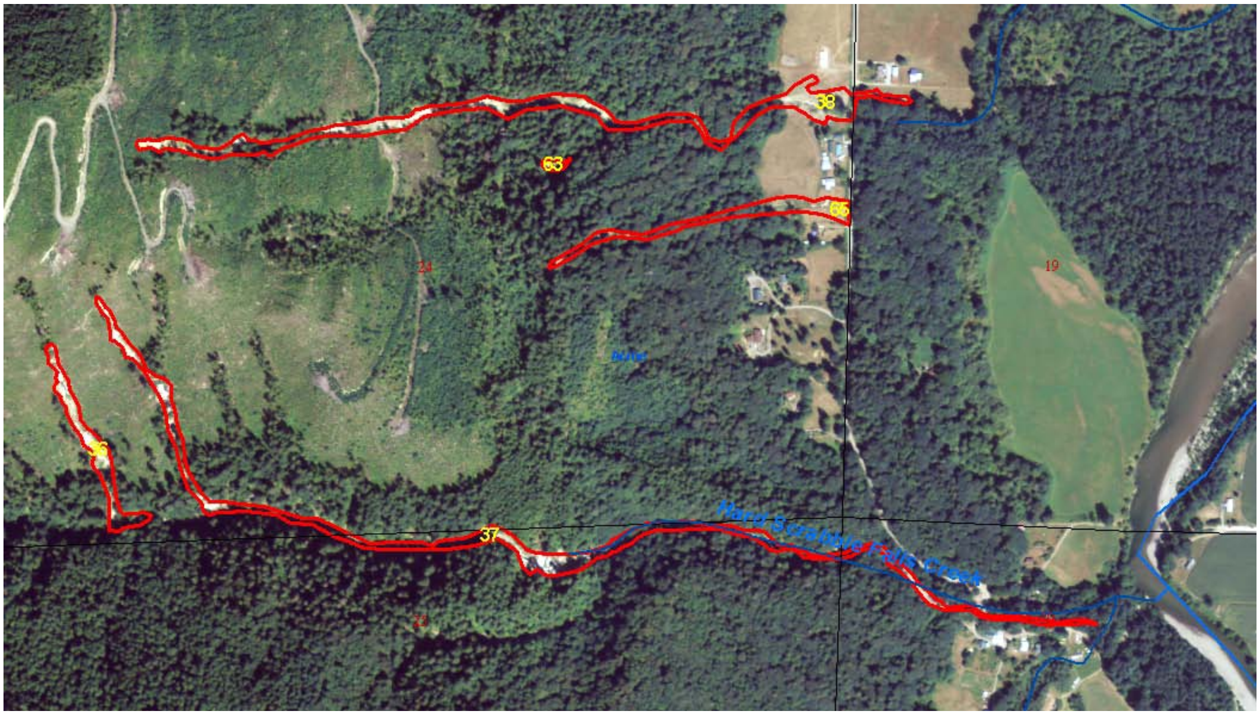

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

Reconnaissance study of landslides related to the January 2009 storm in the Acme Watershed

January 2010

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WASHINGTON STATE DEPARTMENT OF
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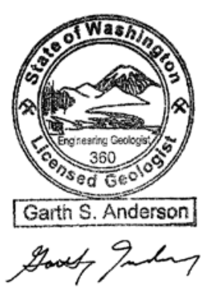

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Executive Summary

This report describes a reconnaissance study of landslides that occurred in the Acme Watershed Administrative Unit (WAU), during the period from 2006 to late 2009 (Figure 1). Most of these landslides occurred during a major precipitation event in January of 2009 which triggered hundreds of landslides throughout Washington State and caused extensive property damage within the Acme watershed of central Whatcom County. The rainfall return interval for the January 7-8, 2009, storm is on the order of 50 to 100 years (Grizzel and others, 2009).

The January 2009 storm, while rare, is the type of event that produces widespread mass wasting and associated impacts. The Acme watershed has a long history of landslides (Kovanen and Slaymaker 2007; Orme 1990). Orme found major events like the 1917 and 1983 landslide producing storms occur every 60 to 70 years.

This report is based solely on interpretation of oblique photos taken on Nov. 4, 2009, and National Agriculture Inventory Project (NAIP) orthophoto imagery from August 2009. No fieldwork was conducted to verify findings from photo analysis. For these reasons, this report must be regarded as a reconnaissance study. A total of 101 landslides were inventoried. The following is a summary list of findings.

1. This study suggests the Acme Watershed Analysis and the current Forest Practices Rules are effective at identifying areas prone to shallow landsliding.
2. Twelve road related failures were found (12 percent of the slides verses 43 percent of road related slides inventoried in the Acme Watershed Analysis, 1999).
3. Low road-related failures appear to reflect the higher standards of road construction and maintenance since the 1983 storm event
4. A total of 78 landslides appear to have initiated from high hazard Mass Wasting Map Units (MWMUs) delineated in the Acme Watershed Analysis. While issues related to standard mapping discrepancies were noted, the lack of field verification precludes detailed conclusions relating to specific MWMUs.
5. The Acme Watershed is regulated under watershed analysis prescriptions; however, 73 landslides occurred within landforms that appear to be “rule identified” under standard forest practices rules (Appendix C).
6. Most landslides (87) originated from slopes likely having initiation gradients greater than 70 percent. Of these, 74 had gradients likely in excess of 80 percent,
7. A total of 61 slides initiated outside of current forest management areas. They initiated in buffers on unstable slopes or in mature timber (50+ years old).
8. Twenty slides were from harvest units (0 to 20 years old) and eight were from young forests (20 to 50 years old).
9. Thirty-eight landslides reached the floor of the South Fork Nooksack Valley. Two of these were from forest roads and 5 landslides initiated from areas that had been harvested since implementation of the Acme Watershed Analysis MWMU prescriptions in 2000. The rest were from mature forest or non-harvested buffer zones near unstable landforms.
10. A majority (71 percent) of all landslides initiated in areas harvested 20 to 50+ years ago. These areas were harvested under previous Forest Practices rules that afforded less protection to unstable slopes or landforms than do the current rules.

