Logging and Forest Roads Related to Increased Debris Slides in Southwestern Oregon

Reprinted from the
JOURNAL OF FORESTRY
Vol. 83, No. 4 April 1985

Michael P. Amaranthus, Raymond M. Rice, Nicholas R. Barr, and Robert R. Ziemer

ABSTRACT*-Debris slides over a 20-year period were inventoried on 137,500 acres of forested land in the Klamath Mountains of southwest Oregon. Frequency during the study period was about one slide every 4.3 years on each 1,000 acres-an erosion rate of about 1/2 yd^3 per acre per year Erosion rates on roads and landings were 100 times those on undisturbed** areas, ***while erosion on harvested ureas was seven times that of undisturbed areas. Three-quarters of the slides were found on slopes steeper than 70 percent and half were on the lower third of slopes. The study area was subdivided into nine geomorphological erosion response units which exhibited profound differences in natural erosion rates and responses to disturbance. The results serve as a guide to appraising slide risk associated with planned timber harvests or mad construction on forested slopes.

Many of the most productive forests in the Pacific Northwest grow on marginally stable slopes where timber harvests and road construction increase the likelihood of erosion. Despite attempts to hold erosion below an acceptable amount, management-related increases-mainly from mass movements-have been reported over the years, beginning with Bishop and Stevens's (1964) study in Alaska and more recently that by McCashion and Rice (1983) in northwestern California. Historically, damage from mass erosion has concerned land managers in the Klamath Mountains area as well. Increased mass erosion reduces site productivity and water quality, causes loss of fish habitat, and damages roads and bridges.

This article reports a study of mass erosion on the Siskiyou National Forest in southwestern Oregon. Objectives were to estimate quantitatively the effects of forest management activities on the frequency and volume of mass movements, and to collect information concerning conditions at landslide sites which might serve as a guide to appraising future risks of landslides.

Description of Area

The Klamath Mountains of southwest Oregon lie between the southern Cascade Mountains and the Pacific Ocean. The Klamaths are characterized by steep, rugged terrain, heavy vegetation, and unstable slopes. The overall structural pattern of the Klamath province consists of north-south bands that curve to the northeast. The study area consists predominantly of pretertiary sediments and volcanics that have been folded, faulted, and intruded by serpentinized masses of ultra-basic and granitoid rocks at fault contacts between the bands. The area is generally between 2,000 and 5,000 feet in elevation, and is highly dissected with narrow canyons. Annual precipitation, mainly winter rain, ranges from 50 to over 150 inches. The Klamath region produces timber, water, and fisheries of high value. It supports a complex pattern of natural communities in response to steep climatic gradients, diverse parent materials, and a transitional geographic location where species common to the Pacific Northwest and California merge.

Sites Studied

We used data from 24 randomly selected Total Resource Inventory compartments on the Siskiyou National Forest. The sample, about 137,500 acres, included about 14 percent of the total area of the forest. Using a mirrored stereoscope with 8 X magnification, we inspected 1:15,840-scale aerial photos taken in 1956 and 1976, and recorded site variables and the volume (to the nearest 100 yd^3) of mass movements entering drainage-ways during the 20-year interval. We felt that such mass movements would produce almost all of the effects of concern to land managers.

Photo measurements were verified by field checking 125 of the inventoried 699 mass movements. The volumes of the first 50 tallied were field checked and corrected to the field measurements. The comparison of volumes revealed no bias in the photo measurements. Consequently, no adjustment was made to later photo measurements.

Mass movements were categorized according to type of movement. (debris slide or slump-earthflow), ownership (private or Forest Service), and site (natural, road, mine, or harvest area). Debris slides are defined as shallow sliding of residuum or colluvium lying upon bedrock or mantle material layers having higher strength and lower permeability. Slump-earthflows are a combined process of earth movement involving rotational movement of a block of regolith along a failure plane with subsequent downslope transport by flowing or a sliding of a series of blocks. Natural slides or slumps were those on undisturbed slopes with no apparent relationship to management activity Road-related failures were those occurring within the road prism, adjacent to landings, or having an obvious connection with the road, such as culvert outfall or ditchline obstruction. Harvest area failures were those within clear-cut boundaries with no apparent relationship to roads or landings.

