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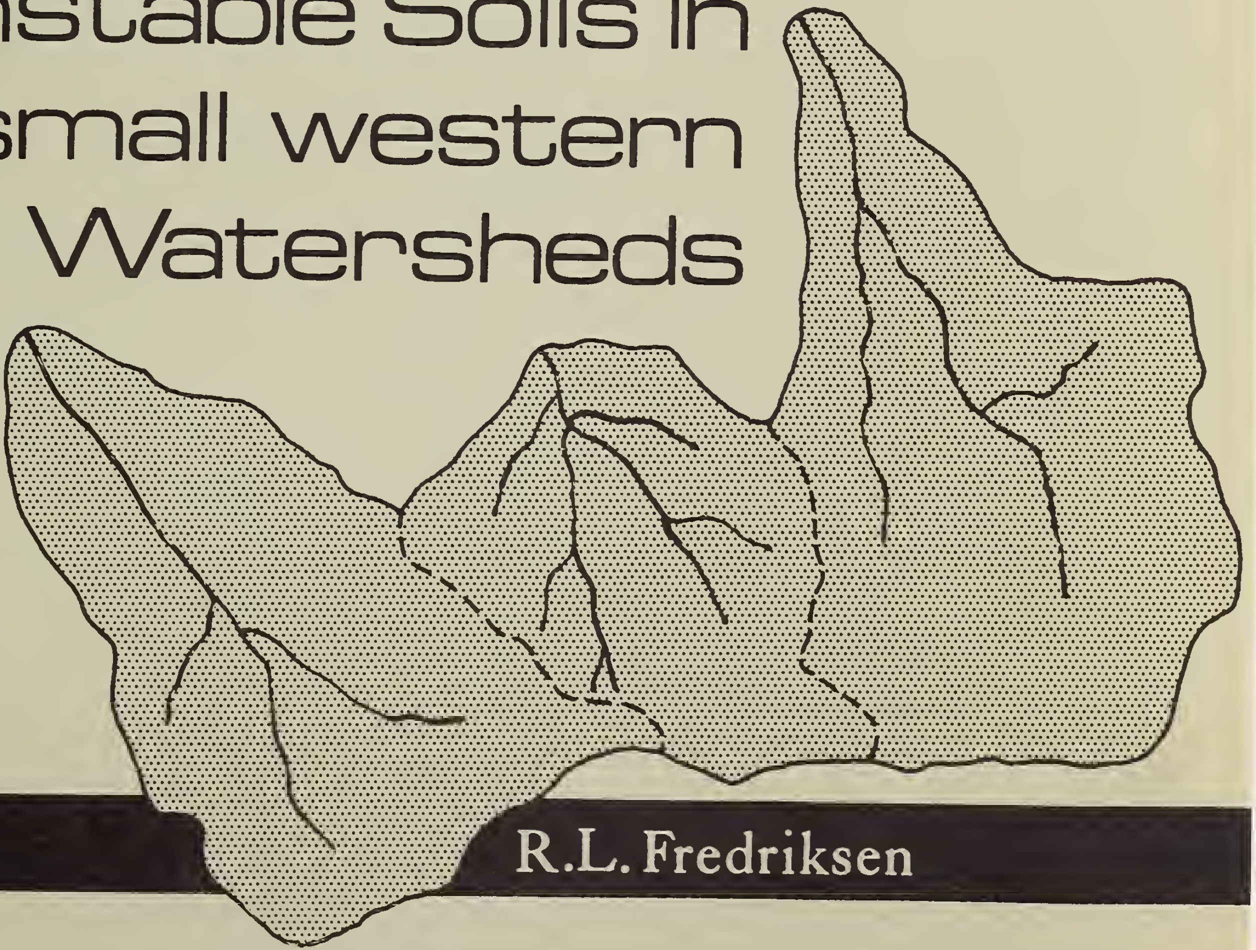
Erosion and Sedimentation following Road Construction and Timber Harvest on Unstable Soils in three small western Oregon Watersheds



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INTRODUCTION

Douglas-fir stands in the mountainous topography of western Oregon are usually harvested in patch clearcuts by high-lead yarding to forest roads. Main-line logging roads are normally located in valley bottoms and along ridgetops. Where side slopes are too long to reach timber, one or more levels of midslope road may be necessary. In the Western Cascades Range Province (Peck et al. 1964), in which this study was conducted, about 430 miles of logging road are constructed each year to harvest 1.4 billion board feet of timber from National Forest land.[1] Harvest of timber from these lands under U.S. Forest Service management supplies 27 percent of the annual income to counties within this province.[2] Although the local economy is largely dependent on income from timber, soil stability problems related to timber harvest (Rothacher and Glazebrook 1968) should be another consideration in management of the forest.

The U.S. Forest Service began a watershed study in 1952 to evaluate the impacts of timber harvest on water quality. The characteristics of three small watersheds while undisturbed have been described in detail by Rothacher et al. (1967). This article will report on erosion in these watersheds and sedimentation rate in their contributing streams after road construction, timber harvest, and debris burning.

