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RATES OF SOIL EROSION BY SURFACE AND MASS EROSION PROCESSES IN THE WILLAMETTE NATIONAL FOREST

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This report was prepared at the request of, and under funding from, the Willamette National Forest to provide a summary of available data on soil erosion by surface and mass erosion processes on Forest lands. These data were to be summarized in terms of Soil Resource Inventory (SRI) units (Legard and Meyer, 1973) and type of management treatment. The summarization of mainly unpublished data was to be completed in three weeks.

In addition to providing the basic data requested, we discuss briefly (a) the field methods and assumptions involved in generating these numbers, (b) limitations and qualifications of these estimated erosion rates, (c) the relationship between measured erosion rates and SRI units, and (d) some thoughts on how to improve the data base and methods of analysis for the next round of planning. Also included is a table reviewing data on soil disturbance by various logging systems in western U.S. and Canada.

SURFACE EROSION

Background

Surface erosion as used here refers to the particle-by-particle downslope movement of material under the influence of rainsplash, dry ravel, animal, and freeze-thaw activity. Overland flow has rarely been observed on other than highly disturbed surfaces in the Forest.

Surface erosion has been measured in the Willamette National Forest in a variety of ways in a variety of studies with different research objectives, but there has been no effort to systematically sample surface erosion by SRI unit and management treatment. Consequently, we can provide measurements of surface erosion rates for only a few combinations of SRI units and management histories. Furthermore, the variety of measurement techniques used adds an extra measure of uncertainty in comparing values between studies.

Methods and Assumptions

All of the studies cited in this report measured surface erosion rates with collection boxes placed along the hillslope, and periodically cleaned of the accumulated soil material. The collected material was separated into an organic and inorganic fraction, dried, sieved, and weighed. Studies differed as to the size and number of collectors, periodicity of sampling (table 1), whether the boxes were systematically distributed across the site or placed to measure specific local rates, whether the contributing upslope area was bounded or unbounded, and whether the site itself was modified as part of an experiment or as the result of standard management activity.

In all cases, the method of analysis of the raw data was similar. Only the inorganic fraction was used. The total weight of material accumulated over the course of each year was determined for each box. On Watersheds 9 and 10 (streamside) the total weight from all boxes was used. Whenever data for a particular collection period was missing; results from the two adjacent periods were averaged and used as an estimate of the missing period.

For all sites, except Watersheds 9 and 10, the accumulated weight was divided by the estimated contributing catchment area to give an annual yield rate per unit area. Since the collectors in Watersheds 9 and 10 were unbounded and located along the stream perimeter, a slightly different procedure was used. The total annual weight of material collected was divided by the total length of collector opening to give a weight collected per unit length of opening. This result was then multiplied by the length of the stream perimeter along which the collectors were placed, yielding the annual delivery of material to the stream. Dividing this delivery rate by the basin area (21 acres in Watershed 9 and 25 acres in Watershed 10) yielded an annual yield rate per unit area. The close correspondence of rates computed in this manner with rates computed by the local catchment area method suggests that the two methods are comparable. Weights were transformed into volumes by the assumption that the specific weight of inorganic sediment was 1.5 gr/cm^3. Hence, 1 gram equals 8.47×10^{-7} yd^3.

The results, by SRI unit and treatment history, are presented in Table 2. Both best estmates and raw averages are presented. Except in the case of Watershed 1 studies, results are not areally weighted. In most areas, areal weighting would only slightly modify the results. Best estimates differed from the raw average in those cases where it was felt that rates from individual boxes were anomalously high and not characteristic of the site in general, in which case those boxes were not averaged in with the others. Where this has been done, it is noted in the footnotes to Table 2.

Results

Summarized values of surface erosion rate are surprisingly consistent except for some explainable outliers (Table 2). This is true despite high spatial variability in surface erosion rates in small areas. A general rate for steep forested conditions is about 0.02 yd^3/ac/yr, 0.09 yd^3/ac/yr for clearcut and unburned sites, and 0.05 to 0.7 yd^3/ac/yr for clearcut and burned sites.

Variability within a given SRI unit or individual study site is very high for the areas sampled. Average rates for each study were strongly influenced by the high volume of material trapped in only one or two collectors even where the total number of collectors exceeds 30. For example, during the period 4/02/75 to 4/30/75, a total of 91.47 grams of sediment were collected from 10 boxes on HJA-9; the average collection per box was therefore, 9.15 grams. However, the actual weight of sediment per box ranged from .02 grams to 77.73 grams. Hence, 85% of the total came from one box while the other nine contributed 15%. This is not atypical as over the five year period of monitoring in forested Watershed 9, 30 of the 47 periods sampled had 40% or more of the total amount contributed by a single box. The siting of collection boxes relative to local hillslope source areas, such as bare soil from a root wad, has a great deal to do with the yield rates observed.

There are a few anomalously high yield rates reported in the table, specifically Sites II and V of the McCorison boxes. If these points are eliminated from the data set, very consistent yield rates are obtained for all forested sites ($\bar{x}$ = .0265 yd^3/ac/yr, s = .0202). It is reasonable to exclude these samples from the description of general conditions, because McCorison selected his forested Sites I to VI to provide estimates of maximum rates of surface erosion for forested conditions. These sites had slopes of 80 to 100% and 5 of the 6 had ground cover of less than 100%.

Surface Erosion and SRI Units

Surface erosion data are available for only 8 SRI units, so it is not possible to judge the usefulness of SRI designations of surface erosion potential against actual measurements of erosion rate. Furthermore, the very high variability within SRI units observed in several studies indicate that a very large number of samples would be needed to distinguish surface erosion rates for different SRI units. Furthermore, the available data samples a narrow range of surface erosion potential classes (table 2) so these data do not provide a good check on surface erosion potential as a relative measure of surface erosion rates.

A summarization of surface erosion rates in terms of slope gradient and duff cover (tables 3-5) indicates that these two variables are strongly correlated with surface erosion rates and could be used as a basis for estimating surface erosion at sites where no measurements have been made.

Surface Erosion for Different Management Activities

No data are available for comparing surface erosion for various management activites. McCorison measured surface erosion from skid trails in a partial cut unit while other values are for managed areas in clearcuts where skyline logging was used. These logging systems met with mixed success in achieving full suspension (ground disturbance for Watershed 1 documented by Dyrness (1967 in footnote 5, Table 6), and for Watershed 10 by McCorison, pers. communication, (Table 6)).

One way to estimate surface erosion for various treatments would be to average McCorison's value for skid trail erosion for the percent of area disturbed by each treatment with an average rate of clearcuts (burned or unburned as appropriate) for the rest of the area. Table 6 is a summary of soil disturbance data for the Pacific Northwest.

