutslopes is now end hauled rather than added to fillslopes. Past construction of excessive fills has resulted in overweighting and destabilizing of the soil mantle downslope from the road. Many of the landslides in the study area resulted from this condition. Efforts to improve road siting and construction will reduce the expense of reconstruction of roads damaged by landslides (Figures 14 and 15).

An additional factor limiting the usefulness of these results in predicting management impacts on erosion rates is that this study documents only one of the several erosion processes operating in the Alder Creek basin. Deep-seated mass movements in the watershed contribute unknown amounts of sediment to stream channels. There is also some indic-



Figure 14

Reconstruction of Road 1814A at top of Landslide #43.



Figure 15

Road damage on Road 1857 at top fo Landslide #20.

action that infrequent catastrophic landslides may be associated with these unstable areas. Until more is known about these processes and other erosion processes it is impossible to accurately determine the natural levels of erosion activity in the study area and how that activity is modified by land management practices.

The Alder Creek drainage represents a small proportion of the Western Cascades. Slope stability conditions of the Alder Creek watershed are only indicative of areas with similar geology and geomorphic history. But the dramatic increase in landslide erosion due to forest management activities observed in this watershed is by no means unique to this area, since similar conditions can be observed in many areas throughout the Cascades.

SECONDARY EROSIONAL PROCESSES ON LANDSLIDE SURFACES

Methods

Two experimental methods were adopted for use in measuring erosion on steep landslide surfaces. Time did not permit extensive sampling so the results of this study offer only a general indication of the erosional conditions that exist.

The first method utilized large tin cans with a volume of 3,264 cubic centimeters (200 cubic inches) which were implanted in the landslide surface between two boards which served to catch material moved from the slope above. (Figure16)

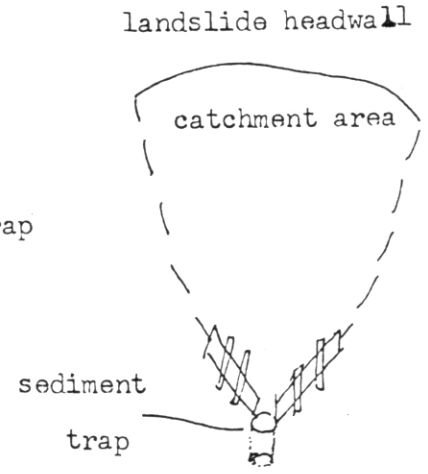


Figure 16

Sediment Trap Design

Two cans were placed on Landslide #15 and two cans on Landslide #19 B about forty feet below the top of the landslide. Catchment areas were calculated by rolling small pebbles down the slope and determining points on the perimeter of the area and measuring the distances between points. The cans were usually checked every two weeks and emptied if necessary.

In the second method for measuring erosion two stakes were driven deeply into the soil at two points across the width of several landslides. A cord was strung taut between the stakes. Both the cord and the stakes were marked so that the cord could be replaced at a later date in the same position and with the same amount of tension. The cord was then marked at one half meter intervals and the depth to the landslide surface was measured using a plumb bob and a millimeter ruler. The cord was then removed. Five months later the cord was replaced and the points remeasured.

Observations of erosional processes were made throughout the year on both landslides and road cuts. Precipitation was measured with a rain gauge at the same dates that the sediment cans were checked. These observations were useful in determining the activity of various erosional processes.

Results

The sediment traps were checked periodically on both Landslide #15 and Landslide #19B. The cans on Landslide #15 were destroyed in late December 1974 when a salvage logging operation was skidding logs up the landslide. The sediment cans were not replaced after this incident. The catchment areas of sediment traps on Landslide #19B were calculated as mentioned above. Trap A has a catchment area of 310 square feet and lies near the head of a small gully. Trap B has a catchment area of 495 square feet and lies on an open face.

Both are near the top of a debris avalanche associated with road failure.

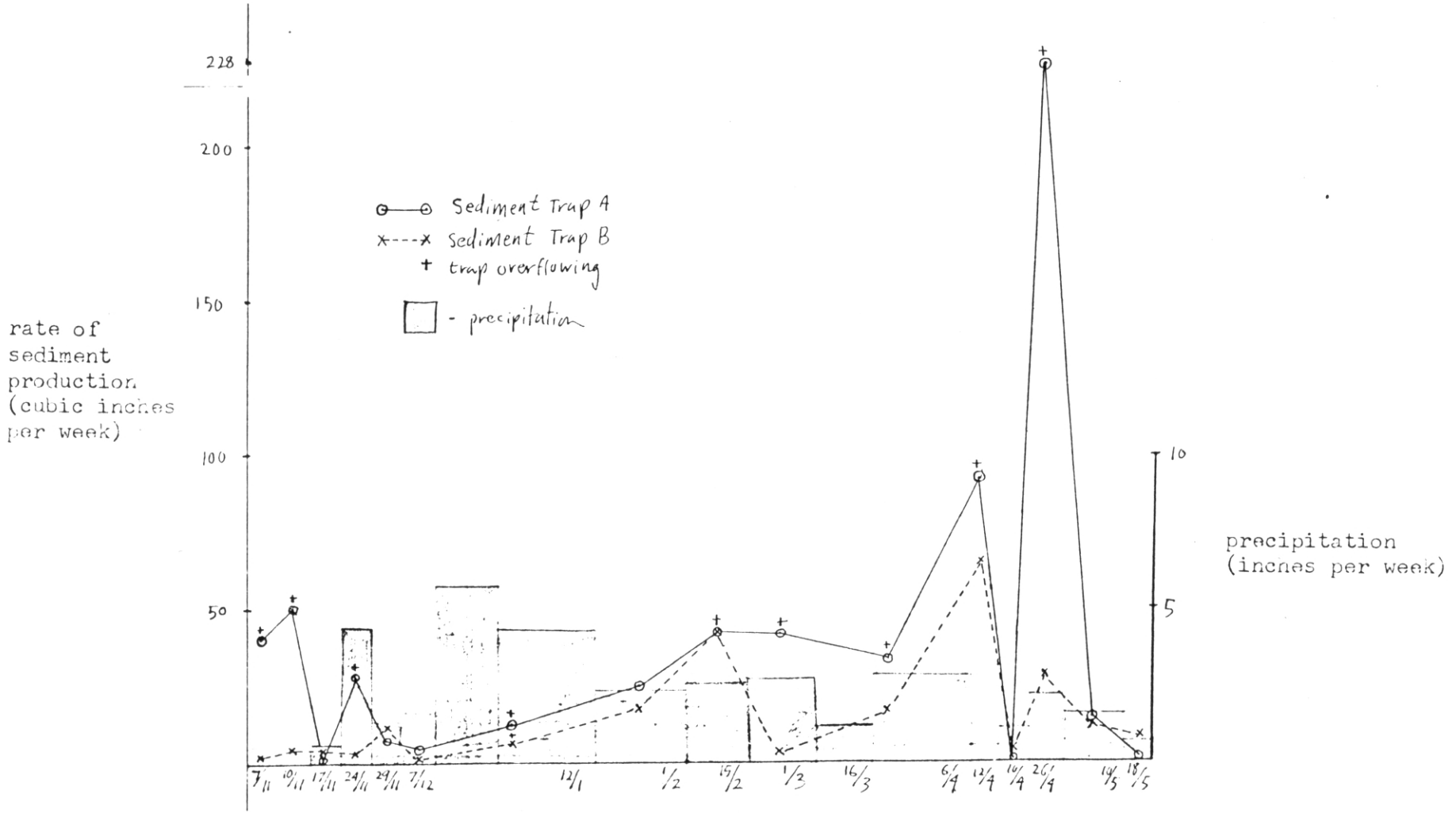
Sediment collected in traps on Landslide #19B was plotted against precipitation (Figure 17). Precipitation varied from rain to snow, but snow predominated during December, January and February. Sediment periodically overflowed the traps and these times are marked with a '+' on Figure B. The data presented therefore only represent a minimum estimate of sediment production.

Although some general trends can be deduced from Figure 17 much information is obscured by the high level of background noise created by the distribution of major storms, by the lack of a systematic sampling period and by periodic small slumps on the landslide scar. The major peak in sediment production occuring during the week of April 26 is due to a small slump and flow of road fill material at the head of the landslide scarp. Although the catchment area of Trap B is 63% larger than the catchment area of Trap A, more sediment was collected by Trap A due to its location in an actively eroding gully. Trap A also appears to be more responsive to precipitation fluctuations. This may be correlated with the observation that overland flow in the gully was common during storms while overland flow was less frequent on the open face where Trap B is located.

