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THE RESPONSE OF FOREST ROADS ON STEEP, LANDSLIDE-PRONE TERRAIN IN WESTERN OREGON TO THE FEBRUARY 1996 STORM

by

Arne Skaugset and Beverly Wemple

ABSTRACT: Following the February 5-9, 1996 storm in western Oregon, a large, infrequent landslide-producing storm, two inventories of road-related landslides were undertaken to evaluate the response of contemporary forest road networks to large storms. A total of 386 miles of forest road were driven or walked and 128 road-related landslides were inventoried on federal, state, and private land in both the Oregon Coast and Cascade Ranges. Both landscape variables, such as road age and topographic position, and site-specific road variables, such as road grade, length, cutslope height, and fill depth, among others, were collected. When the results of the inventories of road-related landslides following the February 1996 storm were compared with the results of previous inventories of road-related landslides on the same or similar terrain, there was no obvious difference in landslide density values either on a road length or road prism area basis. This indicates that there is a cost of doing business when roads are constructed in steep, landslide-prone terrain. However, the data also showed that the average landslide volume had decreased, in some cases significantly, and contemporary road densities were less than actual or predicted road densities from previous decades. This means that while the density of road-related landslides hasn't decreased, with fewer roads and, on average, smaller landslides there should have been less road-related erosion generated per unit area of forest in the 1996 storm. On a site-specific scale, approximately half of the shallow, translational landslides that initiated in the road fill were associated with the outfall of surface road drainage structures, which means that road drainage is a feature of forest road systems that simply must be accounted for. Also, cutslope heights greater than 15 feet were positively correlated with both the occurrence and volume of road-related

landslides. On a landscape scale, most of the road-related erosion came from roads constructed during or before the 1960's rather than roads constructed since the 1960's. Also, the majority of the road-related erosion was associated with roads occupying a midslope topographic position versus ridge or valley bottom roads.

KEY WORDS--Slope stability, landslides, landslide inventory, road-related landslides, forest roads, forest road drainage, February 1996 storm

INTRODUCTION

One of the more visible and enduring legacies of the timber heritage in the Pacific Northwest is the extensive network of logging roads on private industrial forest land, state owned forest land, and the national forest system. These roads, as they exist today, represent a continuum of timber harvesting systems, from railroad logging and tractor logging to contemporary cable and helicopter systems, and road construction practices and standards that evolved over the past several decades. Road-related landslides are considered to be the dominant source of accelerated erosion associated with timber harvesting (Dyrness, 1967; Swanson and Dyrness, 1975; Swanston and Swanson, 1976; Swanson, et al, 1977). The legacy of these roads remains today.

The environmental consequences of the contemporary road network are manifest primarily during storms, and particularly during large, infrequent floods. These consequences, while they occur on a localized, site specific scale, are manifested on a watershed or landscape scale. On a watershed scale, the geology, soils, geomorphology, and climate of a watershed affect the environmental consequences of forest roads. On a local scale, site specific standards and practices including road location, grade, and drainage standards affect the environmental consequences of roads.

Over the past two to three decades, considerable effort has been expended to improve the environmental performance of forest roads (Sessions, et al, 1987). Some of the practices that have been undertaken to improve forest roads include:

- increased use of skyline and other long span logging systems to reduce the amount of roads needed,
- ridge top road systems,
- high gradient roads to get to and stay on ridges top locations,
- full-bench, end haul road construction practices, and
- improved road drainage standards.

The degree that these improved practices have improved the environmental performance of forest roads is, to some degree, unknown. Session, et al (1987) undertook a landslide inventory of road-related landslides in the central Oregon Coast Range to study the degree that improved practices reduced the occurrence of landslides. The authors found that the improved practices reduced both the density and volume of road-related landslides. However, these results are less than conclusive because at the time, the proportion of the road system that was constructed using the improved practices had not been subjected to a large, landslide-producing storm.

During February 5-9, 1996, a large, landslide-producing storm occurred throughout the north and central Oregon

Coast and Cascade Ranges. For some parts of the Coast Range, this storm became the storm of record surpassing rainfall amounts and peak flows that occurred in the infamous 1964 storm. Certainly for large extents of the Coast and Cascade Ranges, this was the type and magnitude of storm that could test the environmental performance of improved road standards.

Despite this research opportunity, there are challenges to understanding the response of the road system to this large flood. The current road network was developed during a time of evolving road design and construction standards. The occurrence of road-related landslides is most likely a function of both the road design and construction practices of the time, as well as the inherent geologic stability of the roaded landscape. In addition, each landslide-producing storm varies spatially and temporally in total rainfall, antecedent precipitation, and precipitation intensity. All of these factors affect the ability of a storm to trigger landslides. Furthermore, research from different disciplines using different methods will undoubtedly result in different, yet hopefully complimentary, insights into the effect of large floods on erosion from contemporary road systems.

