NATURAL RESOURCES

Summary Report: Landslides, State Trust Lands, and the January 2009 Storm in Whatcom County

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Executive Summary

In early January 2009, rain and melting snow from a strong Pacific storm triggered hundreds of landslides in western Washington. A significant number of these landslides occurred in Whatcom County, several dozen of which began on lands managed by the Washington Department of Natural Resources (DNR; hereafter referred to as State Trust Lands). Some of the landslides that originated from State Trust Lands in Whatcom County impacted private properties at the base of Sumas Mountain, Slide Mountain, and Van Zandt Dike. The impacts ranged from minor mud and debris deposition on lawns or pastures to significant structural damage to homes and outbuildings. Soon after the storm, two DNR geologists began investigating 25 of these landslides. The primary objective of the investigations was to determine if, and to what extent, past management activities on State Trust Lands contributed to landslide initiation.

Of the 25 landslides investigated, 20 began in unmanaged areas while the remaining five originated in managed areas. Unmanaged areas include fully intact mature forest and buffers or "leave areas" of mature forest within or along the margins of previously harvested areas. Managed areas include sites where roads or recent timber harvesting are immediately adjacent, or in close proximity, to the landslide initiation point. Of the 20 landslides that began in unmanaged areas, 15 occurred at sites where there was no contribution or influence from forest management activities on State Trust Lands. These landslides initiated in fully intact mature forest stands, some of which were between 100 and 200 years of age. The five remaining "unmanaged area" landslides originated within leave areas of mature forest within or along the margins of two recently harvested DNR timber sales.

Of the five "managed area" landslides, four began at sites that were harvested in the late 1980's or early 1990's. At the time of the harvesting, Washington's Forest Practices Rules did not include specific protections for potentially unstable slopes as they do now. In addition, the parcels were in private ownership when they were harvested and DNR acquired the properties after the logging was completed. The one remaining "managed area" landslide began when an orphaned road grade collapsed and triggered a dam-break flood. Under the State Forest Practices Rules, roads are considered "orphaned" when they haven't been used for forestry activities since 1974.

The 25 landslides investigated affected 42 separate private properties and impacted 23 homes. Of the 23 homes impacted, all are located in areas where landslides have historically deposited. Eighteen (18) of the homes are located on alluvial fans while another is located on a toeslope. The four remaining homes, while affected by the landslides, were not on alluvial fans or toeslopes. According to Whatcom County's Geologically Hazardous Areas mapping, six of the homes are within "alluvial fan hazard areas" while another is immediately below a "landslide hazard area".

Introduction

On January 7th and 8th, 2009 heavy rainfall and melting snow from a strong Pacific storm triggered more than 1400 landslides across western Washington (Figure 1). One of the highest concentrations of landslides was in Whatcom County. Many of these landslides originated in steep forested terrain and traveled hundreds or even thousands of feet before depositing at the base of mountain slopes. Most began on private, State, and Federal forestland including lands managed by the Washington State Department of Natural Resources (DNR; hereafter referred to as State Trust Lands). Several of the landslides that began on State Trust Lands impacted downslope private properties. These landslides deposited mud, boulders, trees and woody debris on many of the properties and in some cases also damaged homes or other structures.

Immediately following the storm, DNR staff began assessing damage from the landslides that originated on State Trust Lands. Management in DNR's Northwest Region requested assistance from the agency's Land Management Division (LMD) in investigating those landslides that impacted private properties. Two LMD geologists began conducting field-based reconnaissance investigations in February and concluded their work in October 2009. The objectives of the investigations were to:

- confirm that the landslide originated on State Trust Lands;
- determine if the landslide initiation points were in areas of past management activity;
- determine if management activities contributed to landslide initiation, and;
- determine the degree to which management activities contributed to landslide initiation.

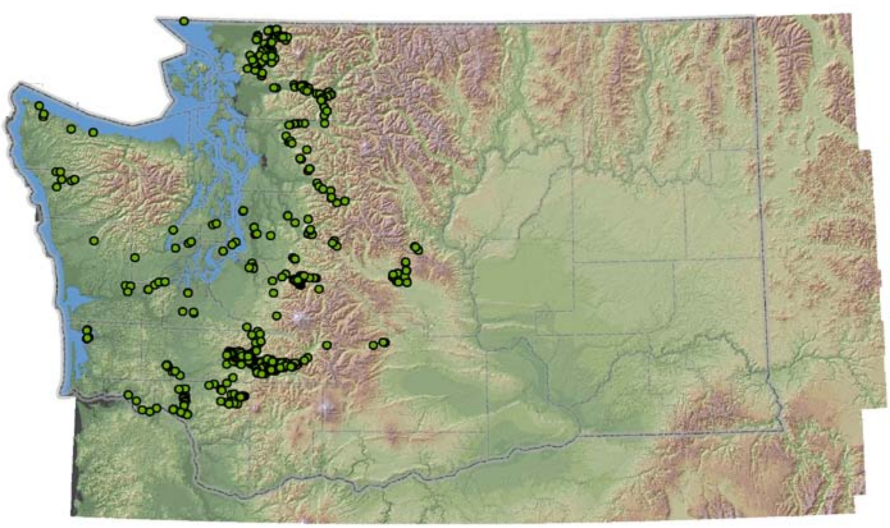

Figure 1. Map of Washington showing the distribution of the more than 1400 landslides that resulted from the January 2009 storm (data courtesy of DNR Division of Geology and Earth Resources).

In total, LMD geologists investigated 25 landslide initiation points that produced debris flows and debris floods that affected 42 private properties. Nine (9) separate engineering geologic field reconnaissance reports were prepared. These reports are included as appendices to this report (Appendices A through I) and a copy of each has been sent to the applicable affected private property owners.

This report summarizes the findings of the nine reconnaissance reports in a single document. The intended audience includes DNR, Whatcom County government, and local communities. In addition to summarizing the reconnaissance reports, we also provide additional analysis of the storm's magnitude based on recently acquired data and discuss the broader policy implications of the storm, the landslides, and the resulting impacts.

The Landslides

The distribution of the landslides investigated is illustrated in Figure 2. The landslides are located along a north-south trending line in western Whatcom County that extends from the southwestern part of Sumas Mountain to the northwestern flank of Van Zandt Dike. The landslides initiated at elevations ranging from 700 to 2100 feet above sea level although most occurred between 1000 and 1500 feet. The affected private properties are located along Goodwin Road, Siper Road, Mount Baker Highway, Marshall Hill Road, North Fork Road, Clipper Road, and Nelson Road.

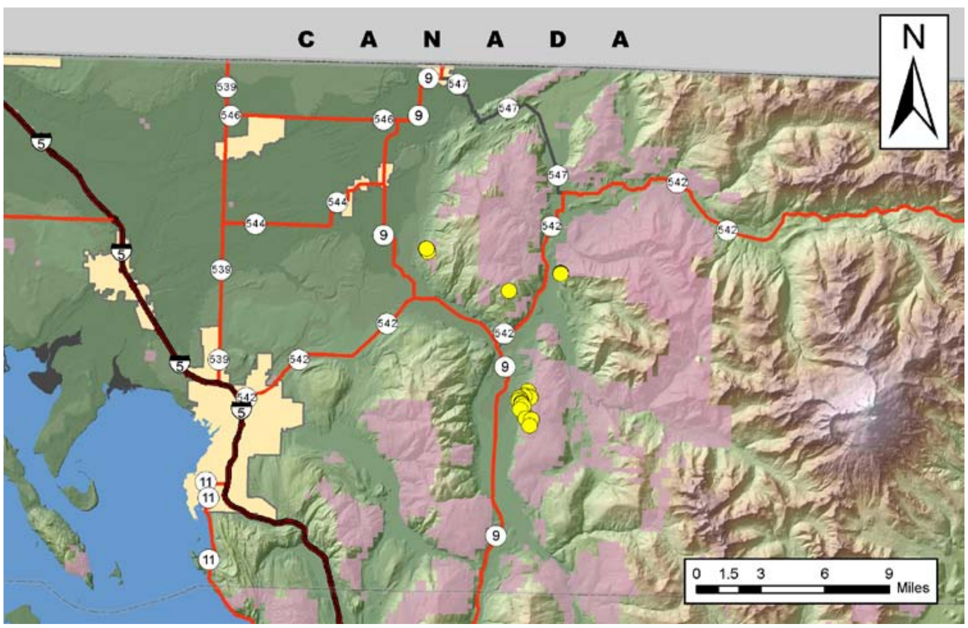

Figure 2. Map of Whatcom County showing the initiation points of landslides (yellow circles) on State Trust Lands that impacted private properties. State Trust Lands are shown in pink.

