Forest Practices Technical Note Number 6

Version 1.0

Determination of Rapidly Moving Landslide Impact Rating

September 1, 2003

Purpose

This technical note is intended to help a geotechnical specialist determine the rapidly moving landslide impact rating(s) for a proposed forest operation. The impact rating categorizes the potential for serious bodily injury or death due to shallow, rapidly moving landslide impact to structures or vehicles. The geotechnical specialist should note that the focus of the impact rating determination is on the geomorphic characteristics of the hillslope or channel that influence debris flow transport and deposition.

Regulatory Framework

Policy and authority for protection of the public from landslide hazards is found in 1999 Senate Bill 12. The Shallow, Rapidly Moving Landslide and Public Safety Rules, OAR 629-623-0000 through 0800, became effective January 1, 2003. Forest Practices Technical Note 2, version 2.0, provides a summary of administration and application of the Landslides and Public Safety Rules and outlines how operations can be screened for high landslide hazard locations and exposed structures and roads. Proposed forest operations identified with a potential to affect the risk to public safety from rapidly moving landslides must be evaluated. Determination of the public safety risk level and the corresponding rules that apply to a forest operation requires a number of steps. This document provides technical guidance specifically for completing one of those steps, determining the rapidly moving landslide impact rating (OAR 629-623-0250). This determination should be based on site specific field observations, measurements, and professional judgement.

When combined with exposure categories, impact ratings are intended to prevent forest practices that increase public safety risk to levels greater than the substantial risk determined by Board of Forestry. However, in many cases, the natural risk for structures or roads will be well above the substantial risk level. The Shallow, Rapidly Moving Landslides and Public Safety Rules can keep the risk from becoming even greater (at least in the short-term), but cannot reduce the background risk, so people in these locations remain at substantial risk of serious bodily injury or death, regardless of forest practices regulations and the resulting upslope forest practices.

Table 1 is a matrix that shows how the *Exposure Category* (OAR 629-623-0200) and the *Rapidly Moving Landslide Impact Rating* (OAR 629-623-0250) are used to determine the *Public Safety Risk Level* (OAR 629-623-300). Most forest operations are prohibited if the downslope public safety risk is substantial. There are significant restrictions on operations if the downslope public safety risk is intermediate.

Table 1. Public Safety Risk Levels

Exposure Category	Rapidly Moving Landslide Impact Rating			
	EXTREME	***SERIOUS***	***MODERATE***	***UNLIKELY***
A	Substantial	Substantial	Intermediate	Low
B	Substantial*	Intermediate	Low	Low
C	Intermediate*	Low	Low	Low

*** if site specific conditions warrant as determined by the State Forester**

Terminology

A ***debris fan*** is a deposit formed as a debris flow comes to rest. Debris fans are typically located at the mouth of a canyon or anywhere else a channel loses confinement. They can also be located at the base of a steep slope. Debris fans typically consist of an unsorted deposit of fines, sand, and gravel, as well as boulders and wood debris.

A ***debris flow*** is a rapidly moving slurry of rock, soil, wood and water that can travel hundreds to thousands of feet on steep slopes or in steep channels. There are two types of debris flows, open-slope debris flows and debris torrents.

> An ***open-slope debris flow*** is a debris flow that never enters a confined channel. They travel tens to hundreds of feet from the initiating high landslide hazard location and typically deposit on gentler lower slopes or at the base of consistently steep slopes.
>
> Once a debris flow enters a confined channel, it is considered a ***debris torrent,*** or a channelized debris flow. ***Debris torrents*** often entrain channel materials along channel reaches with steep gradients, leaving in place rock exposed in channel beds and along channel banks. Debris torrents can increase in size by several orders of magnitude and travel hundreds or thousands of feet beyond the site of initial failure. Wood material and water can affect how far they travel on relatively low channel gradients. Terminal deposition is often related to geomorphic factors like channel confinement, channel gradient, and channel junctions.

Exposure categories [OAR 629-600-0100 (21)] are used to designate the likelihood of persons being present in structures or on public roads during periods when shallow, rapidly moving landslides may occur.