OBJECTIVES

- To investigate how the existing forest road network in 1996 responded to the rare and extreme storm and flood of February 5-9, 1996.
- Also, to compare this response with how forest roads have responded previously to rare and extreme storms and floods in both the Cascades (1964) and the Coast Range (1975).
- To examine the effect of both landscape variables and site specific road standards on the response of the road network to the '96 storm.

METHODS

Oregon Department of Forestry Study Areas

After the February 1996 storm, Oregon Department of Forestry (ODF) personnel selected six areas in which the interaction of contemporary forest practices with the storm would be investigated. Each study area was, nominally, two miles wide west to east and five miles long north to south for an area of 10 square miles. Of particular interest in these study areas was the interaction of forest practices, both harvesting and roads, with the occurrence of landslides. Because of the interest in landslides, three of the study areas were not randomly located but were chosen primarily because they were in areas that had high densities of landslides compared with surrounding areas. These three study areas, referred to as the "red zones," are the Mapleton, Tillamook, and Vida study areas. In addition to landslide density, the "red zone" study areas were located to include a portion of unmanaged forest and a mixture of ownership including both federal and private forest land.

The other three study areas were chosen to represent a background or control condition as a counterpoint to the three "red zone" study areas. These study areas consisted, primarily, of private industrial forest land that was roaded, was being intensively managed, and was not visibly more impacted by the flood than immediately surrounding areas. Like the "red zone" areas, these areas were not randomly located, but their selection had a component of randomness to it that was greater than the selection of the "red zone" study areas. These three study areas are the Dallas, Estacada, and Vernonia study areas.

Within each of the six study areas, all of the roads were driven or walked and all the roads and road-related landslides were inventoried. To inventory the roads, they were first divided into distinct segments bounded by surface road drainage structures that included cross drain culverts, live stream crossing culverts, waterbars, ditchouts, bridges, and other engineered and non-engineered drainage features. Each road segment was characterized by a number of parameters including but not limited to road segment length, road grade, and average road width, hillslope gradient, fill depth, and cutslope height among other variables.

When a landslide was encountered within the road right-of-way on a road segment it was inventoried. For the purposes of this inventory the road right-of-way or road "prism" extends from the top of the cutslope to the toe of the fill slope. To inventory the landslide, it was first uniquely identified with the road segment and then the landslide was characterized by a number of variables including but not limited to landslide type, location, and dimensions, hillslope gradient, cutslope height and fill depth among other variables.

Blue River and Lookout Creek Study Areas

Examination of flood impacts in the Lookout Creek and Blue River watersheds were conducted by an interdisciplinary group of scientists from Oregon State University and the U.S.D.A. Forest Service (Dyrness et al, 1996; Swanson et al, 1998). Previous studies in these watersheds documented mass erosion associated with significant storms and the density of landslides in forested, harvested and roaded areas. This study examined the density and distribution of road-related landslides associated with the February 1996 storm. Additional work, described elsewhere, examined a full range of erosional and depositional processes associated with roads and the extent of process linkages (Wemple, 1998).

Within the Lookout Creek and Blue River watersheds, all the roads were driven or walked and all road-related landslides were inventoried. Field measurements of the length, width and depth of erosional scars were used to estimate landslide volumes. The position of the landslides was located on 7.5' topographic maps and was then digitized and stored in a geographic information system (GIS). The age and hillslope position of each landslides was characterized using GIS analysis.

RESULTS

Oregon Department of Forestry Study Areas

For the six ODF study areas, 60 mi^2 or 38,400 acres of forest land was inventoried. The cumulative length of road inventoried was approximately 170 miles, which results in an average road density of approximately 2.8 mi/mi^2. Using the estimated road widths collected during the road inventory, 1.8 percent of the area studied was estimated to be in forest roads. There were 85 landslides inventoried that initiated within the right-of-way of the 170 miles of road studied, which results in an average landslide density of approximately 0.5 per mile of road studied, 0.12 per acre of road right-of-way, and 1.4 per mi^2 of forest area studied. The voids representing the initiation sites of the 85 landslides had a volume of 24,332 yds^3 that results in an average landslide volume of approximately 286 yds^3. On average, the erosion rate attributed to road related landslides for the six study areas was 35 yds^3 per acre of road right-of-way and 0.63 yds^3 per acre of forest area studied.