Geologists often classify landslides according to their physical characteristics and movement mechanics. An overview of landslide classification is useful in helping the reader understand the factors that contributed to landslide occurrence and the resulting impacts. We provide such an overview in the following paragraphs.

One common landslide classification scheme distinguishes landslides according to their depth. **Shallow** landslides are those in which the rupture surface (or bottom of the landslide) is relatively close to the ground surface – typically within about 10 feet. **Deep-seated** landslides are those in which the rupture surface is further below the ground surface (>10 feet). Generally, shallow landslide occurrence is more strongly influenced by the type and character of vegetation growing on a particular site. This is because the roots of vegetation are usually within a few feet of the ground surface, helping reinforce the soil mantle and increasing its resistance to failure. The influence of roots on deep-seated landslide occurrence is thought to be relatively minor since the rupture surface is well below the maximum rooting depth of vegetation. Of the landslides investigated, all were shallow; however, one of the shallow landslides initiated along the margin of an existing deep-seated landslide.

Shallow landslides are further divided into channelized landslides and non-channelized landslides. **Channelized** landslides include debris flows and debris floods. Debris flows and debris floods occur when a landslide enters a stream and moves down the channel, scouring streamside vegetation and picking up or "entraining" woody debris and sediment that has accumulated in the channel. It is not uncommon for a debris flow or debris flood to begin as a relatively small landslide (<100 yards^3) and grow by several orders of magnitude (to 10,000 - 100,000 yards^3) before it finally comes to rest on an alluvial fan or valley floor. Additionally, these types of landslides can move rapidly, often attaining speeds of 30 miles per hour. These two factors (volume and velocity) explain why such events can be so damaging when they encounter homes, roads, bridges, or other structures located in their path. **Non-channelized** landslides include debris slides and debris avalanches that occur on hillslopes as opposed to stream channels. These types of landslides have lower water contents and tend to be less mobile relative to debris flows and debris floods, but still can cause damage to structures in their path. Often, landslides that begin as debris slides or debris avalanches transform into debris flows or debris floods if they enter a narrow, steep stream channel. Of the landslides investigated, all began as shallow debris slides or debris avalanches except one landslide that resulted from the collapse of an orphaned[1] road grade. Additionally, all of the landslides transformed into debris flows or debris floods that eventually reached the base of Sumas Mountain, Slide Mountain, and Van Zandt Dike where the affected properties are located.

[1] Under Washington's Forest Practices Rules, orphaned roads are defined as forest roads that have not been used for forest practices since 1974.

Factors Contributing to Landslide Initiation

Landslide initiation results from the interaction of multiple factors. Most often, the main factor triggering a landslide is a significant natural disturbance such as a large magnitude precipitation event or earthquake. Other factors, including topography, geology, reduction of material strength over time due to weathering and land use history can predispose a site to slope failure and contribute to instability. In this section, we discuss the factors that contributed to the initiation of landslides during the early January 2009 storm that originated on State Trust Lands in Whatcom County.

THE STORM

In western Washington, high-intensity rain or rain-on-snow storms are the main factor contributing to the development of most shallow landslides. These storms typically occur during the fall and winter months with the strongest resulting from a powerful, persistent flow of warm, moist air from the waters near Hawaii. Often known as "pineapple express" storms because of their origins in the south Pacific, they commonly produce heavy rainfall, rapid snowmelt, landslides and flooding. The January 7th-8th event was a classic example of such an event. Figure 3 shows a satellite image of the storm's moisture plume stretching far into the Pacific. During these storms, the high rate of water input to the soil from rain and melting snow elevates the water table and reduces the soil's shear strength, sometimes to the point of failure. When failure occurs, the soil mass begins to move downslope under the force of gravity, producing a landslide.

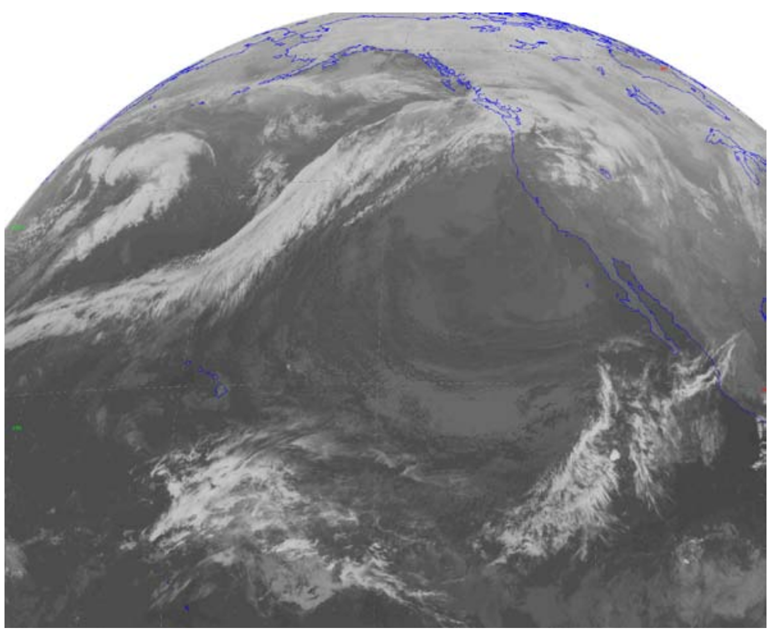

Figure 3. Infrared satellite image taken January 7th, 2009 showing the "pineapple express" moisture plume extending from the south Pacific into Washington and southern British Columbia.

While the individual reconnaissance reports address the severity of the January storm in general terms, a detailed analysis of the storm's magnitude was beyond the scope of the investigations. Instead, the investigations focused on locating landslide initiation points and assessing the degree to which past management activities contributed to landslide initiation (see objectives in the **Introduction**). In preparing this summary report, we took a closer look at the severity of the storm by compiling and analyzing rainfall data from multiple locations in northwest Washington.

The most common way to assess the magnitude of a particular storm is by determining the storm's recurrence, or return, interval. A storm with a return interval of 5 years has a 20 percent chance of occurring in any given year. Thus, a 5-year storm is expected to occur more frequently than a 10-year storm, but not as frequently as a 2-year storm. Frequency and magnitude are inversely related; as the frequency of a storm increases, its magnitude decreases. For example, a storm with a return interval of 5 years occurs more often, but is of smaller magnitude, than that of a 10-year storm. In the following paragraphs, we characterize the magnitude of the January $7^{th}/8^{th}$ storm using rainfall data and corresponding return intervals published by the National Oceanic and Atmospheric Administration (NOAA).

When measured in terms of rainfall intensity, the magnitude of the January 2009 event was quite variable across the region. Table 1 shows rainfall totals for January 7^{th} and 8^{th} (the peak storm period) and corresponding 24- and 48-hour return intervals for locations in Whatcom, Skagit, and Snohomish counties. Return intervals based on maximum 24-hour rainfall totals ranged from less than 2 years to more than 100 years although most fell between 2 and 10 years. Based on 24-hour return intervals alone, the storm was of moderate magnitude in most locations. The one exception was the weather station in Concrete which recorded nearly five inches of rain in 24 hours, yielding a return interval that exceeded 100 years.

Return intervals derived from 48-hour rainfall totals indicate that in several locations the storm was of greater magnitude than the 24-hour totals suggest (Table 1). Four locations in central and eastern Whatcom County and one location in central Skagit County received between 7.9 and 8.5 inches of rain on January 7^{th} and 8^{th}, resulting in return intervals from 25 to more than 100 years. Such large magnitude storms, especially when accompanied by significant snowmelt, often produce the type of widespread slope failure that occurred during the early January storm.