Time Trends

It is difficult to define variations in the surface erosion rate through time after treatment because the relevant data are very limited. The studies in Watershed 1 (clearcut, burned) involve sampling for about one year each in two different periods beginning 10 months and 12 years after burning. Mersereau and Dyrness (1970) remark that they probably missed 60+% of the first two years of erosion because of not sampling the extremely high rates typically observed during and immediately following burning (Bennett 1982). When Lienkaemper and Swanson resampled 12 years later, at 7 of the 8 sites, erosion rates had declined to the level typical of forested conditions. Only at the most unstable site (80% slope, bare, south aspect) was the rate high, yet this rate was similiar to rates observed by McCorison on steep (100%) forested slopes. Thus, in many sites, surface erosion rates following management activity may decline to rates typical of forested areas within 10 years. Table 2 shows estimates of surface erosion rates for the first decade after cutting and burning in Watershed 1 (SRI unit 14 = 0.75 yd^3/ac/yr; unit 310 = 0.67, unit 331 = 0.053) based on the simple procedure of averaging the year 1 and year 12 post-burning data. Table 3 shows estimated first decade estimates for clearcut, burned conditions for three slope classes, based on methods described in the footnotes.

Surface erosion rates in Watershed 10 (clearcut, unburned) show a slight, general decline over the first four years after treatment. If we assume a gradual decrease to the forest rate (0.022 yd^3/ac/yr) over 10 years, the average rate for the first decade would be about 0.056 yd^3/ac/yr .

The Ryder Creek studies of the Department of Soil Sciences, Oregon State University, provide only a 2 year record post-burning. In each of the three slope classes, surface erosion rates increased from the first to second year after burning. Predicting a time trend from these observations must await additional sampling and data analysis.

Qualifications

This report contains data collected with a variety of methods. An important variation was the use of both bounded and unbounded plots. Some studies calculated erosion for plots with contributing areas bounded by natural features (Mersereau and Dyrness 1972) and others used constructed boundaries to define contributing area. Studies in Watershed 9 and 10 used unbounded plots for which contributing area was not estimated. The sediment collected by each method can be expressed on an areal basis, but we are uncertain how comparable the data are. The key problem is that we do not know rates of downslope movement of soil particles by surface erosion processes. If we divide the volume of collected material by an apparent contributing area larger than the actual contributing area, the surface erosion rate will be underestimated. Rates of particle transport (Bennett 1982) and effects of slope length are very different in the case where overland flow is unimportant, as on the Willamette National Forest, than in agricultural lands where overland flow dominates erosion.

A basic study of mechanics of surface erosion and effects of slope length on erosion rate are needed for west-side forest lands. Such a study would aid interpretation of existing data.

A better evaluation of surface erosion on the Forest would require much more extensive sampling. D. G. Moore (PNW, Corvallis) is beginning a study of alternative means of brush control in the western Cascades that may help provide substantial new data. He is setting up approximately 200 erosion collectors at widely scattered locations with a range of site treatments, soil types, and slope gradients.

Surface Erosion From Roads

A limited number of studies have attempted to document rates of surface erosion from forest roads. The most detailed analysis of sediment production from roads in the Northwest is probably Reid's (1981) work in the Olympic Mountains of Washington where surface erosion was measured as a function of road type and traffic intensity. The effect of logging roads on sediment production has also been documented in the granitic uplands of the Idaho Batholith (Megahan 1978, Megahan and Kidd 1972a, b). In the Willamette, road erosion studies have primarily assessed different seeding treatments for reducing erosion on bare cut and fillslopes (Wollum 1962, Dyrnesss 1975).

Because of the high variability of site conditions, methods and results, only those studies carried out in the Willamette National Forest are reported here (Table 7). While SRI units are listed in the table, the limited data set makes extrapolation of road-related erosion rates to other parts of the Forest uncertain. However, it is clear that road erosion rates are an order of magnitude greater than rates for clearcut and burned sites. It is also evident from Table 7, that erosion rates decline as vegetation becomes established on the bare slopes. It appears that soil erosion rates on roads approach the clearcut/burned rate after 5-7 years.

DEBRIS SLIDES

Background

Debris slides are shallow, rapid mass failures which typically occur during periods of intense precipitation, often augmented by snowmelt. Debris slides have been inventoried in six studies in the Willamette National Forest, using combinations of aerial photographic and field investigation techniques. Detailed studies in the H. J. Andrews Experimental Forest (Dyrness 1967, Swanson and Dyrness 1975, Swanson, unpub. data), Alder Creek (Morrison 1975), and Blue River (Marion 1982) were done with comparable methods and standards. We use data from these studies as the basis of this analysis. Chesney (1982), Hicks (1982), and Lyons (1981) also inventoried slides in all or part of the Forest, but data from these studies are not included because methods are sufficiently different that results should not be merged.

The study areas analyzed in this report total 33,600 acres or about 3% of available commercial forest land in the Forest.

Methods and Assumptions

Landslide data for the three study areas were compiled from aerial photographs and field traverses. Only those inventoried events greater than 100 yd^3 which occurred since first management entry in about 1950 were used in this report. Slide areas and volumes were determined from estimates of scar width, length, and depth measured in the field. Slides were assigned to an SRI unit based on their mapped position and were classed by whether they occurred in natural, managed (clearcut), or roaded areas[1]. Data on total acreage in natural and managed condition and road mileage by SRI unit (as of October 1981) were provided by the Willamette National Forest. Road acreage was computed as 8 acres per linear mile; this area was then subtracted from the natural category so that total acreage in each SRI unit remained constant. While a more

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[1]Natural areas consist of: (1) pole stands greater than 63.99 acres, (2) large and small sawtimber stands, (3) old growth stands, and (4) noncommercial, rocky, and permanent grass areas. Managed areas consist of: (1) pole stands less than or equal to 63.99 acres, (2) non-stocked areas, and (3) areas with established seedlings and/or saplings. Definitions and areas determined by the Willamette National Forest Planning Staff.

accurate procedure might have been to apportion the road acreage between natural and managed areas, the area in road right-of-way is small so the results would not change significantly.

Slide frequencies for each SRI unit were determined by dividing the number of events in each management class by 30 years (the period of record) to give an average annual rate. An areal rate was then determined by dividing this annual rate by the area in each management class thus giving the frequency of events in terms of events per acre per year by SRI unit and management history (Table 8). We grouped SRI units on the basis of (a) the Expected Mass Movement Potential rating from the SRI table of Erosion and Hydrologic Interpretations (Table 9) and (b) the slope and rock type characteristic of each SRI unit (Tables 10 and 11) to yield annual slide frequency per unit area for each SRI group and each management class.

Annual area and volume rates are also given based on an areal weighting of the average area disturbed and volume per slide as reported in the three original studies.

Results in Terms of SRI Units and Groupings

We report slide frequencies for the 51 individual SRI units in the study areas and by Natural, Managed, and Road conditions (Table 8). The value of relating slide frequency to SRI unit is that different slope and soil conditions reflected in the SRI designations have different potentials for mass failure. SRI units can be used as a basis for transferring slide frequency data from study areas to parts of the Forest which have not been investigated.