Of the 85 road related landslides that were inventoried, 23 were cutslope failures and three were landslides that could have been called in-unit landslides because they initiated immediately below the road fill on the hillslope. The remaining 59 landslides all initiated within the fill of the road and, of these, three were rotational failures. Thus, the balance and bulk of the road related landslides inventoried were shallow, translational landslides or debris flows that originated within the road fill. Of these 56 shallow, translational landslides that initiated within the road fill, 25 were simply fill failures and 31 were associated with surface road drainage features. Finally, both the occurrence of a landslide and the volume of the landslide were positively correlated with height of the road cutslope. For existing road systems, cutslope height is an indicator of the potential for a road-related landslide.

There was a clear difference in study area attributes associated with "red zones" versus non-red zones or the background study areas. The "red zones" had, on average, steeper side slopes (56 versus 28 percent), fewer roads (62 versus 108 miles) and more landslides (61 versus 24) than the control or background study areas. The difference in the extent of the road network is a function of the fact that the "red zones" all had some minor portion of the study area that was undeveloped where the background study areas were all more completely developed with a road network. The difference can also be attributed to the effect the difference in slope would make on the average yarding distance of the logging systems that would be used and thus the amount of roads needed. Because the "red zones" had more landslides and fewer roads, the comparison of landslide densities for the different study areas was marked. The "red zones" had landslide densities of approximately 1.0 per mile of road length and 2.0 per mi^2 of forest area inventoried versus values of 0.2 and 0.8 for the background study areas, respectively.

It is worthwhile to look in more detail at the descriptive statistics for the three "red zones" because they represent differences in geology, geomorphology, ownership, and total rainfall amount and intensity during the February storm. The Vida study area has the most roads with 25.9 miles followed by Mapleton and Tillamook with 18.4 and 17.8 miles, respectively. Because each study area is 10 mi^2, the road density can be determined simply by dividing the road length by 10. Using the estimated average road width for each road segment collected during the road inventory, the area in the road prism was determined to be 0.20 mi^2 for Vida, 0.14 mi^2 for Mapleton, and 0.13 mi^2 for Tillamook. The percent area in roads can be determined by simply dividing these numbers by 10, also. Mapleton had 29 road-related landslides followed by Vida with 22 and Tillamook with 10. The average volume of the road-related landslides was 229, 162, and 157 yd^3 for Vida, Tillamook, and Mapleton, respectively. The road-related landslide densities and erosion rates are presented in Table 1.

For the three "red zone" study areas, most of the road-related landslides occurred on roads classified as midslope. This is due in large part to the fact that most of the roads are in this slope position. Out of a total of 62 miles of road, 42 miles, or 68 percent, are considered midslope and these midslope roads account for 90 percent (55 out of 61) of the road-related landslides. Only 7 percent of the slides occurred on valley bottom roads, which make up 15 percent of the road network, while only 3 percent of the slides occurred on ridge roads, which make up 17 percent of the road network. Landslide density and erosion rate followed

Table 1. Descriptive statistics, landslide densities, and landslide erosion rates for road related landslides in the "red zone" study areas of the ODF flood monitoring study.

	Mpltn	Vida	Till	Total
Road length (mi)	18.4	25.9	17.8	62.1
Road Prism Area (mi^2)	0.14	0.20	0.13	0.47
Number of Landslides	29	22	10	61
Landslide Density (#/mi)	1.6	0.8	0.6	~1.0
Landslide Density (#/acre of prism)	1/3	1/6	1/8	1/5
Ave. Landslide Volume (yd^3)	157	229	162	184
Erosion rate (yd^3/mi)	247	195	91	181
Erosion rate (yd^3/acre of prism)	51	39	19	37
Erosion rate (yd^3/mi^2 forest area)	455	504	162	374

the trend of the overall statistics. Midslope roads had a landslide density of 1.3 per mile of road and an erosion rate of 255 yd^3/mile. Ridge roads and valley bottom had landslide densities of 0.2 and 0.4 per mile, respectively and erosion rates of 20 and 23 yd^3/mile, respectively.

Blue River and Lookout Creek Study Areas

Road related landslides were inventoried for approximately 216 miles of forest road in the Blue River and Lookout Creek watersheds of which 63 miles were ridge roads, 127 miles were midslope roads, and 63 miles were valley bottom roads. There were 43 landslides inventoried that initiated within the road prism, 12 were cutslope failures and 31 were fill failures. Five landslides originated from ridge roads, and they were all fill failures. Eight cutslope failures and 22 fill failures, for a total of 30 landslides, originated from the midslope roads. Eight failures originated from valley bottom roads, and they were evenly divided between cutslope and fill failures with four each.