While the 48-hour data from most inland locations suggest the storm magnitude was relatively large, rainfall totals for low-elevation locations near Puget Sound were not exceptional. The 48-hour return intervals for Blaine, Bellingham, Arlington, and Everett are all less than two years (Table 1), indicating the storm was a fairly typical winter rainfall event for these locations. The "average" nature of the storm in much of the northern Puget Sound lowland reflects the strong rain shadow effect of the Olympic

Table 1. Rainfall totals and corresponding 24-hour and 48-hour return intervals (Tr) for the January 7th/8th, 2009 storm for selected locations in northwest Washington.

Station (Elevation[1]/County)	Rainfall[2] (inches)		Tr (years) 24-Hour[3]	Tr (years) 48-Hour[4]
	Jan 7	Jan 8		
Arlington (100/Snohomish)	1.24	0.42	<2	<2
Bellingham (15/Whatcom)	1.91	0.87	2-10	<2
Blaine (60/Whatcom)	0.92	1.05	<2	<2
Clearbrook (64/Whatcom)	1.96	1.38	<2	2-5
Concrete (195/Skagit)	4.89	3.57	>100	>100
Diablo Dam (891/Whatcom)	3.79	4.12	2-10	50-100
Everett (60/Snohomish)	0.42	0.70	<2	<2
Newhalem (525/Whatcom)	4.38	4.02	2-10	25-50
Ross Dam (1236/Whatcom)	3.79	4.13	2-10	50-100
Sedro Woolley (60/Skagit)	2.57	1.70	2-10	5
Startup (170/Snohomish)	2.00	2.20	<2	2
Baker Dam (690/Whatcom)	4.22	3.85	2-10	50-100

1 – Station elevation in feet above sea level.
2 - Rainfall data was obtained from the National Weather Service website: (http://www7.ncdc.noaa.gov/CDO/dataproduct).
3 - 24-hour return intervals were derived from isopluvials prepared by MGS Engineering Consultants Inc. under a contract with the Washington Department of Transportation: (http://www.mgsengr.com/precipfrq.htm).
4 - 48-hour return intervals were derived from isopluvial maps included in National Weather Bureau Technical Paper No. 49 (see references cited section).

Mountains. This effect is most pronounced during storms with predominately westerly or southwesterly flow. These conditions existed during the early January event, resulting in relatively low rainfall totals for locations on the lee side of the Olympics.

While the rainfall data presented in Table 1 help characterize the storm at a regional scale, they may not provide an accurate picture of conditions at the actual landslide initiation sites. Clearbrook is the closest weather station to the landslide sites and is located 8 to 15 miles away at an elevation of 75 feet above sea level – in most cases more than 1000 feet lower than the initiation points. While other stations are at similar elevations (e.g., Upper Baker Dam, Diablo Dam, Ross Dam), they are located 23 to 50 miles southeast of the landslide sites. Given the complex nature of storms in areas of high topographic relief such as Whatcom County, relatively small differences in distance and elevation can yield substantial differences in rainfall totals.

The most representative rainfall dataset we were able to locate was compiled by Mr. Robert Haner who lives in the community of Wickersham, approximately 7 to 15 miles south of the landslide sites but at an elevation of 400 feet in the foothills of the Cascade Range. Mr. Haner is a National Weather Service “weather spotter” and has been recording weather data at this location since 1981. During the early January storm, he recorded 5.0 inches of rain in slightly more than 24 hours and 7.3 inches of rain in just over 48 hours[2]. Using this data and applying the same National Weather Service isohyets[3] used to develop rainfall return intervals in Table 1 yields a 24-hour rainfall return interval of between 25 and 50 years and a 48-hour return interval of 100 years. Based on Mr. Haner's data and data from the higher elevation stations listed in Table 1, we believe the rainfall return interval for the early January storm in the vicinity of the landslide initiation points is probably on the order of 50 to 100 years.

Thus far, the discussion of rainfall totals and storm magnitude has not addressed the snowmelt component of the storm. Several anecdotal accounts indicate 12 to 18 inches of snow were present at low elevations in the South, North and Middle Fork Nooksack valleys in the days immediately preceding the storm (D. Hooks, pers. comm., T. Smith, pers. comm., T. Schaad, pers. comm.). It is likely that at least the same amount of snow was present at the elevations where the landslides initiated. At elevations below about 1000 feet, nearly all of the snow had melted by the end of the storm on January 8th. According to Natural Resource Conservation Service snow hydrologist Scott Pattee, the water content of the snowpack in the days leading up to the storm was about 15 to 20 percent (S. Pattee, pers. comm.). This means at low elevations, an additional 1.8 to 3.6 inches of water probably entered the soil during the storm as a result of snowmelt. At higher elevations, the snowmelt contribution may have been even greater if more snow was present.

Based on rainfall totals alone, the early January storm was of sufficient magnitude in many locations to trigger the type of shallow landslide processes common throughout much of western Washington. The fact that the rainfall coincided with significant snowmelt at low- to mid-elevations increased the severity of the storm, producing widespread landsliding throughout much of the region including parts of Whatcom County.

TOPOGRAPHY

Next to storm intensity, topography is usually the most important factor influencing shallow landslide potential. Slope gradient, slope form (or shape), and landform type are topographic attributes that often determine where debris slides and debris avalanches originate. These same attributes often determine if debris slides and debris avalanches transform into channelized debris flows or debris floods, how far the landslide mass travels, and where the resulting slurry of water, woody debris, and sediment ultimately comes to rest. This section of the report describes these topographic attributes and their contribution to landslide initiation and downslope movement.

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[2] The 5.0 inches fell between 9:36 PM on January 6th and 9:48 PM on January 7th while the 7.3 inches fell between 9:36 PM on January 6th and 10:22 PM on January 8th.

[3] An isohyet is a line joining points of equal precipitation on a map.

A total of 25 landslides that initiated on State Trust Lands and impacted downslope private properties were reviewed. Except for two, all of the landslides began on slopes that exceed 70 percent gradient (Figure 4). The one landslide that initiated on relatively gentle slopes began in a low-gradient stream channel when an orphaned road collapsed and produced a dam-break flood.

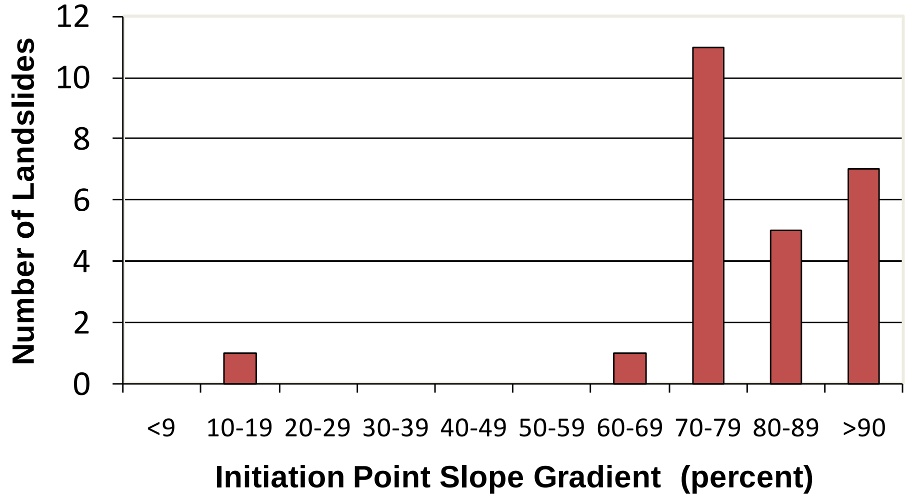

Figure 4. Bar chart of landslide initiation points by slope gradient class for the 25 landslides that began on State Trust Lands and impacted private properties during the January 2009 storm in Whatcom County.