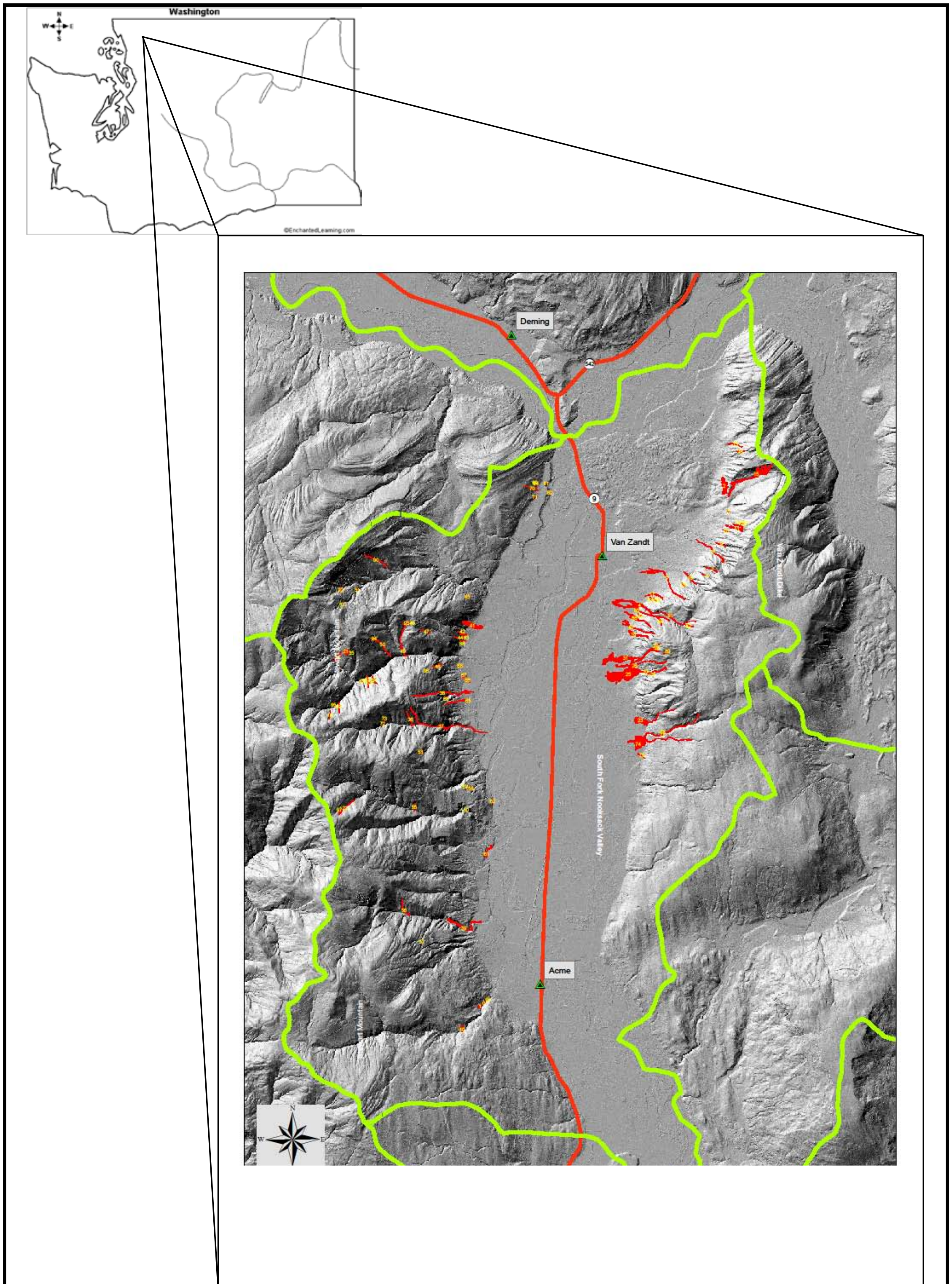

Figure 1. Location map with lidar representation of the Acme WAU showing landslides which appear to have initiated during the 2009 storm event. (DNR)

Introduction

The Acme Watershed is located in central Whatcom County along the lower South Fork of the Nooksack River (Figure 1). This reconnaissance study of the watershed was performed to review landslides that occurred between 2006 and 2009. This report is based solely on remote sensing; no current air photos were available at the onset of the project, so oblique aerial photos were obtained on November 4, 2009. These observations were augmented with 2009 NAIP orthophoto aerial imagery and Whatcom County lidar. No observations were field verified. However, Sierra Pacific Industries and DNR foresters provided locations for several landslides that occurred during the 2009 storm.

These data suggest that most of the landslides described in this report resulted from a large storm on January 7 and 8, 2009. Intense rainfall along with melting snow in the upland areas likely saturated the ground and triggered many landslides; we identified 101 landslides that occurred during the 2006–2009 time window covered by our data sets, and many more are likely present but not identified owing to canopy cover (see Brardinoni, 2002). A total of 38 landslides extended from forested uplands onto the South Fork Nooksack River Valley where some damaged property including homes and roads. Appendix A lists attributes of these landslides using the Landslide Hazard Zonation protocol insofar as practical (http://www.dnr.wa.gov/Publications/fp_lhz_protocol_v2_1_final.pdf).

Objectives and limitations

The primary objective of this study is to characterize landslides that resulted from the January 2009 storm by gathering information as to landslide type, slope gradients at initiation areas, and land use. We also investigated the relation to:

1. Land use;
2. Forest stand age;
3. Forest Practices "apparent" rule-identified landforms; and
4. High hazard landforms from the Acme Watershed Analysis.

The chief limitation of this effort was an inability to view slopes on the ground due to schedule and budget constraints. Field verification would have allowed positive determinations as to the correspondence of landslides and the 2009 storm event through the use of detailed vegetation and soil weathering characteristics. It is important to note that potentially unstable slopes and landforms must be field verified by the Department to qualify as 'rule identified' under the Forest Practices rules (WAC 222-16-0501(d)). This requirement helps assure that unstable slopes are properly identified and reduces the number that might be misidentified through the use of aerial photography alone. Although the availability of high-resolution Light Detection and Ranging (lidar) images increases confidence in remote identification of unstable slopes, we use the term '*apparent rule identified'* throughout this report for accuracy.

In addition, some landslides may have been missed owing to the scale of remote sensing tools and reliance on oblique aerial photography (rather than multiple sets of stereo aerial photography typically used in such studies).

Watershed overview

The 36-square-mile Acme Watershed Administrative Unit (WAU) is located in Whatcom County approximately 11 miles east of Bellingham (Crown Pacific Limited Partnership, 1999). It contains the communities of Van Zandt and Acme (Fig. 1).

The dominant landform of the WAU is the gentle South Fork Nooksack Valley (average elevation ~ 280 ft), which comprises about 40% of the WAU. The western margin of the WAU follows the crest of Stewart Mountain at 2,600-3,000 feet, while the lower Van Zandt Dike (~ 2,000 ft) forms the eastern boundary. East-facing slopes on Stewart Mountain are incised by a series of small drainages including Jones Creek, Hardscrabble, Sygitowicz, and Todd Creek on the north. The flanks of the Van Zandt Dike are moderately sloping on the southern end, but become increasingly steep north of Tinling Creek, the only sizable stream in this area.

These differences in topography reflect the influence of the WAU's major geologic materials: alluvium, sandstone and associated sedimentary rocks, and phyllite. Most of the western slopes and the northern half of the Van Zandt Dike are underlain by sandstone and associated sedimentary rocks of the Chuckanut Formation (Dragovich, 2002). In areas underlain by these sedimentary rocks, hillslopes tend to be steep, soils are shallow, and shallow landsliding is the dominant erosional process. South of Tinling and Jones Creeks, slopes are underlain by phyllite and other metamorphic rock types, which are thinly layered (foliated) and locally shattered. Hill slopes formed from these metamorphic materials weather to produce more moderate slopes and deeper soils than slopes underlain by the Chuckanut Formation. Alluvium is subject to failure only along meander bends of the Nooksack River.

The area is influenced by a predominantly maritime-type climate with mild, wet winters and cool, dry summers. The area receives frequent and sometimes intense storms that approach from the Pacific Ocean. Yearly rainfall is estimated to average about 70 inches in the lower elevations to about 100 inches/year at higher elevations. In general, the majority of rainfall occurs between mid-October and late February (Crown Pacific Partnership, 1999).

The 2009 storm

An analysis of the January 2009 storm is presented in Grizzel and others (2009) who report that about 5.0 inches of rain fell in 24 hours and about 7.3 inches of rain fell during a 48 hour period. In addition, they note that 12 to 18 inches of snow was present at lower elevations prior to the storm, but most of this accumulation melted below 1,000 feet elevation during the storm. Their conclusion is that the rainfall return interval for the storm is on the order of 50 to 100 years (note that these values are probabilities, and as a consequence, fewer or more storms of this magnitude may actually occur during any given 50 to 100 year time period). Statewide, the 2009 storm event produced several clusters of landslides (Fig. 2).