THE STUDY

The study was conducted on three small experimental watersheds located on the H. J. Andrews Experimental Forest about 50 miles east of Eugene, Oregon (fig. 1). Timber on one watershed was harvested by a method used throughout the province for at least 20 years. In this method of harvest, small clearcuts are separated by uncut blocks of forest. Logs on the small clearcuts are moved to landings (yarded) by high-lead cable methods where they are loaded onto trucks and transported from the watershed on a system of parallel logging roads. This type of harvest is designated "patch-cutting" in this report. Skyline yarding *without forest roads* was chosen as the second harvest method because (1) forest roads were already highly suspect as a major source of increased sedimentation following timber harvest, and (2) Wooldridge (1960) had shown that surface soil disturbance is minimized by skyline yarding. The watershed which was skyline yarded is referred to as "clearcut" in this report. The third watershed remained undisturbed and has served as a "control" throughout the experiment.

The following details the harvesting done on the watersheds.

Patch-cut Watershed

One watershed (250 acres) was harvested by the conventional practice of patch-cutting with a system of logging roads (fig. 1). Three levels of roads completed in 1959 covered a total distance of 1.65 miles and 6 percent of the drainage--4 percent initially bare soil on fills and cutslopes and 2 percent stabilized road surface (fig. 1). Construction met Forest Service specifications for an all-weather road with culvert cross drains, base rock, and a crushed

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[1] Unpublished information from Region 6, U.S. Forest Service.

[2] Unpublished information from Oregon State Tax Commission, Salem, Oreg.

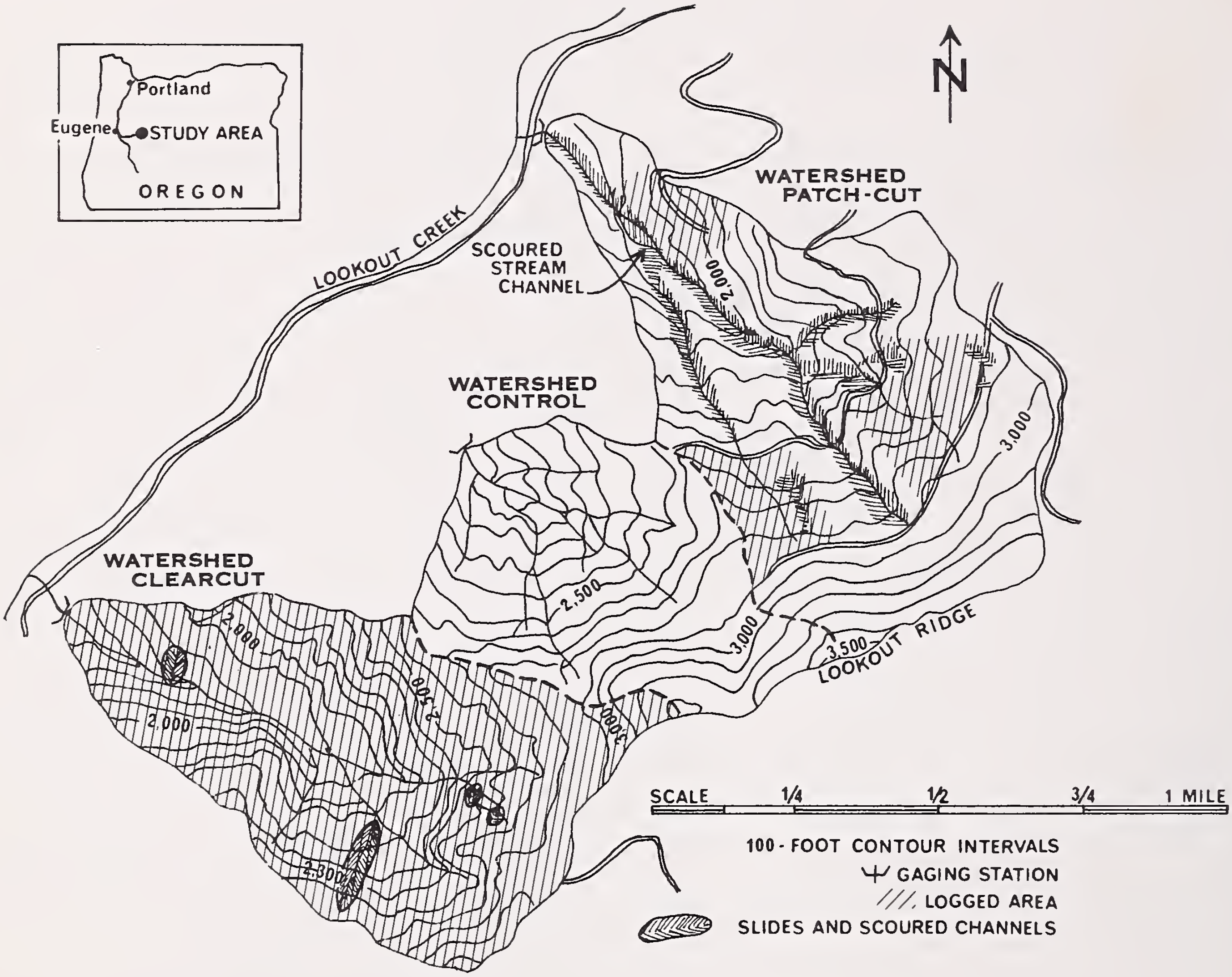

Figure 1.—Experimental watersheds, H. J. Andrews Experimental Forest.

rock running surface. Stream crossings were soil or rock fills depending on available material. Although part of the excavated material was used to construct fills, some was wasted on the hillside below the road. Construction exposed 2.5 acres of soil on backslopes, 8.0 acres on fillslopes, and 5.1 acres on the roadbed. Backslopes and fillslopes were seeded with a grass-legume mixture in the fall of 1959. Although the seeding did not produce a permanent vegetative cover, the straw mulch applied with the seed temporarily protected the soil from rain.