The Forest Practices Rules ("the Rules") include definitions of slopes and landforms that qualify as "potentially unstable" (WAC 222-16-050(1)(d)). Logging proposals that involve rule-defined potentially unstable slopes or landforms are subject to a higher level of environmental review under the Rules and State Environmental Policy Act. The most common potentially unstable landforms in Whatcom County are known as "bedrock hollows" and "inner gorges". These are landforms with convergent (or concave) slope shapes and steep (>70 percent) slope gradients. Of the 25 landslides investigated, 15 originated in bedrock hollows that qualify as potentially unstable under the Rules while seven originated in rule-defined inner gorges. Of the three remaining landslides, two originated on steep slopes that, depending on the topographic, geologic, and soil conditions at the site prior to failure, may have been considered "potentially unstable" under the Rules. Without knowing the pre-failure conditions, it is impossible to know whether these sites would have been judged as having a high landslide potential. As described in the preceding paragraph, one landslide began in a low-gradient stream channel when an orphaned road collapsed. This site would not have been considered "potentially unstable" under the Rules. As a result, at least 88 percent of the landslides investigated occurred at sites considered "potentially unstable" under the Rules.

Of the 25 landslides reviewed, 18 occurred in the Acme watershed administrative unit (WAU), an area that includes the eastern slopes of Stewart Mountain and the western slopes of Van Zandt Dike. In 1999, Trillium Corporation conducted a landscape-scale assessment of forestlands in the Acme WAU known as watershed analysis under the auspices of the Rules. As a result of that analysis, forest management activities in landslide-prone areas of the Acme WAU are now subject to approved watershed analysis prescriptions and not the statewide Rules. The watershed analysis identified multiple moderate and high hazard “mass wasting map units”. These areas are similar to the rule-defined “potentially unstable” landforms described above in that landslides are more likely to occur in these areas relative to other parts of the landscape. A group of moderate and high hazard mass wasting map units known as Area of Resource Sensitivity (or ARS) #1 includes bedrock hollows, inner gorges and other steep slopes with a history of shallow landslides. Of the 18 landslides that occurred on State Trust Lands in the Acme WAU and impacted private property, all originated on slopes and landforms that qualify as part of ARS #1.

While the topographic conditions at nearly all of the sites contributed to landslide initiation, the hillslope and stream channel conditions below the initiation points promoted landslide growth and development. In almost all cases, the debris flows and debris floods began as relatively small debris slides many hundreds or even thousands of feet uphill. These debris slides entered narrow, steep, fast-flowing stream channels and transformed into debris flows. The debris flows (and in one case a dam-break flood) grew quickly as they moved downstream, picking up sediment and woody debris stored in the channels, soil accumulated on adjacent hillslopes, and trees that were growing along the streambanks. Narrow gorges and high channel gradients at most of the sites allowed these channelized landslides to propagate. Only when the flows exited their gorges and emptied into broader river valleys did they lose momentum, spread, and begin to deposit. In almost all cases, the private properties that were most severely impacted were located at or near the junction of the high-gradient stream channels and river valleys on landforms known as alluvial fans. Thus, the topographic conditions at each site help explain where the landslides initiated, how and why they developed and grew, and ultimately, where they deposited.

GEOLOGY

Like topography, the geologic setting of western Whatcom County also affects where, why, and how shallow landslides occur. Broadly speaking, there are two main geologic factors that contributed to shallow landslide initiation at the 25 sites investigated: 1) the effects of past glaciations on terrain and soil characteristics, and 2) the influence of the underlying bedrock on groundwater hydrology.

Glacial ice has shaped nearly all of Whatcom County. A series of continental ice sheets have left a legacy of broad river valleys and steep hillslopes such as those on Sumas and Slide Mountains and Van Zandt Dike. After the last ice sheet retreated northward into Canada some 10,000 years ago, streams began carving their way into these hillslopes, creating the steep, convergent landforms described earlier. This stream carving or "downcutting" continues today and is one factor contributing to the potentially unstable conditions of many of the landslide initiation sites.

While 10,000 years may seem like a long time, from a geologic perspective it represents a very short period. As a result, geologists consider the Whatcom County landscape "young". One characteristic of young landscapes born of glaciation is thin soils. Unlike parts of southwest Washington that have not been glaciated and have soil and regolith (i.e., weathered bedrock) profiles that are often tens of feet thick, soil depths in Whatcom County are rarely more than a few feet. This was evident at many of the landslide initiation points where soil and colluvial material failed along a bedrock contact and the depth to bedrock was less than five feet. Thin soils have a limited water storage capacity and during intense precipitation events such as the January 2009 storm, the soil profile is easily saturated. Saturated soils are heavy and the water within the soil matrix exerts pressure on individual particles, forcing them apart and making the entire profile more buoyant and subject to failure.

Almost all of the landslides investigated occurred in areas underlain by sedimentary rocks of the Chuckanut or Huntingdon formations. Sedimentary rocks begin as layers of sediment deposited at the mouths of rivers or the bottom of oceans or inland seas. As a result, they exhibit distinct layering or "bedding" that is discernable where the rocks are exposed in natural outcrops or road cutslopes. Such rocks also exhibit a fair degree of fracturing which appears as both **joints** (fractures that have opened but are not displaced) and **faults** (fractures that are displaced). In most cases, landforms in which landslides initiated had developed due to bedding and jointing in the bedrock. Fracture patterns and bedding orientation also can influence groundwater flow which can, in turn, affect slope stability.

Groundwater often follows bedding planes or fractures, sometimes resulting in subsurface flow patterns that do not mimic the surface topography of a given site. Unlike topographic attributes, fracture and bedding patterns are not often discernable because soil and colluvium[4] commonly blankets the underlying bedrock, hiding them from the observer's eye. Of the 25 initiation points investigated, bedding orientation and/or fracture patterns were identified as potential contributing factors in the initiation of two landslides. This is not to say that these geologic attributes did not influence landslide initiation at any of the other sites.

[4] Colluvium consists of loose accumulations of soil and rock that have been deposited on a slope, transported there by gravity.

FOREST MANAGEMENT ACTIVITIES

Perhaps the most important reason for conducting the field-based investigations was to determine the degree to which management activities contributed to landslide initiation. From a scientific perspective, the information gathered will improve our understanding of the cause-and-effect relationships that exist between forest practices and landslide processes. From a policy perspective, the findings will allow us to assess our (State Lands) landslide risk management strategy including the effectiveness of our internal environmental review process. The following section provides a look at landslide initiation during the January 2009 storm in light of past management activities on State Trust Lands.

Landslide Initiation Based on Land Use Status

A total of 25 landslides that initiated on State Trust Lands and impacted downslope private properties were reviewed. Twenty of the landslide initiation points are located in unmanaged areas while five are located at sites where some type of forest management activity has occurred in the past (Figure 5). **Unmanaged areas** include sites where the landslide initiation point is surrounded by mature forest cover and no direct influence from forest roads or timber harvesting was identified (for purposes of this report, we define “mature forest” as stands where the overstory vegetation is at least 50 years of age). This includes fully intact mature forest and buffers or “leave areas” of mature forest within or along the margins of recently harvested areas. **Managed areas** include sites where roads or recent timber harvesting are immediately adjacent, or in close proximity, to the landslide initiation point (for purposes of this report, we define “recent” as being within the past 20 years).

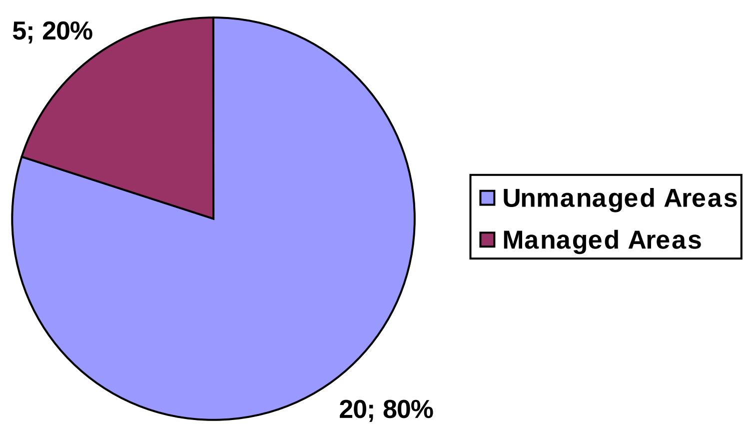

Figure 5. Distribution of 25 landslides that originated on State Trust Lands during the January 2009 storm based on the land use status (managed or unmanaged) of the landslide initiation site.