The data from the sediment traps are summarized in Table 8 . It represents a minimum figure for surface erosion on the top of this landslide scar for a 29 week period between

Figure 17

Rate of Sediment Production Correlated with Weekly Precipitation



November 3, 1974 and May 18, 1975.

Table 8

Sediment collected on Landslide #19B from November 1974 to May 1975

Sediment trap	A	B	average
Total sediment (cubic inches)	6,320	2,430	4,375
Average sediment from catchment area (cubic inches/ square foot)	204	49	126
Average depth of soil eroded from catchment area (inches)	0.14	0.03	0.085

Sediment traps on Landslide #15 collected a combined total of 254 cubic inches of sediment from a catchment of approximately 1,000 square feet before they were destroyed by logging operations. An average of about 0.3 cubic inches per square foot eroded off these catchments compared to an average of about 1.0 cubic inch per square foot for the catchments on Landslide #19B between November 3 and December 7. This indicates that the rates observed on Landslide #19B are high compared to landslides with more vegetative cover such as Landslide #15.

Results from the erosion transect method gave a better indication of which areas on the landslide surface had the fastest erosion rates but were not useful in determining the timing of the erosion. All erosion transects were established on October 17, 1974 and rechecked on May 18, 1975.

Two transects were placed on Landslide #2. Line 1A was

run across the scar about 100 feet from the top and Line 1B was run across the upper middle portion of the scar. The average depth change on Line 1A was a decrease of 0.7 millimeters (more soil deposited than eroded). This is probably not a significant change since the average experimental error may be as high as 5 mm. Some places along the transect were filled by material deposited from above, while others were eroded away. Overall, these areas balanced one another. On the other hand, the average depth change on Line 1B was a decrease of 17.4 ± 5 mm. Thus a significant amount of soil was removed from the middle portion of the scar. The bottom of the gullies eroded as much as 77 ± 5mm. whereas other areas decreased in depth as much as 31 ± 5 mm. due to aggradation and microscale slumping of the gully sides.

Two erosion transects were placed across Landslide #15 but several stakes were displaced by logging operations.

Two erosion transects were placed across gullies on Landslide #19B. Line 3A was measured every 5 centimeters. An average depth increase of 26 ± 5mm. was observed. The profile of the gully is shown in Figure 16. The greatest depth increase was at the bottom of the gully where 102 ± 5mm. of soil was eroded away. Microscale slumping appeared to be partially responsible for the area of deposition on the right side of the gully.

Another gully was measured with Line 3B. In this case depths at selected points along the width of the gully were

Figure 18

Gully Profile from Erosion Transect 3A on Landslide #19B

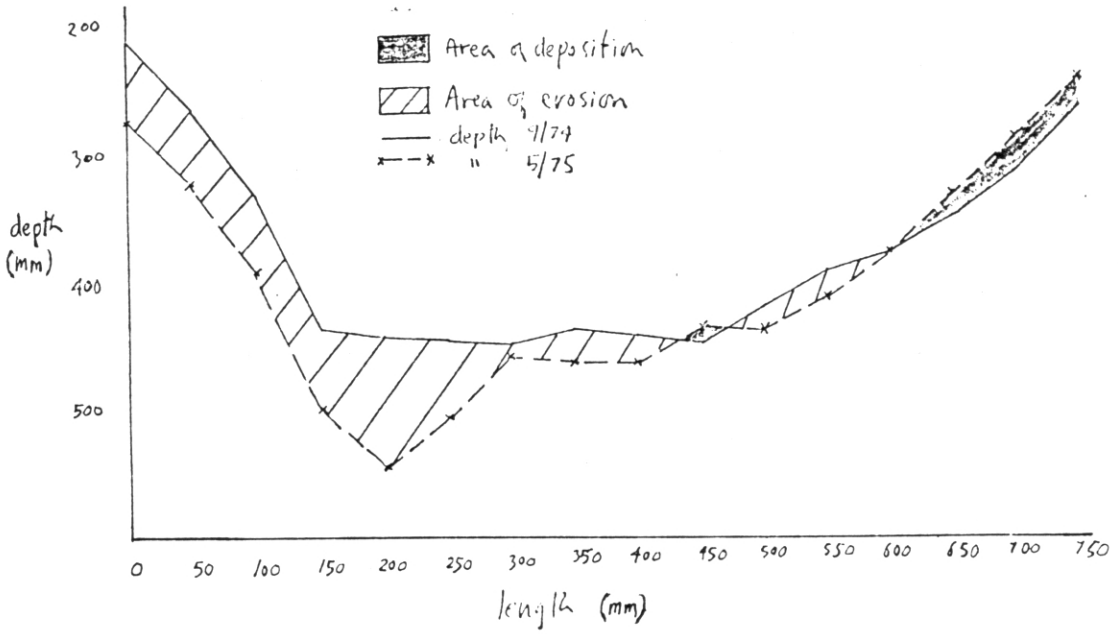
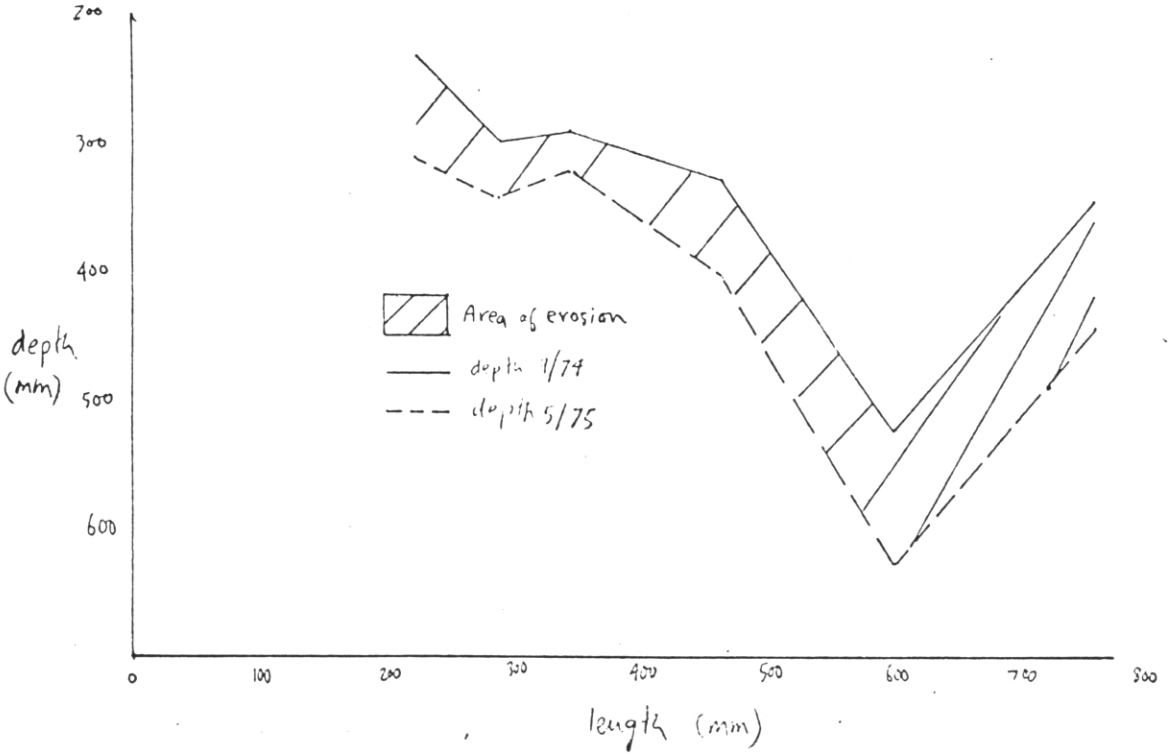


Figure 19

Gully Profile from Erosion Transect 3B on Landslide #19B



measured as represented in Figure 19. On this erosion transect an average depth increase of 72 ± 5mm. was observed. This is the greatest amount of soil erosion recorded in all of the areas studied. The maximum erosion took place at the bottom of the gully which was lowered 103 ± 5mm.

Discussion

Once a landslide removes the protective cover of vegetation and plant litter the exposed subsoil is susceptible to subsequent erosion. Subsequent small scale slumping often occurs both within the scar and on the margins. headwall slumping is particularly important in some cases. The bare scar face is also eroded by gullying, raindrop impact, sheet erosion, freeze-thaw dislodgement of soil and by dry ravel activity.

