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Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon

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ABSTRACT
The H. J. Andrews Experimental Forest can be divided into two zones of approximately equal area, each with strikingly different susceptibilities to erosion by rapid soil movements. A stable zone occurs at elevations above 900 to 1,000 m in terrain underlain by lava-flow bedrock. Since logging and road cutting began in 1950, only two small road-related slides have taken place in the stable zone. In contrast, the unstable zone, located at elevations below 1,000 m and underlain by altered volcaniclastic rock, has been the site of 139 slides during the same period.

Slide erosion from clear-cut areas in the unstable zone has totaled 6,030 m²/km², or 2.8 times the level of activity in forested areas of the unstable zone. Along road rights-of-way, slide erosion has been 30 times greater than on forested sites in the unstable zone; however, only about 8 percent of a typical area of deforested land in the unstable zone is in road right-of-way.

At comparable levels of development (8 percent roads, 92 percent clear-cut), road right-of-way and clear-cut areas contribute about equally to the total impact of management activity on erosion by landslides in the unstable zone. The combined management impacts in the unstable zone (assuming 8 percent road right-of-way and 92 percent clear-cut) appear to have increased slide activity on road and clear-cut sites by about 5 times relative to forested areas over a period of about 20 yr.

INTRODUCTION
In recent years the environmental impacts of forest management practices, especially clear-cut logging, have been the subject of heated, unresolved controversy in technical and popular literature and before legislative committees. Much of the concern has focused on the role of erosion as a mechanism of soil and nutrient export from the forest ecosystem and the possibility that accelerated erosion rates may result in decreased forest productivity. Increased erosion may also have negative impacts on water quality and stream and lake environments downstream from the site of timber harvest.

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A major objective of the research program of the Coniferous Forest Biome (U.S./International Biological Program) is to develop a quantitative, holistic understanding of erosion processes in the productive timber lands of the Pacific Northwest. This paper is a progress report on one phase of the erosion studies—an evaluation of the occurrence of rapid mass-wasting events early in the management history of an experimental forest.

We have studied displacements of shallow soil masses in the H. J. Andrews Experimental Forest, where abundant background information on hydrology, geology, geomorphology, and history of land management activities is available. In all these respects, the forest is representative of much of the western Cascade terrane. Analysis of the slide history offers a measure of the impact of forest land management on mass-movement processes in this geologic-geomorphic terrane.

The inventoried mass movements are rapid, shallow (generally less than 5 m in depth) failures of more than 75 m² of soil-mantle material. The events include debris slides, slumps, rapid earthflows, debris avalanches, and debris flows, as defined by Varnes (1958). To simplify this discussion, we will refer to them collectively as slides.

Several lines of evidence suggest that shallow slides are dominant erosion processes in the western Cascade Range of Oregon. Fredriksen's (1970) work based on 13 yr of data on three experimental watersheds in the experimental forest indicates that the level of slide activity is a sensitive indicator of overall erosion rate. Further-
more, slides may be the ultimate form of delivery of soil material to stream channels in situations where other processes, notably creep and deep-seated mass movement, have accomplished much of the downslope transport of soil material. Overland flow and surface erosion are generally assumed to be unimportant on undisturbed soils in the region (Rothacher and others, 1967). However, since soil mass movements expose bare mineral soil, accelerated surface erosion is a consequence of increased slide erosion.

STUDY SITE

The H. J. Andrews Experimental Forest is located at the eastern edge of the western Cascades, in the Willamette National Forest, about 80 km east of Eugene, Oregon. The forest boundaries surround a 6,100-ha watershed in which elevation ranges from 450 to 1,630 m and typical slopes vary between 10° and 36° (Dyrenness, 1967). At elevations below about 1,350 m, Douglas fir and western hemlock are the dominant tree species; higher elevation timber stands are characterized by Pacific silver fir. Average annual precipitation totals approximately 240 cm and falls mainly between October and April.

Geology of the area may be divided into two units: predominantly altered volcanioclastic rocks at elevations below 900 to 1,000 m and, at higher elevations, unaltered lava flows. Much of the area above 900 m was glaciated during late Pleistocene time. The modern landscape in the volcanioclastic terrane bears abundant evidence of geologically recent slow, deep-seated earthflow and rapid shallow slides (Dyrenness, 1967; Swanson and James, 1975).