Debris slides were by far the most prevalent type of mass erosion, comprising about 80 percent of the volume and 90 percent of the events tallied. Because debris slides can be more clearly interpreted from aerial photos than can

THE AUTHORS-Michael P. Amaranthus is soil scientist, Siskiyou National Forest, Grants Bass, Oregon. Raymond M. Rice and Robert R. Ziemer are hydrologist and supervisory hydrologist, Pacific Southwest Forest and Range Experiment Station, Arcata, California. Nicholas R. Barr, who at the time of the study was geologic technician, Siskiyou National Forest, is principal geologist, Mt. Emily Mining Company, Brookings, Oregon.

slump-earthflows, and in order to clarify the relationship between slides and site characteristics, we restricted our study to debris slides. For similar reasons, mining-related failures were not considered and landing-related slides were combined with road-related slides. These restrictions reduced the number of mass movements studied from 699 to 644.

Site variables measured included slope angle, position on slope, aspect, mean annual precipitation, and geomorphological erosion response unit (GERU). The GERUs were nine soil and geologic types grouped to reflect rock types or landforms expected to have similar responses to disturbance (*table 1*).

Forest Management

Almost 1.5 million yd^3 of debris slide erosion occurred during the 20 years spanned by the inventory *(table 2).* Slide frequency was about one slide every 4.3 years on each 1,000 acres and the erosion rate was about l/2yd^3 per acre per year Roads, occupying only 2 percent of the area inventoried, were the sites of over half of the slides and 60 percent of the slide volume. Harvest areas, occupying 10 percent of the area inventoried, yielded 34 percent of the slides and produced 18 percent of the slide volume. The remaining 88 percent of the study area, which was in a natural condition, produced only 22 percent of the slide volume.

Both frequency and volume of debris slide erosion in private harvest areas exceeded those in Forest Service harvest areas *(table 2*). The difference is even greater when harvest-area erosion rates are compared with corresponding natural erosion rates on Forest Service or private land. Forest Service logging was associated with an almost 6-fold increase in slide volume, whereas private logging was associated with a 45-fold increase. The difference is smaller with respect to slide frequency: a 17-fold increase on Forest Service harvest areas and a 38-fold increase on private harvest areas.

These differences might be explained by the usual time lag between logging and the resulting debris slides (Ziemer 1981). There had been considerable logging on private land before 1956, but very little on Forest Service land. The private land, therefore, may have contained a greater proportion of logged areas that were susceptible to failure during the study period. In addition, forest practices substantially improved during the period investigated, especially in preventing or controlling erosion. Forest Service harvests, being on the average more recent, would therefore have been conducted under improved procedures. If this is the case, then the observed differences reflect merely a trend of improving practices over time, not differences between Forest Service and private logging practices. We believe nonetheless that the differences related to ownership per se are appreciable.

Slope

Slide sites were divided into three slope classes: less than 50 percent, 50 to 70 percent, and steeper than 70 percent. Debris slide frequency and erosion rate were strongly associated with slope *(fig. 1).* Terrain with slopes less than 50 percent comprised 68 percent of the study area but contained only about 1.5 percent of the total debris-slide ero-

Table 1. Geomorphological erosion response units (GERUs). Units derived by authors for the study.

Name	Description
Umpqua	Includes Roseburg, Flournoy, Lookingglass, and Humbug Mountain Formations as well as the Galice Formation on the west side of the Klamath Mountains. Rocks include sandstones, slaty mudstone and siltstone, conglomerate, and pillow basalts.
Colluvial	Occurs across many geologic types. Formed by the gravitational movement of soil and rock material downslope. Soil textures typically clayey with abundant coarse, unweathered rock fragments. Landform deeply dissected and convex.
Dothan	Predominantly graywacke sandstone, massive and mixed layers of mudstone, shale, or siltstone.
Hummocky	Occurs across many geologic types. Characterized by discontinuous benchy landform and often irregular drainage pattern. Hilly uneven landscape is a result of past deep-seated mass movement. Soils range from shallow clay loams in headwall areas to deep clayey-and often poorly drained-soils in basin areas.
Intrusive	Includes granitics, diorites, gabbros, and related dike rocks. Widely scattered throughout the study area.
Galice/ Applegate	Primarily metasedimentary and metavolcanic rocks of the Galice Formation on the east side of the Klamath Mountains and Applegate Formations. Galice metasediments primarily shale or slate and volcanic rock, thick andesitic flow rocks, and flow breccias. Applegate rocks mainly volcanic-altered flow breccias and tuffs.
Colebrook	Vast assemblage of quartz-mica phyllite and schist. Highly contorted and sheared.
Serpentine	Includes serpentine and periodotite. This ultrabasic rock group is widespread throughout the study area mainly in thrust plates and fault zones. Usually highly fractured or sheared.
Tyee	Primarily the Tyee Formation. Thick, rhythmically bedded sandstone with thin, interbedded dark-colored mudstone.