Dry ravel was observed to be active during the summer months on both landslides and on road cuts and fills. Clay minerals that are susceptible to shrinkage on drying are abundant in the weathered pyroclastic rocks and in the soils of the study area. Unfortunately I was not able to measure dry ravel activity on landslides in the study area. The work of Mersereau and Dyrness (1972) on dry ravel in clearcuts does suggest that a significant amount of soil would be transported down slope. As Mersereau and Dyrness observed, these soils are less cohesive when dry and significant downslope movement can occur during the summer months. Weathered

bedrock exposed on landslides was actively spalling (Figure 20). This process is due to the shrinkage of rocks during the dry season and is similar to dry ravel (Swanson, 1972).

I observed that much of the material dislodged by dry ravel did not move far downslope and often accummulated in small cones. These cones disappeared once the winter rains began. Apparently much of this material was carried down the landslide by fluvial processes during first months of the wet season.

The sediment collected before late November by the sediment traps (Figure 17) resulted from the processes described above. After this initial period, sediment production was reduced until freeze-thaw activity and periods of runoff and associated surface erosion during the winter and early spring months began to contribute substantial amounts of coarse sediment to the traps. It is interesting to note that the highest sediment production occurred several months after the peak precipitation was recorded. This is an indication of the importance of freeze-thaw activity as a mode of surface erosion during the late winter and early spring months. In the afternoon on a warm day in the winter one could observe a steady stream of small rock and soil fragments falling off landslide and road cut faces as ice crystals melted. When patches of snow were present this debris would accumulate on the snow and would be highly visible (Figure 21).

Overland flow was an important means of transporting soil particles loosened by dry ravel and freeze-thaw processes.



Figure 20

Green Breccia Bedrock Spalling of Landslide #45
and Stunted Douglas-fir 6 to 8 Years Old.



Figure 21

Cone of Colluvium on Fresh Snow due to
Freeze-Thaw Activity
(road cut, Road 1857)

Water was observed running down the landslides and into the traps only an hour after rainfall began, even though the weather had been quite dry for the previous week. This was a good indication that the subsoil has a low infiltration capacity and high susceptibility to overland flow. Legard and Meyer (1973) note that most of the subsoils in the study area are highly susceptible to surface erosion (see Table 18 in Appendix).

By May, sediment accumulation in the traps was greatly diminished. This coincided with a decrease in rainfall and the onset of warm weather. Little freeze-thaw activity was apparent after the middle of April at the 2000 foot elevation.

Various erosional processes operating on the landslides probably vary according to the elevation and aspect of the site. Freeze-thaw activity is predominant during much of the wet season on higher elevation sites while raindrop impact, sheet erosion and fluvial erosion are more important erosional processes on low elevation sites. Dry ravel activity is highest on sites with a southerly aspect (Mersereau and Dyrness, 1972).

The results from the erosion transects indicated that the upper slopes of the landslide scar were accumulating as much material as was eroded. Lower on the scar, where gullying was active, erosion rates were greater. This was also indicated by the fact that sediment Trap A, which was situated in a gully which was actively eroding, collected substantially

more sediment than Trap B located on an open face (Figure 17).

Data from the erosion transects also revealed that while the overall landslide surface was eroding, sediment was accumulating in other areas. Gullies would often have sections where downcutting was dominant followed by short areas where deposition took place behind a constriction in the gully where a few large stones were lodged.

Gully erosion is the most evident aspect of the secondary erosional processes operating on the landslides. The data indicate that the bottoms of the gullies often erode 3.1 inches (8cm.) or more during the wet season. The gullies where these measurements were taken were often two or three feet deep. This indicates that erosion rates for gully bottoms of 3± 1 inch per year is not unreasonable.

Although there was insufficient sampling to estimate accurately the volume of material eroded off an entire landslide during the study period, it is possible to make a general extrapolation from these data. Erosion transects on Landslide #2 experienced an average depth increase of 0.33 inches (8.5 mm.) over a seven month period. The landslide has a surface area of 35,250 square feet. At the average erosion rate observed, about 35 cubic yards of material was eroded off the landslide between November and May. If the sediment trap data for Landslide #19B were extrapolated for this same area, about 9 cubic yards of material would be eroded during that time period. Both Landslide #2 and Landslide #19B have

little vegetative cover and are actively eroding. They are by no means characteristic of all landslides in the study area.

From the data it does appear that a substantial amount of material does erode off unvegetated landslides every year. This is also evidenced by the deep gullies present on many landslides and by large alluvial cones constructed by post-slide erosion at the base of most ten year old landslides. From data in the following section on plant succession on landslide surfaces it appears that vegetation may not become fully established for 20 years or more after landslide occurrence. Surface erosion will continue to be active until plant cover is nearly complete. Prior to complete revegetation of the scar approximately 450 cubic yards of soil may be eroded from the scar. Although this is incidental to the original landslide volume it constitutes a significant input into stream systems.

PLANT SUCCESSION AND CONIFER REGENERATION ON LANDSLIDE SCARS

Methods

Cursory observations of revegetation were made while measuring 90% of the landslides in the survey. Note was taken of the general degree of revegetation and the most common species present. A wide range of the vegetative cover could be generally correlated to aspect, slope, time since disturbance and depth of soil to bedrock. Further refinement and analysis of such data could provide a detailed predictive model for revegetation of landslides in similar areas of the Cascades.

A chronosequence of landslide scars was also studied in detail. Only the upper portions of the landslides were sampled. Deposit areas and stream scour areas were not included, but general observations of these areas were made.

The initial onset of plant colonization was observed on several three to five year old landslides. Species present were recorded and the most common ones were noted. A rough estimate of amount of vegetative cover was made but no quantitative measurement techniques were employed. These landslides were observed from March through May 1975.

Two ten year old landslide scars that originated during the winter of 1964-1965 were studied during October and November of 1974. These are Landslides #2 and #5 below Road 1857. Two line intercept transects were laid out along the contours

of the landslides and measurement of amount of cover of four different cover types was made. The four cover types referred to above are 1) bare soil or rock, 2) plant litter covering soil or rock (no vegetative cover), 3) moss covering soil or rock, and 4) vegetation other than moss. In the last cover type plant litter was usually present and moss was sometimes present. Note was made of the plant species encountered along each section of the transect and estimates of their relative abundances were made. In addition, conifer species present along the transect or adjacent to the transect were dated and measured and estimates of average annual growth were computed from these data.

Minor error may have been generated by conducting these measurements outside of the peak growing season. A few species of herbs were withered at this time, but an attempt was made to estimate their approximate cover during the growing season. Knowledge of the growth habits of these ephemeral plants enabled this approximation. Observations of slide scars throughout the year indicated that most of the vegetation present on the scars during October and November 1974 represented full cover and that estimates of the cover of ephemeral herbs was representative.

After an exhaustive search several old landslides were found in undisturbed portions of the watershed. These were located by a detailed survey of 1946 and 1959 airphotos and by ground checks.

Landslide #82 located in the center of the watershed (SW¼ Sec. 7, T.18S.,R.3E.) has several sections that failed at different times. The largest section appears to have failed about 45 years ago. Two line intercept transects were sampled as with the 10 year old landslides. A fifth cover type of tree canopy was recorded since some tree canopy had developed on the landslide scar. Also trees from the surrounding forest added canopy cover to the sides of the slide scar. When tree canopy cover was present, ground vegetation, moss, and plant litter were also recorded. Bare soil was recorded when neither tree canopy or the other cover types were present.

Two more old landslides (#125 and #126) were found in the NE¼ Sec. 11, T.18S., R.2E. These two adjacent scars are about 80 years old. Due to the well developed tree canopy it was impractical to run a line intercept transect. Instead, four 100 square foot quadrats were randomly distributed on the slide scars and basal area of trees was recorded, and ground cover was also estimated. Selected trees were dated and growth rates were computed.

Results

The shallow soil mass movements in the study area often remove most of the soil mantle leaving several inches of subsoil or bedrock exposed on the scar. All vegetation including root material is removed from the scar, except for occasional residual vegetation remaining on small slump blocks. Colonization of the scar takes place with seed germination of invading species. In some cases vegetation that periodically slumps off the headwall or side of the landslide scar contributes to the revegetation process. Successional trends vary considerably depending on aspect, soil depth, soil moisture, surrounding seed stock, shading vegetation and parent material.

Three to Five Year Old Landslide Scars.

Colonizing vegetation differed somewhat on four landslides sampled. These landslides are fairly representative of the range of initial colonization of landslides in the study area. Data of species present and percent of vegetative cover are presented in Table 9. Many invading species such as Whipplea modesta, Anaphilis margaritacea, Epilobium angustifolium, Senecio sylaticus, grass species and others were common on the young landslides. Residual shrubs such as Gaultheria shallon and Berbevis nervosa were often present. It was apparent that vegetation characteristic of surrounding forests was occasionally transported onto the scar by small slumps on the landslide margins.