Headwalls are concave slopes (as seen in plan view) that can concentrate water to increase landslide susceptibility. Headwalls are typically located at the heads of channels or swales. Landslides occurring in these locations are more likely to move as debris flows than landslides that initiate in other areas of the slope.

A ***high landslide hazard location*** [OAR 629-600-0100 (31)] is a specific site that is subject to initiation of a shallow, rapidly moving landslide. Specific criteria for identification of high landslide hazard locations are described later in this note.

A ***shallow, rapidly moving landslide*** [629-600-0100 (61)] is any detached mass of soil, rock, or debris that begins as a relatively small landslide on steep slopes and grows to a sufficient size to cause damage as it moves down a slope or stream channel at a velocity difficult for people to outrun or escape. Shallow, rapidly moving landslides are the most common type of landslide associated with forest practices. Robison et al. (1999) found that the typical initiating landslide that occurs on high landslide hazard locations is 40 feet long, 30 feet wide, 3 feet deep and has a planar failure surface.

The ***Tyee Core Area*** [629-600-0100 (74)] is a location with geologic conditions including thick sandstone beds with few fractures. These sandstones weather rapidly and concentrate water in shallow soils creating a higher shallow, rapidly moving landslide hazard. The Tyee Core Area is located within coastal watersheds from the Siuslaw watershed south to and including the Coquille watershed, and that portion of the Umpqua watershed north of Highway 42 and west of Interstate 5. Within these boundaries, locations where the bedrock is highly fractured or not of sedimentary origin, as determined in the field by a geotechnical specialist, are not subject to the Tyee Core area slope steepness thresholds.

Determination of Substantial Risk

The risk of rapidly moving landslide-related fatalities in Oregon was assessed (Mills and Hinkle, 2001). According to historical records, there have been at least 25 fatalities attributed to rapidly moving landslides in Oregon since 1890. Since 1950, the rapidly moving landslide related fatality rate has averaged about one fatality every five years for the entire population of Oregon. The risk of being killed by a rapidly moving landslide in Oregon for the average citizen is relatively low, about 0.02 fatalities per 100,000 people per year. However, the risk can be several orders of magnitude greater, up to 70 fatalities per 100,000 people per year, for small segments of the population known to be living, working, or traveling through locations with the greatest shallow, rapidly moving landslide hazard. The risk to any individual depends in part on the exposure, determined by how much time they spend in these locations. Note that of the 25 known fatalities, 15 occurred within the Tyee Core Area.

The Oregon Board of Forestry defined “substantial risk” as one death per 100,000 people per year from rapidly moving landslides for the populace most at risk. If the background risk is greater than one death per 100,000 people at risk per year, the risk is considered to be substantial. If it is close to one death per 100,000 people per year, it is considered to be intermediate.

Impact Ratings

The impact rating identifies the relative risk of serious bodily injury or death due to rapidly moving landslide impact to structures or roads. Property damage alone is not considered in determination of impact rating, unless such damage is of such severity where serious injury or death to those inside the structure or vehicle can reasonably be expected. The impact rating reflects both the suspected frequency and expected severity of impact.

Rapidly moving landslide impact potential is rated as **unlikely, moderate, serious** and, in limited cases**, extreme,** as described below**.**

- **"Unlikely"** impact rating indicates that any shallow, rapidly moving landslide initiating within the operation area is unlikely to directly impact a structure or road.
- **"Moderate"** impact rating indicates that it is uncertain whether any shallow, rapidly moving landslide initiating within the operation area is likely or unlikely to directly impact a structure or road.
- **"Serious"** impact rating indicates that any shallow, rapidly moving landslide initiating within the operation area is likely to directly impact a structure or road.
- **"Extreme"** indicates that any shallow, rapidly moving landslide initiating within the operation area is likely to directly impact a structure or road. In addition, there are unusual conditions that make dangerous impacts almost certain, such as a structure or road located in the transport zone of a potential debris torrent.