Landslides from Unmanaged Areas

We have further subdivided the “unmanaged” and “managed” categories based on the likelihood that management activities contributed to landslide initiation (Figure 6). Of the 20 landslides that initiated in unmanaged areas, 15 occurred without any contribution or influence from forest management activities on State Trust Lands. This represents 60 percent of all landslides investigated (Figure 6). These landslides began in fully intact mature forest stands, some of which were between 100 and 200 years of age. In all cases, no forest roads were present immediately upslope from the initiation point and no previous timber harvesting had occurred upslope. The landslide that affected the van den Heuvel property located at 3800 Nelson Road is an example of a landslide that occurred in the absence of any upslope management activities (Figure 7).

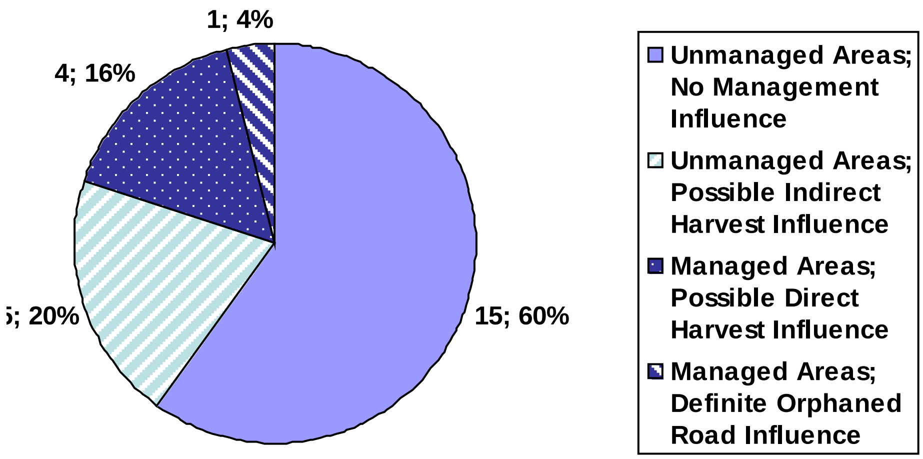

Figure 6. Distribution of 25 landslides that originated on State Trust Lands during the January 2009 storm based on land use status (managed or unmanaged) and likely degree of management influence (none, possible, or definite).

The five remaining “unmanaged area” landslides originated within buffers or leave areas of mature forest within or along the margins of two recently harvested DNR timber sales. Three of these landslides originated in leave areas adjacent to the “Jack Straw Aerial” timber sale along the west side of Van Zandt Dike; the other two landslides originated in a leave area embedded within the “Gasping Goodwin” timber sale on the southwest side of Sumas Mountain (Figure 8). Based on a review of the timber sale files and communication with staff familiar with these sales, the sites where these five landslides initiated were identified as potentially unstable during the pre-sales review process; as a result, DNR staff decided to exclude them from the proposed harvest units in an effort to mitigate landslide hazard.

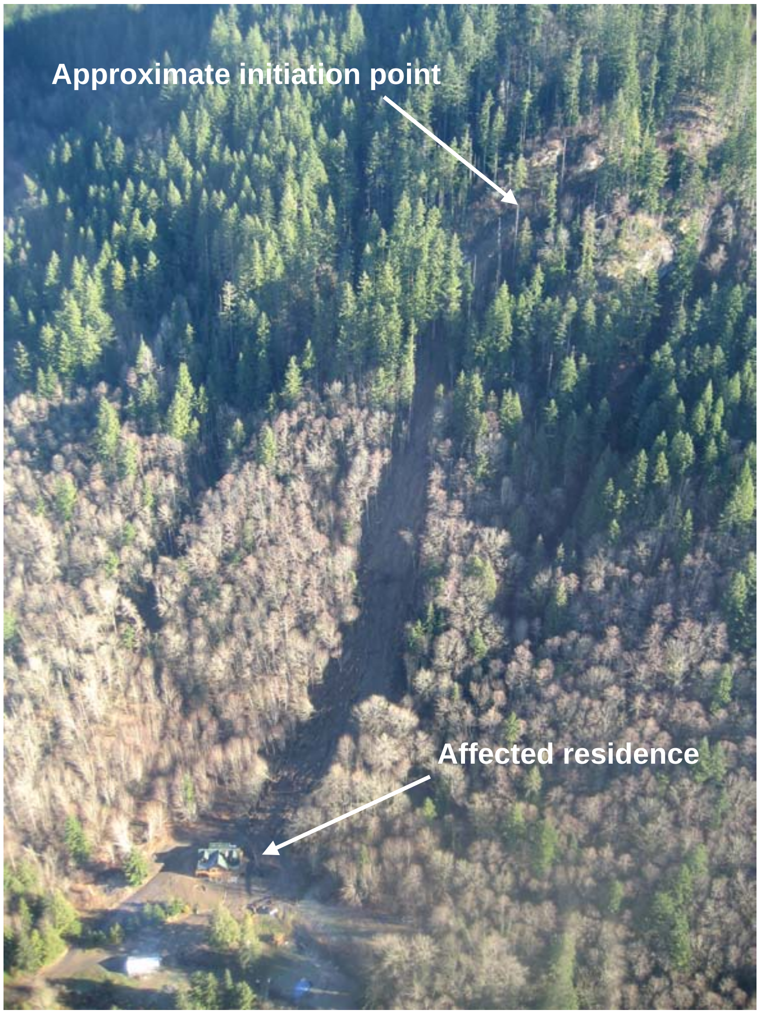

Figure 7. Oblique aerial photograph taken January 20th, 2009 showing the landslide that affected the van den Heuvel property at 3800 Nelson Road. Photo credit: D. Hooks.

While the sites where these five landslides occurred were excluded from the timber sales due to slope stability concerns, areas directly upslope from the initiation points and associated leave areas were harvested. Given this, a question arises as to if the upslope harvesting could have contributed to landslide initiation in the leave areas. The short answer is "it's possible, but there's no way to be sure". The mechanism by which timber removal can contribute to landslide initiation at sites downslope from harvested areas is through alterations in slope hydrology. During rain-on-snow events such as the early January storm, removal of the forest canopy can reduce snow interception and allow more snow to accumulate on the ground. Canopy removal also can allow a higher rate of heat transfer from warm rain and wind to the snowpack, potentially causing more rapid snowmelt. A higher rate of snowmelt combined with more snow available for melt can mean more water entering the soil. As described earlier, high rates of water input to the soil elevates local water table levels, sometimes reducing soil shear strength to the point of failure.

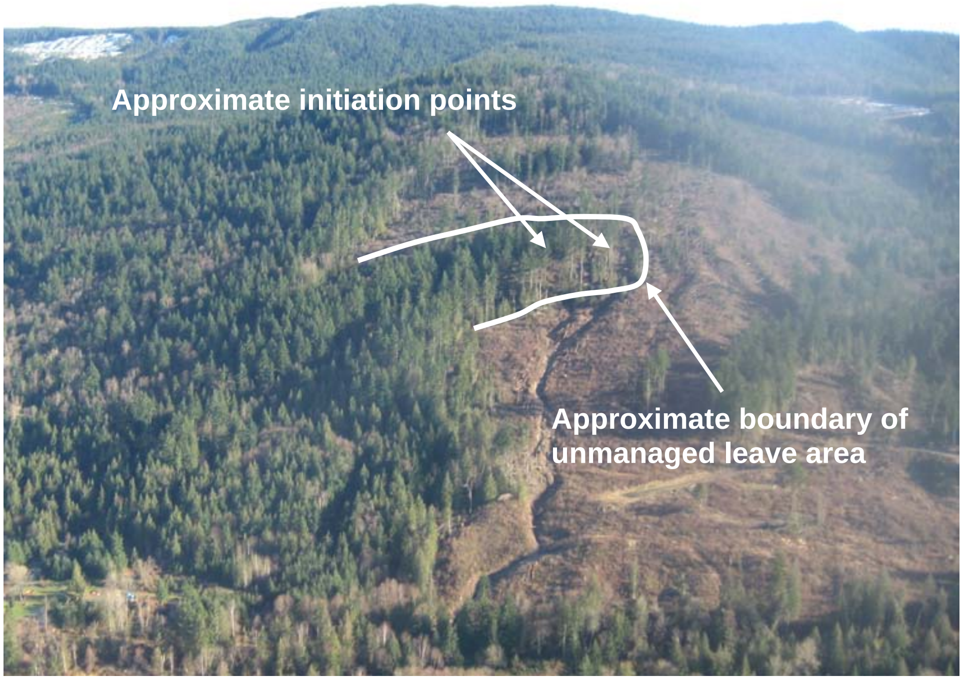

Figure 8. Oblique aerial photograph taken January 20th, 2009 of the two landslide initiation points that originated in an unmanaged leave area within the DNR "Gasping Goodwin" timber sale. The resulting debris flow track is visible below the initiation points in the harvest unit. Affected properties along Goodwin and Siper Roads are not visible. Photo credit: D. Hooks.