Even though a large area and 363 slides are in the data set, when these events are broken down into 3 condition classes and 51 landscape units, many condition/SRI unit combinations have too few slides or too little acreage to give a good measure of slide frequency. Therefore, SRI units were first grouped into three classes on the suggestion of Hal Legard (Willamette National Forest) who was involved with the original SRI mapping and description of relative stability of different SRI units. The groupings are (a) Unchanged, (b) Increased and locally increased, and (c) Greatly Increased (Table 9) as defined in the Expected Mass Movement Potential ranking of slope stability in the Erosion and Hydrologic Interpretation table of the Soil Resource Inventory.

The observed frequencies of slides in the three stability classes correspond fairly well with the subjective evaluations of relative stabililty (Table 9). There are successively higher slide frequencies in Managed and Road conditions for each stability class. The slide frequencies for each treatment are progressively higher in the more unstable classes of SRI units for Managed and Road conditions. However, the Natural slide frequency decreases with the more unstable classes. Judging from the data in Table 8, it appears that this is due to the presence of several SRI units rated as "unchanged" with anomalously high landslide rates (notably SRI units 162 and 168). The terminology should probably be changed because, although the "unchanged" class is most stable, the frequency of slides does increase with cutting and roading. We suggest stable, moderately stable, and unstable as replacements for Unchanged, Increased, and Greatly Increased.

An alternative somewhat more quantitative approach to grouping SRI units would be to rank them in terms of slope and bedrock conditions described in the SRI with minor modifications based on slide frequency data (Table 8). In this way we defined three groupings: stable units with gentle slopes (less than 40%) of any rock type, moderate slopes (40-60%) with hard rocks (basalt and andesite flows), and rock outcrops with little or no soil; moderately stable units with steep slopes (60+%)/hard rocks and moderate slopes/soft rocks (tuffs, brecias); unstable units with steep slopes/soft rocks. SRI units 13 (earthflow areas) and 15 (streamside areas) probably belong in the moderately stable class, because, although they have gentle slopes, localized steep areas are quite prone to sliding. Assignment of stability classes for sampled SRI units are listed in Table 8.

Based on the above slope and rock type criteria, we assigned all SRI units in the Forest to stability classes (Table 11). In several cases we changed the stability class because of observed slide frequency characteristics of sampled units; any changes and reasons for them are noted in the Comments column in Table 11. For SRI complex units we assigned the stability class of the major unit in the complex, except where the two stability classes were U and S, we assigned M to the complex.

This system appears to give more realistic stability groupings (Table 10) than Expected Mass Movement Potential (Table 9) because (a) for natural conditions it shows higher slide frequency in the more unstable SRI units, and (b) it makes greater distinctions between stability groups, as reflected in greater differences between stability groups for a particular condition. Stability groupings could be improved substantially with additional slide frequency data.

Time Trends

In a sample of 26 debris slides inventoried in clearcut areas in the H. J. Andrews Experimental Forest, 88% took place in the 10 years after cutting. In terms of a general value, it is reasonable to assume that 90% of slides in clearcut areas occur in the first decade after cutting.

Based on a sample of 74 road-related events in the H. J. Andrews, 68% occurred in the first 10 years after construction and there were no road failures from roads more than 20 years after construction. Elsewhere, slides from road segments older than 20 years have been observed where decomposition of slash buried in fills caused a slow loss of stability. We believe that perhaps 80% of slides from roads built to current Forest Service standards occur in the first decade and 20% in the second.

There is some uncertainty in the representativeness of these numbers because the history of cutting, roading, and slide-triggering storms has not been optimal for getting a clear measure of the relative timing of slides and management activities.

Qualifiers

Time constraints and available data have necessitated a number of shortcuts in this analysis. Basic assumptions and computational shortcuts are described in the Methods and Assumptions section; here we identify some broader scale qualifications.

1. The use of slide frequency data for forested areas as a "natural" rate probably underestimates the true natural rate, because periodic wildfire in the pre-management period probably triggered episodes of greatly increased sliding. We have some data on frequency of wildfire in the Forest, but no information on slide activity following fire. If we assume a natural crown fire frequency of 200 years and acceleration of sliding similar to that after clearcutting, the actual natural rate might be 20% higher.

2. Two major storms in Dec. 1964 and Jan. 1965 caused many of the slides. The 1964 storm may have had a return period in excess of 100 years, so it was over-represented in the 25 to 35 year study periods used here. This has the probable effect of giving us an overestimate of long-term slide frequency. However, this may not change the estimates of effects of clearcutting and roads.

3. Some of the road failures included in this analysis were on roads built with techniques and located in landscape positions no longer used. Estimates of future sliding frequency might, therefore, be adjusted downward to reflect improved construction methods, location of roads in more stable areas, and better road maintenance.

Further refinement of this slide inventory system could yield estimates of slide frequency from roads with different construction standards. This would provide a better estimate of future slide frequency from roads and a basis for judging benefits in terms of reduced sliding from roads with different construction costs.

4. In this analysis we used acreage in Natural, Managed, and Road at a point about 30 years into the first rotation. As described in Swanson _et al_. (1977, 1981) this may cause an over-estimation of the frequency in Natural conditions and underestimation of Managed and Road slide frequencies. In the case of Managed events, the method use here treats clearcuts of ages 0 to 30 years the same.

   In Swanson _et al_. (1977, 1981) we suggest a method for keeping track of the history of slides and management activities on a yearly or decadal basis and for providing a more realistic analysis of management effects. This system of analysis could, for example, be used to describe the slide frequency for clearcuts in different age classes. It would be easy to make this analysis if slide and SRI data were meshed with the TRI system.

Thoughts on Debris Slides and Future Forest Planning

Slides could very easily and appropriately be dealt with in the regular context of Forest planning and monitoring. It would be appropriate to do so because slides are a dominant erosion process in many parts of western Oregon and because they strongly affect improvements and timber and aquatic resources. It would be easy to do this by pursuing the track begun in this analysis and round of planning. The methods of analysis and a good data base are now available.

The basic strategy is to use existing slide inventory data to document the past frequency of sliding for different landuse and landscape units. These data can then be projected into the future for different management scenarios to predict consequences in terms of landsliding of alternative types, patterns, and rates of development. The analysis would be substantially improved with a modest increase in the area and number of slides inventoried.

A three phase approach can be used by merging slide frequency data with (a) soil volume moved and percent delivery to channels to predict sediment production, (b) average area per slide scar and data on Douglas-fir growth and stocking on slide areas (described by D. Miles, F. J. Swanson, C. T. Youngberg, manuscript in preparation) to predict effects on timber production, and (c) percent of slides triggering debris torrents down stream channels to predict effects on aquatic habitat. The slide inventory can also be used to examine changing slide frequency through time for a particular management practice, such as road construction, to determine the benefits of improved standards in terms of reduced slide frequency and associated effects on timber and aquatic resources.

Slumps and Earthflows

Background

Large, slow-moving (less than ft/day) mass movement features (slumps and earthflows) are an important part of the Willamette National Forest landscape, but their distribution, movement rates, and response to management activities are very poorly documented. Large portions of some subbasins in the Willamette Forest have been shaped by earthflow processes, but these areas are not mapped systematically in the SRI system. For these reasons, it is not possible to describe erosion rates by slumps and earthflows in terms of SRI units and management activites.