DETERMINATION OF IMPACT RATING

Documentation of the geotechnical determination of impact rating(s) [OAR 629-623-0250(3)] should include data and observations supporting that impact rating. Individual sites within an operation may have different impact ratings. Behavior of shallow**,** rapidly moving landslides is complex, depending on the interaction of many factors. **Geomorphic characteristics which may influence initiation, transport and deposition of shallow, rapidly moving landslides are discussed below; the geotechnical specialist may determine there are additional or other factors controlling the impact rating which are not presented below.** After the geotechnical specialist has submitted information and their impact rating determination, the State Forester will review the impact rating and make the final determination (OAR 629-623-0250(5)).

Shallow, rapidly moving landslides

The path of a shallow, rapidly moving landslide can be broken into three main phases (Figure 1):

I. Initiation (high landslide hazard location);

II. Transport (ability of a slope or channel to transport a rapidly moving landslide); and

III. Deposition (terminal deposition of a rapidly moving landslide).

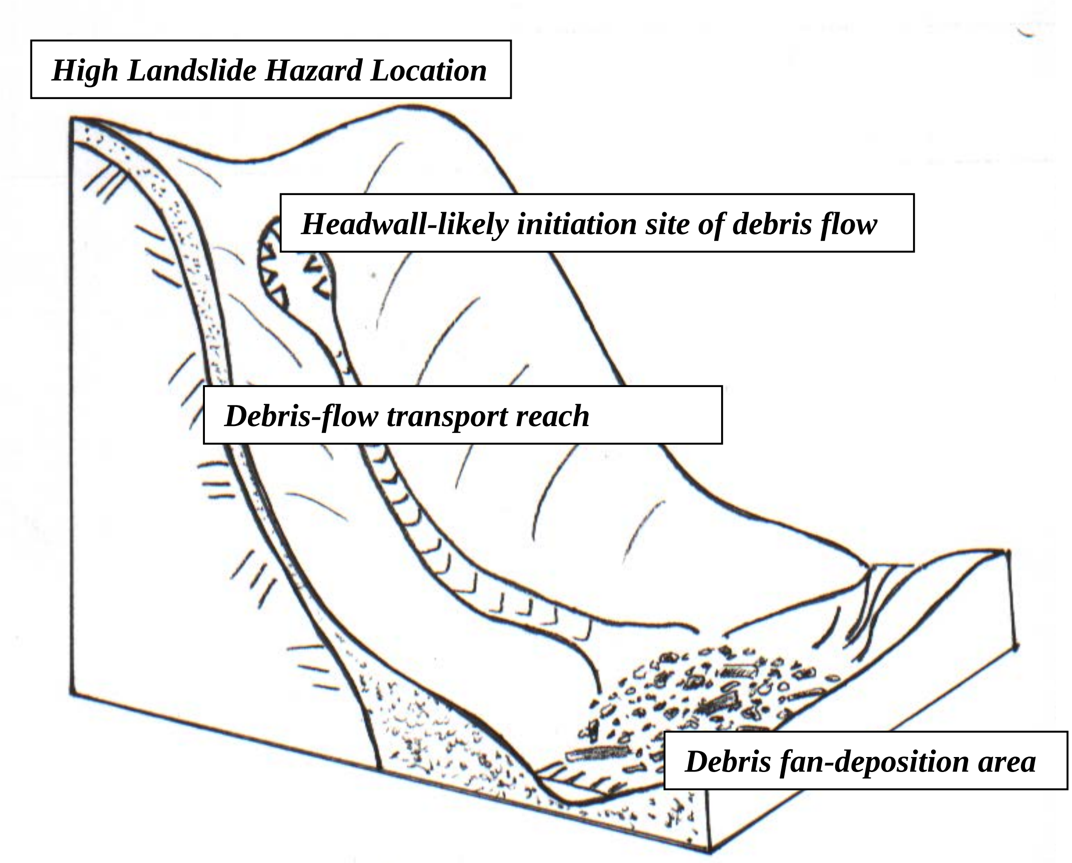

Figure 1. Debris flow initiation, transport, and depositi

I. INITIATION - HIGH LANDSLIDE HAZARD LOCATIONS

Specific criteria for determination of high landslide hazard locations are described in OAR 629-623-0100(3) and are further described in Forest Practices Technical Note 2, version 2.0. The criteria are:

(a) The presence, as measured on site, of any slope in western Oregon (excluding competent rock outcrops) steeper than 80 percent, except in the Tyee Core Area, where it is any slope steeper than 75 percent; or

(b) The presence, as measured on site, of headwalls or draws in western Oregon steeper than 70 percent, except in the Tyee Core Area, where the headwall or draw slope is steeper than 65 percent.