Logging of old-growth Douglas-fir timber by high-lead cable methods was completed during the winter of 1962-63 on three clearcuts of 13, 20, and 28 acres. The logging removed timber from 25 percent of the watershed (fig. 2). Logging debris was burned in September 1963.

Figure 2.—Patch-cut watershed contains three small clearcuts totaling 25 percent of the watershed area and 1.65 miles of logging road.

Clearcut

On the second watershed, timber harvest was begun in the fall of 1962 and completed during the summer of 1966 (figs. 1 and 3). Skyline yarding equipment removed timber from the entire 237 acres of this watershed. With this method, the back end of the logs are dragged to a fixed overhead cable, then lifted free of the ground for transport downhill to the landing. No roads were constructed in this watershed. Debris burning in October 1966 consumed most of the fine logging debris on the slopes and that accumulated in the stream channel. Cull logs remaining in the channel were cut and piled above high water one-fourth mile upstream from the gaging station to prevent the formation of debris jams.

Figure 3.—Clearcut watershed contains no roads. Timber was yarded by a skyline cable system.

CHARACTERISTICS OF THE WATERSHEDS

The watersheds are in the province of the Western Cascades Range of Oregon, a land mass that slopes generally westward from the Cascade Crest and extends from the Columbia River on the north to the Siskiyou Mountains on the south. Parent materials for soils in the watersheds are predominantly tuffs and breccias, volcanic ash deposits of Miocene to Oligocene age.

Topography

The watersheds occupy strongly dissected topography characteristic of western Cascades relief (fig. 1). They occupy the sideslope of Lookout Ridge facing to the northwest and rising 1,400 to 1,850 feet in a mile from valley floor to back ridge (table 1). The three small streams draining these watersheds occupy channels that are deeply incised into the hillside. Sideslopes and headwalls of the small drainages exceed the sideslope of the main ridge by 20 to 30 percent. Slopes range up to 110 percent with a substantially larger area of steep slopes in the clearcut and control watersheds compared with the patch-cut watershed.

Hydrology

A mean annual precipitation of 90 inches consists primarily of rain during the winter months from October through April. Peak runoff in the streams follows long-duration, low intensity rainstorms, often associated with melting snow, that may deliver up to 13 inches of rain in 4 days. Warm rainfall on a snowpack causes the steepest stream rises, and we assume that the largest volume of water is held in temporary storage in the soils of the watersheds under these conditions. Most of the erosion and sedimentation to be reported here occurred during three runoff events of this latter type.

Soils

Soils developed from tuff and breccia parent materials are more common in the watersheds than those from basalt and andesite (Rothacher et al. 1967). They commonly have a thin granular and porous A1 horizon covered by 1 to 3 inches of litter. It has been noted that these soils resist surface erosion as long as this horizon is intact and uncompacted. Medium to fine textured B horizons are often underlain by weathered tuff and breccia parent materials to considerable depths--sometimes greater than 50 feet. These soils are generally very porous and, therefore, rapidly conduct water through the profile (Dyrness 1969).

Soils store maximum amounts of water during the winter months. Water affects the mass stability of the soil mantle in two ways. First, it increases the bulk weight of the soil and, therefore, the downhill gravity force acting on the soil mantle. Second, it reduces the resistance of the soil mantle to shear failure by reducing the cohesive forces that hold soil particles together. Other factors adding to the mass instability of these soils are their large water storage capacity (Dyrness 1969) and the presence of expanding clays in the subsoils of some of the soil series.[3] Because of these soil properties, abundant rain, and steep sideslopes, the dominant erosion process is by landslides.

DISTURBANCE CAUSED BY LOGGING AND BURNING

A dense cover of vegetation and a nearly complete mat of forest floor material (table 2) protects the surface soils from erosion while the forest remains undisturbed. Harvest operations and broadcast burning on two watersheds destroyed a large part of the existing shrub and ground cover. Burning, which followed completion of logging

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[3] Robert C. Paeth. Genetic and stability relationships of four western Cascade soils. Ph.D. thesis, Oreg. State Univ., 126 pp., 1970.

