Oregon Department of Forestry
Storm Impacts and Landslides of 1996: Final Report

June 1999

Executive Summary

The Storms of 1996

During the months of February and November 1996, two very large storms affected most of Western Oregon and parts of Northeast Oregon. The February storm was a high intensity, long duration rainfall event that affected the northern portion of the state. The November storm was a shorter duration and higher intensity rainfall event than the February storm, and affected an area south of the February storm. Both the storms resulted in large numbers of landslides, debris torrents, and altered stream channels.

Study Design

With oversight from a team of experts in the landslide and natural resource field, the Oregon Department of Forestry implemented a 3-year monitoring project to evaluate the effects of these storms. This project was primarily a ground-based study. However, remote sensing techniques (aerial photographs in particular) have commonly been used both to predict where landslides will occur and to inventory where landslides and channel impacts have occurred. Therefore one goal of the project was to determine the accuracy and precision of remote sensing data in identifying landslides, channel impacts, and landslide-prone areas. A second goal of the project was to determine landslide frequency and channel impacts, particularly as they relate to forest practices. Specific forest practices that were considered include harvest practices that may have caused ground disturbance (i.e. yarding, site preparation), treatment of slash, road construction, and road drainage. Past research and monitoring has related landslide frequency to stand structure (particularly dominant tree species and age). Therefore a related goal of this project was to examine relationships between storm impacts and forest stand structure adjacent to landslide initiation points and along stream channels.

Eight study areas were monitored over a two-year period. Six areas were within the February storm boundaries and two areas were in the November storm boundaries. This ground-based study was designed to: find and measure every landslide that delivered sediment to the stream channel; document and measure the associated debris flows and channel impacts; and gather site information regarding forest practices that may have contributed to the impacts. The most unique aspect of this ground-based survey was comprehensively locating all landslides that delivered sediment to the stream channel. Field data were combined with information gathered in the office or from aerial photographs for analyses.

Five of the study areas were intentionally located in areas estimated to have the highest disturbance in terms of channel impacts, landslides, debris flows, and debris torrents (referred to as red zones). This study focused on areas representing the most severe impacts from the 1996 storms. Therefore, results from red zones do not represent the average forestland responses to these 1996 storms. In addition, by only measuring landslides that resulted from the February and November storms, the study focuses on individual storm events and results can not be extrapolated to predict long-term conditions. Finally this study focused on landslides that delivered sediment to stream channels because these are considered to have the greatest potential to impact public safety and natural resources.

Landslide Detection Using Aerial Photographs

Most landslide inventories rely either in part or completely on air photos for determining the occurrence, location, and characteristics of landslides. Prior to this study, relatively little was known about potential biases in aerial photo inventory methodologies. Although aerial photographs have utility for many purposes, their use for identification of shallow-rapid landslides results in biased and incomplete landslide inventories. This bias significantly underestimates the landslide frequency and erosion volume across all forest stand age classes.

Seventy-two percent of all landslides identified from the ground-based survey were not detected using 1:6000 aerial photographs. The majority (72 to 98 percent) of shallow-rapid landslides were not visible on aerial photographs of any scale. In terms of erosion volume, the landslides that were not identified from aerial photographs (1:6000 scale) accounted for 53 percent and 41 percent of the total landslide related sediment volume delivered to stream channels in two study areas. Landslide identification is most problematic in areas with mature or semi-mature timber. For instance, roughly 50 percent of the landslides were detected in recently harvested areas (0-9 years old) but less than 5 percent of the landslides were detected in mature stands (older than 100 years). Aerial photo analysis will significantly magnify landslide density and erosion volume per unit area for recently harvested areas relative to older forested areas.

Slope and Landform Characteristics Using Digital Elevation Models

Topographic maps, and digital elevation models (DEMs) based on topographic maps are commonly used to identify landslide prone locations. Maps and DEMs can be used in the office, and enable rapid assessments over large areas. DEMs are also used to run landslide hazard models that enable assessment across landscapes.

Digital elevation models (DEMs) at various resolutions were evaluated for their usefulness in identifying areas and sites susceptible to landslides. Slope data collected at the site of each landslide were compared with those derived from a commonly available 30 meter DEM, and also with less commonly available 6 and 1-meter DEMs. On a site-specific basis, slope measurements from 30-meter DEMs were poorly correlated to site-specific slopes at landslide locations measured in the field. DEMs with a higher resolution might better correlate to site-specific slopes, but even their effectiveness in providing accurate values

could not be confirmed in this analysis. On an area basis, the 30-meter DEM under-represents the steepness of very steep slopes (over 70%), and over represents moderate slopes (under 50%) over broad areas (hundreds of acres) as compared to the 6 and 1-meter DEMs.

Landslide Occurrence in the Study Areas

There were 506 landslides which entered stream channels in the "core areas" of the eight study areas. "Core areas" are lands where all channels were surveyed for landslides. The total "core area" surveyed was 45.8 square miles. Landslide density is summarized as the number of landslides entering stream channels per each square mile of study area. Landslide density varied from 0.4 to 24.4 landslides per square mile.