Table 9

Vegetative Cover and Species Encountered on 3 to 5 Year Old Landslides

Landslide #	43	61	70	112
% bare ground	95%	85%	75%	95%
% vegetative cover	5%	15%	25%	5%
parent material	green breccia (all)			
elevation (feet)	2000	3040	2900	2300
slope (degrees)	38	40	32	38
aspect	NW	SW	SE	E
age (years)	3	5	5	5
PLANT SPECIES				
HERBS:				
moss spp.	x	x	x	
grass spp.	x	x	x	
Petasites frigidus palmatus		x		
Equisetum telmateia		x	x	
Juncus sp.			x	
Viola sempervirens	x		x	
Trillium ovatum		x		
Synthyris reniformis		x		
Iris chrysophylla		x		
Phacelia heterophylla		x		
Epilobium angustifolium		x		
Anaphilis margaritacea		x	x	
Boykinia elata	x		x	
Penstemon sp.			x	
Whipplea modesta	x	x	x	x
Polystichum munitum		x	x	
SHRUBS:				
Alnus sinuata		x		
Berberis nervosa			x	
Rubus ursinus		x		
Gaultheria shallon			x	x
Salix sp.		x		
Acer circinatum			x	
TREES:				
Alnus rubra	x			
Thuja plicata			x	
Tsuga heterophylla	x		x	x
Pseudotsuga menziesii	x	x	x	x

After five years vegetative cover was minimal on two of the landslides studied but the vegetation covered was approximately 25% of the surface of one landslide. However in all cases bare eroding ground was abundant. Very little plant litter had accumulated. Areas on the landslides that were moist had up to 75% of the surface under vegetative cover depending on the degree to which surface erosion was active. The establishment of conifer species had begun on all scars through natural reseeding. Sucessful conifer germination was delayed two years after the failure occurred. Seedlings often appeared chlorotic and growth rates did not exceed 0.13 feet in height per year. Mortality of some seedlings due to excessive summer drying and exposure of roots by surface erosion was observed.

Revegetation was patchy on all young landslide scars visited. Vegetation was usually limited to areas adjacent to ephemeral streams or to areas of moist soil. More xeric parts of the scars remained unvegetated.

Ten Year Old Landslide Scars

Among the 10 year old landslide scars successional trends were quite variable. A few scars had greater than 50% vegetative cover while many were essentially unvegetated. Landslide #15 was representative of many of the 10 year old landslides. It is located below Road 1857 (NE¼ Sec. 13, T.18S.,R.2E.) at 2200 feet elevation with a northeast aspect

and a slope of 41°. Green to tan colored breccia is exposed in the scar. The scar is surrounded by uncut forest. The results of the cover type transects are summarized in Figure 22 Plant cover was well developed in some areas but bare soil and rock or very sparse plant cover were common elsewhere.

An average of 32% of the landslide scar was covered by vegetation, 12% of which was moss. Plant litter covered an additional 6% of the scar not covered by vegetation. Bare soil or rock was predominant covering 62% of the landslide surface. Plant cover was greatest on the margins of the slide scar and generally thinned toward the center. The center of the scar was predominantly bare soil and surface erosion was active.

A greater diversity of species was present than on the five year old landslides. Western hemlock (Tsuga heterophylla), Western red cedar (Thuja plicata) and Douglas-fir (Pseudotsuga menziesii) were dominant at the shrub level. Whipplea modesta, Epilobium angustifolium, Anaphalis margaritacea, two unidentified grass species and moss were dominant herbs. A list of species encountered is presented in Table 10.

Table 10

Species Encountered on Landslide #15

Trees	Shrubs	Herbs
Pseudotsuga menziesii	Rubus nivalis	Two unidentified grass species
Tsuga heterophylla	Berberis nervosa	Moss spp.
Thuja plicata	Rubus spectabilis	Lycopodium sp.
	Rubus ursinus	Blechnum spicant
		Coptis lacinata
		Anaphalis margaritacea
		Epilobium angustifoliu
		Whipplea modesta
		Polystichum munitum
		Viola sempervirens
		Senecio sp.
		Peltigera sp., (a soil lichen
		Carex sp.

Table 11

Species Encountered on Landslide #2

Trees	Shrubs	Herbs
Pseudotsuga menziesii	Salix sp.	Whipplea modesta
Tsuga heterophylla	Rubus ursinus	Anaphalis margaritacea
Alnus rubra		Galium sp.
Thuja plicata		Petasites frigidus palmatus
		Epiplobium angustifoli

Figure 22

Plant Cover on Landslide #15

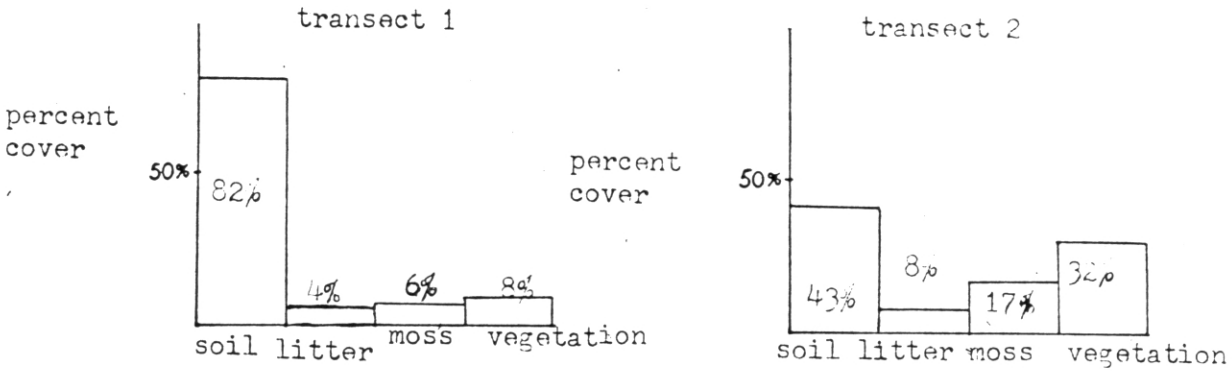
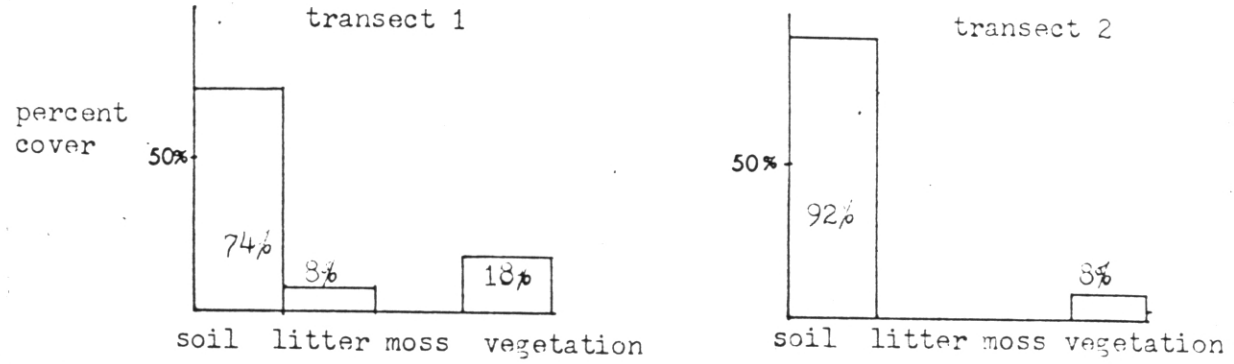


Figure 23

Plant Cover on Landslide #2



Landslide #2 below Road 1857 in clearcut unit Z13C3 (SW¼ Sec. 18, T. 18 S., R.3E.) was also sampled using similar methods. This landslide has a northeast aspect, and elevation of 1850 feet, a slope of 38° and green breccia bedrock. The slide scar is surrounded by a clearcut replanted in 1969. Apparently the slide scar was replanted at that time with Douglas-fir but few trees have survived. This landslide was sampled because regeneration was representative of that of ten year old landslides in clearcuts.

Plant cover on landslide #2 was less than on Landslide #15 (Figure 23). Bare soil or rock occupied 83% of the scar surface while only 13% was covered by revegetation. Also species abundance was dramatically less than Landslide #15 (Table 11). Apparently the difference in revegetation of the two scars was due to greater solar insolation on Landslide #2 due to its open unshaded condition amidst a clearcut. This could result in excessive summer drying and increased dry ravel erosional processes, both of which would be detrimental to the establishment of vegetation. Plant roots were often exposed due to secondary erosional processes operating on Landslide #2.