Table 1.--*Topography of the three watersheds*

Item		Patch-cut	Clearcut	Control
Area	acres	250	237	149
Length	feet	5,280	4,950	3,630
Elevation change	feet	1,850	1,400	1,500
Mean slope	percent	53	63	61
Area greater than 80 percent slope	percent	3	14	14

Table 2.--*Total understory vegetation cover and exposed mineral soil after clearcutting of timber and after burning of logging residue*

Year	Patch-cut watershed			Clearcut watershed		
	Condition	Vegetation cover[1]	Bare ground[2]	Condition	Vegetation cover[1]	Bare ground[2]
		Percent	*Percent*		*Percent*	*Percent*
1962	Undisturbed	70	3	Undisturbed	86	4
1963	Clearcut	10	16	Being harvested	--	--
1964	After burning	15	29	Being harvested	--	--
1965	Revegetating	49	28	Being harvested	--	--
1966	Revegetating	54	30	After logging	54	12
1967	Revegetating	62	28	After burning	30	53
1968	Revegetating	80	27	Revegetating	76	54

Source: Dyrness--1965, 1967b, and unpublished data.

[1] Sum of leaf cover in the understory tree layer, shrub layer, and herb layer is additive.

[2] According to this classification, bare ground may occur under leaf cover, and vegetation cover plus bare ground can add to greater than 100 percent.

by several months, reduced vegetation cover more on the patch-cut than on the clearcut watershed. In the clearcut watershed, regrowth of some more fire resistant species during the 3 years required to complete logging may have been responsible for the large cover of vegetation the year following burning (1967). Revegetation was rapid in the case of both watersheds, but a sizable proportion of the soil surface remained bare of litter for several years following burning. On the patch-cut watershed, the herb-rich vegetation established the first 2 years following burning gradually gave way to a rapidly expanding cover of shrubs and trees. By 1968, the total vegetation cover on the clearcuts in the patch-cut watershed exceeded the cover measured under the undisturbed forest in 1962.

Dyrness (1967b) measured the effect of the logging operations and broadcast burning on disturbance to the soil and litter layer. High-lead logging in the patch-cut watershed resulted in double the area of deep soil disturbance (10 percent) and nearly three times the area of compacted soil (9 percent) of that in the clearcut watershed. A larger proportion of the clearcut watershed was burned, and a slightly larger fraction of the burned area was severely burned. The severity of the burn on these watersheds was moderate. Dyrness and Youngberg (1957) and Tarrant (1956), studying intensity of slash burning, found the severely burned area to range from 2.8 to 8.0 percent of the total area burned.

Class	Patch-cut	Clearcut[3]
	- - - Percent - - -	
Severely burned	6.2	6.8
Lightly burned	50.2	61.5
Unburned	42.8	28.1
Nonsoil areas	.8	3.6
	100.0	100.0

EROSION BY LANDSLIDES

Two periods of landslide erosion increased the sedimentation rate in the patch-cut watershed. The first landslide, in December 1961, originated from soil spilled over the hillside below a road being constructed (Fredriksen 1963). This landslide, as is often the case, triggered a mudflow which scoured over one-half mile of the stream channel, depositing about 5,000 cubic yards of debris where the stream passes through the lower logging unit (fig. 1).

Thirty-two landslides occurred in the patch-cut watershed during the storm of December 1964. They moved an estimated 39,200 cubic yards of soil within the watershed.

Condition of terrain	Number	Volume
		Cubic yards
Roads and clearcut	2	230
Roads and green timber	4	36,070
Clearcut only	11	1,200
Green timber only	15	1,700
Total	32	39,200

All but three landslides were adjacent to stream channels. Although the size of most of these landslides ranged from 5 to 1,000 cubic yards, the largest volume came from a single slide located at the head of the principal drainage just downstream from the upper road (fig. 1). Few slides occurred adjacent to roads, but these few accounted for 93 percent of the total volume. The lesser importance of landslides at clearcut and green timber sites is indicated by a much smaller volume of soil lost. Material from nine of these slides (two in clearcut and seven in green timber for a total of 1,540 cubic yards) was not removed from the channel. These landslides occurred after the last mudflow passed down the stream channel, and some of them may have occurred a

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[3] Unpublished data, C. T. Dyrness.

month later during the storm of January 28, 1965. Subsoils exposed adjacent to streams left 2.5 acres of bare soil along channel margins. The landslides of 1961 and 1964-65 created three new types of sediment sources: (1) exposed soils along streambanks, (2) regraded stream channels, and (3) exposed soil on landslide areas. Erosion from these sources has continued to the present time.

Landslide erosion in the clearcut watershed occurred during the January 1965 storm. An estimated 800 cubic yards of soil moved in four landslides (fig. 1). The soil from these landslides came to rest behind logging debris which had accumulated in the stream channel. Although a large amount of this soil was carried away by the stream after the logging debris was burned in 1966, considerable soil remains in the stream channel as terraces.

Erosion in the control watershed has been confined to the stream channels and streambanks. No landslide erosion has occurred here, but landslides have been observed in other undisturbed areas in the Experimental Forest.

METHODS

Field Sediment Measurements

Streamflow was measured at trapezoidal flumes where the streams leave the watersheds. Duplicate depth-integrated water samples for suspended sediment analysis were taken here in pint bottles. Most of the 350 suspended sediment samples for each watershed were taken during periods of storm runoff. Coarse (bedload) sediments were measured annually in small, 0.04-acre, debris basins, which trapped bedload but passed fine sand and silt-size particles.