Figure 2. Landslide locations from the January 2009 storm event (modified from Sarikhan, 2009). Also see http://www.dnr.wa.gov/ResearchScience/Topics/GeologicHazardsMapping/Pages/ger_quickreport.aspx.

Previous work in the Watershed

Several other investigations have been conducted in the Acme Watershed area. Chief among these is the Crown Pacific Limited Partnership (1999) Watershed Analysis, which includes a Mass Wasting Module. This module consists of a landslide inventory and landslide hazard analysis, which describes extent of moderate and high-hazard landslide areas as interpreted by the authors. Kerr Wood Leidel Associates Ltd. (2004) prepared a report on behalf of Whatcom County Public Works Department describing the Jones Creek alluvial fan. This report gives the history of debris flows in the drainage and their effects on the Jones Creek fan and on the community of Acme. This report includes risk mitigation alternatives. Kovanen and Slaymaker (2007) analyzed debris flow histories of several streams draining Stewart Mountain. Grizzel and others (2009) provide a detailed analysis of eighteen landslides related to the January 2009 storm that occurred on State Trust lands located on the western slopes of the Van Zandt Dike.

Project design and methods

Approximately 300 oblique aerial photographs were taken on November 4, 2009, using a Cessna-182 aircraft and hand-held digital cameras. Figure 3 shows the flight path. An additional 100 oblique aerial photographs were collected from other flights taken over the watershed immediately after the January 2009 storm event. A total of 101 landslides are identified; therefore, the number and percentage of landslides are essentially identical and are used interchangeably herein.

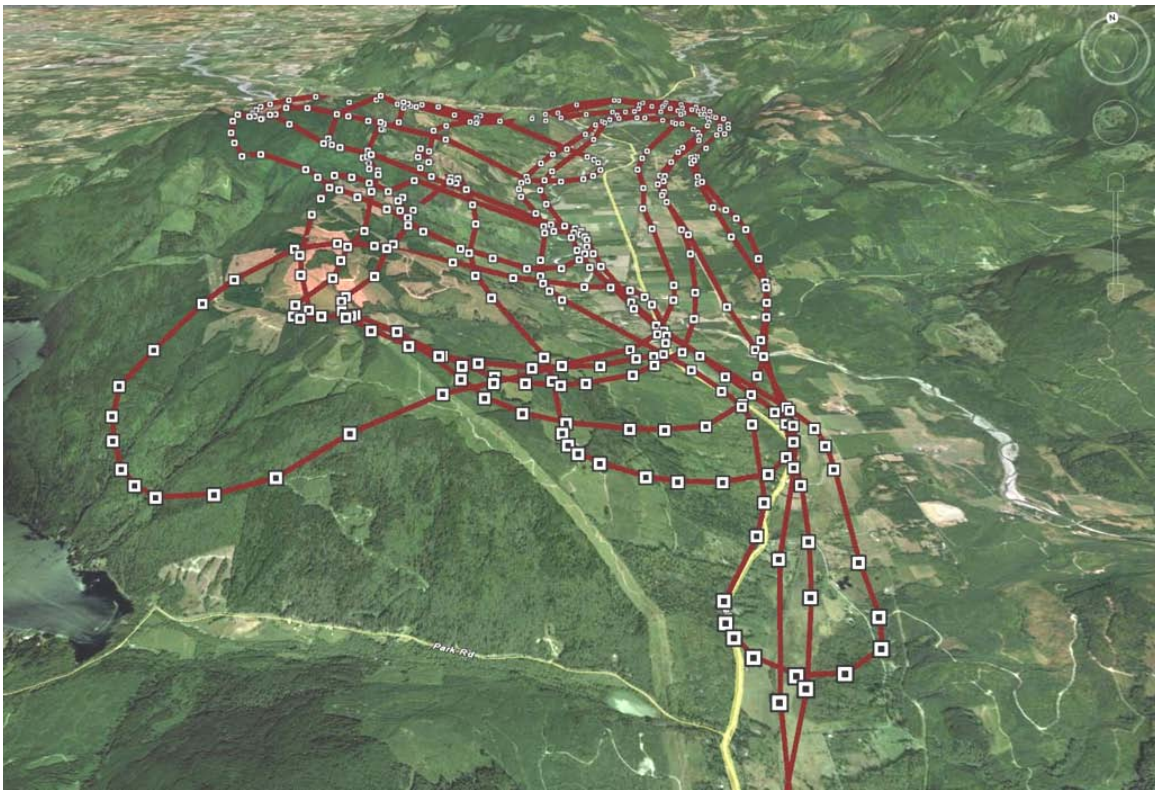

Figure 3. Oblique aerial photo flight-path taken of the Acme Watershed. Lake Whatcom is on the left and the South Fork Nooksack Valley with State Route 9 (in yellow) is shown. View is to the north and covers about ten miles from west to east. White boxes are changes in flight direction.

Landslides in the watershed (Map 1) were located, using the November 4, 2009 low-resolution oblique photographs, 2009 NAIP orthophoto images with one-meter resolution, and lidar images sub-meter resolution. Landslides were digitized directly into a GIS shape file using the 2009 orthophoto and 2006 lidar layers including 10-foot contour and slope gradient layers. Despite high-resolution, small landslides are difficult or impossible to detect unless they occurred where forests were recently harvested or where landslides flowed through open areas in the canopy.

To help in determining whether a landslide is related to the 2009 storm, only those landslides visible on the 2009 photos but not visible on the 2006 orthophotos were inventoried. If a 2009 landslide is a significant enlargement of a pre-existing landslide, that portion of the landslide that appears in the 2006 ortho-image was also inventoried. Twenty-five of the 101 landslides visible on 2009 orthophotos were also visible on 2006 orthophotos, but with a lesser extent. Landslide types are classified using generally applied Landslide Hazard Zonation project protocols as:

- *Debris slides* are shallow landslides that form from the disaggregation of materials on a steep slope and involve rapid movement of the soil and regolith.
- *Debris avalanches* are extremely rapid shallow flows of partially or fully saturated debris on a steep slope, without confinement in an established channel, (Hungr, 2001)
- *Debris flows* are shallow landslides that flow within a channel. These consist of soil and water with varying quantities of woody debris and are characterized by channelized flow, and often have long runout paths. Debris flows may include landslides such as mud flows, debris torrents, hyper-concentrated slurries, and landslide dam-break floods.
- *Deep seated landslides* are those in which most of the area of the slide plane or failure zone lies below the maximum rooting depth of forest trees, to depths from several to hundreds of feet.

See http://www.dnr.wa.gov/BusinessPermits/Topics/LandslideHazardZonation/Pages/fp_lhz_review.aspx

Figure 4 shows a typical debris avalanche in the Acme watershed.

Figure 4. Air photo of a debris avalanche north of Sygitowicz Creek. The landslide area is approximately six acres.

A spreadsheet was created containing data fields for each landslide (Appendix A, Landslide Inventory). "A variety of factors govern the certainly with which an analyst can remotely identify a landslide including ground cover, age and size of landslides, the scale, aspect or lighting conditions of an aerial photographs" (Adaptive Management program, 2004 pg 15, http://www.dnr.wa.gov/Publications/fp_lhz_protocol_v2_1_final.pdf) The level of mapping uncertainty for each landslide is determined by two geologists. These ratings are:

D = Definite: The author is certain that this is a landslide;
P = Probable: The author is almost certain that this is a landslide; and
Q = Questionable: The author is uncertain as to whether a specific anomaly is actually a landslide, but has included the feature for completeness.