Growth rates of conifer species was examined on both landslides. Eighteen trees were sampled. The results are presented in the following table.

Table 12

Growth Rates of Conifer Species on 10 Year Old Landslides.

Species	Western Hemlock	Douglas-fir	Western red cedar
Sample size	3	7	8
Average Height Growth Rate (feet/year)	0.20	0.28	0.35
Standard Deviation	± 0.05	± 0.15	± 0.22

In some cases the trees that were sampled were growing close enough to others to be in competition for water and nutrients. In other cases the trees were solitary on the exposed scar face. Many of the trees on the landslides appeared chlorotic. Three Douglas-fir trees growing in adjacent clearcuts were growing at a rate of approximately 1.5 (± 0.36) feet per year, over five times the growth rate observed on landslides. The marked reduction of growth on the landslides is probably due to low moisture and nutrient conditions of the thin subsoil. Competition with other trees on relatively good sites on the scar may also result in reduction in growth rates.

On a few ten year old landslides in the study area revegetation was much more complete than on the landslides discussed above. Revegetation of Landslide #1 (N aspect, 40° slope) and Landslide #71 (NE, 42° slope) both below Road 1857 (NW¼ Sec. 19, T.18S., R.3E.) at 1700 feet elevation was the

most complete of the ten year old landslide scars. Total vegetative cover averaged about 60% for the two landslides. Litter probably covered an additional 10%, leaving approximately 30% bare soil or rock. A list of species present is included in Table 13.

Red alder (Alnus rubra) accounted for much of the increase in vegetative cover on these two landslides. Well developed alder groves were present in the top portion of both scars. The alders were often twenty to thirty feet tall and basal areas ranged from 3 to 15 square inches. The oldest alders sampled were eight years old. On the average, alder growth rates were 3 feet in height per year. On these sites conifer growth rates appeared similar to those studied in Landslide #15 and Landslide #2. This tenfold difference in growth rates suggests that Red alder is much better suited to some landslide sites than conifer species.

Sampling of environmental parameters was not sufficient to determine why certain sites were rapidly colonized by alders. Both sites mentioned were at a low elevation in the study area. Alder was abundant in surrounding streamside areas and clearcuts; therefore an adequate seed source was present. Soil moisture differences could also have been an important factor.

Table 13

Plant species on Landslide #1 and Landslide #71

Trees	Shrubs	Herbs
Alnus rubra	Rubus parviflorus	Oxalis oregena
Pseudutsuga menziesii	Rubus ursinus	Belchnum spicant
Tsuga heterophylla		Polystichum munitum
Thuja plicata		Adiantum pedatum
		Anaphalis margaritacea
		Galium sp.
		Senecio sp.
		Aralia californica
		Thalictrum occidentale
		grass spp.
		moss spp.
		Peltigera - a soil lic

Table 14

Plant species encountered on Landslide #82

Trees	Shrubs	Herbs
Tsuga heterophylla	Acer circinatum	Polystichum munitur
Thuja plicata	Vaccinium parvifolium	Blechnum spicant
Pseudotsuga menziesii	Berberis nervosa	Polypodium glycy-
Cornus nuttallii	Gaultheria shallon	rrhiza
Acer macrophyllum	Rosa gymnocarpa	deciduous fern -
		(probably Athyrium
		filix-femina)
		Boykinia elata
		Galium sp.
		Oxalis oregana
		Viola sempervirens
		Synthyris reniformi
		Trillium ovatum
		Calypso bulbosa
		Adiantum pedatum
		grass
		unidentified compos
		ite.
		Peltigera - soil
		lichen
		Aralia californica
		Asarum caudatum
		moss
		Vancouveria hexandr
		Thalictrum occiden
		ale

Landslide#82: a 45 year old landslide

This landslide occured in undisturbed timber approximately 45 years ago. It lies at an elevation of 2240 feet, has an east facing slope of 45°, and is underlain by green breccia bedrock. Most of the scar is completely revegetated and plant litter covers soil where vegetation is absent (Figure 24). Tree canopy had developed on those parts of the scar with deeper soil mantle. Species diversity was quite high but species composition differed considerably from vegetation found on 10 year old landslides (Table 14).

Although coniferous trees were dominant in a part of the scar where soil was deeper, much of the scar was covered only with small shrubs and herbs. Deeper soils near the top of the scar appeared to be partially due to sluffing of the headwall scarp. Several species of ferns, including Polystichum munitum, Blechnum spicant and a deciduous fern (Athyrium filix-femina?) were abundant. Aralia californica and Oxalis oregana, were also common herbs. Vaccinium parvifolium, Berberis nervosa and Gaultheria shallon were common shrubs.

A greater species diversity as measured by the total number of species was present on Landslide #82 than on any of the others studied. The plant community that had developed appeared to be quite unique compared to the surrounding forests or cut over areas. Many of the common species, such as Aralia californica, Boykinia elata, Calypso bulbosa, Adiantum pedatum, Asarum caudatum and others, found on the

Figure 24

Cover Types on a 45 Year Old Landslide (#?2)

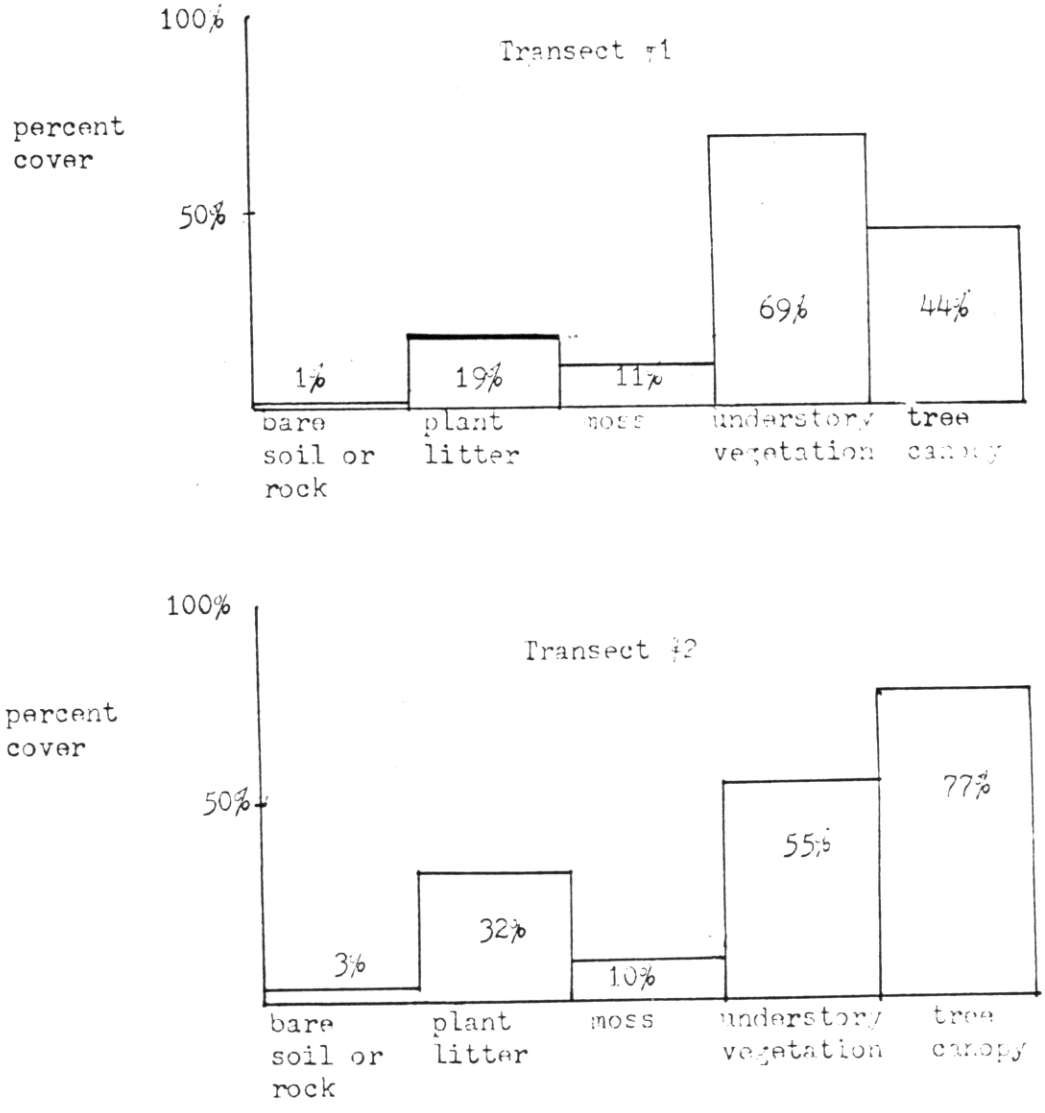


Table 15

Conifer Growth rates on Landslide #82 45 yr. old

	Tree Species	Western Hemlock	Red Cedar	Dogwood
Thin soil	Average height growth (feet/year)	0.13	0.31	0.95
	Average basal area growth ($in.^2$/year)	0.046	0.075	0.35
Deeper soil	Average height growth (feet/year)	0.7 (approximate)	-	-
	Average basal area growth ($in.^2$/year)	1.60	-	-