Determination of Sediment Yield

Mean suspended sediment concentration was obtained in the following manner for the 6-month winter period from November through April. This period includes the important peak flows of these streams and 89 percent of the annual runoff. Streamflow was divided into discharge classes from low to peak flows. Hours of streamflow in each class were further subdivided according to the time that the stream was rising and falling. Mean suspended sediment concentration for each class was estimated separately for rising and falling flows from hand-fitted curves relating concentration to streamflow. As sedimentation rate changed with condition of the watershed, new curves were drawn. Six distinctly different sedimentation rates were evident in the data from the patch-cut watershed, five rates for the clearcut watershed, and a single rate for the undisturbed watershed.

Annual bedload yield was derived from the volume of sediment trapped in the basin and an estimated sediment density of 62 pounds per cubic foot. Total sediment yield was the sum of the estimated suspended and bedload yields for each watershed and year.

Accuracy and Precision

The mean concentration data in figure 4 are subject to several sources of error. Errors are of the following types: (1) variation in sediment concentration about the hand-fitted curves, (2) poorly defined data near peak flows, (3) error in concentration due to sampling technique, and (4) errors in partitioning sediment into a suspended and a nonsuspended fraction. Curve-fitting errors (type 1) are small and compensating. Type 2 errors may be large. Only the 1964-65 sedimentation peak for the patch-cut watershed, shown by the broken line in figure 4 is of this type. The type 3 error is systematic in that openmouthed bottles underestimate the true concentration carried by the stream. The type 4 error is small since particles larger than fine sand were removed from the sample. The suspended sediment data underestimates the true concentration carried by the stream, particularly when the concentrations were large. When the curve is well defined, estimates are ± 10 percent or better.

Bedload sediment measurement errors are probably no larger than ± 5 percent of the values indicated in figure 5, except for the years 1965 and 1966 at the patch-cut watershed. In 1965, an unknown but comparatively small quantity of the material carried in mudflows was lost downstream. In 1966, part of the bedload trapped in the new basin was lost when the dam failed.

RESULTS

Sedimentation From Undisturbed Watersheds

All three streams carried only small amounts of sediment while their watersheds were undisturbed. Mean annual winter season concentration ranged from 1 to 45 parts per million (p.p.m.) of suspended sediment in response to the proportion of winter flow that occurred as storm runoff (fig. 4). Mean suspended sediment concentration was highly correlated in these streams while their contributing watersheds remained undisturbed. But streams in both patch-cut and clearcut watersheds contained higher mean concentrations of suspended sediment while their watersheds remained undisturbed--1.9 and 1.2, respectively, times the mean concentration in the control stream. These factors are used to estimate the changes in suspended sedimentation rate after the contributing watersheds of these streams came under management.

The amounts of sand and gravel carried along the streambed were also small. Bedload from the control watershed totaled 23 cubic feet per acre for 12 years for an annual average of nearly 2 cubic feet per acre (fig. 5). The accumulation was about half for the other two watersheds while they were undisturbed.

Maximum concentrations of sediment normally occur at the time of peak flow from winter storms. Measured peak concentrations seldom exceed 200 p.p.m. of suspended sediment. In the control stream, the maximum measured concentration (1,300 p.p.m.) occurred once during the storm in 1964-65, a storm with a likelihood of recurrence estimated at 100 years.

Sedimentation From Patch-cutting and Roads

Sedimentation increased in the fall of 1959 soon after the roads were completed. The first fall storm, on September 29, carried a peak concentration of 1,850 p.p.m.--250 times the expected concentration from this watershed in an undisturbed condition. This initial flush of sediment receded to about nine times the expected concentration 9 weeks later (Fredricksen 1965). For the next 2 years until the storm of December 1961, concentration increase remained at two to three times the expected undisturbed concentration (fig. 4). Only a modest rise in bedload sediment is evident for this period (fig. 5).

A landslide from the midslope road in late December 1961 again increased sedimentation (Fredriksen 1963). The mudflow resulting from this slide scoured over one-half mile of stream channel. Mean concentration for 1961-62 rose to 34 times the expected undisturbed concentration (fig. 4), and bedload sediment increased by 11 cubic feet per acre (fig. 5). An acre of bare soil left by the slide adjacent to the channel and debris deposited in the