The forest practices land use at landslide initiation area was recorded as:

- Forest road, abandoned road, orphan road, and landing;
- Harvest unit, young forest, mature timber; or
- Unstable slope buffer or riparian buffer.

Age classes for timber at the landslide initiation areas are generalized because of the lack of detailed and uniform harvest and planting information across the watershed. The stand age classes are:

- 0 to 5 years;
- 5 to 20 years;
- 20 to 50 years; and
- 50+ years

In many, if not most cases, landslides initiate on the steepest portions of slopes. In order to estimate the slope at the landslide initiation areas, polygons are defined using convergence and slope calculations from 2006 lidar together with the author's experience and geologic principles. Average slope gradients at these initiation polygons are calculated using a GIS application tool created by DNR SE Region staff. This GIS application tool averages slope gradient in a polygon digitized near the crown of the landslide and/or in what appears to be the initiation area.

A potential problem with this technique is that the method averages all pixels in the initiation area; for example, a slope of 55% in one pixel will be averaged with 96% slope in an adjacent pixel thus producing an average slope of 65%. Therefore, this method likely tends to under-estimate the slope at the initiation area. However, very-high-resolution pre-2009 lidar data are used, and for this reason, we believe our approach yields credible worst-case approximations of pre-failure slope angles at the initiation areas.

Lidar data are used to determine whether each landslide initiated in an apparent rule identified landform as defined in WAC 222-16-50. By way of review, these landforms are:

a. Inner gorges, bedrock hollows, and convergent headwalls with gradients greater than 70%;
b. Toes of deep-seated landslides with slopes greater than 65%; or
c. Outside edges of meander bends along high terraces or valley walls.

Other areas containing features indicating the presence of potential slope instability, which cumulatively indicate the presence of unstable slopes are also present, but without field verification, we were unable to evaluate these features.

Each landslide is evaluated as to whether it appeared to have reached a public resource. In addition, each landslide is also evaluated as to whether it flowed out onto the South Fork Nooksack River valley floor which is a surrogate for impacting private or public resources, such as roads, bridges, or houses.

The DNR GIS hazard unit layer was queried to check for landslide initiation points mapped in 1998 during the Acme Watershed Analysis landslide inventory and to determine the watershed analysis Mass Wasting Map Units (MWMUs) at the 2009 initiation area. MWMUs were verified per this study using lidar, gradients and topography.

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Findings

Map 1 shows landslides mapped for this project that apparently occurred as a result of the January 2009 storm. The numbers on the map correspond to the landslide numbers in the inventory in Appendix A.

We include all observed landslides without respect to landownership. Most forest management in the Acme watershed is regulated by specific prescriptions in the Acme Watershed Analysis (Crown Pacific Limited Partnership, 1999). Five landslides occurred in areas that are not regulated by the DNR, but are still included in this report.

Frequency of landslides by type

We assume that most landslides inventoried herein occurred during the 2009 storm. These include:

- Sixty-four debris flows. (This high percentage may, in part, reflect the lack of field observations which is more effective in locating debris avalanches and slides under the forest canopy.);
- Nineteen debris slides;
- Fifteen debris avalanches; and
- Three deep seated landslides.

Mapping uncertainty

Figure 5 shows the assigned level of certainty by landslide type. Debris slides had the lowest uncertainty; almost half of those mapped were designated as ‘Probable” due to their small size and relatively confined nature.

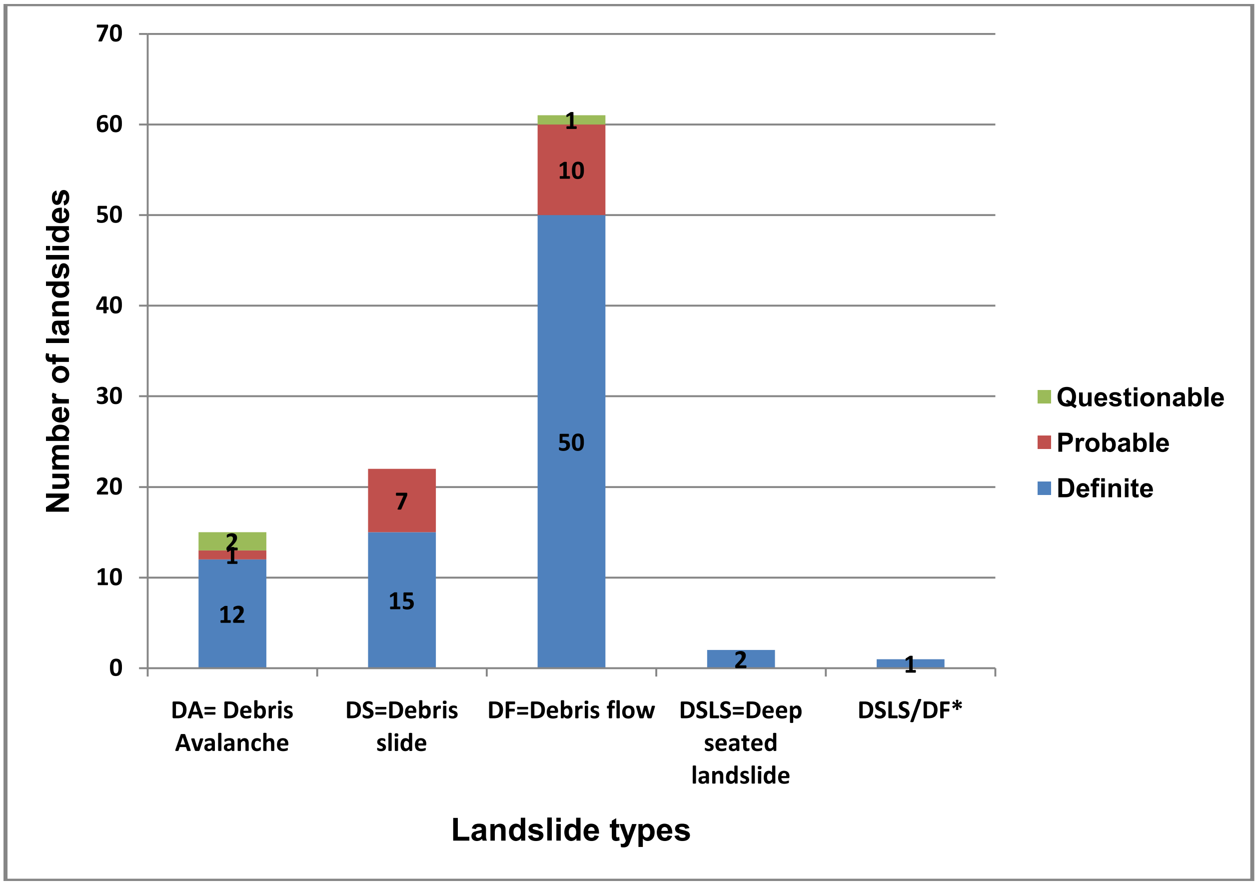


Figure 5. Distribution of landslide uncertainty by landslide type.

Slope gradients at landslide initiation areas

Figure 6 shows the slope gradients at the initiation areas of inventoried landslides. (Three 'indeterminate' designations shown on this graph are located in the Radonski Creek area where heavy canopy cover precluded identifying the initiation areas on the orthophotos.)