Table 16

Results of Vegetation Sampling on Landslides #125 and #126 90 yr. old

	Tree Species	Red cedar	Western Hemlock	Douglas-fir
Frequency	Average no. of trees per 100 ft^2 quadrat	2.0	2.25	0.25
Dominance	Average basal area per quadrat (in^2/100 ft^2)	47.0	14.4	17.7
Relative growth	Average basal area per tree ($in.^2$)	23.5	6.4	70.9
Growth rates	Basal area ($in.^2$/year)	1.16	0.13	0.43
	Height (feet/year)	0.6	0.3	0.5

Average Ground Cover

Vegetation = 25% Plant Litter = 70% Soil or rock = 5%

Understory Species Present

Shrubs:

Gaultheria shallon
Vaccinium parvifolium

Herbs:

Linnaea borealis
Coptis lacinata
Viola sempervirens
Polystichum munitum
Oxalis oregana
Trillium ovatum
Blechnum spicant
moss sp.

landslide scar were not common in nearby clearcuts or undisturbed forest. It appeared that coniferous trees would gradually become dominant throughout the scar, eventually shading herbaceous vegetation.

Growth rates of coniferous species varied considerably on different sites on the landslide scar. Trees growing on shallow soil were extremely stunted while those growing on deeper soils had only somewhat diminished growth rates (Table 15). The growth rates on the poor sites were similar to those obtained on the ten year old landslides. Western hemlock growing in the deeper soils grew nearly seven times faster in height than on the poor sites. Dogwood (Cornus nuttallii) grew quite well on the poor sites.

Ninety year old landslides

A well developed forest canopy makes Landslides #125 and #126 very difficult to locate on air photos. However a long section of stream channel was scoured below the landslides and this is readily apparent on the air photos. The landslides were discovered by tracing the stream scour back to its origin. These landslides are located at 2400 feet, and have NE aspects, slopes of 35° and green breccia bedrock. Vegetation is similar to that of the surrounding forests except that the trees are stunted. Trees are often gunstocked indicating that soil creep is active. Forest canopy of trees growing on the scar covers approximately 70% of the surface area. The results of four 100 square foot quadrats distributed

on the landslides are presented in Table 16.

On these old landslide scars Western red cedar is the dominant tree and has the fastest growth rates of the three conifer species present. Western hemlock is the most frequent tree species encountered but is often stunted and growth, especially in basal area, is much less than Red cedar. Douglas-fir is the least abundant tree species but growth rates appear intermediate between the two other species. Tree mortality was high in the stand that was sampled. This apparently was due to excessive competition for the limited nutrients of the site. Understory vegetation is sparse on the 90 year old landslide scars but plant litter covers most of the surface area. The small shrubs and herbs present are typical of understory vegetation in the surrounding mature forest.

Discussion

Succession on landslide scars seems to vary in response to a variety of environmental parameters but general trends can be deduced from the landslides that were studied.

Colonization of the scars is a relatively slow process. After a landslide occurs the scar may remain essentially unvegetated for more than five years. During this initial period, species often found in unburned portions of young clearcuts are common, yet species diversity is significantly less than that for clearcuts as reported by Dyrness (1973).

Ten years after the failure, scars were found in various stages of succession. Revegetation on many landslides in clearcuts was similar to Landslide #2. In this case I observed little improvement in total vegetative cover over that observed on young landslides. Surface erosion was active on many ten year old landslides and often roots of vegetation had become exposed. Shallow rooted vegetation appears to be inadequate in combating this active surface erosion. Conifer species often grow at slow rates, and rooting depth is restricted by shallow soils so that establishment is difficult. Red alder takes hold rapidly in some situations and aids in the establishment of other vegetation. It has an added effect of contributing nitrogen fixed by bacteria living in its root nodules to the nitrogen deficient subsoil.

Revegetation is more complete on landslide scars surrounded by forest. This is due to presence of a better seed source and to partial shading by the bordering trees. Where more mesic conditions prevail and surface erosion is not too active, moss becomes established and is very effective in stabilizing the soil. Herbaceous vegetation was observed to be moderately effective in stabilizing the soil surface where it is abundant. On some areas a soil lichen, Peltigera sp., is common and appears to be effective in reducing surface erosion. It has an added benefit that the blue green algal symbiont actively fixes nitrogen from the atmosphere and renders it usable to other plants (Pike, 1971).

Plant cover was essentially complete on the 45 and 90 year old landslides. Since only two sites were sampled it is not possible to tell whether this is indicative of all landslides of that age. Sparse coniferous forest canopy had developed on the 45 year old landslide whereas a moderately dense canopy was present on the 90 year old landslides. It appears that in some cases a stunted forest will eventually develop on landscars in this area.

Growth rates of conifer species were substantially reduced on all landslides studied. It is interesting to note that growth rates did not change more than a factor of two throughout the 90 year chronosequence for the conifer species sampled. Red cedar was the fastest growing species in all cases and appeared to be growing almost twice as fast on the 90 year old landslide than on the younger landslides although sampling was insufficient to determine if there was a statistical difference between landslides of different ages. Western hemlock growth rates remained almost constant throughout the 90 year chronosequence.

It is difficult to determine if this longterm reduction in growth rates is typical of many landslides in this area due to the small number of older landslides sampled. Until studies prove otherwise, it should be assumed that site productivity is markedly reduced until a time when sufficient soil has developed on the scar for adequate rooting depth.

SYNTHESIS AND IMPLICATIONS FOR MANAGEMENT

A variety of mass movement processes were investigated in the Alder Creek basin. Both deep-seated and shallow soil mass movements appear to be important determinants of geomorphic characteristics of the basin. Land management activities significantly influence the level of activity of the shallow soil mass movements although modifications of some practices may bring about a substantial reduction in landslide erosion rates. There are many secondary ecological effects of mass movements in the study area. The effects of landslide erosion on aquatic communities and productivity of terrestrial ecosystems are discussed below.

Deep-seated mass movement phenomena are probably the most significant erosional force operating in the study area under premanagement conditions. Recently active deep-seated earthflows have formed a hummocky subdued topography over a substantial fraction of the northern part of the Alder Creek basin. Drainage patterns in this earthflow dominated terrain are irregular and poorly developed due to disruption by ground movement. Slumps off the toes and margins of an earthflow into a stream channel are common and may result in debris torrents which entrain much additional earthflow material. Total sediment production by deep-seated mass movements is unknown and may be greater than the sediment volumes indicated by the slumps and debris torrents occurring along

earthflow margins.

Occasional landslides at the headwalls of deep-seated mass movements and small streamside slumps remove vegetation and expose subsoils from a small proportion of the area affected by deep-seated mass movements. Except for these few slide areas, vegetative cover on the earthflow areas is generally complete and site productivity is moderately high. Deep soils are common and consequently revegetation of streamside slumps is relatively rapid. While deep-seated earthflows may contribute substantial amounts of soil to streams and thereby adversely affect aquatic habitat, there is little indication that these processes significantly affect forest productivity.

Where slopes on earthflows are gentle, management activities do not appear to significantly increase the occurrence of landslides relative to the occurrence of landslides in forested areas on earthflow terrain. Roads constructed on earthflows may have to be reconstructed periodically due to development of tension cracks and road displacement between areas of contrasting rates of movement. Management activities appear to dramatically increase landslide activity where earthflow slopes are steep, such as in Clearcut Z9B3 where a small earthflow is active. It would be wise to identify such areas and avoid any alteration which might increase landslide activity.

Shallow soil mass movements contribute to the deve-

lopment of steep, highly dissected hillslopes characteristic of much of the study area. Landslides cut troughs into the hillslopes removing vegetation and the deeply weathered soil mantle, exposing subsoil and underlying bedrock. Commonly the troughs lie below the water table and intercept groundwater. During the wet season overland flow is common on the landslide scars. Frequently water becomes channelized in gullies in the lower portion of the scar and further incision of the hillslope ensues. As a result of these processes ephemeral or intermittent streams develop on many landslide scars. By continued incision of hillslopes and interception of groundwater it is evident that the drainage network is significantly expanded by landslide activity.