While basin-scale studies of rain-on-snow hydrology suggest timber harvesting has the potential to increase peak streamflows, few studies have looked at the site-scale effect of timber harvesting on soil water inputs. From a landslide initiation perspective, localized, site-scale increases in soil water input can increase the potential for shallow slope failure. One study that investigated harvest-induced changes in snowmelt during rain-on-snow events in Skagit County found that open areas (i.e., recently harvested sites) and younger forests (18 to 42 years of age) generally had higher rates of snowmelt than mature forests (Coffin and Harr 1992). However, in some cases, younger forests actually had up to 21 percent less snowmelt than nearby mature stands. The authors concluded that *"the wide range of outflow differences observed during this study emphasizes the extremely complex and highly variable nature of the biologic and meteorologic systems monitored during rain-on-snow"*.

Without knowing the characteristics and patterns of rainfall, snowmelt, and slope hydrology that existed at each of the five landslide sites during the early January storm, it is difficult to confidently say if, and to what extent, upslope harvesting contributed to landslide initiation in the leave areas. As a result, we have classified these five landslides as having a "possible indirect harvest influence" even though they began in unmanaged areas (Figure 6).

Landslides from Managed Areas

In addition to the 20 landslides that originated from unmanaged areas, there were five landslides that began in managed areas (Figure 6). Four of these landslides initiated on slopes that had been harvested. This represents 15 percent of all landslides investigated. Three of the four harvested landslide initiation points are located in an area that was clearcut about 16 years ago (Figure 9). This area is referred to as the "TAT" harvest in the corresponding investigation report (Appendix A). The other harvested landslide initiation point is located in an area that was clearcut about 21 years ago. This area is referred to as the "Strand Extension" harvest in the corresponding investigation report (Appendix G). It is important to note that at the time the TAT and Strand Extension harvests occurred, neither parcel was under DNR management. Both parcels were privately owned and DNR acquired the parcels in 1993, after the logging was completed. Additionally, the Forest Practices Rules in place at the time of the harvesting did not specifically address logging on potentially unstable slopes. Since that time, the Acme watershed administrative unit (in which these sites are located) has undergone watershed analysis and approved management prescriptions are in place that restrict harvesting in landslide-prone areas such as these four sites.

Figure 9. Oblique aerial photograph taken January 20th, 2009 showing the three landslides that initiated in the "TAT" timber sale that was harvested circa 1992. These landslides coalesced into a debris flow that impacted properties along Nelson Road. Part of the DNR "Jack Straw Aerial" timber sale is visible in the upper right portion of the photo. Photo credit: D. Hooks.

Because the trees surrounding the four landslide initiation points described above were cut, it is possible the harvesting contributed to landslide initiation. Tree removal at the landslide sites probably led to reductions in root strength. Tree roots provide lateral reinforcement and vertical anchoring of shallow soils and root decay can reduce soil shear strength and resistance to failure. Once trees are removed, root strength associated with the harvested trees begins declining while the regenerating forest is adding root strength. The net effect is a reduction in overall root strength for several years following harvest, with root reinforcement reaching a minimum about seven years after trees are cut (Figure 10). The timing of the TAT and Strand Extension harvests 16 and 21 years ago, respectively, suggests that root strength, while increasing, was probably not fully recovered at either site at the time the landslides occurred.

Tree removal at the four harvested landslide sites may have also caused changes in site-scale slope hydrology. As described earlier, timber harvesting can lead to greater snow accumulation and faster melt rates during rain-on-snow events. Such changes can increase the rate of soil water input and raise water tables, reducing the soil's resistance to failure.

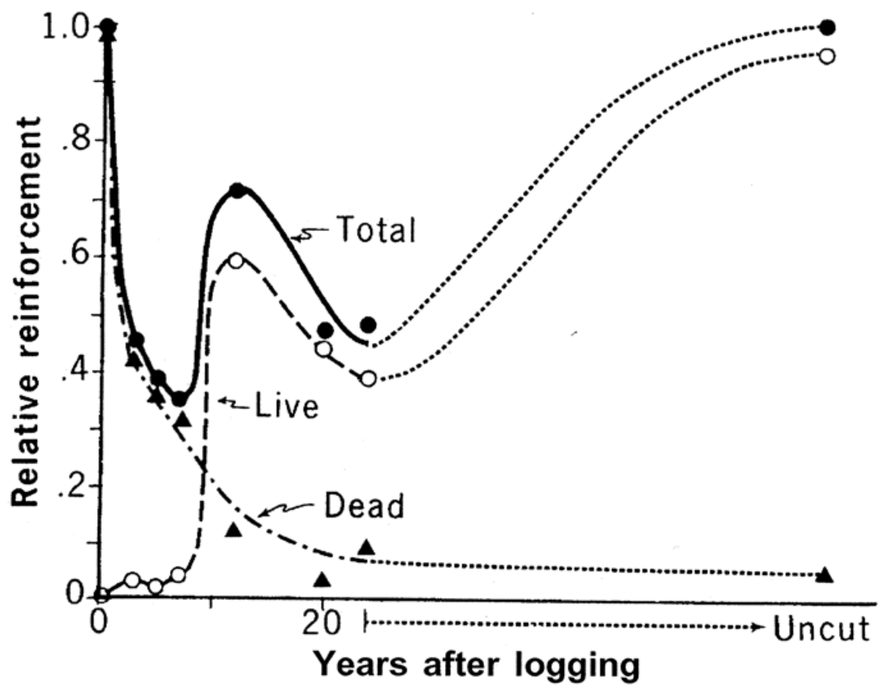

Figure 10. Relative soil reinforcement by tree roots from a study in northwestern California. Soil reinforcement by live roots generally increases while that of dead roots rapidly decreases with increasing time after timber harvesting. The total reinforcement by live and dead roots drops to a low point about seven years after harvesting (from Ziemer 1981).

However, the age of the trees at the TAT and Strand Extension sites (16 and 21 years respectively) somewhat mitigates any harvest-related increases in snow accumulation and melt rates that may have occurred during the January storm. Recent snow hydrology research from southern coastal British Columbia indicates forest stands with an average height of 13 feet exhibit about 50 percent hydrologic recovery while those 25 feet in height exhibit about 75 percent recovery (Hudson 2000). The average heights of trees at the TAT and Strand Extension sites are estimated at between 15 and 20 feet, suggesting the stands are more than 50 percent recovered. Like the case of the landslides that initiated in unmanaged leave areas associated with the "Jack Straw Aerial" and "Gasping Goodwin" timber sales, it is difficult to know with any degree of certainty the extent to which tree removal at the four harvested landslide sites produced changes in slope hydrology which, in turn, contributed to landslide initiation.

Because there is no obvious or readily detectable management-related landslide trigger at any of the four harvested sites, but the potential for harvest-induced changes in root strength and slope hydrology exists, we have classified them as having a "possible direct harvest influence" (Figure 6). As discussed in the investigation reports associated with each of these sites, it is certainly possible that one or more of these landslides may have occurred even if the sites had not been harvested. The 15 landslides that occurred in the absence of any upslope management activity attest to the capacity of the January $7^{th}/8^{th}$ storm to initiate landslides even under mature forest conditions.