The average non-road associated landslide (the initial failure only, and not including the subsequent debris flow) was 24 feet wide, 43 feet long, and 2.5 feet deep (with a maximum depth of 4.3 feet). Landslide erosion is the volume of sediment (soil and rock) that entered stream channels. Total landslide erosion (initial landslide plus debris flow) was 288,376 cubic yards for the eight study areas. For the 45.8 square mile study area, this is an average storm erosion of 6,290 cubic yards of sediment per square mile, or 9.9 cubic yards per acre.

Landslides were common in red zones. The majority of landslides were not associated with roads. There are extreme variations in landslide characteristics between study areas. Caution must be exercised when comparing landslide statistics, especially landslide erosion. Overall, landslide dimensions as identified in this study are similar to those identified in previous studies conducted in the Oregon Coast Range; however, the land area affected by landslides was less than reported in earlier studies.

Landslide Initiation Sites

Landscape differences are very important because geologic factors have a large influence on landslide processes. Stream channels also have major influences on landslides, due both to direct undercutting of slopes by stream erosion and also because of longer-term hillslope processes. The highest hazard for shallow rapid landslides was found on slopes of over 70% or 80% steepness (depending on landform and geology). There was a moderate landslide hazard on slopes of between 50% and 70%.

Landslides that entered stream channels during the storms of 1996 typically occurred in very steep landscapes, or adjacent to stream channels. Even landslides that initiate as relatively small debris slides can mobilize into debris flows that mobilize large volumes of material and move long distances. Landslide characteristics vary greatly according to local landscape and geologic factors. Debris flows that were not initiated by up-slope landslides were uncommon. A debris flow occurs when landslides move downslope, scouring or partially scouring soils from the slope along its path.

Landslides occurred on many different landforms. Concave shaped slopes with larger drainage areas appear to be more susceptible to landslides than other landforms.

However, landslides occurring on concave slopes also tend to be smaller than landslides which occur on other landforms.

At least 78 percent of the up-slope landslides occurred on "high risk sites." As any landslide hazard designation includes slopes of lesser steepness, it will include more of the overall landscape. Determination of appropriate changes to the high risk site designation will require additional landscape level slope steepness information. These results do suggest that a reduction in the slope used to designate concave landforms as "high risk sites" in one geologic unit may be appropriate. Identification of high risk sites outside of areas where landslides are common may be more difficult than in areas with steep slopes.

Landslides and Forest Stand Age

The effects of forest cover on landslide occurrence has been the subject of much study. Previous studies have speculated that the greatest increase in landslide occurrence occurs after roots have decayed and before new roots have completely taken their place, typically from a few years to a few decades after timber harvesting. Although some root strength theories would suggest the highest incidence of landslides 3 to 15 years after timber harvesting, review of data from this study indicated a higher incidence between 0 and 10 years after timber harvest. Therefore, age classes are grouped as 0 to 9 years (recent clearcut to very young forest); 10 to 30 years (young forest); 31 to 100 years (forest) and older than 100 years (mature forest).

Analysis of variance testing was used to test both landslide density and erosion volume differences between the four age classes on the four multi-age red zone study areas. Partly because of the small number of study areas, there is no significant difference for the four study areas between the four age classes. Nevertheless, in three out of four study areas in very steep terrain both landslides density and erosion volumes were greater in stands which were clearcut in the previous nine years. On the other hand, stands between 10 and 100 years in age typically had lower landslide densities and erosion volumes as compared to forest stands older than 100 years. Landslides in clearcuts are not different in size than landslides in older forests. Because of the increased number of landslides, erosion volume in the 0 to 9-year age class was also increased in three out of four study areas.

There is no observable difference in landslide depth by age class. Therefore, if basal root reinforcement had an influence on slope stability, this influence was not large enough to be observed. This could indicate that other factors associated with removal of vegetation are more important than root reinforcement, that root reinforcement was similar across all age classes, or that root reinforcement is not dependent on soil depth.

There were great differences in landslide characteristics between the study areas. Some of the greatest differences were observed between two study areas that are in the same geologic unit, experienced the same storm event, and are only separated by a distance of 10 to 15 miles. These two sites also had the most contrasting differences in the effects of stand age on landslide occurrence. These differences in landslide characteristics between

and within study areas do not appear to help explain the differences in landslide occurrence by stand age.

Compliance with the Forest Practices Requirements for Timber Harvesting on High Risk Sites

Current forest practice rules are designed to limit ground disturbances on high risk sites. These rules are intended to prevent local oversteepening and slope gouging by cable yarding. Rules also require operators to minimize slash accumulations on these sites, and especially in steep channels below high risk sites. The construction of skid trails on high risk sites is prohibited.

Observable physical ground disturbance was not correlated with initiation of the non-road associated landslides. Operators complied with the forest practice rules for timber harvesting on high risk sites in the locations adjacent to the landslides identified in this study. Any effects from forest management should therefore be related to removal of the vegetation. Slash loading at the landslide initiation site was not a factor in debris flow movement. This does not rule out the possibility that wood lower in the debris flow or torrent path might be a factor in travel distance or severity of impacts.