Landslides and debris torrents result in undercutting of some slopes, thereby removing support and increasing the probability of other landslides. A period of secondary landslide activity may ensue after a large event disturbs the surrounding area.

Shallow soil mass movements are common on steep portions of the study area even under undisturbed, forested conditions. Large storms periodically trigger landslides by developing excessive pore water pressure in soils, increasing the weight of the saturated soil and swelling of clay-rich subsoils. Blowdown of timber may frequently be the final triggering event. Landslides occur in the study area under forested conditions at a minimum average rate of one landslide every three years.

Land management activities significantly increase the level of landslide activity. During a fifteen year period after the initiation of roadbuilding and clearcutting, landslides occurred in disturbed areas at a rate of nineteen per three year period. Landslides associated with roads and clearcuts transported 154.4 cubic yards per acre of disturbed land over a 15 year period. This amounts to an apparent 39 fold increase of total landslide erosion due to forest management activities compared to undisturbed, forested conditions.

Undesirable road construction on steep midslope positions accounted for a great proportion of the increase in sediment transported by landslides. Considerable reduction in the impact of roadbuilding could be achieved by modifications in siting and construction techniques. In the study area road related landslides with a northwest, north and northeast aspect accounted for 162,660 cubic yards, or 88% of the total volume moved by road related landslides. These landslides accounted for 76% of the total volume moved by all landslides over the past 25 years. Since slopes with a north component aspect occupy only 19% of the study area, it is obvious that an enormous reduction in the impact of roadbuilding could have been achieved by minimizing road mileage on these slopes.

Identification of potentially unstable areas associated with green breccia bedrock and steep midslope positions is also essential to careful road siting in this terrain. If roads are constructed on ridgetops and slopes with gradients less

than 30° there will be a substantial reduction in the level of mass movement activity.

There is need for more research into road construction techniques for potentially unstable forested land. New methods of road siting and construction are being developed that will minimize some of the problems associated with roads in the study area. End hauling of fill material will reduce fill slope related landslides which have been predominant in the Alder Creek basin. Other improvements such as better maintenance and design of drainage systems, reduction in road width, and use of trestles to span drainage ways may reduce the impact of roads. New methods of construction and siting of roads should be explored and applied to landscapes with similar characteristics.

The two fold increase in landslide activity in clearcuts is difficult to control since it appears to be due to the gradual loss of soil strength following decomposition of tree roots and possibly to an increase in ground water levels in clearcuts (Gray, 1970; Swanson, et al.,1973). A considerable proportion of the landslides in clearcut areas occurred along streamsides or in incipient drainage ways. Leaving uncut bands along streamsides and avoiding incipient drainageways in clearcut units could significantly reduce landslide activity in these areas.

This study and other studies mentioned previously lend considerable support to the recommendation of Wikstrom and Hutchinson (1971) that extremely unstable lands should not be

considered part of the timber growing base and that much potentially unstable land should be withdrawn from commercial timber production until there are significant improvements in timber growing and harvesting techniques, including those which require less road mileage. The assumption that every acre capable of growing commercial timber should be utilized for timber must be challenged where slope stability conditions are similar to marginally stable sites in the study area.

The environmental impact of accelerated landslide activity is many fold. Landslides and debris torrents have caused significant modifications to aquatic ecosystems in the study area. Secondly, significant amounts of commercial timber are rendered unuseable by road related landslides. Furthermore, site productivity is reduced on landslide scars to the point that commercial timber production may be impossible for extended periods of time. A secondary environmental impact of accelerated landslide activity is the creation of many bare landslide scars where surface erosion and subsequent mass wasting may contribute further sediment to streams and further reduce the site productivity of the landslide scar.

Effects of sediment on aquatic ecosystems has been the subject of much recent research. Gibbons and Salo (1973) provide an excellent bibliography of this work. Increases in suspended sediment and bedload sediment have detrimental effects to aquatic vegetation, aquatic invertebrates and fish populations. Turbid discharge waters from Alder Creek into

Big Fall Creek were observed during peak storm flows in the winter months. It is apparent that the effect of increased sediment production from the Alder Creek watershed will be felt by downstream ecosystems.

In the study area debris torrents caused significant modifications to stream channels which are detrimental to aquatic life. In one example in the study area on lower Zog Creek (NE¼ Sec. 13, T. 18 S., R. 2 E.) a series of debris torrents originating from Landslides #15, 16, 17 and 18, scoured 2,950 feet of stream channel during the winter of 1964-1965. This area is marked "SS_3" on Plate 1 . In many areas the channel was scoured to bedrock. Aquatic vegetation was removed and aquatic invertebrate habitat was destroyed. In other areas extensive fine sediment deposits cover stream bottoms to depths of 10 to 20 feet. This material is now being actively reworked and eroded by the stream. Debris jams in the lower portion of the scoured area pose a significant barrier to fish migration and fish habitat is elsewhere impaired. Aquatic food chains appear to be disrupted to the point where it may take years for productivity to recover.

The debris torrents also removed streamside vegetation from a band as wide as 80 feet surrounding the channel. The shading effect of this vegetation is lost, and increases in solar insolation cause excessive stream heating which is detrimental to aquatic life adapted to cold mountain streams (Brown, Swank and Rothacher, 1971). Revegetation on the scoured stream banks is minimal ten years hence and it may

take many years before adequate cover is reestablished.

Vannote (ms. in prep.) discusses the importance of a stable detrital input to the maintenance of downstream trophic relationships. With increasing stream order aquatic communities have adapted to process detrital leakage from upstream communities. Downstream communities are adapted to utilize detrital particles of smaller size than those utilized by upstream communities. In the study area debris torrents, such as those mentioned above, appear to significantly disrupt this situation by flushing an enormous load of unprocessed organic debris down to higher order streams where aquatic communities may be less suited to process large organic debris. Also the removal of streamside vegetation results in a subsequent period of detrital starvation of a portion of the downstream community. This is due to the reduction in plant litter fall into the stream channel. It is difficult to assess these hypotheses because of the very limited state of our knowledge.

The second area where accelerated landslide and debris torrent activity creates a considerable environmental impact is that of loss of commercial timber due to landslide removal and decline in productivity on landslide sites. In the Alder Creek basin road related landslides in uncut forest removed a considerable volume of commercial timber and rendered it unuseable by breakage, burial and transportation considerable distances down stream channels. Some salvage logging has taken place along Road 1857 but it is evident that only about 10% of the downed timber was recovered. The immediate economic

loss incurred in the study area due to this process has not been calculated but amounts to a substantial loss.

The longterm reduction in site productivity on landslide scars documented in the study will probably entail a greater economic loss than the immediate removal and destruction of timber. All the landslides and debris torrents studied denuded 44.7 acres or 1.0% of the study area. Landslides and debris torrents associated with roads and clearcuts denuded 39.8 acres or 0.9% of the study area. The plant succession studies indicate that it may be impossible to grow commercial timber on this land for an undefined length of time. The loss of potential timber production from this area is a serious longterm economic loss and reduces the forest's potential to produce renewable raw materials on a sustained yield basis. Successional trends differ with respect to various environmental parameters on different landslide sites, but reduction in conifer growth rates was noted on all landslides studied and was pronounced in some cases. It is difficult to project longterm successional development of communities occupying landslide scars, but all indications lead to the conclusion that a productive forest will not develop until adequate soil forms on the landslide site. This may mean that original site conditions will not be regained for several centuries.

The impact of accelerated landslide activity is compounded by active surface erosion observed on exposed subsoils

on the landslide scars. Continual surface erosion impedes seedling establishment and often exposes roots of vegetation that manages to colonize the scar. Surface erosion rates do not decrease until plant cover becomes well established on the scar. A positive feedback becomes effective where erosion impedes reduction of erosion rates. Gradually plant cover becomes established and by the third decade after the initial failure erosion rates appear to decline. On the 45 and 90 year old landslides plant cover was nearly complete and surface erosion appeared minimal.

Efforts to rehabilitate landslide scars and shorten the time period during which surface erosion is active could reduce the overall effect of the accelerated landslide activity observed in the study area. Although examination of methods of artificial revegetation of landslides was beyond the scope of this study, several recommendations can be made on the basis of observations of natural vegetation. Conifer species grow very slowly and are often outstripped by surface erosion. Deciduous tree species such as Red alder (Alnus rubra) and Western dogwood (Cornus nuttallii) grow more rapidly on the landslide scars. On certain sites artificial seeding or planting of these trees could speed up revegetation. Moss species and a soil lichen, Peltigera sp., appeared to be successful in halting surface erosion of some steep landslide scars. Artificial seeding of these plants and other herbaceous plants naturally occurring on landslide scars could achieve considerable success in reducing surface erosion.