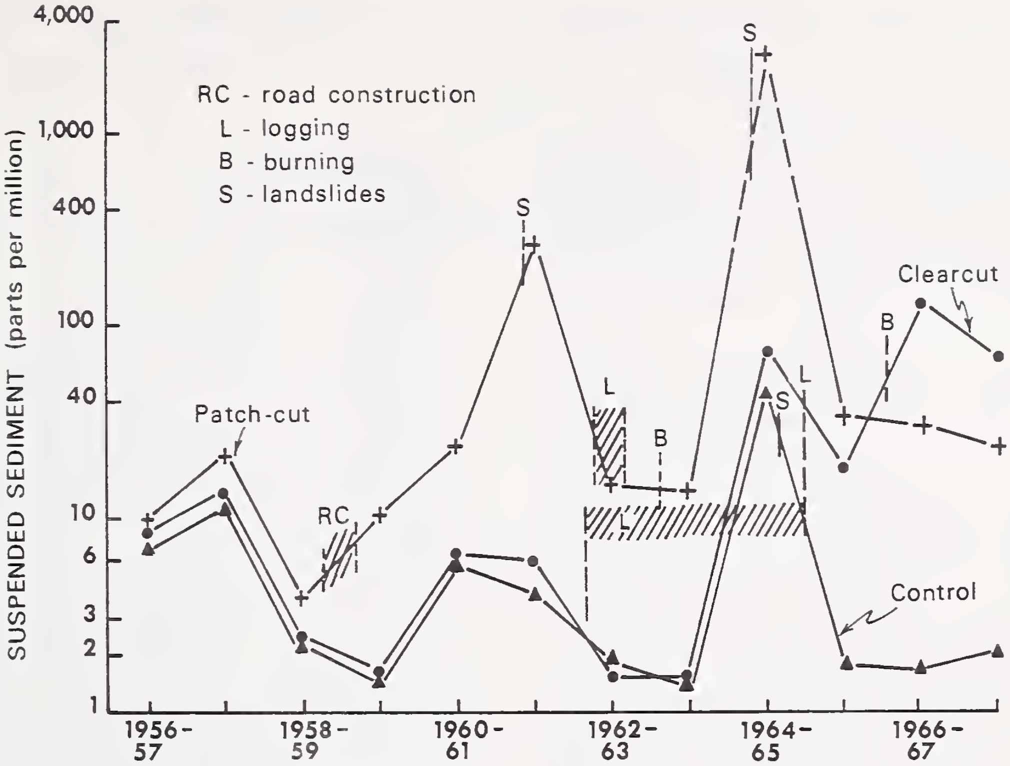

Figure 4.—Mean concentration of suspended sediment during the winter season high runoff period.

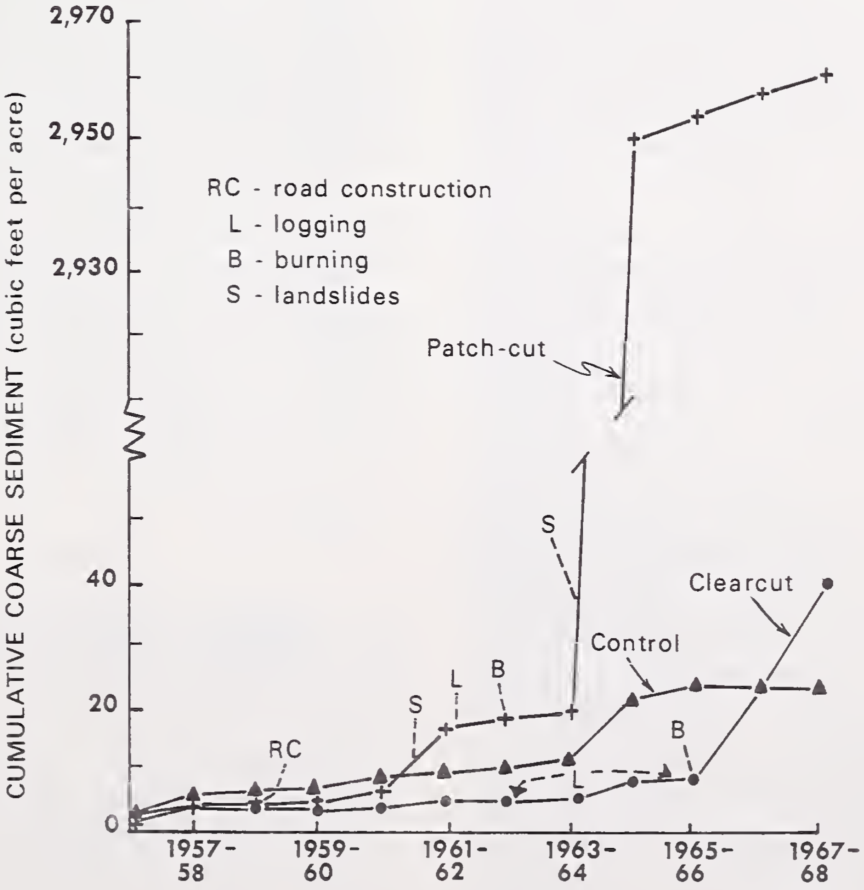

Figure 5.—Accumulated volume of coarse sediment trapped in catch basins.

channel became new sources that maintained the sedimentation during 1962-63 and 1963-64 at a level of five times the expected undisturbed concentration (fig. 4). Logging during the winter of 1962-63 and burning during the fall of 1963 caused no discernible rise in the sedimentation rate above the level created by the slide of December 1961.

The greatest sedimentation resulted from the landslide erosion and mudflows that scoured the stream channels in the patch-cut watershed during the largest storm to date, December 1964 (Fredriksen 1965). Mean concentration of 2,470 p.p.m. for 1964-65 was 34 times the expected undisturbed concentration (fig. 4). But a much larger proportion of the total sediment was moved as bedload (83 percent) during this year. The total volume of soil and rock deposited in the stream channel and covering the gaging station was 150 times the volume moved from the control watershed.