The mean initiation slope gradient is 86%. This average initiation slope gradient is high as compared to the threshold used in the Forest Practices rules to define landslide prone slopes (>70%) or as compared with less-consolidated rocks further to the south. However, 86% is consistent with initiation angles in relatively hard bedrock units elsewhere in the North Cascade Range (e.g., Lingley and Brunengo, 2007).

Eleven out of the 101 landslide had initiation area gradients <70% (i.e.; less than the threshold for rule identified inner gorges, bedrock hollows, and convergent headwalls). Some of these lower slope-gradient measurements resulted from averaging with the GIS tool utilized. Field data from Grizzel and others (2009) and more detailed GIS examination show localized zones with very steep slopes (>70%) within most of these 11 landslide initiation areas.

The Acme Watershed Analysis - Mass Wasting Module states "shallow landsliding becomes more probable on slopes greater than 73% because shallow soils (3-6 feet) can easily become saturated during intense precipitation when slope angles exceed the friction angle of the soil [commonly 70%]". (Benda and Coho *In* Crown Pacific Limited Partnership, 1999, p 3-17).

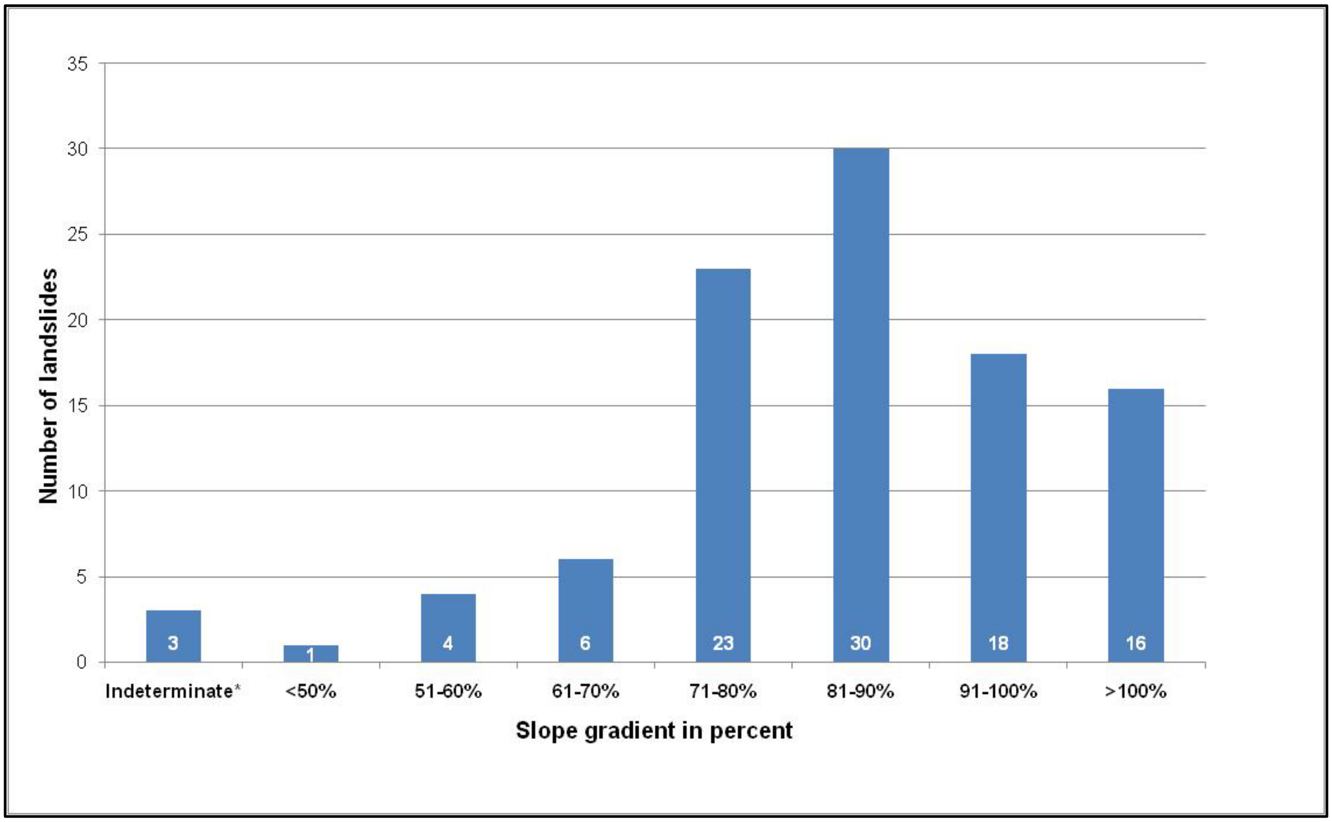


Figure 6. Slope gradients at landslide initiation areas for 101 landslides.

Figure 7 shows slope initiation gradients for 73 landslides associated with apparent rule identified landforms. Of these:

- A total of 68 landslides in apparent rule identified landforms are on topography steeper than 70%.
- Landslides in bedrock hollows and inner gorges occur in all gradient classes above 70%.
- Landslides in convergent headwalls were found only on slopes greater than 81%.
- A total of four deep seated landslides were reactivated from the 2009 storm.
- The one landslide that is below 50% was referenced in the State Trust Land's report by Grizzel and others as localized evacuation area of 50 to 70%; however, to be consistent, the GIS tool estimate was used.