Table 2. Debris slide inventory on the Siskiyou National Forest, southwestern Oregon, 1956-1976.

Site condition	Area sampled	Slides		Erosion rate	
		Total number	Total volume	Frequency	Volume
	Acres		*Yd^3*	*Freq. · 10^3 / ac · yr*	*Yd^3 / ac · yr*
All slides	137,474	644	1,433,500	0.23	0.52
Natural	119,312	100	317,200	.04	.13
Roads	2,978	328	864,500	5.51	14.51
Harvest areas	14,184	216	251,800	.76	.89
Private	2,223	40	56,000	.90	1.26
Forest Service	11,961	176	195,800	.74	.82

sion. At the other extreme, terrain steeper than 70 percent made up 9 percent of the sample area but contained 76 percent of the debris-slide erosion. Slide frequencies were similarly distributed among slope classes.

Slides found in the less-than-50-percent slope class in natural forests may be misleading because a debris slide is not likely to occur on a slope less than 50 percent. The probable explanation for the anomaly is that the slides tallied in this class were actually on small, atypically steep facets within otherwise gentle terrain. This phenomenon has been noted before (Rice et al. 1969). Even though the terrain may be too flat for debris slides, road and landing construction creates slopes that are steep enough to fail. Consequently, the erosion rate for roads and landings in this slope class is believable.

Position on Slope

Over half of the slides and nearly half of the slide volume occurred on the lower third of slopes *(fig. 2).* This trend was not matched by slide volume. Slides occurring on the upper third of the slope were, on average, larger than those on the lower two-thirds of the slope. This increase in slide volume on the upper third of the slope was likely an artifact of our counting only slides that reached a drainageway. The average size of slides that meet this criterion would be expected to be greater upslope.

Aspect

There was no definite relationship between aspect and erosion rate or slide frequency. The distribution of slides with respect to aspect is more likely due to chance or some factor not considered in our analysis. Furbish and Rice (1983) used aspects effectively to predict slide risk on a relatively small area (54 mi^2), but found that it was almost useless for a much larger area (1,027 mi^2, spanning 20 of latitude). They concluded that, although aspect might be useful in a restricted climatological and geomorphological setting, its effect was masked by other, more important variables in a larger area with greater diversity.

Precipitation

We estimated mean annual precipitation for each of the slide sites using an isohyetal map prepared by the Siskiyou National Forest staff. Slide frequency showed a slight, though erratic, upward trend with increasing mean annual precipitation. Erosion rate showed a similar trend except for the 70- to 80-inch rainfall class. The erosion rate in this class was affected by a few large slides. The class contained the smallest acreage but included the largest and fourth-largest events measured. Although precipitation is unquestionably important to the initiation of debris slides, mean annual precipitation is not a good indicator of this relationship. The relationship is probably clouded by differences in rainfall intensity, timing, and the proportion of the precipitation that falls as snow on the windward and leeward sides of the Klamath Mountains.

To test whether the study area was subject to anomalously high meteorological stress, we compared precipitation during the study period (1956-1976) with annual rainfall, mean seasonal rainfall (October through April), and maximum monthly rainfall in long-term records from Port Orford (60 years), Grants Pass (65 years), and Brookings (93 years), Oregon. In most instances, precipitation during the 20-year study period was less than that in the long-term record. Although debris slides are associated with rainfall of shorter duration than that in the records analyzed, we believe our results probably do not misrepresent long-term trends.