(c) Notwithstanding the slopes specified in (a) or (b) above, field identification of atypical conditions by a geotechnical specialist may be used to develop site specific slope steepness thresholds for any part of the state so that the hazard is equivalent to (a) or (b) above. The State Forester shall make the final determination of equivalent hazard.

Atypical Conditions: The definition of high landslide hazard locations assumes homogenous geologic and subsurface conditions. Section (c) recognizes that there are site-specific characteristics, which may give the geotechnical specialist reason to modify the slope thresholds in Sections (a) or (b***)***. For example, slope thresholds might be adjusted to be steeper on a site in the Cascade Range with a well-drained talus slope. Conversely, evidence of slope instability, such as actively failing slopes, may justify the decision to lower the slope thresholds. There are several factors which may influence initiation hazard such as soil depth, soil material properties, slope-shape, vegetative characteristics, bedrock characteristics, subsurface water flow, and others. The geotechnical specialist will have to present supporting evidence to demonstrate that modification of the standard slope thresholds is appropriate for the specific site.

Standard measurements and observations: Slope steepness of the high landslide hazard location should be measured on-site. Short pitches of steep slopes that are generally less than 30 feet slope length in otherwise relatively gentle terrain are not considered high landslide hazard locations. Constructed cut slopes are not considered high landslide hazard locations. Sidecast and fill slopes are considered high landslide hazard locations only if they meet both the slope steepness and slope length criteria. Slope measurements up and down the slope should be averaged to determine actual slope steepness if slopes are very close to high landslide hazard location thresholds. Slopes that appear planar or convex in plan view should be considered uniform. Slopes that appear concave in plan view should be considered a headwall or draw.

II. TRANSPORT

The characteristics of transport and deposition are different for the two types of shallow, rapidly moving landslides. Structures and paved roads located very near the base of a steep slope with high landslide hazard locations are most at risk for open-slope debris flows. Structures and roads located within or near confined channels or canyons are most at risk from debris torrents. The following characteristics are known or thought to influence transport and deposition of open-slope debris flows and debris torrents. The geotechnical specialist should investigate these factors, where applicable, and use them to determine the rapidly moving landslide impact rating(s) for the proposed forest operation.

Open-Slope Debris Flows: Open-slope debris flows are controlled primarily by slope steepness. Open-slope debris flows can travel tens to hundreds of feet on steep slopes, but deposition is expected to begin on slopes of 40% or less. Open-slope debris flows commonly deposit at the base of steep slopes, but may also deposit on mid-slope benches, usually of 50-foot slope distance or more. Benda (1999) has developed a combined theoretical-empirical model for predicting landslide runout on open-slopes.

Hillslope steepness and the presence and width of mid-slope benches between the high landslide hazard location(s) and the structure or road should be measured on site and included in the geotechnical report.

Debris torrents: Channel confinement, gradient, and junction angles exhibit the most control over debris torrent transport and deposition. However, other factors such as the amount and type of material available to be entrained, the potential energy available, and obstructions or barriers can affect debris torrent transport and deposition.

Channel junction angles: Benda and Cundy (1990) developed a simple empirical model for predicting debris torrent deposition based on channel junction angles and channel gradient. Channel junction angles of 70 degrees or greater were found to predict deposition of most debris torrents, as long as the channel gradient of the receiving channel has a gradient of 36 percent or less. Robison et al. (1999) validated the Benda-Cundy model with their study of 361 debris torrents. Methods for determining a junction angle can be found in Benda and Cundy (1990).

Angle of debris flow entry to channel: Open-slope debris flows entering channels from steep side-slopes can be expected to deposit and not continue on as debris torrents where the receiving channel has a relatively gentle gradient.

Table 2. Typical impact parameters for debris torrents, from (Robison and others, 1999).