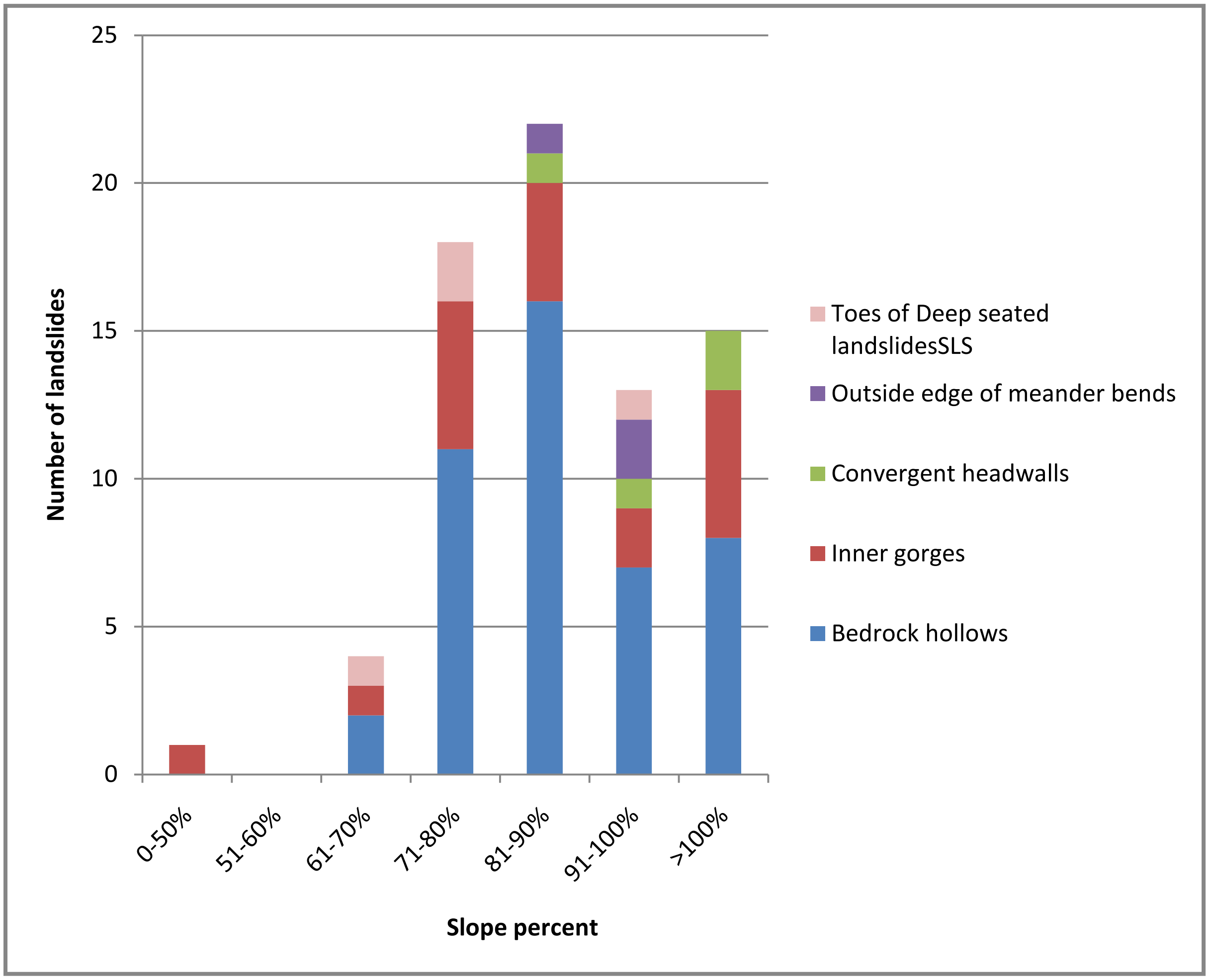


Figure 7. Landslide initiation slope gradients and apparent rule identified landform.

Twenty-five landslides not associated with rule identified landforms are:

- Eight forest roads;
- Eight harvest units aged 5-20 years old;
- Five harvest units aged 0-5 years old;
- Three mature timber units 50+ years old; and
- Onebuffer on an unstable slope (Coyle and Hanell, 2009),

Land use and stand age at landslide initiation areas

The history of land use in the watershed includes a period of land clearing from the 1880s to the mid 1900s. A large wildfire shortly before 1885 burned much of the forest along the western slopes of the watershed. A railroad line into the valley was established in 1891. By the 1940s, aerial photos show that most of the valley bottom had been logged and cleared for agricultural use. Clearing increases the distance landslides run out onto the valley floor. Unburned upland forest was mostly logged by this time, except for some steep lower slopes (Crown Pacific Limited Partnership, 1999).

Private landowners live mostly in the valley bottom. State Trust lands cover the very southwest and one section on Stewart Mountain and most of the Van Zandt Dike. Sierra Pacific Industries' ownership covers most of Stewart Mountain.

Figure 8 shows land use and stand age for the 2009 landslide initiation areas. During this investigation, about 50% of these estimates were checked against stand age data provided by Sierra Pacific Industries. Twelve landslides are associated with roads and landings. Twenty-eight landslides were associated with harvest units (0-20 year old forests) and young forests (20 to 50 years old). Seventy landslides initiated where the forest had not been harvested for at least 20 years. Of these, sixty-one slides occurred in mature forest or on buffers on unstable slopes, and 49 slides were in age class 50+ years. Ten landslides were in the age class of 0-5 years (Figure 10).

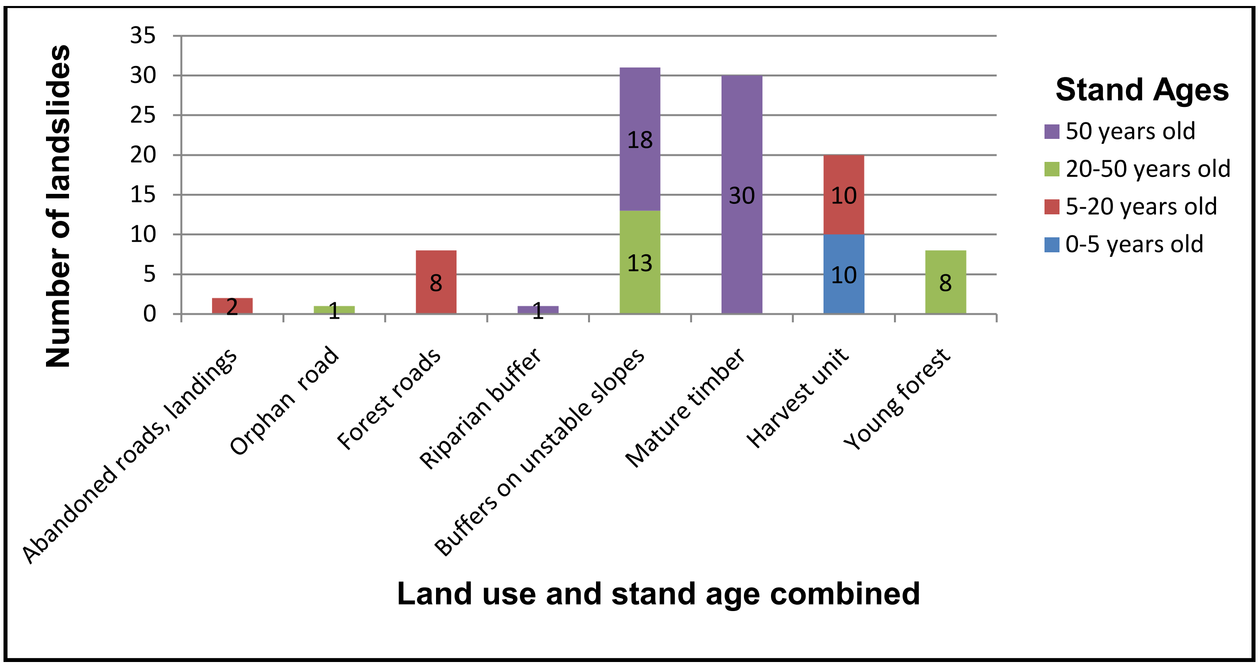


Figure 8. Land use and stand age at initiation areas for 101 mapped landslides.

The Acme Watershed Analysis landslide inventory (191 landslides) used similar land use categories to those used for this report. However the only clear comparison is for roads; Figure 9 show that forest roads were a larger component (82 out of 191 landslides or 43%) of the inventory than are shown for this report (12 out of 101 landslides or 12%). After the Watershed Analysis process, Road Maintenance and Abandonment Plans were adopted. These contain requirements that forest roads meet higher standards before harvest activities are approved.