Available Information

To our knowledge, movement rates are being measured on only four earthflows in the Willamette (Table 12). Rates vary from less than 1 in/yr to 20+ ft/yr. We plan to begin monitoring movement of additional earthflows in the Willamette in the next few years in an effort to (1) determine long-term movement characteristics of earthflows of different sizes, management histories, and geomorphic settings and (2) establish field criteria for estimating movement rates from degree of vegetation and ground disruption.

By joining the results of (2) with maps of large basins showing distribution of earthflows in various movement classes, it will be possible to estimate sediment production from earthflows in large watersheds.

We know of detailed maps of slumps and earthflows for several areas within the Willamette: H. J. Andrews Experimental Forest (Swanson and James 1975) Alder Creek, tributary to Fall Creek (Morrison 1975), and part of the Middle Santiam area (Hicks 1982).

Considerations and Limitations

It is important to distinguish erosion attributable to deep-seated, slow mass movements from shallow, rapid slides for several reasons:

1. Influences of management activities are very different--in the case of clearcutting, root strength strongly controls shallow slides, but hydrologic influences may be the predominate effect of forest cutting on deep-seated features. Consequently, the timing and magnitude of management effects are likely to be different for each type of mass movement.

2. The effect of logging on hydrology has been measured in a number of studies and the response of earthflow movement to natural variations in water availability has also been documented, but the direct link between movement rate and the change in hydrology caused by vegetation manipulation has not been quantified. We cannot predict at present how much, if any, acceleration of earthflow movements will occur if trees are removed from the watershed.

Despite these arguments for distinguishing between large, slow, and shallow, fast mass failures, it is important to recognize the links between the two classes of events (discussed in Swanson and Fredriksen 1982). Many shallow, rapid slides in the Western Cascades occur on slumps and earthflows where slow movement results in oversteepening of head scarp and toe areas, which then fail by debris sliding. In the Lookout Creek watershed, for example, 41% of slides inventoried on natural slopes (forest and clearcut areas in contrast with constructed slopes along roads) are in slump and earthflow terrain. Streamside slides may be the dominant mechanism of sediment delivery from slumps and earthflows to streams. If so, one would be tempted to use a detailed study of streamside slides to judge management effects on sediment production from slumps and earthflows. However, this approach is probably not reliable for dealing with a management history of only a few decades, because cutting may trigger slides from toes of earthflows as a result of reduced root strength while the potential for sliding may have resulted from a long history of earthflow movement under forested conditions. In this case, streamside sliding at earthflow toes is a poor index of effects of management activities on earthflow movement.

Desired Information

To estimate the role of earthflows on sediment production in managed watersheds we need:

1. Maps of earthflows to show degree of linkages between earthflows and the stream network.

2. Measurement of rates of earthflow movement to identify classes of behavior (year-to-year variation) and long-term average rates.

3. Estimation of effects of management practices on movement rate.

Maps of earthflows (item 1) are available for a small part of the Forest. We plan to expand the number of sites where movement is monitored. This is a task that would very reasonably fall within the monitoring program of most west-side Region 6 National Forests. The first step in item 3 is being taken by Marvin Pyles (Depts. of Forest Engineering and Civil Engineering, OSU) who is conducting an engineering analysis of the Lookout Creek earthflow under funding from a PNW cooperative agreement.

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Table 1--Summary of surface erosion studies used in compiling this report.

Investigator(s)	SRI Units	Site location	Site elevation (meters)	Slope range (%)	Period of observations	Length of record (years)	No. of collectors	Width of collector opening (meters)	Contributing catchment area (meters^2)	Frequency of collection (no./year)
Mersereau & Dyrness[a]	14,310,331	HJA-1[b]	455-915	60-80	7/67-9/68	1.18	10	2.45	63-262 (range) 128 (average)	6
Lienkaemper & Swanson[c]	14,310,331	HJA-1	455-915	60-80	8/78-8/79	1.00	8	2.10	63-262	8
Stream Team - streamside[d]	31	HJA-9	425-700	26-55	1/74-6/79	5.50	34	0.5	--[e]	8
	210	HJA-10	425-700	26-55	3/73-5/75	2.15 (pre-cut)	34	0.5	--[e]	8
					9/75-6/79	3.75 (post-cut)				
McCorison[f] - streamside	210	HJA-10	425-700	26-55	6/74-4/75	0.87	34	0.5	--[e]	12
McCorison[g] - forest sites										
Site VI	21	HJA-10	425-700	80	6/74-6/77	3.00	1	16.5	776	4
Sites I & II	31	HJA-9	425-700	95-100	1/74-3/76	3.25	2	15.7-20.2	214-458	4
Sites III, IV, & V	210	HJA-10	425-700	80-88	3/74-4/77	3.00	3	8.9-9.6	124-171	4
D. George-claes, et al.[h] (Dept. Soil Science, Oreg. State Univ.)	641	SFM[i]	625-750	19-61	11/79-9/82	1.00 (cut, un-burned) 2.00 (cut, burned)	24	1.5	2.3	4

[a]Results given by aspect, slope, and duff cover condition - see table 5

[b]H. J. Andrews Experimental Forest - watershed number

[c]Follow-up study to Mersereau & Dyrness 12 years after burning. Boxes in approximately the same location as before.

[d]Boxes placed in clusters along 1400 m stream perimeter.

[e]Unbounded boxes, contributing area not measured

[f]Boxes placed at 20 m intervals along stream perimeter.

[g]All sites selected to represent maximum surface erosion rates for forested conditions.

[h]Results given by slope and duff cover (see table 4). Duff removed by burning. Site artificially cleaned of slash.

[i]Ryder Creek, South Fork McKenzie River

Table 2--Summary of surface erosion data by SRI unit. Double table entries indicate first the best estimate based on criteria in numerically coded footnotes and, in parentheses, the raw average shown as described in alphabetically coded footnotes. Only values footnoted a, e, f represent first decade averages; other values are for shorter periods of time.

		Surface erosion rate (yd3/acre/yr)			SRI Surface
SRI unit	Forest	Clearcut, unburned	Clearcut, burned	Skidtrail	Erosion Potential
14			1.4[1] (.75)[a]		Moderate
21	.019[2]				Severe
31	.026[3] (.096)[b]				Severe
210	.022[4]	.094[5] (.12)[c]			Severe
233				.21[6]	Moderate
310	.014[7] (.18)[d]		2.35[8] (.67)[e]		Severe
331			.09[9] (.053)[f]		Moderate-Severe
641	.0010[10]	.078[11]	.20[12]		Moderate

Footnote	Source	Notes and Limitations
1	Areally weighted average for Mersereau & Dyrness boxes 5, 9; HJA-1	This may reflect higher than normal rates for this unit since box 9 was located in talus which produced very high erosion rates. However, the authors note that since collectors were established 10 months after burning, less than 40% of the total soil movement for the first two years after burning may have been measured.
2	McCorison site VI	
3	Stream Team (Dept. Fisheries and Wildlife, Oreg. State Univ.)	The average of HJA-9 data was used due to the long collection period (5.50 years) and large number of samples. McCorison sites I and II were not included since they measured sites selected to represent highest natural erosion rates.