Channel Impact Type		Impact Width (feet)	Impact Height (feet)	Channel Gradient (%)
	average	20	6	38
	minimum	0	0	0
Scour	5th percentile	6	0.5	9
n = 483	20th percentile	11	2	21
	80th percentile	26	10	55
	95th percentile	45	18	80
	maximum	110	40	110
	average	37	9	23
	minimum	3	0.2	0
Transport	5th percentile	7	1.5	3
n = 583	20th percentile	13	4	8
	80th percentile	50	13	35
	95th percentile	90	20	53
	maximum	300	62	110
	average	62	6	14
	minimum	0	0	0
Deposition	5th percentile	10	1	2
n = 718	20th percentile	22	2.5	3
	80th percentile	90	9	21
	95th percentile	170	16	42
	maximum	350	30	100

Channel gradient: Benda and Cundy (1990) and Robison and others (1999) both found that, in the absence of a sharp channel junction angle, debris torrents typically deposit along channel gradients less than 6 percent. The British Columbia Ministry of Forests (1994) found "Major velocity reductions and significant deposition of materials occur when channel gradients drop below 7 or 8 degrees (12 to 16 percent)", although this range may not be appropriate for debris torrents in Oregon. Channel gradients of less than 6 percent for 300 feet should result in deposition of most debris torrents. There are rare instances where serious impacts may extend more than 300 feet along a channel gradient of less than 6 percent. This might be indicated by debris flow deposits further downstream than would normally be expected. Typically, the channel gradient of the gentlest section of channel is averaged over a distance of 300 feet, and reported in percent. Minimum gradients for channels with direct debris flow impacts from Robison et al. (1999) are shown in Table 2.

Channel confinement: Channel confinement has a significant effect on the transport and deposition of a debris torrent (VanDine, 1985). Confinement is the horizontal distance between valley or canyon walls. Channels flowing within relatively wide canyons are unlikely to carry a debris torrent. Very narrow, low gradient canyons may also stop debris torrents if the material is "wedged" between the canyon walls. Table 2 summarizes debris torrent impact height and widths presented by Robison et al. (1999).

Determination of confinement can be problematic, since it is dependent in part on the volume of the debris torrent. The authors of this technical note are unaware of any published data regarding numeric values for canyon or channel confinement and debris torrent transport and deposition. A rule of thumb for the "typical" Coast Range stream is to measure the width of the confining valley walls at a height of 10 feet above the channel bed (Figure 2). If the horizontal distance as measured from a point approximately 10 feet above the channel bed is greater than 200 feet, the channel is considered to be unconfined. The 200-foot criterion is likely conservative. Note that streams that are narrowly incised in an otherwise broad valley are unlikely to carry a significant volume of material, the 10-foot measurement rule-of-thumb would likely be very conservative in this case.

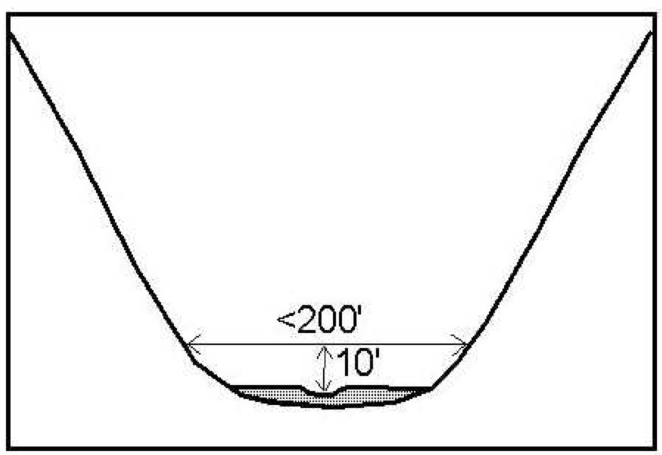

Figure 2. A "marginal" example of a confined channel.

Amount and type of material available to be entrained: There are four types of material typically present in channels that may influence transport and deposition: soil, boulders, down wood, and standing vegetation. Channels which have been recently scoured by a debris torrent or are otherwise lacking in material in the channel or banks will have less material available for debris torrent "bulking" and, therefore, less destructive potential. However, these channels can still transport debris torrents. Debris torrents in channels through deep colluvium may scour an unusually large volume of material.