Of the 25 landslides investigated, one is directly attributable to past management activities on State Trust Lands – specifically, an orphaned road grade (Figure 6). The landslide occurred when the orphaned road collapsed, triggering a dam-break flood that traveled more than 1.5 miles to the base of Sumas Mountain where it destroyed one residence and damaged several others as well as Mount Baker Highway and Marshall Hill Road. The orphaned road collapsed when water became impounded on the upslope side of the road to a depth of approximately eight feet, saturating the base of the road prism. The road is located on nearly flat terrain at the outlet of a wetland approximately 1.5 acres in size.

Under Washington's Forest Practices Rules, orphaned roads are those that have not been used for forest practices since 1974. While the Rules require that these roads be inventoried and assessed for their risk to public resources and public safety, landowners are not required to maintain or abandon (i.e., decommission) orphaned roads to current standards. Unless an orphaned road is recognized as posing an imminent threat to public safety, landowners typically do not take corrective action, instead choosing to invest in the repair and maintenance of forest roads actively used for management purposes.

Although orphaned roads on State Trust Lands on Sumas Mountain were inventoried in 2004, the road that collapsed and triggered the dam-break flood was not included in the assessment because it was not known to exist. DNR staff used historic maps and aerial photos together with field reconnaissance to document orphaned road locations on the south side of Sumas Mountain (LiDAR was not available at the time). Even so, the subject road was not identified and as a result, it was not assessed. Because some orphaned roads were last used many decades ago, they are often overgrown, they sometimes blend into the landscape, and they can be difficult to detect even with the aid of high-resolution LiDAR imaging. This is the case with the collapsed orphaned road. A recent review of LiDAR hillshade imagery of the landslide initiation site revealed no evidence of a road grade in the immediate area. As a result, the fact that the road was not identified during the 2004 assessment is not surprising.

Factors Contributing to Property Damage

The properties affected by the landslides suffered a wide range of impacts. For some, the damage was limited to relatively minor mud and debris deposition on lawns or pastures. For others, homes, garages, and outbuildings were significantly damaged when water, boulders and logs swept through the property. In two cases, residences were completely destroyed. Fortunately, despite the widespread damage and timing of some of the landslides (several occurred at night) no one was injured or killed.

While it is obvious that the landslides themselves caused the property damage just described, what may not be as apparent are two additional factors that help explain the nature and severity of the impacts. The first involves the characteristics of the landslides and specifically, the characteristics of debris flows and debris floods. This has already been discussed in some detail in previous sections of the report, so only a brief restatement of the topic is included here. The second factor involves the location of the properties on the landscape. This will be the focus of this section and will be discussed in more detail.

LANDSLIDE CHARACTERISTICS

As previously described, debris flows and debris floods are fast-moving masses of water, woody debris, and sediment. High streamflows, steep channel gradients, and narrow stream valleys promote their growth and development. The distance and topographic relief between their beginning and ending points largely determine their size, but the nature of the stream channels through which they flow also can influence their composition. The quantity and quality of sediment and woody debris stored in the channel – as well as the size and distribution of trees and other vegetation growing along the stream – often determine the type and character of materials that are transported and ultimately deposited downstream. The type and character of these materials can also affect the nature and severity of damage to private property and public infrastructure.

The larger structural elements contained within a debris flow or debris flood often create the most damage. This includes boulders, logs, and uprooted trees that can break, puncture, crush, and even move structures in their paths. These larger elements are typically among the first things to deposit due to their mass, and deposition typically begins soon after the flow exits a narrow gorge and enters a wider valley. Smaller materials such as cobble- and gravel-sized rocks and small woody debris can be transported hundreds of feet from a gorge mouth while the smallest particles (sands and silts) can travel thousands of feet. Thus, properties located in close proximity to gorge mouths often suffer the most damage while those further away experience less severe impacts. This pattern held true during the January 2009 storm where the most severely damaged structures were located within a few hundred feet of gorge mouths.

LOCATION OF AFFECTED PROPERTIES

Landslides have been occurring in Whatcom County since the last ice sheet retreated north into Canada some 10,000 years ago. Many of these landslides, particularly the larger ones, leave behind a topographic signature on the landscape. Geologists use a combination of aerial photographs, other remotely sensed imagery, and field-based observations of terrain conditions to identify historic landslide locations including places where landslides have initiated and places where they have deposited. Non-channelized landslides typically deposit where there is a significant decrease in the gradient (or steepness) of the hillslope down which the landslide is traveling. These sites are often called “toeslopes” due to their location at the base or “toe” of a hillslope. Channelized landslides such as debris flows and debris floods begin to deposit when the stream valley widens significantly. As described earlier, these are points where narrow stream gorges empty into wider river valleys. It is at these locations where landforms known as “alluvial fans” develop. As the name implies, alluvial fans are fan-shaped. The head, or upslope portion, of the fan is located at the point where the narrow gorge intersects the valley floor. This is also known as the fan “apex”. Downstream from the apex, the fan widens as the stream gradient decreases. As described in the preceding section, the fan apex is where channelized landslides begin to deposit and where large boulders, woody debris, and trees often end up.

The 25 landslides investigated produced debris flows or debris floods that impacted 23 homes and multiple outbuildings. All 23 homes are located in areas where landslides have historically deposited. In our judgment, 18 of the homes are located on alluvial fans while another[5] is located on a toeslope. The four remaining homes, while affected by the landslides, were not on alluvial fans or toeslopes. These conclusions are based on observations made during the course of our field investigations as well as our review of historic aerial photographs, geologic maps, and LiDAR- (Light Detection And Ranging) derived digital elevation models and hillshade images. The availability of high resolution LiDAR data that has

[5] This is the van den Heuvel property located at 3800 Nelson Road.

come about in just the past several years has drastically improved geologists' ability to recognize, identify, and accurately map geologically hazardous areas including alluvial fans and toeslopes.

Six (6)[6] of the affected homes are within "alluvial fan hazard areas" based on the Whatcom County Geologically Hazardous Areas map while another[7] is immediately below a "landslide hazard area". In addition, seven homes at the Mount Baker Highway/Marshall Hill Road site are located on an alluvial fan identified by the DNR Division of Geology and Earth Resources on its geologic map of the area. Thus, a number of the affected homes are in areas previously identified as being subject to landslide hazards.

Conclusions and Policy Implications

The main reason DNR initiated the field-based reconnaissance investigations was to determine if, and to what extent, past management activities on those lands contributed to landslide initiation. However, while conducting the investigations other questions arose. The questions concerned the magnitude of the storm, the relationship between the landslide initiation sites and unstable slope definitions in the Forest Practices Rules and Acme watershed analysis, and the location of the affected residences with respect to historic landslide runout zones. In preparing this report, we've addressed both the original objective and these secondary issues. Our conclusions are summarized in the following paragraphs. In addition, we also have included a discussion of the potential policy implications of our findings.

MANAGEMENT CONTRIBUTION TO LANDSLIDE INITIATION

In most cases, the question of whether past forest management activities contributed to landslide initiation can be addressed with certainty. For 15 of the 25 landslides investigated, past management was definitely not a factor in their initiation. For one landslide, past management was undoubtedly a factor. That leaves nine landslides where there is a fair degree of uncertainty surrounding the role management may have played in their initiation. It is possible that previous timber harvesting at four of the initiation sites caused changes in slope hydrology and/or reductions in root strength that contributed to slope failure. Similarly, it is possible that past timber harvesting upslope of unmanaged leave areas may have influenced landslide initiation in those same leave areas at the five remaining sites. In the absence of detailed geologic, soil, vegetation, hydrologic, and meteorologic data, we cannot be confident about the role management may have played in landslide initiation at these nine sites. Even with such data, it is likely some uncertainty would still exist given the complex and dynamic processes at work in natural systems.

STORM MAGNITUDE

[6] These homes are located on Clipper Road and the south end of Nelson Road.