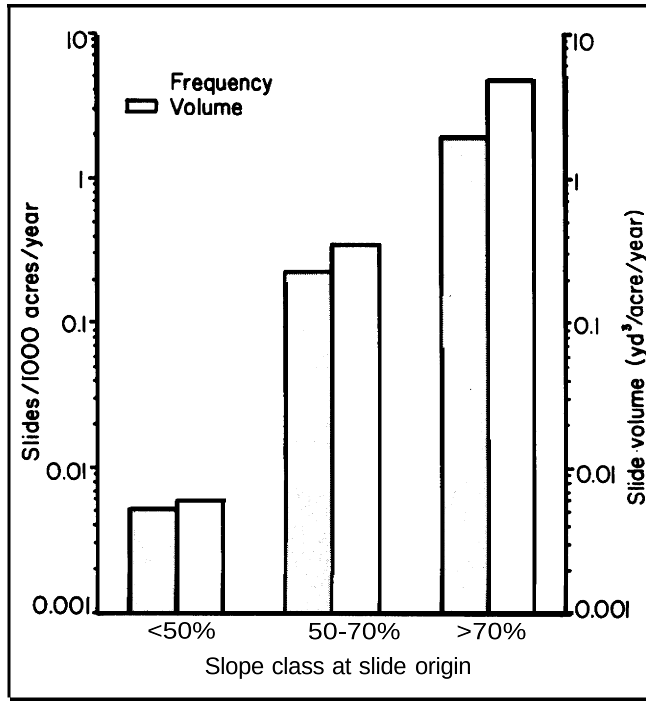

Figure 1. Debris slide frequency and erosion rate on the Siskiyou National Forest, 1956-1976. The rates were strongly associated with slope class.

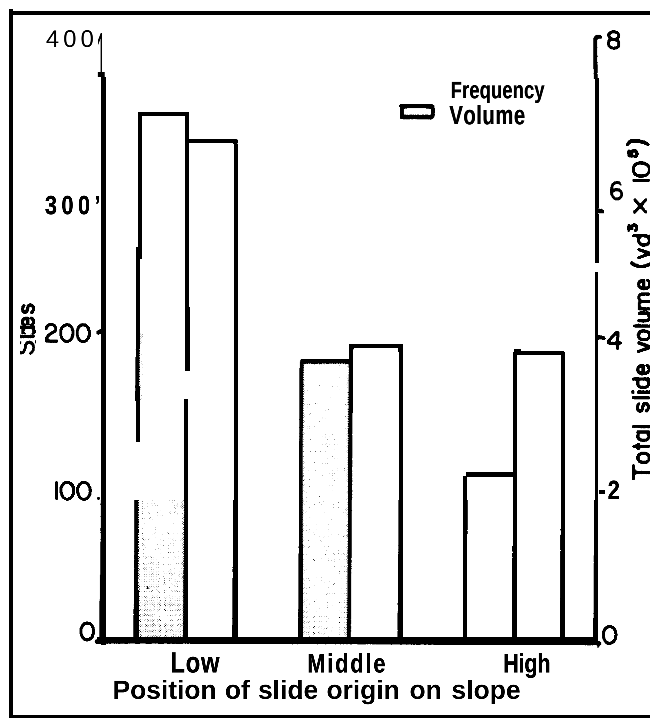

Figure 2. Number of debris slides and total slide volume found differed on three positions on slope, Siskiyou National Forest, 1956-1976,

Geomorphological Erosion Response Unit

The natural debris slide erosion rates and the increases related to management activities varied considerably among GERUs (*table 3*). The colluvial, hummocky, and intrusive GERUs had the highest natural slide erosion rates, but only modest proportional increases when subjected to management. Their absolute increases were, however, similar to the averages of all GERUs. The Umpqua and Dothan GERUs, on the other hand, had low natural slide erosion rates but large increases when disturbed by roads, landings, or logging. The Umpqua GERU had the largest absolute and proportional increases. The Galice/Applegate GERU showed a very modest increase in slide erosion in harvest areas, although erosion due to roads and landings greatly exceeded the natural rates for this GERU.

Pacific Northwest

Our results are comparable to the findings of other studies of erosion in the Pacific Coast mountains *(table 4)* Until erosional processes are sufficiently understood to make practical the models based on physical processes, forest managers will have to look to such empirical studies for guidance concerning the expected magnitude of the effects of logging and forest roads. The increase in erosion rate associated with logging in our study was somewhat greater than that in the other studies. Our observed increase in slide volume was the highest and our increase in slide frequency the second highest. On the other hand, our increases in both volume and frequency of road-related slides were in the middle of the values reported. Considering the variations in site conditions and measurement methods among the various studies, we believe our rates of management-related increases are not anomalously high.