The role of down wood in debris torrent movement is not clear. One model suggests that debris torrents with higher wood content tend to deposit at steeper gradients than debris torrents with less wood (Lancaster et al. 2000). The role of standing trees in the debris torrent path is also unclear. Data from Robison et al. (1999) suggests that mature riparian vegetation along channels where debris flows are starting to lose momentum may cause debris torrents to terminate sooner than expected.

Potential energy available: The potential energy available for a shallow, rapidly moving landslide may be another important factor for evaluating impact potential. Important measures include the elevation drop from the high landslide hazard location to the structure or road and the angle of reach (Johnson, Swanston and McGee, 2000, Corominas, 1996, Benda and Cundy, 1990). The angle of reach is the average slope angle as measured along the slide path.

Obstructions or barriers: Natural or human-made obstructions may influence transport and deposition. For example, road fills, particularly in the deposition zone, may block transport. However, fills in steep transport reaches may fail, and increase the volume of debris and water comprising the rapidly moving landslide.

III. DEPOSITION

ODF field investigation of 18 debris torrents with varying degrees of impacts to roads and structures identified three factors associated with severe debris torrent impacts. These factors are:

1. A structure location that is within 110 feet of the channel at the loss of confinement and within 12 degrees of the channel alignment;
2. Channel gradients over 9 percent in the last 300 feet of channel above structures or roads; and
3. The initiating landslide is a large road fill failure.

Distance of the structure or paved road from the likely depositional area: Debris torrents tend to deposit most of their load over relatively short distances when the channel or canyon loses confinement. For open-slope failures the depositional distances tend to be even less.

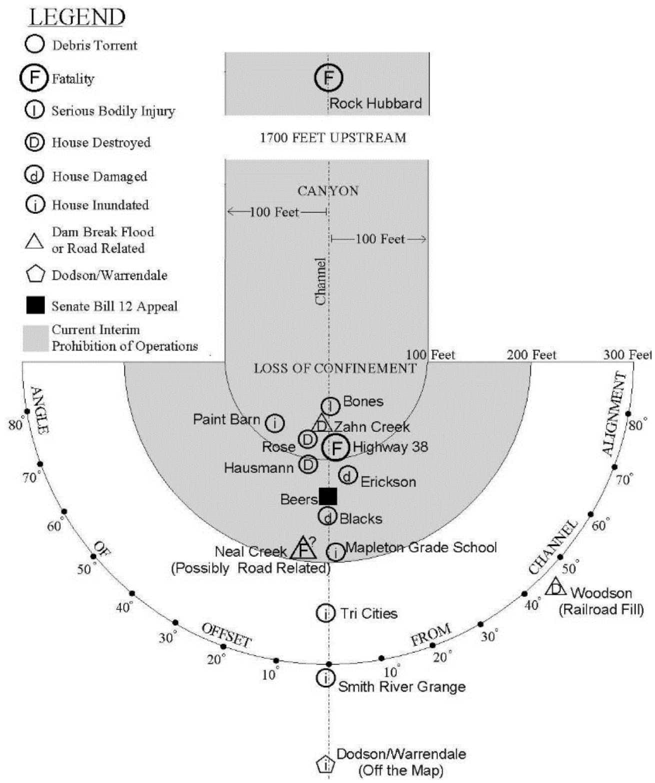

Figure 3. Plot of structures impacted by debris torrents in relation to the point where the delivering channel lost confinement. *Different types of events are represented with different symbols. Letters within those symbols are used to denote the level of impact and the occurrence of fatalities and serious bodily injuries.*

Channel alignment with structure or road: This is measured by the horizontal angle from the mouth of the confined canyon to the structure or road. ODF (2001) found that structures in direct alignment with channels received greater damage from debris torrents (Figure 3). Structures unaligned with channels did not experience significant damage from debris torrents.

Position of the structure or paved road: Structures or paved roads located at an elevation higher than the expected elevation of the debris flow transport/deposition area, or offset from the likely transport/deposition area are likely to be at a lower level of risk.