The estimated combined bedload and suspended sediment lost in this year was 70,200 tons per square mile. The estimated volume of soil from the landslides (37,600 cubic yards) is equivalent to 82,000 tons per square mile. Since a considerable volume of soil carried by the stream was not measured at the gaging site, the total estimated sediment loss of 70,200 tons per square mile for this year appears conservative (figs. 4 and 5).

Sedimentation rate remained elevated during the 3 years following the 1964 event. Sources of this sediment were subsoils bared by landslides, soil exposed along stream margins by mudflows, and soil deposited in the stream channel. Suspended sediment concentration remained at an average of nine times the expected undisturbed concentration (fig. 4), and bedload sediment accumulated at 4.6 times the rate in the control watershed during these 3 years (fig. 5).

Sedimentation From Clearcutting Without Roads

The first 2 years after logging began (1962-63 and 1963-64) were marked by little or no change in sedimentation (figs. 4 and 5). We attribute this to the filtering action of logging debris in the stream channel. Low sedimentation rates prevailed until landslides during the storm of January 1965 brought an estimated 800 cubic yards of soil and rock into the stream channel. Source areas of this material are indicated in figure 1. Although a modest rise in suspended sediment concentration was noted, compared with the expected undisturbed concentration, most of the fine sediment and nearly all the coarse sediment remained in the stream channel trapped behind logging debris.

Burning after completion of logging in October 1966 consumed all of the fine logging debris in the stream channel. Soil and rock in the channel, released by the fire, became a primary source of sediment. Soil exposed by the fire on the hillside slopes (table 1) was an additional source of sediment. These combined sources increased sedimentation during 1966-67 and 1967-68. Mean suspended sediment concentrations were 67 and 28 times the undisturbed level in the 2 respective years (fig. 4). Volume of coarse sediment increased to almost 30 cubic feet per acre for the 2 years compared with less than 0.1 cubic foot per acre from the control watershed.

Sediment Loss From the Patch-cut, Clearcut, and Control Watersheds

Soil loss from these watersheds is related to the type of management on the three watersheds (table 3). In the patch-cut watershed with 25 percent of the area clearcut and 6 percent in forest roads, total sediment yield for the 1960-68 period

Table 3.--*Mean annual soil loss from the three watersheds*

Watershed and means of transport	Yield		Relative yield	Soil loss
	1960-68	1963-68		
	Tons per square mile			*--Inches--*
Control:				
Suspended load	36	46	1.0	0.0006
Bedload	37	47	1.0	.0006
Total load	73	93	1.0	.0012
Clearcut without roads:				
Suspended load	--	195	4.2	.0027
Bedload	--	112	2.4	.0015
Total load	--	307	3.3	.0042
Patch-cut with roads:				
Suspended load	1,430	--	39.0	.0200
Bedload	6,550	--	178.0	.0900
Total load	7,980	--	109.0	.1100

was 109 times the loss measured from the control watershed. It is important that 99 percent of the soil was lost during the 2 years that landslides occurred, and 82 percent of this was bedload (table 4). Soil loss from the clearcut watershed *without* roads was only 3.3 times the loss from the control watershed (table 3), and two-thirds of this was suspended sediment (table 4). Nearly 70 percent of the soil was lost after burning. Mean annual sediment loss of 7,980 tons per square mile from the patch-cut watershed with roads was 26 times the loss of 307 tons from the clearcut watershed without roads.

DISCUSSION

Forest roads have been recognized as a major factor contributing to sedimentation of streams in the western Cascades (Dyrness 1967a, Rothacher and Glazebrook 1968). The relative yield data in table 3 emphasize the importance of secondary logging roads and the lesser importance of clearcutting on sedimentation in the steep headwater streams of this study. This study indicates that timber harvest operations involving high-lead cable yarding to a system of logging roads may increase sediment in streams draining these areas by two to 150 times the amount from undisturbed watersheds in any one year. These increases may average more than 100 times the undisturbed condition over a period of years.

By far the greatest soil loss was associated with landslides and the scouring action of high-velocity mudflows which often pass down the stream channels following a landslide. In fact, 97.7 percent of the sediment yield (table 4) from the patch-cut watershed occurred during the winter season of 1964-65 when 32 landslides occurred during a storm with a return interval estimated at 100 years. An additional 1.3 percent of the sediment yield occurred during an earlier landslide event in 1961-62. Landslides associated with forest roads moved the largest volume of soil. These landslides occurred most often where roads intersected stream channels. Clearcutting apparently had a much smaller influence on the occurrence of landslides.