The ecological and geomorphological effects of mass movements in the Alder Creek watershed are varied and complex. Since many of the effects are interdependent, an interdisciplinary approach to understanding the cumulative impact of mass movement activity is necessary. It is evident that the forest management activities carried out in the study area have greatly increased landslide activity and produced serious adverse environmental impacts on forest and stream ecosystems. These impacts, however, are difficult to assess because of lack of knowledge of the long-term roles of deep-seated mass movememts, creep, surface erosion and naturally occurring landslides in forest ecosystems. The historical role of fire in periodically increasing erosional activity in forest ecosystems is also relatively unknown. These topics should receive attention in future research.

APPENDIX

Table 17

LANDTYPE SOIL CHARACTERISTICS from Legard and Meyer (1973)

Landtype no.	predominant landform	parent material	depth to bedrock (feet)	color	texture	fertility
1	rock outcrop	andesite and basalt	0	NA	NA	NA
3	talus, rock outcrop, low site ridge-tops.	variable	highly variable	-	-	low
8	steep very dissected sideslopes	green and red breccias and tuffs	1 -20	-	variable	low to moderate
14	smooth to somewhat uneven flats, benches and terraces	variable volcanic	10+	dark yellowish brown	shotty to silt loam	high
15	stream valley bottoms	alluvium	12+	very dark grayish brown to brown	loam to gravelly, cobbly, sandy, loam	moderate high
16	smooth to some what dissected midslopes, toe slopes and valley bottoms	variable volcanic	8+	very dark grayish brown to dark yellowish brown	shotty loam to gravelly, stony loam	moderate
21	steep, smooth to moderately dissected upper side slopes and ridges	red breccias and tuffs	3+	dark brown to dark yellowish brown	shotty loam to gravelly clay loam	low
22	gentle, smooth benches and ridgetops	red breccias and tuffs	6+	very dark grayish brown to reddish brown	shotty silt loam to silty clay loam	high
23	smooth to somewhat hummocky lower sideslopes and benches	red breccias and tuffs	5+	very dark brown to brown	loam to clay loam	high

LANDTYPE SOIL CHARACTERISTICS (cont.)

Landtype no.	predominant landform	parent material	depth	color	texture	fertility
35	hummocky, unstable areas, slump basins and landflows	green breccias and tuffs	10+	very dark grayish brown to brown	clay loam to clay	high
61	steep, smooth to moderately dissected sideslopes	basalts and andesites	2	dark brown	gravelly loam	low
63	smooth higher elevation lava flows and benches	basalts and andesites	4	very dark grayish brown to brown	loam	moderate
64	moderate to steep, smooth side slopes	basalts and andesites	4	dark brown to dark yellowish brown	gravelly sandy loam to gravelly loam	low
LANDTYPE COMPLEXES						
Landtype complex no. and composition.	----------see above----------					
201 60% of 21 40% of 31	steep, smooth to dissected sideslopes and ridges	green breccias and tuffs	3	dark brown	very gravelly loam to gravelly loam	low
202 60% of 21 40% of 61	----------see above----------					
212 60% of 21 40% of 23	----------see above----------					
231 60% of 23 40% of 21	----------see above----------					
236 60% of 23 40% of 16	----------see above----------					

LANDTYPE SOIL CHARACTERISTICS (cont)

Landtype complex no. and composition	predominant landform	LANDTYPE COMPLEXES (cont) parent material	depth	color	texture	fertility
256 60% of 25	hummocky, uneven landforms associated with unstable areas	red breccias and tuffs	7+	dark reddish brown to dark yellowish brown	loam to clay	high
40% of 16		see above				
331 60% of 33	moderate, uneven to hummocky lower sideslopes and benches	green breccias and tuffs	4+	very dark grayish brown to dark yellowish brown	loam to clay	moderate
40% of 31		see above				
333 60% of 33		see above				
40% of 23		see above				
644 60% of 64		see above				
40% of 44	moderate to steep, smooth side slopes	breccias and tuffs	5	very dark grayish brown to brown	loam to gravelly, sandy loam	low

TABLE 18

LANDTYPE EROSIONAL CHARACTERISTICS from Legard and Meyer (1973)

Landtype No.	surface erosion potential	subsurface erosion potential	impact of high lead logging	natural stability	expected change in mass movements as a result of man's activities
1	NA	NA	NA	stable	unchanged
3	moderate to severe	moderate to high	high	stable to moderately stable	increased
8	severe to very severe	high	high	stable to moderately stable	greatly increased
14	moderate	moderate to high	low to moderate	stable	unchanged
15	moderate	low	low to moderate	very stable	unchanged
16	moderate	moderate	low to high	stable	unchanged
21	severe	high	moderate to high	stable	increased
22	moderate	moderate	low to moderate	stable	unchanged
23	moderate	moderate	low to moderate	stable to moderately stable	unchanged
35	moderate	high	moderate to high	very unstable	greatly increased
61	severe	high	moderate to high	stable	increased
63	moderate	moderate	low to moderate	very stable	unchanged
64	moderate to severe	moderate	low to high	stable	unchanged
201	severe	high	moderate to high	stable	increased

LANDTYPE EROSIONAL CHARACTERISTICS (cont)

Landtype No.	surface erosion potential	subsurface erosion potential	impact of high lead logging	natural stability	expected change in mass movements as a result of man's activity
202	severe	high	moderate to high	stable	increased
212	severe to moderate	moderate to high	high to moderate	stable	increased
231	moderate	moderate	low to moderate	stable	unchanged
236	moderate	moderate	low to moderate	stable	unchanged
256	moderate	moderate, locally high	moderate to high	unstable to moderately stable	increased
331	moderate to severe	moderate to high	moderate to high	moderately stable, locally unstable	increased
333	moderate	moderate to high	moderate to low	moderately stable to locally unstable	locally increased
644	moderate	moderate	low to high	very stable	unchanged

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ABSTRACT

Ecological and geomorphological consequences of mass movement activity were investigated in the Alder Creek basin in the Western Cascade Mountains of Oregon. The 4,300 acre study area is characteristic of areas in the low elevation Cascades with steep, dissected hillslopes underlain by weathered volcaniclastic rocks. Both slow deep-seated mass movements and shallow soil mass movements are active in the watershed.

One hundred and fourteen shallow soil mass movements occurring over the past 100 years were identified, measured, mapped and described. Landslides occur periodically in undisturbed, forested areas of the watershed but are much more frequently associated with roads and clearcuts. Landslide erosion rates in road right-of-way areas were 309 times that in forested areas. The great difference in landslide activity in road right-of-way areas as compared to forested areas is due to the particular geomorphic characteristics of the watershed; and the siting, design, construction and maintenance of roads. Suggestions for reducing the effect of roads on landslide activity are discussed.

Landslide activity was also significantly correlated to slope, aspect and bedrock characteristics of the study area. Most landslides occurred on slopes between 38° and 42°. Aspect profoundly influenced the frequency and magnitude of landslide activity. Nearly 100 times more landslide

erosion occurred on north aspect sites than on south aspect sites. The average volume per slide was also significantly greater on north aspect sites.

Slow deep-seated earthflows are common in the northern portion of the watershed. They influence at least 12% of the study area. Slumps and debris torrents were common along earthflow margins but the total amount of sediment contributed by earthflow processes is unknown.

Secondary erosion processes were observed on landslide scars during the fall, winter and spring months. Sediment collected from a ten year old, unvegetated landslide averaged 126 cubic inches per square foot of surface area over a seven month period. During this period erosion transects on an unvegetated ten year old landslide experienced an average depth increase of 0.33 inches due to surface erosion. Established vegetation on landslide scars effectively reduces erosion. Surface erosion impedes revegetation of landslide scars by creating an unstable substrate where establishment of vegetation is difficult.

Plant succession and conifer regeneration was observed on a 90 year chronosequence of landslide scars. Establishment of plant cover took many years on most landslides studied. Successional development on landslides appears to have some similarity to seral stages following other disturbances such as fire or logging but is unique in some respects. Conifer growth rates were markedly reduced on all landslides studied and a stunted coniferous forest appears

to develop on old landslide scars.

Environmental impacts of landslide activity on aquatic and terrestrial ecosystems are briefly discussed. Management implications of this study and suggestions for rehabilitation of landslide scars are mentioned in conclusion.