The voids representing the initiation sites of the 43 inventoried road related landslides had an estimated volume of approximately 39,352 yd^3 for an average landslide volume of 915 yd^3. The five landslides that originated on ridge roads had an average volume of 1,427 yd^3 for total erosion from ridge roads of 7,136 yd^3. The 30 landslides from midslope roads had an average volume of 1020 yd^3 for a total road related landslide erosion volume of 30,593 yd^3. Finally, the eight landslides that originated from valley bottom roads had an average volume of 203 yd^3 for a total road related landslide erosion volume of 1,624 yd^3.

The largest proportion of road-related landslides occurred on midslope roads, due in part to the high concentration of roads in this slope position. Roughly 60 percent of the road network in these basins is located in midslope positions, and 70 percent of the road-related landslides occurred on midslope roads. Approximately 19 percent of the slides occurred on valley bottom roads, which make up only 12 percent of the road network, while only 12 percent of the slides occurred on ridge roads, which make up 29 percent of the road network. Landslide density and volume were thus differentially distributed, with frequencies of 0.31 slides/mile on valley floor roads, 0.24 slides/mile on midslope roads, and 0.08 slides/mile on ridge roads.

The landslide data from Blue River and Lookout Creek also show a strong relationship between the age of the road and storm related damage to the road. Much of the road network in Lookout Creek was constructed between 1950 and 1970, while roads in Blue River were constructed mostly between 1960 and 1980. For the two basins combined, approximately 32 percent of the road network was constructed before 1960, 34 percent between 1961and 1970, 25 percent between 1971 and 1980, and the remaining 8 percent was constructed after 1980. Despite the even distribution of road construction through time, 30 of the 43 road-related landslides inventoried, 70 percent, occurred on roads constructed prior to 1960.

DISCUSSION

One of the objectives of the study was to determine the effect of the improved road layout, design, and construction practices that had been developed over the last two or three decades at mitigating the occurrence of road-related landslides during large, landslide-producing storms. To carry out this objective, the results from landslide inventories of road-related landslides that were carried out after the 1996 storm were compared with previous inventories of road-related landslides carried out for the same or similar terrain. Most of the landslide inventories were also carried out after large, landslide-producing storms.

The comparisons for the Oregon Coast Range are shown in Table 2a. The parameters of interest are expressed in terms of unit road length (#/mile and yd^3/mile) so the units are consistent with the previous studies. The most appropriate comparisons are for Swanson, et al (1977), the Sessions, et al, (1987) data for low road standards and high risk terrain, and the Mapleton study area of the ODF flood monitoring study. The landslide densities per unit road length for these three comparisons are, essentially, the same (1.8, 1.5, and 1.7) while the erosion rate per unit road length gets smaller with time (900, 400, and 250). In comparing these three studies, remember that all three are ground-based inventories but only Swanson, et al (1977) and the Mapleton study area of the ODF flood monitoring study followed large, landslide-producing storms. The Sessions, et al (1987) study was carried out during a relatively dry period compared with the other two studies.

The comparisons for the Cascade Range are shown in Table 2b. The parameters of interest are expressed in units of road prism area (#/acre and yd^3/acre) for consistent units with the previous studies. In the previous studies (Swanson and Dyrness, 1975; and Morrison, 1975) the extent of the road system was expressed only in terms of the area of road prism. The road data from those studies is also presented in Table 2b in terms of unit length for the sake of comparison with the Coast Range values. Road length was calculated from road prism area using an assumed width of 41 feet, which was the average width of the roads in the Vida study area of the ODF flood monitoring study. These numbers show a similar, but not identical, trend as the Coast Range values. The Morrison (1975) results

Table 2. Comparisons of inventories of road-related landslides for the a) Oregon Coast Range and the b) Cascades from the literature with the post 1996 ODF flood monitoring study and the PNW inventory of Blue River and Lookout Creek watersheds.

a) Oregon Coast Range Comparisons

	Road Length Mi	Number of Landslides #	Ave. Landslide Volume yd^3	Landslide Density #/mi	Erosion Rate yd^3/mi
Swanson, et al, 1977	50	89	505	1.8	900
Sessions, et al, 1987					
All data	149	93	234	0.62	146
Low Std; Hi Risk	50	75	265	1.5	400
Mapleton (ODF study)	18.4	29	157	1.7	250
Tillamook (ODF study)	17.8	10	162	0.56	91

b) Oregon Cascades Comparisons

	Road R/W Area Acres	Number of Landslides #	Ave. Landslide Volume yd^3	Landslide Density #/acre	Erosion Rate yd^3/acre
Swanson & Dyrness, 75	525	73	1,767	0.14	246
Morrison, 1975	150	75	2,540	0.5	1,240
Vida (ODF study	130	22	229	0.17	1.8
	Mi	#	yd^3	#/mi	yd^3/mi
Swanson & Dyrness, 75	106[1]			0.69	1,217
Morrison, 1975	30.2[1]			2.5	6,300
Vida (ODF study	25.9			0.85	195