RESULTS

Nearly 19 percent of the study area has been clear-cut, and 116 km of roads have been constructed since logging and road-cutting activities began in the forest in 1950. In the same period, more than 140 slides have occurred. Most of the slides took place in response to severe storms in January 1953, November 1953, December 1957, December 1964, January 1965, and November 1971. At least 3 slides were triggered by each of the storms, and 43 were reported for the December 1964 storm (Dyrenness, 1967). During several of these storms, more than 30 cm of precipitation fell in 4 days (Fredriksen, 1965). Studies by Fredriksen (1965) suggest that this storm history is probably typical of the period of recorded observations dating back to the 1850s.

Definition of Stability Zone

The Andrews forest is underlain by geological units and associated soils that are distinctly different in their susceptibility to slides (Dyrenness, 1967). Therefore, slide data will be analyzed for each area separately. Two landscape-stability units may be identified, an unstable zone in volcanioclastic terrane and a stable zone in the overlying lava-flow terrane. The contact between these two contrasting stability zones follows the bedrock contact at altitudes between 900 and 1,000 m (Swanson and James, 1975).

Altitudinal control of rates of snowmelt may reinforce the differences in landscape stability inherent in the two lithologic terre-
TABLE 1. SUMMARY OF DATA ON SLIDES IN THE H. J. ANDREWS EXPERIMENTAL FOREST, 1950-1974

<table>
<thead>
<tr>
<th>Land status</th>
<th>Area [%] (km²)</th>
<th>No. of events</th>
<th>No./km²</th>
<th>Volume material moved (m³)</th>
<th>Volume material moved per km (m³/km²)</th>
<th>Slide erosion relative to forested area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable zone (20.8 km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>62.4</td>
<td>21.4</td>
<td>32</td>
<td>1.5</td>
<td>46,600</td>
<td>2,100</td>
</tr>
<tr>
<td>Clear-cut</td>
<td>25.6</td>
<td>7.9</td>
<td>36</td>
<td>4.6</td>
<td>48,400</td>
<td>6,100</td>
</tr>
<tr>
<td>Road right-of-way</td>
<td>5.0</td>
<td>1.5</td>
<td>71</td>
<td>47.3</td>
<td>98,200</td>
<td>65,470</td>
</tr>
<tr>
<td>Stable zone (77.4 km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>85.9</td>
<td>28.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Clear-cut</td>
<td>12.3</td>
<td>4.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Road right-of-way</td>
<td>1.8</td>
<td>0.6</td>
<td>2</td>
<td>3.3</td>
<td>420</td>
<td>700</td>
</tr>
</tbody>
</table>

considered at comparable levels of development.

We can correct for this difference in road and cutting development by assessing slide erosion on a hypothetical square kilometre of the unstable zone. The data in Table 1 may be used in making this assessment if we assume that the hypothetical area has been entirely clear-cut logged and roaded progressively over the past 25 yr. Assuming that 8 percent of the area was in road right-of-way, there would have been 5,240 m³ of erosion by road-related slides (8 percent of 65,470 m³/km², from Table 1). The 92 percent area that was clear-cut logged would have undergone 5,640 m³ of erosion by slide activity in the clear-cut area (92 percent of 6,130 m³/km²). By these calculations the clear-cut areas would have contributed slightly more than roads to the total erosion by slide activity from the managed site.

The sum of erosion from roads and clear-cuts totals 10,880 m³ over the hypothetical square kilometre of the unstable zone. Assuming that the slide erosion in forested areas (2,180 m³/km², from Table 1) represents the natural background level of slide erosion, management activities result in an increase by 5 times in slide erosion. However, as pointed out in the discussion below, there are several reasons why this assessment cannot be reliably projected to estimate impact of future management activities.