Rainfall data, together with several anecdotal accounts of snow depths preceding the storm and snowmelt during the storm, suggest the January 7th/8th event was of large magnitude. While 48-hour rainfall totals at many locations in the Puget Sound lowland were relatively low, stations at elevations near those of the landslide initiation points recorded upwards of 8.5 inches of rain in 48 hours. Based on rainfall data alone, the storm had a return interval of between 50 and 100 years, meaning there is a 1 to 2 percent chance that a storm of that magnitude will occur in any given year. The significant snowmelt that occurred at low- and mid-elevations increased the severity of the storm by adding as much as 3.6 inches of additional water to the soil. But perhaps the best indicator of storm magnitude is the number and distribution of the landslides themselves. Such widespread slope movement does not result from storms with 5, 10, or even 25 year return intervals. As a result, the January 7th/8th storm was an exceptional event and was not representative of rain-on-snow conditions that typically occur in Whatcom County.

LANDSLIDE INITIATION SITES

In nearly all cases, the landslides that originated on State Trust Lands and impacted private properties began in areas where geologists trained in slope stability analysis would have expected. Twenty-two (22) of the 25 landslides initiated at sites considered “potentially unstable” under the current Forest Practices Rules. Similarly, all 18 of the landslides that occurred in the Acme watershed administrative unit initiated at sites identified as having a moderate or high landslide hazard in the watershed analysis. This suggests our ability to predict where shallow landslides are likely to occur is relatively good.

AFFECTED RESIDENCES

In our opinion, each of the 23 affected residences lies within what we would broadly consider a “landslide hazard area” due to their location on an alluvial fan, toeslope, or landslide runout zone. To those not familiar with landslide processes, alluvial fans and toeslopes often seem like good sites for home construction due to their position above the major river floodplains, their gentle slopes, and the views they often afford. However, to geologists whose jobs involve landslide risk analysis, these landforms are widely recognized as hazardous areas. The fact that some of the affected homes were constructed decades ago yet had never before been impacted by landslides reflects the infrequent and episodic nature of debris flows and debris floods. Large magnitude debris flows and debris floods often have return intervals on the order of hundreds of years. In addition, such events occur naturally as evidenced by the 15 landslides that originated in mature forests where no upslope management activities had occurred. Thus, even in the absence of any forest practices activities in upslope areas, properties located on alluvial fans and toeslopes are still at risk of being impacted by landslides.

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[7] This is the van den Heuvel property located at 3800 Nelson Road.

POLICY IMPLICATIONS

Our findings have several policy implications for DNR-State Lands. We have summarized each below.

State Lands' approach to recognizing and identifying slope stability issues during the pre-sales (i.e., planning) phase of the timber sales process appears to be working. In DNR's Northwest Region, geologists have been addressing landslide-related issues in the State Trust Lands timber sales program since 1987. The geologists' role is to screen proposed timber sales and identify areas of potential instability. Once these areas are identified, a field review with the forester(s) responsible for timber sale design occurs and landslide-prone areas are almost always removed from the sale. Such "leave areas" typically encompass the bedrock hollow and inner gorge landforms described earlier in the report as well as other areas that exhibit signs of instability.

Landslides that began near the recent "Gasping Goodwin" and "Jack Straw Aerial" timber sales initiated in unstable slope leave areas, suggesting the geologist involved in those sales recognized the landslide hazard and worked with the forester to exclude potentially unstable areas from the harvest areas. In the few other cases where shallow landslides originated near DNR timber sales in Whatcom County, anecdotal accounts indicate these landslides also occurred along the margin of, but not inside, recently harvested areas. Based on these findings, it is our opinion that continued geologist involvement in the timber sales program is both important and effective in preventing management-related landslides.

The availability of high-resolution LiDAR data greatly improves geologists' ability to recognize and identify areas of instability. Before LiDAR, landform and landslide mapping was imprecise and subject to a fair degree of error due to the low resolution of the topographic data available. LiDAR-derived digital elevation models allow for the efficient and effective mapping of steep, convergent landforms and other areas where shallow landslides originate. LiDAR gives geologists the ability to identify and map landslide-prone sites before going to the field, allowing them to focus their field review in those areas where slope stability issues are most likely to exist. Once in the field, LiDAR-based maps allow all field staff to navigate complex terrain, increasing the likelihood that all unstable slopes will be identified and addressed.

Geologists in the DNR-Land Management Division are currently developing a LiDAR-based shallow landslide screening tool that can be used to help identify landslide-prone sites during the timber sale planning process. This tool shows great promise and is expected to be available for use within the agency sometime in 2010. While DNR has LiDAR data for most State Trust Lands in western Washington (including Whatcom County), some areas are not yet covered. In addition, some of the early LiDAR data is of poor quality and lacks the resolution of the more recently acquired data.

Acquiring high-quality LiDAR data for all State Trust Lands in western

Washington would improve the effectiveness of State Lands' landslide risk management strategy. Partnering with private landowners and the United States Forest Service (both of whom have informally expressed interest in working with DNR on LiDAR acquisition) would help reduce costs.

DNR should continue assessing the potential for orphaned roads to threaten public safety in light of the orphaned road failure above the Mount Baker Highway/Marshall Hill Road site. Hundreds of miles of orphaned roads exist on State Trust Lands in Whatcom County alone. Many of these roads are in remote areas and/or in locations that do not pose a threat to public safety. Others, like the site above Mount Baker Highway, could threaten public safety if the road were to fail or collapse. DNR identified, mapped, and assessed orphaned roads on State Trust Lands in Whatcom County between 2001 and 2005 but some roads may have been missed. Had LiDAR imagery been available at the time of the assessments, a more complete inventory of orphaned roads would likely have been produced.

Now that LiDAR data is available for all State Trust Lands in Whatcom County, roads missing from the initial inventory may be identifiable. DNR staff could utilize LiDAR to identify and map orphaned roads above populated areas that were not included as part of the 2001-2005 assessment. Once identified and mapped, a field-based evaluation of the roads could be performed to assess landslide risk. Such a project would require significant investments in time and financial resources, both in the form of staff to perform the mapping and assessments and funds to conduct any necessary mitigation work. Preliminary estimates of staff resources needed to complete the orphaned road assessments (excluding mitigation work) on State Trust Lands in Whatcom County range from 9 to 15 staff months.

The initiation of four landslides on two parcels that DNR purchased after they were logged suggests the need for additional geologic review of proposed land acquisitions. DNR regularly purchases, sells, and trades parcels of forestland to achieve a variety of management objectives. Currently, the agency reviews slope stability and related geological information as part of its review and appraisal of potential acquisitions. The agency should consider incorporating a more formal slope stability review process as part of its land acquisition program. Depending on the number and size of proposed land acquisitions, this could be a significant workload that may require additional staff resources.

The uncertainty surrounding harvest effects on landslide initiation at five sites highlights the need for additional research into the cause-and-effect relationship between tree removal and changes in slope hydrology. While some research on this subject has been conducted, much remains to be learned. Investigating how timber harvesting affects water delivery to the soil, water movement through the soil, and water table fluctuations in downslope areas is important in understanding the degree to which tree removal in stable upslope areas can affect landslide potential at unstable sites downslope. Currently, the Cooperative Monitoring, Evaluation, and Research (CMER) Committee of the Forests and Fish Adaptive Management Program is conducting landslide-related research, but this subject is not within the scope of its research program. DNR should consider working through CMER to determine if this research could be incorporated into CMER's existing work plan. If not, DNR should consider partnering with researchers at universities or government agencies (United States Geological Survey or United States Forest Service) to perform the work. Such research is likely to cost between $300,000 and $500,000 and take several years to complete.

Individuals whose homes are located in landslide run-out zones are at risk of being impacted by debris slides, debris avalanches, debris flows, and debris floods. In managing State Trust Lands, DNR works to ensure its activities do not contribute to logging-related landslides that threaten public safety. However, individuals living in landslide hazard areas must recognize the inherent risks they face. These risks exist whether upslope areas are managed for timber production or not. State and local government agencies (including the DNR-Division of Geology and Earth Resources and Whatcom County) should consider an effort to better educate and inform the public about landslide hazards. In addition, Whatcom County might consider reviewing its approach to land use planning and permitting to ensure landslide hazards are recognized, identified and adequately mitigated when new homes are constructed in landslide run-out zones. Several homes impacted by the January 2009 landslides had been constructed in just the past few years.

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