Although the total slide volume from roads over the study period was more than triple that from harvest areas *(table 2)*, this ratio will probably decrease when the entire area has been brought under management. Presently, roads comprise about 17 percent of the total area under management. At the erosion rate observed during the study period, the total volume of road-related debris slides will equal the volume of logging-related slides when the road area is about 6 percent of the area under management. Although road densities in excess of 6 percent are not unheard of, a lower road density is more likely. Other considerations should reduce the long-term road-related erosion rate from that observed during the study period. Recent improvements in roading practices compared to those prevalent during the late '50s should lessen the erosion caused by road building on forestlands. In addition, once the area is completely under management, the debris slide erosion that often accompanies new road construction will be minimized.

Management Implications

In appraising the environmental impact of timber harvest, we believe that soil loss, as measured by slide volume, should be the focus of concern. Slide frequency may be more relevant on road rights-of-way where the number of interruptions to the transportation system might be more important than the volume of material eroded. When considering off-site effects of roads, slide volume again becomes the relevant index of impact.

An erosion rate 6.8 times that in natural areas should not be ignored. Soil is the capital that yields a return in timber products. Prudent management dictates that erosion rates much above background should not be tolerated until there is greater assurance that the soil can be maintained. Aside from the effect that erosion might have on on-site productivity, off-site effects need to be considered. For example, we do not know if aquatic resources were harmed by the nearly sevenfold increase in erosion rate, but such an increase was probably not beneficial. Construction of stable roads and the location of stable harvest units require an understanding of the characteristics of the site. The magnitude of the effort toward achieving stability is, however, a decision based on the manager's perception of the competing values. The following are recommendations for minimizing debris-slide erosion related to forest management activities in southwest Oregon.

Steep slopes. Avoid locating roads on slopes steeper than 70 percent where soil and geologic conditions indicate that slope stability is questionable. For harvest units, avoid steep headwall areas or the heads of small drainages beneath convex breaks in slope. Slopes flatter than 50 percent are almost immune to debris slides.

Geology and soil. Highly faulted and sheared areas provide zones of weakness and water seepage upon which slides can develop. This is particularly true of the Umpqua and Dothan GERUs. Slide hazard is also increased when bedding planes, jointing, or fracturing of a parent material are parallel to the slope. Tension cracks are the result of soil stress and definitely indicate active soil movement, although more likely from creep than from any precursor to

Table 3. Debris slide erosion rates and activity-related increases in erosion on nine geomorphological erosion response units (GERUs) in the Klamath Mountains, southwestern Oregon.

GERU	Erosion rate: Natural	Erosion rate: Roads and landings	Erosion rate: Harvest areas	Activity-related increase: Roads and landings	Activity-related increase: Harvest areas
	....	yd^3/ac/yr	....		
Umpqua	0.03	53.61	1.63	1,787x	54.3x
Colluvial	.62	22.20	1.51	36x	2.4x
Dothan	.04	13.15	.57	329x	14.3x
Hummocky	.30	10.70	1.17	36x	3.9x
Intrusive	.24	9.92	1.11	41x	4.6x
Galice/Applegate	.07	7.28	.08	104x	1.1x
Colebrook	.06	6.06	1.24	101x	20.7x
Serpentine	.02	1.71	.35	86x	17.5x
Tyee	.02	1.52	.08	76x	4.0x
All	.13	14.51	.89	112x	6.8x

Table 4. Slide frequencies, volumes, and erosion rates estimated in seven Pacific Coast studies.

	Record length	Average slide volume	Erosion rate Frequency	Volume	Source
	Years	Yd^3	$\frac{Freq \cdot 10^3}{ac \cdot yr}$	$\frac{Yd^3}{ac \cdot yr}$	
Natural					
Coast Range	15	71	0.33	0.15	Swanson et al. (1977)
Coast Range	15	33	.27	.06	Ketcheson (1978)
Cascades	25	1,908	.02	.19	Swanson and Dyrness (1975)
Cascades	15	2,601	,014	.24	Morrison (1975)
Olympic Peninsula	84	6,091	,009	.38	Fiksdal (1974)
British Columbia	32	3,973	.0023	.06	O'Loughlin (1972)
Klamath Mountains	20	3,231	.04	.13	(this study)
Harvest areas					
Coast Range	I0	144	.63	.59	Swanson et al. (1977)
Coast Range	15	44	.9I	.69	Ketcheson (1978)
Cascades	25	1,751	,058	.70	Swanson and Dyrness (1975)
Cascades	15	575	.I6	.62	Morrison (1975)
Olympic Peninsula	6	–	.0	–	Fiksdal (1974)
British Columbia	32	1,503	.013	.I3	O'Loughlin (1972)
Ktamath Mountains	20	1,085	.76	.89	(this study)
Road rights-of-way					
Coast Range	15	555	4.97	18.52	Swanson et al. (1977)
Cascades	25	1,804	.83	9.36	Swanson and Dyrness (1975)
Cascades	15	2,444	5.03	82.53	Morrison (1975)
Olympic Peninsula	6	732	11.94	62.43	Fiksdal (1974)
British Columbia	32	4,614	.53	1.49	O'Loughlin (1972)
Klamath Mountains	20	2.305	5.51	14.51	(this study)

debris sliding. These symptoms require field examination before activities begin.