4	Average of Stream Team and McCorison HJA-10 streamside precut	
5	Average of yearly averages for Stream Team - HJA-10 post-cut	
6	McCorison - HJA-7	
7	Average of McCorison sites III and IV	Site IV was not included in the analysis since it was anomalously high, in part, because this site was chosen to represent highest natural surface erosion rates.
8	Areally weighted average of Mersereau & Dyrness boxes 1-4, 6, 10; HJA-1	This may reflect higher than normal rates for this unit since box 10 was located in talus. However, see note 1.
9	Areally weighted average of Mersereau & Dyrness boxes 7-8, HJA-1	See note 1.
10	Average of D. George-Claes forest control sites	
11	Average for all D. George-Claes sites in this category	This may overestimate the erosion rate since all slash was removed from sites as part of the experiment.
12	Average for all D. George-Claes sites in this category	This may overestimate the erosion rate since all slash was removed from sites as part of the experiment.

[a] Average of Mersereau and Dyrness (M-D) box 5 with Lienkaemper and Swanson (L-S) Box 5 measured after 12 years.

[b] Non-weighted average of HJA-9 and McCorison Sites I and II

[c] Average for first two years following cutting

[d] Average for McCorison sites III, IV, and V

[e] Average of M-D boxes 1-4 and 6, with L-S boxes 1-4 and 6, measured after 12 years.

[f] Average of M-D boxes 7 and 8 with L-S boxes 7 and 8 measured after 12 years.

Table 3--Summary of surface erosion data by slope class for all SRI units

Slope class	Surface erosion rate				
	Forest	Clearcut, unburned (2 yrs after treatment)	Clearcut, unburned (first decade)	Clearcut, burned (2 yrs after burning)	Clearcut, burned (first decade)
(%)	(yd3/acre/year)				
0-30	4.7×10^{-7} [a]	.0012[b]	.00060	.068[c]	.034[d]
30-60	.023[e] (.014)	.12[f]	.072	0.39[g]	.22[h]
60+	.13[i]	--		2.0[j]	1.1[k]

[a]D. George-Claes, forest control; SRI #641
[b]Average of D. George-Claes clearcut, unburned data; SRI #641
[c]Average of D. George-Claes clearcut, burned data; SRI #641
[d]Average of a and c
[e]Average of watershed 9 and 10, streamside data. Number in parantheses is average of all sites in this class; SRI #31, 210
[f]Average of both Stream Team and D. George-Claes data for first year following cutting; SRI #210, 641
[g]Average of D. George-Claes clearcut, burned data with Mersereau and Dyrness (M-D) sites 5, 6, 7, 8; SRI #74, 310, 331, 641.
[h]Average of M-D and Lienkaemper and Swanson (L-S) sites 5-8.
[i]Average of all McCorison forest sites; SRI #21, 31, 310.
[j]Average of M-D sites 1-4; SRI #310
[k]Average of M-D and L-S sites 1-4; SRI #310.

Table 4--Effect of slope and duff cover on surface erosion rates.

Slope	Forest rate	Clearcut unburned (% duff cover)			Clearcut burned (% duff cover)		
		0	50	100	0	50	100
(%)		(yd^3/acre/year)					
28	4.9×10^{-7}	0	.00080	.0015	.12	.072	.0065
41	.00010	.0038	.020	0	.26	.040	.045
58	.0028	0	.51	.17	.14	.47	.65

Source: D. George-Claes et al.

Table 5--Effect of slope, ground cover, and aspect on surface erosion rates for sites clearcut and burned, 1 and 12 years before (Watershed 1, H. J. Andrews Experimental Forest). Boxes 9 and 10 were in talus.

	Bare	Vegetated	Bare	Vegetated	Bare	Vegetated	Bare	Vegetated	Bare	Bare
	80%-South		80%-North		60%-South		60%-North		80%-West	80%-North
Mersereau and Dyrness, 1967-1968 - 1 year following burn										
Box #	1	2	3	4	5	6	7	8	9	10
yd^3/acre/year	2.9	3.8	1.8	0.40	1.5	0.01	0.15	0.065	2.4	12.
Lienkaemper and Swanson, 1979-1980 - 12 years following burn										
Box #	1	2	3	4	5	6	7	8		
yd^3/acre/year	0.21	0.050	0.0030	0.018	0.0042	0.0049	.0090	0.022		
Percent of original rate	7.3	1.3	0.17	4.5	0.29	49	14	34		

Table 6--Summary of Pacific Northwest studies of soil disturbance and compaction by various yarding systems. Data are in percent of harvest unit area in soil disturbance class. Number in parantheses denotes source of data. High-lead data from sources (1), (4), and (9) are averages of samples from 3, 11, and 4 units, respectively. Tractor data from (4) average of two units and skyline data from (9) average of four.

	Clearcut										
	Yarding System										
Soil disturbance	Tractor-skidder				High lead		Skyline			Balloon	Helicopter
class	(1)	(2)	(3)	(4)	(1)	(4)	(2)	(3)	(5)	(6)	(4)
Undisturbed	36	58			57		73		64	78	
Slightly disturbed	26	14	12	11	22	18	9	8	24	16	2
Deeply disturbed	9	29	16	58	10	11	24	3	5	3	3
Compacted	27	31			9		27		3	2	
Non-soil area	2				2				4	2	
"Disturbed by roads"											
Summer	40(7)				11(7)		0(7)				
Winter	21(7)				16(7)						
"Bare mineral soil"	22(3)				16(9)		5(3)				5(4)
	69(4)				29(4)		6(9)				
	21(8)										
Skid trails	22(2)										
compacted	26(10)										

Thinning

Soil disturbance class	Tractor-skidder (2)	High lead	Skyline (2)	Balloon	Helicopter
Undisturbed	43		70		
Slightly disturbed	24		16		
Deeply disturbed	35		13		
Heavy compaction	31		14		
"Bare mineral soil"			4(11)		
"skid trails"	20(11)		8(11)		
	20(2)				
"Compacted"	20(11)		0(11)		

(1)Dyrness 1965. J. For. 63:272-275.
(2)F. M. McCorison, pers. commun. USFS, Petersburg, Alaska, For. H. J. Andrews Exp. sites.
(3)Wooldridge 1960. J. For. 58:369-372.
(4)Bockheim et al. 1975. Can. J. For. Res. 5:285-290.
(5)Dyrness 1967, U.S. For. Serv. Res. Note PNW-55.
(6)Dyrness 1972, U.S. For. Serv. Res. Note PNW-182.
(7)Smith and Wass 1976, Can. For. Serv., Pac. For. Res. Center, Victoria, B.C.
(8)Garrison & Rummell 1951, J. For. 49:708-713.
(9)Ruth 1967, J. For. 65:251-255.
(10)Steinbrenner & Gessel 1955, Soil Sci. Am. Proc. 19:372-376.
(11)Aulerich et al. 1974, For. Ind. 101:42-45.