Road Associated Landslides

Past studies have shown that most landslide related impacts on forestlands were related to roads. For this reason, roads are the current focus of the forest practice rules for landslide prevention. The road associated landslides found in this study were typically about four times larger in volume than non road associated landslides. However, these road-associated landslides were smaller than landslides associated with roads as found in prior studies. Landslides associated with old roads (sometimes called abandoned or legacy roads) were typically smaller than the landslides associated with actively used roads. Landslides that were associated with forest roads made up a smaller percentage of the total number of landslides in this study than the road-associated landslides did in most previous studies. However, these road-associated landslides were still several times larger on average than landslides not associated with roads.

Roads on steep slopes have the majority of the landslides. Because landslides were not found on steep slopes where drainage waters were not directed to those slopes, keeping fill off steep slopes appears to reduce landslide hazard. However, at sites where there was drainage water, either intentionally discharged by a culvert or other relief structure, or through drainage system blockage, landslides occurred regardless of fill depth.

Extent of Stream Channel Impacts Due to Landsliding

The type of impacts that occurred during the 1996 storms were delineated. A highly impacted channel was characterized by massive scour and/or fill and overturn of sediments along with considerable damage to the vegetation along the edge of the channel. In order to have this level of impact, a debris flow, debris torrent, or debris flood would have to occur. Overall, 32% of the total of the 145 stream miles surveyed had high impacts due to landslide

related effects. For the deliberately chosen high impact "red zone" study areas, this percentage increased to 37%. For the three stratified random areas the percentage was 10%.

Road associated landslides were wholly or partially associated with a large percentage of the highly impacted stream channels at three study areas. The extent of landslide related channel impacts was extremely variable between sites. The percentage of channel length surveyed with highly impacted stream channels was greater than found in past studies.

Differences Between High and Low Impact Storm Reaches

Impact width refers to the width that high water or debris impacted the channel and banks. As would be expected, impact widths were consistently greater for streams impacted by debris torrents as compared to non-impacted stream channels across all stream orders. Stream channels influenced by landslide related impacts were on average more open with less shade and occurred on streams with steeper slopes. However, for several stream size classes the average active channel width was similar for debris torrent impacted reaches as compared to those that had no recent debris torrent impacts.

Slash Loading and Timber Harvesting

The level of slash (i.e., small and large woody debris consisting of generally limbs and branches as well as unmerchantable logs) is believed to affect both travel distances of debris torrents and the amount of damage that they incur. Stream channels in which adjacent stands were recently clearcut harvested had greater slash accumulations as compared to older forests. However, these surveys were in streams un-impacted by debris torrent activity from the 1996 storms and done only in two study areas.

Debris Torrent Travel Distance

Debris torrents are debris flows enter the stream channel and usually contain much large wood. Since they were the cause of a great deal of the stream impacts observed, better understanding of their behavior is critical. Information on the physical characteristics of streams where debris torrents stopped (usually depositing a large "debris jam") were carefully collected.

An existing model correctly predicted debris torrent travel distances for 258 out of 361, or 71 percent, of the debris torrents identified in this study. Debris torrent travel distance is most dependent on channel junction angles and channel gradient. Factors such as initial landslide size or condition of the riparian stand along the channels were found to be of secondary significance.

Key Conclusions

- Landslide inventories using only aerial photographs without significant on-the-ground surveying do not identify the majority of shallow-rapid type landslides.
- Coarse-scale digital elevation models underestimate slope steepness, especially in areas with irregular, steep slopes.
- Ground-based investigation provides the most reliable information on landslide occurrence and their characteristics in the forests of western Oregon.
- Timber harvesting can affect landslide occurrence on the steepest slopes. In three out of four study areas, higher densities and erosion volumes were found in stands that had been harvested in the previous nine years, as compared to forests that were older than one hundred years.
- Forested areas between the ages of 10 and 100-years typically had lower landslide densities and erosion than found in the mature forest stands.
- Landslides from recently harvested and older forests had similar dimensions, including depth, initial volume and debris flow volume.
- In the locations adjacent to landslides, landowners and loggers complied with the forest practice harvesting rules (as changed in 1983) to minimize ground disturbance and slash accumulations on landslide prone sites.
- Based on the low numbers of road-associated landslides surveyed in this study and on the smaller sizes of these landslides (as compared with previous studies), current road management practices are reducing the size of road associated landslides, as well as the number of landslides.
- Stream channel impacts varied greatly by study area. Impacts were not directly related to the number of landslides. Large, up-slope landslides that enter stream tributaries with small stream junction angles and steep channel gradient slopes resulted in the greatest stream channel impacts.
- When evaluating debris flow or torrent risks to resources based on potential run-out, one should consider the potential for large initiating landslides as well as channel junction angles, stream channel gradients, and the riparian condition along the debris flow/torrent path.