Vegetative indicators. Avoid steep areas supporting hydrophytes or phreatophytes. Avoid slopes dotted with small (less than 0.1 acre) patches of brush or young timber. The patches may be old debris-slide scars. In areas where rain rather than snow is the major component of winter precipitation, pistol-butted trees may indicate slope instability. Tipped trees, jackstrawed trees, or trees that have a sharp angle to the stem are more certain indicators of a shift in the soil mantle.

Timber harvest units. Avoid swales in the inner gorge, especially near the stream and just below the slope break. In areas where there are indications that debris-slide potential is high, vegetative leave areas should be considered. Root systems of vegetation increase the shear strength in unstable soils. Roots can anchor the soil mass to bedrock materials and provide support along local zones of weakness within the soil mass.

Road construction. Avoid locating roads on the lower third of slopes where excess moisture is most likely. Ridgetops are the best road locations. End-haul excavated material away from steep, marginally stable slopes or slopes that will not support a stable fill. Roll the road grade to avoid unstable areas. Short, steep pitches of adverse or favorable grade may be included. Reduce road widths to minimize needed excavation. Avoid concentrating water on unstable slopes by careful location of culverts. Compact road fills to accepted engineering standards and minimize cutslope heights in deep soil areas to lessen the probability of road prism failures.

‡

The difference in slide erosion between private and Forest Service timber harvest areas-regardless of the cause-indicates that modifications of forest practices can substantially reduce erosion. Site conditions that we found to be associated with debris slides can alert managers to potential problems. However, skillful application of forest practices is still necessary if the detrimental effects of roads and timber harvest are to be kept to an acceptable level. ■

Literature Cited

BISHOP, D.M., and M.E. STEVENS. 1964. Landslides on logged areas in southeast Alaska. USDA For. Serv. Res. Pap. NOR-l, 18 p.

FIKSDAL, A.J. 1974. A landslide survey of the Staqualehe Creek Watershed: supplement to final report FRl-UW-7404. 9 p. Fish. Res. Inst., Univ. Washington, Seattle.

FURBISH, D.J., and R.M. RICE. 1983. Predicting landslides related to clearcut logging, northwestern California, U.S.A. Mt. Res. and Dev. 3(3):252-259.

KETCHESON, J.L. 1978. Hydrologic Factors and Environmental Impacts of Mass Soil Movements in the Oregon Coast Range. 55 p. M.S. thesis, Oregon State Univ., Corvallis.

MCCASHION, J.D., and R.M. RICE. 1983. Erosion on logging roads in northwestern California. J. For. 81(1):23-26.

MORRISON, P.H. 1975. Ecological and Geomorphological Consequences of Mass Movements in the Alder Creek Watershed and Implications for Forest Land Management. 102 p. B.S. honors thesis, Univ. Oregon, Eugene.

O'LOUGHLIN, C.L. 1972. An Investigation of the Stability of the Steepland Forest Soils in the Coast Mountains, Southwest British Columbia. 147 p. Ph.D. thesis, Univ. British Columbia, Vancouver.

RICE, R.M., E.S. CORBETT, and R.G. BAILEY. 1969. Soil slips related to vegetation, topography, and soil in southern California. Water Resour. Res. 5(3):647-659.

SWANSON, F.J., and C.T. DYRNESS. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 1:393-396.

SWANSON, F.J., N.M. SWANSON, and C. WOODS. 1977. Inventory of Mass Erosion in the Mapleton Ranger District, Siuslaw National Forest. 61 p. Unpubl. Rep. on file, For. Sci. Lab ., PNW For. & Range Exp. Stn., Corvallis, OR.

ZIEMER, R.R. 1981. The role of vegetation in the stability of forested slopes. P. 297-308 in Proc. XVII IUFRO World Cong., 6-17 September 1981, Kyoto, Japan.