Also see: W. E. Powers 1974, USDI BLM Tech. Note T/N-256.
H. A. Froehlich 1973 - In: Even-age management, Hermann & Lavender (eds.), School of For., O.S.U. 199-200.
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1978 - In: Proc. 1977, Nat. Conv. Soc. Am. For., Albuquerque, NM 229-237.

Table 7--Summary of data on surface erosion from road cutslopes in the Willamette National Forest.

Site location	Period of observation	Length of observation (years)	Treatment	Yield (yd^3/acre/year)	SRI unit	SRI ranking: Cutbank Erosion Potential	SRI ranking: Fillslope Erosion Potential	Reference
HJA (L105)	9/58-9/59	1.0	Bare 7-year old cutslope	9.8	23	Moderate to high	High	Wollum (1962)
	9/59-9/60	1.0	Grass seeded 7-year	3.2				
	9/60-9/61	0.92	old cutslope	1.8				
HJA	9/65-6/72	6.75	Bare 5-year old cutslope[a]	28.7[b]	212	Low to moderate	Moderate	Dyrness (1975)
	9/65-8/66	6.75	Grass seeded 5-year old cutslope[c]	0[d] (23.2)				
Blue River drainage	8/67-6/72	4.83	Bare, newly constructed cutslope	36.2[e] (114.3)	23	Moderate to high	High	Dyrness (1975)
	8/67-6/72	4.83	Grass seeded, new cutslope	7.8[f] (42.0)	23			

[a] 5-year old cutslope. Native vegetation allowed to initiate during course of experiment.
[b] Average over 6.75 year period
[c] Five different vegetative treatments used including different combinations of mulch and grass seed mixtures.
[d] Average for all five vegetative treatments over 6.75 years. Number in parentheses is average for first year following seeding.
[e] Average over 4.83 years. Number in parentheses is average for first year following construction.
[f] Average over 4.83 years. Number in parentheses is average for first year following construction. See note C.

Table 8--Slide history by soil unit for all sites.

SRI	Total number of slides			Total area (acres)			Number/acre/year			SRI Mass	Alternative
#	Natural	Managed	Road	Natural	Managed	Road	Natural	Managed	Road	Movement Potential[1/]	Stability Ranking[2/]
1	0	0	0	85	0	0	0	0	0	U	S
2	0	0	0	32	0	0	0	0	0	U	S
3	1	0	1	957	470	25	0.000035	0	0.0013	I	M
6	0	0	0	777	149	12	0	0	0	U	S
7	0	0	0	43	0	0	0	0	0	U	S
8	4	19	79	2587	981	90	0.000052	0.00065	0.029	GI	U
13	1	1	1	469	341	64	0.000071	0.000098	0.00052	U	M
14	0	0	2	464	107	5	0	0	0.013	U	S
15	4	2	6	854	341	64	0.00016	0.00020	0.0031	U	M
16	0	1	3	620	704	20	0	0.000047	0.0050	U	M
21	4	13	41	1058	554	30	0.00013	0.00078	0.046	I	U
22	0	0	1	56	64	8	0	0	0.0042	U	S
23	0	5	16	1580	384	84	0	0.00043	0.0063	U	M
25	0	0	3	299	21	20	0	0	0.0050	I	M
33	0	0	0	37	21	5	0	0	0	I	M
35	0	0	0	60	21	4	0	0	0	GI	M
44	0	0	0	21	43	0	0	0	0	U	M
61	2	2	4	545	85	11	0.0012	0.00078	0.012	I	M
63	1	0	0	37	0	6	0.0090	0	0	U	M
64	0	0	0	60	0	4	0	0	0	U	S
71	0	0	0	43	0	0	0	0	0	I	M
132	1	1	3	582	171	37	0.000057	0.00020	0.0027	U	M
161	0	0	0	42	21	1	0	0	0	U	M
162	5	5	1	270	64	8	0.0062	0.0026	0.0042	U	M
165	7	1	0	278	21	20	0.00084	0.0016	0	I	M
168	5	2	3	95	64	10	0.0018	0.0010	0.0100	U	U
201	0	0	4	1186	448	50	0	0	0.0027	I	M
202	0	0	0	87	21	0	0	0	0	I	M
203	1	0	7	1044	341	22	0.000032	0	0.011	I	M
210	0	0	3	1013	192	32	0	0	0.0031	I	M
212	5	5	12	1099	192	2	0.00015	0.00087	0.20	I	U
231	7	2	6	533	235	21	0.00044	0.00028	0.0095	U	M
233	3	7	4	685	234	40	0.00014	0.0010	0.0033	I	M
235	2	2	5	1287	256	57	0.000052	0.00026	0.0029	I	M
236	0	0	0	84	64	1	0	0	0	U	M
253	0	0	2	39	0	4	0	0	0.017	I	M

1/SRI Mass Movement Potential Classes are U = unchanged, I = increased, GI = greatly increased as defined in SRI narrative.
2/SRI Mass Movement Potential Classes are U = unstable, M = moderately stable, S = stable. See text for discussion.

Table 8 (cont.)

310	1	9	5	868	277	7	0.000038	0.0011	0.024	I	M
313	0	2	1	443	192	5	0	0.00035	0.0067	I	M
331	2	1	5	575	128	22	0.00012	0.00026	0.0076	I	M
333	2	2	2	145	64	4	0.00046	0.0010	0.018	I	M
335	0	0	0	73	0	12	0	0	0	I	M
353	2	0	0	128	21	0	0.00052	0	0	I	M
441	0	0	0	1338	64	6	0	0	0	U	M
446	0	0	0	405	0	0	0	0	0	U	M
602	0	0	0	354	128	8	0	0	0	I	M
610	1	0	0	1090	127	19	0.000031	0	0	I	M
614	0	0	0	145	43	4	0	0	0	I	M
641	0	0	0	84	43	1	0	0	0	U	S
646	0	0	0	275	21	2	0	0	0	U	S
710	0	0	0	64	0	0	0	0	0	I	S
714	0	0	0	35	0	8	0	0	0	I	S
TOTAL	61	82	220	25030	7718 3125ha	855	0.000081	0.00035	0.0086		

1/SRI Mass Movement Potential Classes are U = unchanged, I = increased, GI = greatly increased as defined in SRI narrative.
2/SRI Mass Movement Potential Classes are U = unstable, M = moderately stable, S = stable. See text for discussion.

Table 9--Summary of slide data by groups of SRI units on the basis of the Expected Mass Movement Potential defined in the SRI.