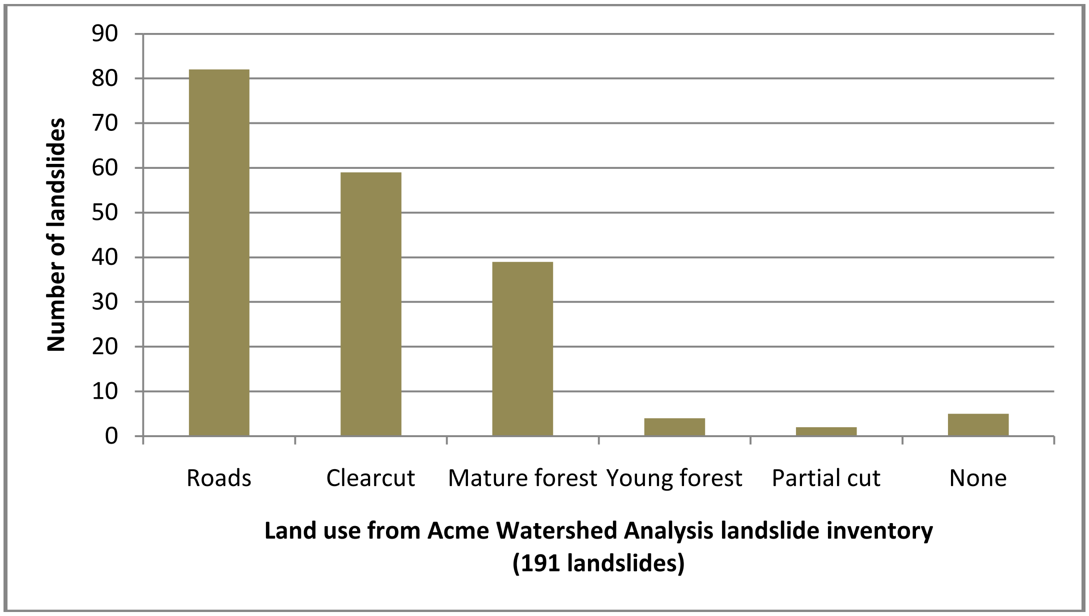


Figure 9. Land use data from the Acme Watershed Analysis.

Differing harvest-related land use characterization precludes further comparison among the two reports. For example, there is no comparison for Watershed Analysis unstable slope buffers by land-use category and the current Forest Practices rules, which were adopted in 2001.

Landslides and delivery to a public resource

Acme watershed prescriptions have been in effect since February 2000. Stand ages used in this report (0-5 and 5-20 year old) overlap this time frame. It is beyond the scope of this reconnaissance report to determine the specific Forest Practices application for each landslide, but we can attempt to describe those landslides which delivered debris to a public resource or threatened public safety.

None of the landslides that initiated in harvest units with trees ranging from 0 to 5 years old delivered to a public resource or threatened public safety (see Figure 10). However, nine out of 11 landslides that initiated in harvest units having a forest age class of 5 to 20 years old delivered to a public resource. Most of the landslides that initiated in young forest (20 to 50 years) and in mature timber (50+ years) delivered to a public resource.

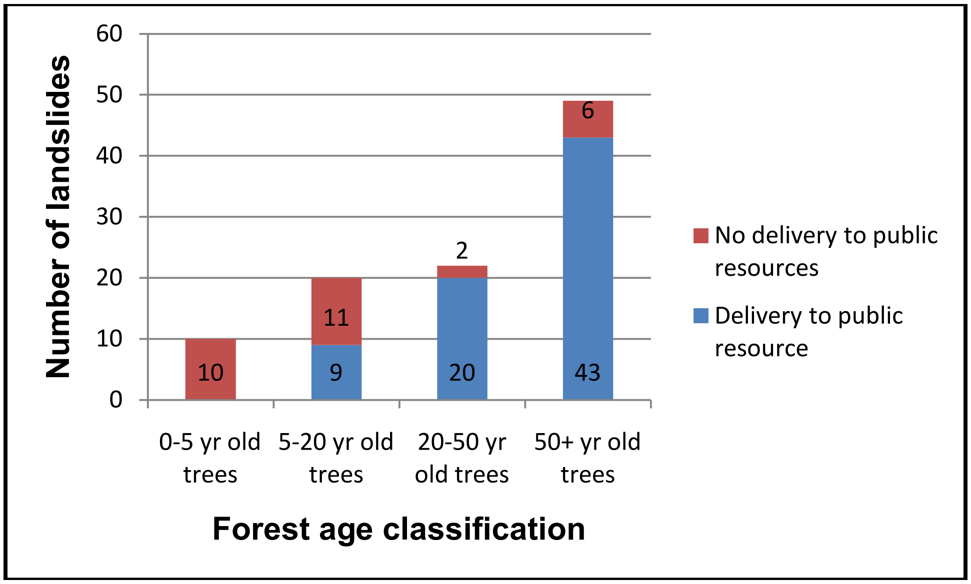


Figure 10. Landslides that delivered to public resources by forest age class.

Landslide delivery to the South Fork Nooksack River Valley

Some landslides deposited sediment and debris on the South Fork Nooksack River Valley; several of which impacted private property or public infrastructure. For example, Figure 11 shows impacts of debris flows delivering to the valley bottom of the South Fork Nooksack Valley south of Sygitowicz Creek.

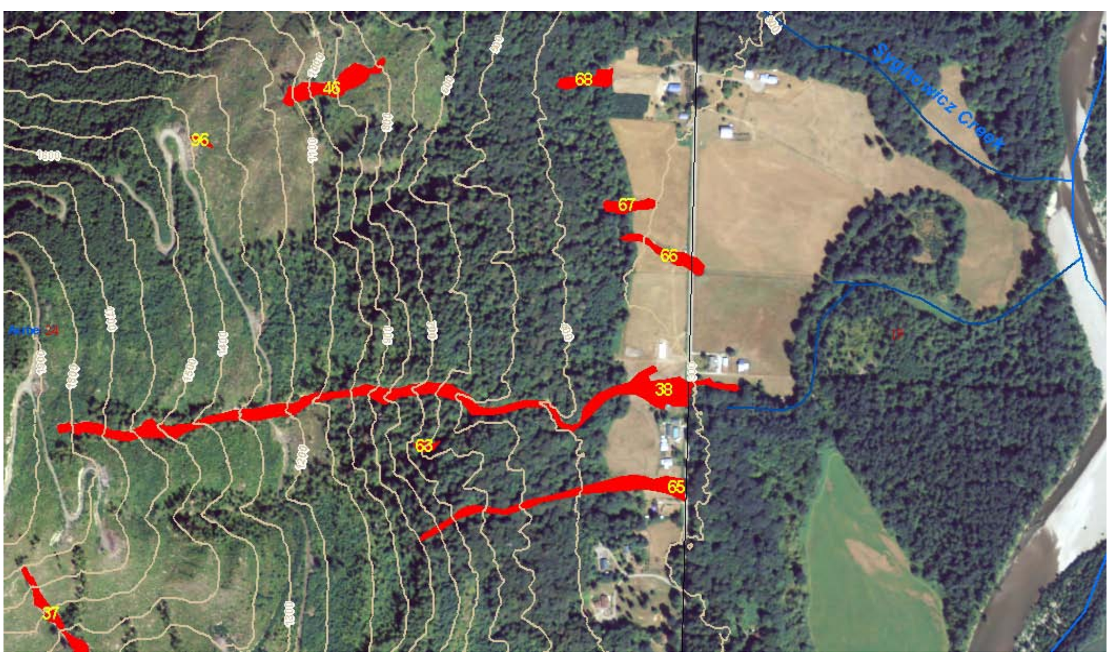


Figure 11. NAIP orthophoto image flown in August 2009 showing several debris flows (red) south of Sygitowicz Creek. Numbers refer to landslide Inventory numbers in Appendix A

The area considered the South Fork Nooksack Valley of the Acme WAU is outlined (dashed red line) on the geologic map in Figure 12. (‘Valley’ as used in this report includes flatter terrain below the valley walls comprising alluvial surfaces, alluvial fans, peat, landslide deposits, and glacial deposits, which form the valley floor). Valley bottom is also used as a demarcation proxy for public safety.