Table 4.--*Distribution of total sediment yield during selected subperiods of the treatment phase of the clearcut and patch-cut watersheds*

Treatment and period of measurement	Suspended sediment	Bedload sediment	Total sediment
	- - - - - - *Tons per square mile* - - - - - -		
Clearcut watershed:			
Undisturbed, 1956-62	130	100	230 -
Harvest, 1962-64	9	5	14 (0.8%)
Harvest and landslides, 1964-66	470	70	540 (29.5%)
After burning, 1966-68	680	590	1,270 (69.7%)
Mean annual, 1962-68	195 (64%)	112 (36%)	307 (100%)
Patch-cut watershed:			
Undisturbed, 1956-59	130	80	210 -
Roads only, 1959-61	120	40	160 (0.2%)
First landslide--roads only, 1961-62	700	220	920 (1.3%)
Harvest and burning, 1962-64	80	40	120 (.2%)
Second landslide, 1964-65	11,700	58,500	70,200 (97.7%)
After second landslide, 1965-68	240	190	430 (.6%)
Mean annual, 1959-68	1,430 (18%)	6,550 (82%)	7,980 (100%)

Sources for the remaining 1.0 percent of the yield reported in table 4 (710 tons per square mile) arose from the newly constructed roads and sediment sources created by landslides--i.e., exposed subsoils on landslide areas, disturbed stream channels, forest road repair activities, and bare soil along stream margins for the 7 years when there were no landslides. These sediment sources maintained the suspended sediment concentration at an annual average level five times greater than the expected concentration of an undisturbed watershed (fig. 4).

Dyrness (1967a), from a much larger sample of landslide events following the 1964 storm on the H. J. Andrews Experimental Forest, also concluded that landslides were more frequent adjacent to forest roads. He found landslides slightly more frequent in logged areas compared with areas in green timber and that they occurred most frequently on slopes steeper than 60 percent. Dyrness points out that

> it should be borne in mind that in an area such as the Andrews Experimental Forest, where slopes are steep and a large portion is underlain by soft, deeply weathered pyroclastic rocks, the stage is set for extensive mass movements during high rainfall periods whether or not a disturbance is a factor. Therefore, it is perhaps often true that man's activities accelerate the occurrence of

> mantle failure events in an already unstable area, rather than contribute in any significant way to this basic instability. In other words, disturbance may cause some small and, by itself, insignificant change which is nonetheless sufficient to upset the tenuous equilibrium and trigger mass soil movement [a landslide event].

One not so surprising result was the relatively small soil loss attributable to surface erosion phenomena. Although surface runoff is seldom observed in the Experimental Forest on undisturbed areas, it is conceivable that changes in the soil surface, such as logging compaction and severe burning, could affect infiltration of water. However, in the clearcut watershed in 1962-63 and 1963-64, the initial effect of skyline logging had little or no influence on the sedimentation rate. There was also no significant increase in the prevailing sedimentation rate resulting from logging and burning in the clearcut areas of the patch-cut watershed. Mean concentration of suspended sediment did increase two to three times during 1959-60 and 1960-61 mainly as the result of surface erosion on 10.5 acres of cut- and fillslopes that remained after the completion of road construction. This sedimentation rate was small compared with sedimentation following landslide erosion.

Most of the sedimentation from these watersheds occurred during winter season periods of intense storm runoff. The three periods of extensive erosion by landslides in the experimental watershed occurred in conjunction with major storm runoff events characterized by very rapidly rising streamflow. Concentration of water in the soil must reach a maximum at the time of rapid stream rise. The three storm events were generated by the combined effects of rain and melting snow (Fredriksen 1963, 1965). Two other rainfall-induced runoff events have caused mass movements of soil in the Experimental Forest in the past 17 years. This short-term record indicates a short recurrence period of 3 to 4 years for these storms (Fredriksen 1965).

One other study reports sediment yields from forest land in the western Cascades of Oregon. Anderson (1954) estimated erosion potential of the upper McKenzie River drainage, including the H. J. Andrews Experimental Forest, at 110 to 140 tons per square mile per year. This estimate, which includes only suspended sediment yield, was made on the basis of 6.1 percent of the drainage in recent clearcuts and 0.1 percent of the area in roads. Mean annual suspended sediment yields from our study of 40 and 200 tons per square mile, respectively, for the undisturbed and clearcut watersheds are in the same order of magnitude as Anderson's estimates for the undisturbed and clearcut condition. As he indicated, sediment production may be far above the average where land use is heavy. Therefore, it is not surprising that average annual suspended sediment yield of 1,430 tons per square mile from the patch-cut watershed with 6 percent of the area in forest roads exceeds Anderson's estimate by one order of magnitude. Silen and Gratkowski (1953) estimated that roads disturb approximately 6 percent of the forest area under management when harvest is by patch-cut logging compared with 0.1 percent estimated by Anderson.

CONCLUSIONS

Although this report is limited to one set of three watersheds and a relatively short period of time, it clearly provides an estimate of sedimentation that can and does occur in the western Cascades. Where topography in this province is steep (valley sideslopes and drainage headwalls greater than 60 percent) and where soils are naturally unstable (derived predominantly from tuff and breccia parent material), landslides are the major source of stream sedimentation. Their occurrence is more frequent where logging roads intersect stream channels. Slide-producing storms occur in this province at 3- to 4-year intervals and must be considered in harvesting plans.

This study suggests that we can expect a minimal deterioration in water quality arising from sedimentation where disturbance from road construction is minimized by reduction of midslope road mileage through the use of specially designed yarding systems. Where midslope roads must be constructed across steep sideslope or headwall areas, all knowledge available to the engineer should be used to stabilize roads. In the logging operation, every effort should be made to minimize disturbance to the streambed by keeping slash and debris out of the streams.

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2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

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