DISCUSSION

Analysis of data collected on the forest reveals an apparent increase in erosion by slides as a result of both logging and road construction. Deforestation of hillslopes results in a number of changes that may increase the probability of shallow failures of the soil mantle (see general reviews by Gray, 1970, and Swanston, 1970): (1) rooting strength is decreased, lowering the "apparent cohesion" of the soil (Swanston, 1970) and possibly releasing creep-generated stresses in the soil-root complex; (2) transpiration is decreased (Bethlahmy, 1962); and (3) snowmelt runoff may be increased (see, for example, Anderson, 1969; Rothacher and Glacebrook, 1968). These factors have been cited as contributing to a period of increased slide frequency after deforestation, especially between the time of decomposition of root systems of killed trees and establishment of stabilizing roots by incoming vegetation (Bishop and Stevens, 1964; Swanston, 1970; Nakano, 1971, and others). This temporal relationship between deforestation and slide activity has also been observed in the Andrews forest, where most hillside failures in clear-cut areas occurred in the first 12 yr after cutting.

Since logging began in the unstable zone, the net result of deforestation has been an increase in slide erosion by a factor of 2.8. During the same period, no slides occurred in clear-cut areas in the stable zone. This indicates that on marginally stable sites, the stabilizing effect of vegetation is an important check on erosion but is of little consequence in more stable areas.

Many authors have observed that road construction is a more important factor than deforestation in accelerating erosion (Dyrenness, 1967; Fredriksen, 1970; O'Loughlin, 1972, and others). Roads increase potential slope instability through all of the factors imposed by deforestation. However, they also create several additional critical problems: (1) interruption of surface drainage associated with road surfaces, ditches, and culverts (described by Dyrenness, 1967); (2) alteration of subsurface water movement due to redistribution of soil and rock material, especially where road cuts intersect a water table (Parizek, 1971; Megahan, 1972); and (3) change in distribution of mass on a slope surface by cut-and-fill construction. As in the case of deforestation, maximum impact of roads probably occurs during the first few severe storms after disturbance. By 15 to 20 yr after construction, most unstable areas have undoubtedly failed. However, the 25-yr period of observation in this study is too short to reveal a clear attenuation of the impact of roads. In several cases in the forest, reconstruction of roads in problem areas appears to have contributed to failure during subsequent storms due to insufficient control of reconstruction work or inadequate correction of the original cause of failure.

Since road cutting began in 1950, the volume of slide material moved from road right-of-way in the unstable zone has been 65,470 m³/km², which is 30 times the rate of slide activity in undisturbed forested areas and about 10 times that in clear-cut areas. The fact that only two small, road-related slides occurred in the stable zone underscores the contrasting effects of roads in the two terranes.

When road impact is assessed at a level of development comparable to timber cutting, roads contribute about half of the total management impact. The combined impact of roads and clear-cut logging has constituted a fivefold increase in landslide erosion relative to undisturbed forested areas.
Figure 1. Relation of slide erosion ("slide erosion factor") to time since clear-cutting and road construction, based on the assumption that harvested forest land is 5 percent right-of-way and 92 percent clear-cut. Slide erosion factor is a measure based on a unit that equals erosion by slide activity in cubic meters per square kilometre observed in forested areas of the unstable zone.

Therefore, the curve for the stable zone shown in Figure 1 simply denotes a small but finite possibility of soil-mantle failure. To evaluate how man's activities are modifying long-term erosion rates, it is necessary to take a temporal perspective even broader than the 50-yr time scale shown in Figure 1. Because erosion rates fluctuate in response to any severe disturbance of the vegetation, it is important to be able to compare the frequency and erosion impacts of disturbances under both management and premanagement conditions. However, there is not yet sufficient information to reliably contrast erosion rates under premanagement conditions of severe wildfire every several centuries with the projected erosional history of the same site over several timber management rotations.

There are two additional reasons why data in Table 1 do not completely reflect management impact on erosion rates. First, not all slide material directly reached stream channels; however, 85 percent of the slides, including all of the larger ones, transported most of the slide debris into or adjacent to streams. The second consideration is that many interrelated erosional processes are operating on the landscape. In the H. J. Andrews Experimental Forest, removal of dissolved solids, surface erosion, creep, and slow, deep-seated earthflow take place in conjunction with slides to transport soil material from hillslopes into stream channels and eventually out of the forest ecosystem. All of these processes are being monitored as part of several studies now underway in the forest. The ultimate objective of this research is to develop estimates of rates of erosion by each process and to determine how the rates are influenced by management activities.

REFERENCES CITED

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