Evidence of past debris flow or torrent deposition: Evidence of past debris flow or debris torrent deposition may be used to indicate the past depositional history as well as the likelihood of future occurrence. ***Debris fans or deposits*** indicate past debris flow deposition at a site. Debris fans can be differentiated from alluvial fans in several ways. Debris fans are composed of unsorted deposits of coarse materials and fines and often have a noticeable amount of gravels, cobbles, and large boulders. Large wood debris may be present in younger fans. Alluvial fans are composed of sorted deposits of gravel and finer materials. Generally, debris fans have steeper snouts than alluvial fans. Debris flow processes can be thought of as different than alluvial processes in terms of the competence of the flow, i.e. debris flows can transport rock fragments and “debris” of sizes which cannot be transported by normal fluvial processes. In many cases, after significant fluvial re-working of debris flow deposits, material which the stream cannot transport with typical fluvial mechanisms remain as lag deposits. Therefore, the presence of large rock fragments (boulders) may be one of the more reliable indications of previous debris flow deposition when finer material has been eroded away.

Mitigation

Structural mitigation can be used to lower the rapidly moving landslide impact rating, as described in OAR 629-623-0800 (1) and (2). Structural methods that mitigate deposition or impact may be constructed by the landowner under the direction of a geotechnical specialist. Deflection berms or walls, driven piles, structural elevation, and other forms of mitigation can be considered if they reduce the public safety risk. Mitigation must be completed before the start of the forest operation and must be proposed in a written plan submitted by the operator. The geotechnical specialist should inspect the mitigation site after construction to see if mitigation is properly constructed and if unforeseen conditions exist.

Geotechnical Reports

The geotechnical report should include a map of the proposed operation along with a determination of the rapidly moving landslide impact rating with a discussion and documentation of the geomorphic characteristics or other factors which the geotechnical specialist used to reach their conclusion.

References

Benda, L. and T. Cundy. 1990. Predicting deposition of debris flows in mountain channels. Canadian Geotechnical Journal. Volume 27, Number 4. pp 409-417.

Benda, L. 1999. Acme Watershed Analysis 1999, Crown Pacific and Washington Department of Natural Resources, Appendix 1.

Corominas, J. 1996. The angle of reach as a mobility index for small and large landslides. Canadian Geotechnical Journal. Volume 33, pp 260-271.

Johnson, A.C., D.C. Swanston, and K.E. McGee, 2000. Landslide Initiation, Runout, and Deposition Within Clearcuts and Old-Growth Forests of Alaska. American Water Resources Association. Volume 36, No.1, pp 17-30.

Lancaster, S.T., Hayes, S.K. and Grant, G.E., 2000. Modeling sediment and wood storage and dynamics in small mountainous watersheds. In: Geomorphic Processes and Riverine Habitat. F.A. Fitzpatrick (Eds.). American Geophysical Union, Washington, D.C. 4, pp. 85-102.

Millard, T. 1999. Debris-Flow Initiation in Coastal British Columbia Gullies. Forest Research Technical Report TR-002. British Columbia Forest Service.

Mills, K. and J. Hinkle, 2001, "Forestry, Landslides and Public Safety," An Issue Paper prepared for the Oregon Board of Forestry.

Robison, E.G., K. Mills, J.T. Paul, L. Dent, and A. Skaugset. 1999. Oregon Department of Forestry 1996 Storm Impacts Monitoring Project: Final Report. Forest Practices Technical Report # 4. Oregon Department of Forestry, Salem, Oregon. 141 pp.

VanDine, D.F., 1985. Debris Flow And Debris Torrents In The Southern Canadian Cordillera. Canadian Geotechnical Journal. Volume 22, Number 1. pp 44-68

Oregon Department of Forestry Field Offices

For more information about the Oregon Forest Practices Act or the Forest Practice Rules, please contact your local Oregon Department of Forestry office which can be found at http://www.oregon.gov/ODF/Working/Pages/FindAForester.aspx *or the headquarters office at 2600 State Street, Salem, Oregon 97310. 503-945-7200.*