	Total Slides			Total Area (acres)			Events/Acre/Yr[b]			Acres Disturbed/acre/year[c]			$Yard^3$/acre/year[d]		
Group[a]	Nat.	Man.	Road	Nat.	Man.	Road	Nat.	Man.	Road	Nat.	Man.	Road	Nat.	Man.	Road
Unchanged	24	19	42	8806	2880	354	.000091	.00022	.0040	.000024	.000042	.0010	.25	.46	8.
Increased	33	44	99	13577	3836	407	.000081	.00038	.0081	.000021	.000073	.0020	.22	.80	16.
Greatly increased	4	19	79	2647	1002	94	.000050	.00063	.028	.000013	.000121	.0071	.14	1.3	56.
TOTALS	61	82	220	25030	7718	855	.000081	.00035	.0086	.000021	.000067	.0022	.22	.74	17.

[a] SRI groupings based on Expected Mass Movement Potential classes defined in the SRI table of erosion and hydrologic interpretations.

[b] Time base for this calculation is 30 years

[c] Areal factors for each management history computed as a weighted average of the areal factors for the three inventoried sites (HJA, Blue River, Alder Creek) are : Natural = .265 acres/event, Managed = .192 acres/event, Road = .252 acres/event.

[d] Volume factors for each management history computed as a weighted average of the volume factors for the three sites are: Natural = 2702 yd^3/event, Managed = 2105 yd^3/event, Road = 1988 yd^3/event

Table 10--Summary of slide data grouped on basis of slope and rocktype described in SRI.

	Total Slides			Total Area (acres)			Events/Acre/Yr[b]			Acres Disturbed/acre/year[c]			$Yard^3$/acre/year[d]		
Group[a]	Nat.	Man.	Road	Nat.	Man.	Road	Nat.	Man.	Road	Nat.	Man.	Road	Nat.	Man.	Road
Stable	0	0	3	2120	427	44	0	0	.0023	0	0	.00058	0	0	4.6
Moderately stable	43	43	82	17,171	5500	679	.000083	.00026	.0040	.000022	.000050	.0010	.22	.55	8.0
Unstable	18	39	135	5735	1791	132	.00010	.00073	.034	.000027	.00014	.0086	.27	1.5	68.
TOTALS	61	82	220	25,030	7718	855	.000081	.00035	.0086	.000021	.000067	.0022	.22	.74	17.
		363			13603ha										

[a]As defined in text
[b]Time base for this calculation is 30 years
[c]Areal factors for each management history computed as a weighted average of the areal factors for the three inventoried sites (HJA, Blue River, Alder Creek) are: Natural = .265 acres/event, Managed = .192 acres/event, Road = .252 acres/event
[d]Volume factors for each management history computed as a wieghted average of the volume factors for the three sites are: Natural = 2703 yd^3/event, Managed = 2105 yd^3/event, Road = 1988 yd^3/event

Table 11--Assignment of stability ranking for all SRI units based on slope and rocktype conditions described in SRI. Rules for assigning stability ranking are described in the text. Comments described reasons for deviating from rules for several of the sampled SRI units.

SRI#	Slope	Rock Type[a]	Stability Class[b]	Comments
1	30-100	A,B (r.o.)	S	
2		Br (r.o.)	S	
3	steep headwalls	talus (r.o.)	M	
4	0-30	lava flows	S	
5	40-80+	cinder cones	M	
6	gentle-steep	marshy, boulders	S	
7	ridgetops	glacial cirques	S	
8	steep	GBr, RBr	U	
9	steep	A,B,Br	M	
12	0-25	A,B	S	
13	0-40	Br,T	M	see text
14	5-35	A,B,Br,T	S	
15	0-20	Al	M	see text
16	20-70	A,B,Br,T	M	
17	0-20	Al	M	
19	0-45	Br	M	
21	60-90	RBr,T	U	
22	0-20	RBr,T	S	
23	20-60	RBr,T	M	
25	15-40	BR,t	M	
31	60-90	T,GBr	U	
33	20-60	GBr,T	M	
35	5-40	GBr,T	M	
44	40-80	Br	M	
54	35-65	Br,A,B	M	
55	40	Br,T	M	
56	0-30	A	S	
57	30-60	A	S	
61	60-90+	A	M	
62	0-35	lava flows	S	
63	0-35	A,B	M	raised from S due to slide in natural condition
64	40-80	A,B	S	
66	0-40	A,B	S	
67	0-40	A,B	S	
68	30-60	A,B	S	
69	0-30	A,B	S	
71	45-90	A,B	M	
73	0-30	A,B	S	
74	35-55	A,B	S	
75	0-35	A,B	S	
81	40-90+	A,B	M	
82	0-30	A,B	S	
85	0-15	A,B	S	
91	55-90+	A,B	M	
92	0-35	A,B	S	
93	0-40	A,B	S	
94	35-60	A,B,Br	S	
95	0-35	A,B,Br	S	

[a]Rock type abreviations: A = andesites, Al = alluvium, B = basalts, Br = breccia, GBr = green breccia, RBr = red breccia, r. o. = rock outcrop, T = tuffs.
[b]Stability classes: S = stable, M = moderately stable, U = unstable.

Mapping Unit Number	Mapping Unit Components	Stability Class	Comments
132	60 percent Unit 13 and 40 percent Unit 23	M	
133	60 percent Unit 13 and 40 percent Unit 33	M	
134	70 percent Unit 13 and 30 percent Unit 44	M	
135	50 percent Unit 13 and 50 percent Unit 55	M	
137	70 percent Unit 13 and 30 percent Unit 64	M	
142	60 percent Unit 14 and 40 percent Unit 23	S	
143	70 percent Unit 14 and 30 percent Unit 33	S	
145	60 percent Unit 14 and 40 percent Unit 25	S	
157	50 percent Unit 16 and 50 percent Unit 57	M	
161	60 percent Unit 16 and 40 percent Unit 61 1/	M	
162	60 percent Unit 16 and 40 percent Unit 23	M	
163	60 percent Unit 16 and 40 percent Unit 33	M	
164	60 percent Unit 16 and 40 percent Unit 44	M	
165	70 percent Unit 16 and 30 percent Unit 25	M	
166	70 percent Unit 16 and 30 percent Unit 35	M	
167	60 percent Unit 16 and 40 percent Unit 64	M	
168	60 percent Unit 16 and 40 percent Unit 21 2/	U	Raised from M due to high slide frequency
169	50 percent Unit 16 and 50 percent Unit 56	M	
194	70 percent Unit 19 and 30 percent Unit 44	M	
195	60 percent Unit 19 and 40 percent Unit 55	M	

1/ May contain Units 21 and 31 may also be present.

2/ May contain Units 61 and 31 may also be present.