[1] Assumed a 41 foot road prism width. Assumption used average road width for "red zone" study areas from the ODF flood monitoring study.

are obviously the maximum values collected and reported. Swanson and Dyrness (1975) and the Vida study area show similar landslide densities (0.14 and 0.17) but very different erosion rates (246 and 1.8). Both of these inventories were ground-based and were carried out after a large, landslide-producing storm.

Comparisons of findings from the 1996 storm with previous landslide inventories point to two important interpretations. First, for both the Coast and Cascade Ranges, there were similar landslide densities from the older to contemporary studies. This indicates that even though there were significant upgrades in road standards from the earliest to the latest inventories, on a per unit road length or per unit area of road prism basis, landslides occurred at about the same rate. This seems to indicate that there will always be some cost of doing business. If forest roads are built in steep, landslide-prone terrain, some level of accelerated erosion due to landslides will occur. Second, while landslide density did not decline noticeably, lower road densities in some geographic areas may reduce the overall impact of roads on erosion production. For the three "red zone" study areas, the road densities were 1.8, 2.6, and 1.8 mi/mi^2 and the percent area in road right-of-way was 1.4, 2.0, and 1.3. These latter values are in contrast to reported values from the literature for percent area in roads of 4 to 8 percent (Swanson and Dyrness, 1975; Swanson, et al (1977; Gresswell, et al (1979). While cross-study comparison does not indicate a reduction in the density of landslides, reductions in road length apparent in these comparative analyses might result in an overall reduction in road-related landslides per unit area of forested landscape.

The data do show that average landslide volume, erosion rate per unit road length, and erosion rate per area of road prism have declined through time, in some cases very significantly. There are multiple interpretations that may explain this observation. These interpretations include differential storm magnitude and intensity, armoring or hardening of the road system, and improved practices. All of these interpretations probably play some role. While improved practices are a likely part of the explanation, the magnitude of the improvement that can be attributed to improved practices is not known. So, despite the fact that landslide occurrence per unit of road length hasn't declined over time, the average landslide volume has decreased and the road density has decreased thus, the expected effect would be that less accelerated erosion from roads is being generated at a landscape scale.

Despite evidence suggesting that efforts to improve road practices over the last two to three decades have been successful in reducing road-related erosion, there is obviously still room for improvement. As we look not only for ways to build better roads, but also for ways to retrofit and, in places, remove roads, the data from these inventories can help provide direction. On a landscape scale, the Blue River and Lookout Creek data showed that old roads, or those constructed during or before the decade of the 1960's had disproportionately high densities of landslides compared to newer roads. There are undoubtedly several explanations for this observation, including the intensity and form of precipitation during the storm, spatial distribution of roads relative to inherently unstable terrain, and differential standards represented by the different ages of the roads. The latter explanation deserves further consideration.

CONCLUSIONS

The results of the two inventories of road-related landslides that were carried out after the February 1996 storm showed that contemporary road systems were a significant source of accelerated erosion from the occurrence of landslides. On a site-specific basis, surface road drainage was correlated with the occurrence of approximately half of the shallow, translational landslides that initiated from road fills, confirming the importance of road drainage to accelerated erosion from road. Road cutslope height was correlated with both the occurrence and volume of road-related landslides. On a landscape level, road age and topographic position were indicators of erosion related damage to roads. Older roads, those constructed during or before the 1960's, were the source of significantly more erosion than roads constructed since the 1960's. Also, midslope roads produced more erosion than either ridge or valley bottom road locations.

Despite the improvement in road standards over the past two to three decades, the density of landslides from logging roads was roughly the same as it was for inventories of road-related landslides from the 1970's. This illustrates that if roads are constructed in steep, landslide-prone terrain, regardless of the standards, there will be a cost of doing business. However, the data also showed that the average volume of landslides had decreased and road densities were less indicating that while road-related landslides were still occurring in response to landslide-producing storms, the total accelerated erosion from roads should be less per unit forested area.

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THE AUTHORS

Arne Skaugset is an Assistant Professor in the Department of Forest Engineering, Oregon State University, Corvallis, Oregon, Email: skaugsar@ccmail.orst.edu and Beverly Wemple is with the USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, Oregon, E-mail: wempleb@fsl.orst.edu.

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