Mapping Unit Number	Mapping Unit Components	Stability Class	Comments
201	60 percent Unit 21 and 40 percent Unit 31	M	Reduced from U due to low slide frequency
202	60 percent Unit 21 and 40 percent Unit 61	M	"
203	40 percent Unit 21, 30 percent Unit 31, and 30 percent Unit 61	M	"
204	40 percent Unit 21, 30 percent Unit 31, and 30 percent Unit 2	M	"
210	60 percent Unit 21 and 40 percent Unit 2	M	
212	60 percent Unit 21 and 40 percent Unit 23	U	
213	70 percent Unit 21 and 30 percent Unit 33	U	
214	60 percent Unit 21 and 40 percent Unit 44	U	
215	40 percent Unit 21, 30 percent Unit 23, and 30 percent Unit 61	M	
216	60 percent Unit 21 and 40 percent Unit 16	U	
225	60 percent Unit 22 and 40 percent Unit 25	M	
231	60 percent Unit 23 and 40 percent Unit 21	M	
232	60 percent Unit 23 and 40 percent Unit 61	M	
233	60 percent Unit 23 and 40 percent Unit 33	M	
234	70 percent Unit 23 and 30 percent Unit 64	M	
235	60 percent Unit 23 and 40 percent Unit 25	M	
236	60 percent Unit 23 and 40 percent Unit 16	M	
237	40 percent Unit 23, 30 percent Unit 33, and 30 percent Unit 21	M	
238	60 percent Unit 23 and 40 percent Unit 56	M	
251	60 percent Unit 25 and 40 percent Unit 21	M	
252	60 percent Unit 25 and 40 percent Unit 13	M	

Mapping Unit Number	Mapping Unit Components	Stability Class	Comments
253	60 percent Unit 25 and 40 percent Unit 23	M	
254	60 percent Unit 25 and 40 percent Unit 14	M	
255	60 percent Unit 25 and 40 percent Unit 35	M	
256	60 percent Unit 25 and 40 percent Unit 16	M	
261	40 percent Unit 23, 30 percent Unit 16, and 30 percent Unit 61	M	
301	60 percent Unit 31 and 40 percent Unit 21	U	
302	60 percent Unit 31 and 40 percent Unit 61	U	
303	40 percent Unit 31, 30 percent Unit 21, and 30 percent Unit 61	U	
304	40 percent Unit 31, 30 percent Unit 21, and 30 percent Unit 44	U	
305	40 percent Unit 31, 30 percent Unit 61, and 30 percent Unit 33	U	
310	60 percent Unit 31 and 40 percent Unit 2	M	
313	60 percent Unit 31 and 40 percent Unit 33	M	Reduced from U due to low slide frequency
331	60 percent Unit 33 and 40 percent Unit 31	M	
332	50 percent Unit 33, 25 percent Unit 31, and 25 percent Unit 21	U	
333	60 percent Unit 33 and 40 percent Unit 23	M	
334	60 percent Unit 33 and 40 percent Unit 25	M	
335	60 percent Unit 33 and 40 percent Unit 35	M	
336	60 percent Unit 33 and 40 percent Unit 16	M	
337	70 percent Unit 33 and 30 percent Unit 61	M	
353	60 percent Unit 35 and 40 percent Unit 33	M	
356	60 percent Unit 35 and 40 percent Unit 16	M	

Mapping Un Number	Mapping Unit Components	Stability Class
441	60 percent Unit 44 and 40 percent Unit 21	M
443	50 percent Unit 44 and 50 percent Unit 33	M
444	60 percent Unit 44 and 40 percent Unit 64	M
446	60 percent Unit 44 and 40 percent Unit 16	M
447	40 percent Unit 44, 30 percent Unit 64, and 30 percent Unit 16	M
553	60 percent Unit 55 and 40 percent Unit 13	M
554	70 percent Unit 55 and 30 percent Unit 44	M
559	60 percent Unit 55 and 40 percent Unit 19	M
563	70 percent Unit 56 and 30 percent Unit 33	S
564	60 percent Unit 56 and 40 percent Unit 54	S
601	70 percent Unit 61 and 30 percent Unit 31	M
602	60 percent Unit 61 and 40 percent Unit 21	M
603	40 percent Unit 61, 30 percent Unit 21, and 30 percent Unit 31	U
604	40 percent Unit 61, 30 percent Unit 31, and 30 percent Unit 33	M
605	40 percent Unit 61, 30 percent Unit 21, and 30 percent Unit 44	M
606	40 percent Unit 61, 30 percent Unit 31, and 30 percent Unit 64	M
607	60 percent Unit 61 and 40 percent Unit 54	M
608	60 percent Unit 61 and 40 percent Unit 57	M
610	60 percent Unit 61 and 40 percent Unit 1	M
614	60 percent Unit 61 and 40 percent Unit 64	M
615	60 percent Unit 61 and 40 percent Unit 44	M

Mapping Ur Number	Mapping Unit Components	Stability Class	Comments
616	60 percent Unit 61 and 40 percent Unit 16	M	
617	50 percent Unit 61, 25 percent Unit 33, and 25 percent Unit 16	M	
633	70 percent Unit 63 and 30 percent Unit 33	M	
641	60 percent Unit 64 and 40 percent Unit 61	S	Reduced from M due to low slide frequency
644	60 percent Unit 64 and 40 percent Unit 44	M	
646	60 percent Unit 64 and 40 percent Unit 16	S	Reduced from M due to low slide frequency
710	60 percent Unit 71 and 40 percent Unit 1	S	"
714	60 percent Unit 71 anc 40 percent Unit 74	S	"
731	70 percent Unit 73 and 30 percent Unit 1	S	
736	70 percent Unit 73 and 30 percent Unit 6	S	
737	70 percent Unit 73 and 30 percent Unit 7	S	
740	70 percent Unit 74 and 30 percent Unit 1	S	
741	60 percent Unit 74 and 40 percent Unit 71	S	
812	70 percent Unit 81 and 30 percent Unit 82	M	
821	60 percent Unit 82 and 40 percent Unit 81	S	
825	70 percent Unit 82 and 30 percent Unit 85	S	
852	70 percent Unit 85 and 30 percent Unit 82	S	
910	60 percent Unit 91 and 40 percent Unit 1	M	
914	60 percent Unit 91 and 40 percent Unit 94	M	
920	60 percent Unit 92 and 40 percent Unit 1	S	
923	60 percent Unit 92 and 40 percent Unit 93	S	
924	60 percent Unit 92 and 40 percent Unit 94	S	
926	70 percent Unit 92 and 30 percent Unit 6	S	
932	60 percent Unit 93 and 40 percent Unit 92	S	

Mapping Uni Number	Mapping Unit Components	Stability Class
940	70 percent Unit 94 and 30 percent Unit 1	S
941	60 percent Unit 94 and 40 percent Unit 91	S
942	60 percent Unit 94 and 40 percent Unit 92	S
954	60 percent Unit 95 and 40 percent Unit 54	S

Table 12--List of earthflows on the Willamette National Forest for which movement data are collected.

Site name	SRI unit	Site condition	Movement rate (ft/yr)	Period of record	Source
Lookout Creek	441,165	Road, 15% clearcut	0.3	1974 to present	Swanson and Swanston 1977, Swanson (unpub.)
Art's Slump	231	Partial cut,	2-9 (movement '78-'80, essentially stopped thereafter)	1978 to present	Swanson (unpub.)
Jude Creek	25	Natural forest, road, minor salvage	12	1979 to present	Hicks (1982), Swanson (unpub.)
Mid-Santiam	256	Clearcut and roaded mid-1960's	22	1979 to present	Hicks (1982), Swanson (unpub.)