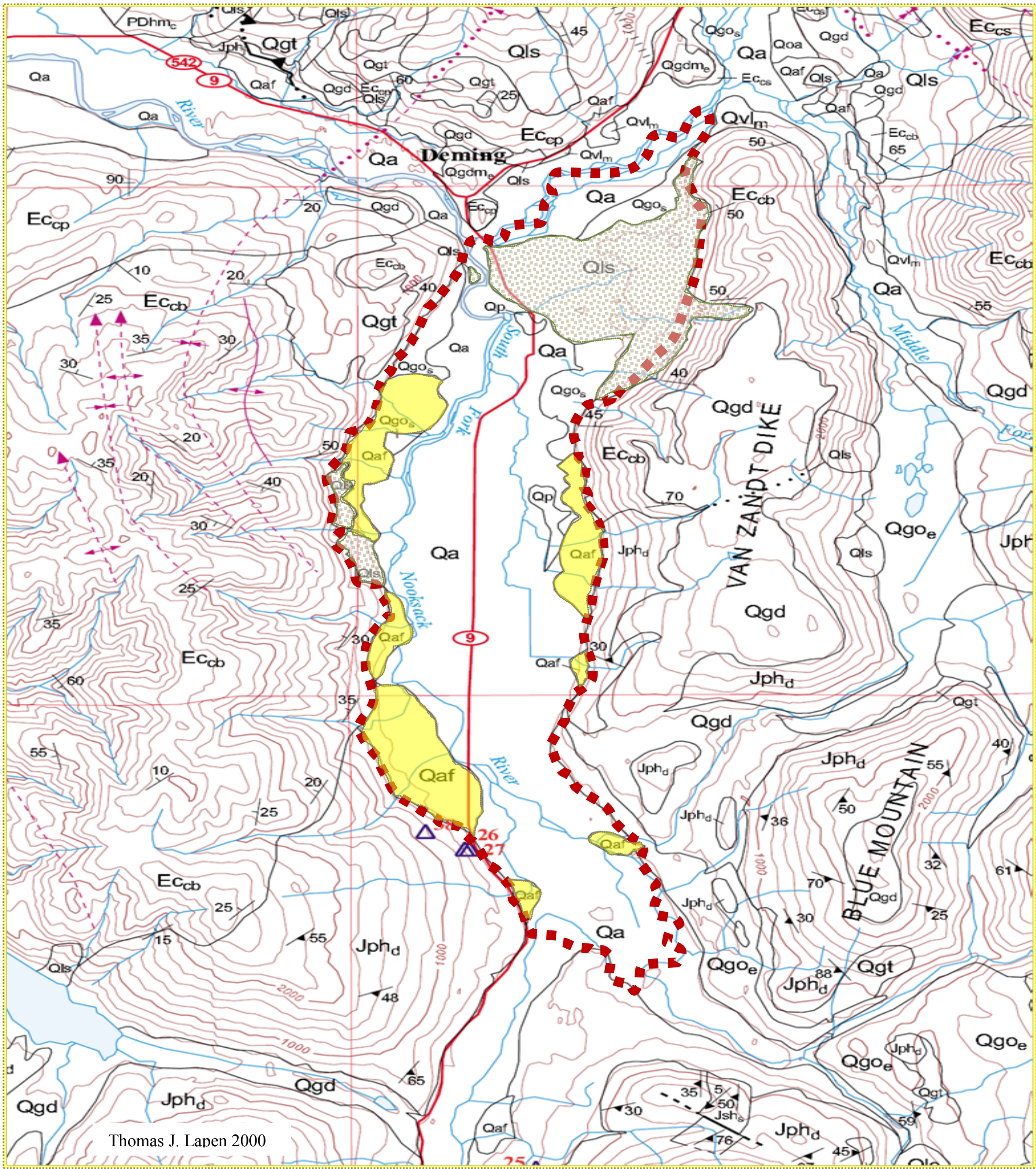


Figure 12. A portion of the Geologic map of the Bellingham 1:100,000 Quadrangle by Lapen (2000) delineating the area considered the South Fork Nooksack Valley for the purpose of this report (red dashed line).

Geologic units Qa (alluvium), Qaf (alluvial fans- yellow polygons), Qp (peat), Qls (landslide deposits, stippled polygons), and Qgo and Qgos (continental glacial outwash deposits) make up the geologic valley bottom (shown with red dashed line). Sandstone is shown as unit Ec_{cb} and Ec_{cs}. Phyllite is shown as unit Jph_d.

The western portion of the South Fork Nooksack Valley is composed of continuous alluvial fans and landslide deposits. All fans and landslide deposits in the Acme WAU presumably developed since the latest glacial retreat, approximately 12,000 years ago. Regional investigations of alluvial fans discussed in the Kerr Wood Leidel (2004) report and Orme (1990) suggest that these very large fans are associated with debris flows with return periods of 480 years. Major landslides occur every 60 to 70 years. Larger mapped landslide deposits (Qls) in the northeast section of the WAU are apparently associated with bedrock slab failures in the Devil's slide, an ancient deep seated landslide/rockfall (Benda and Coho, 1999).

Figure 13 shows the distribution of landslides delivering to the valley. A total of 38 landslides reached the valley. The 53 that deposited debris in the upland usually ended in stream channels. These totals do not include seven questionable landslides that appear to end in higher elevation streams with no clear evidence that sediment flowed onto valley. Three landslides on fluvial terraces delivered directly to the Nooksack River.

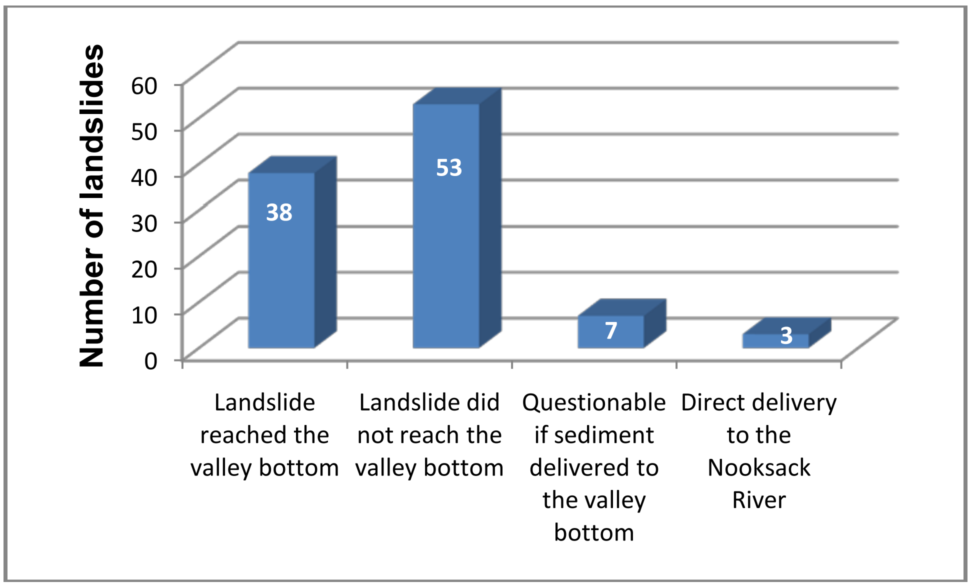


Figure 13. Landslides that delivered to the South Fork Nooksack Valley.

Figure 14 summarizes land use associated with landslides that deposited on the South Fork Nooksack Valley. Figure 15 shows the frequency of landslides by forest age-class at the initiation area for 38 landslides that reached the valley bottom.

There were 22 landslides that originated in mature forests greater than 50 years old. Of these the slope gradients at initiation areas were predominantly greater than 70%. Three of these landslides were located in the steep topography near Radonski Creek and the initiation area was not evident.

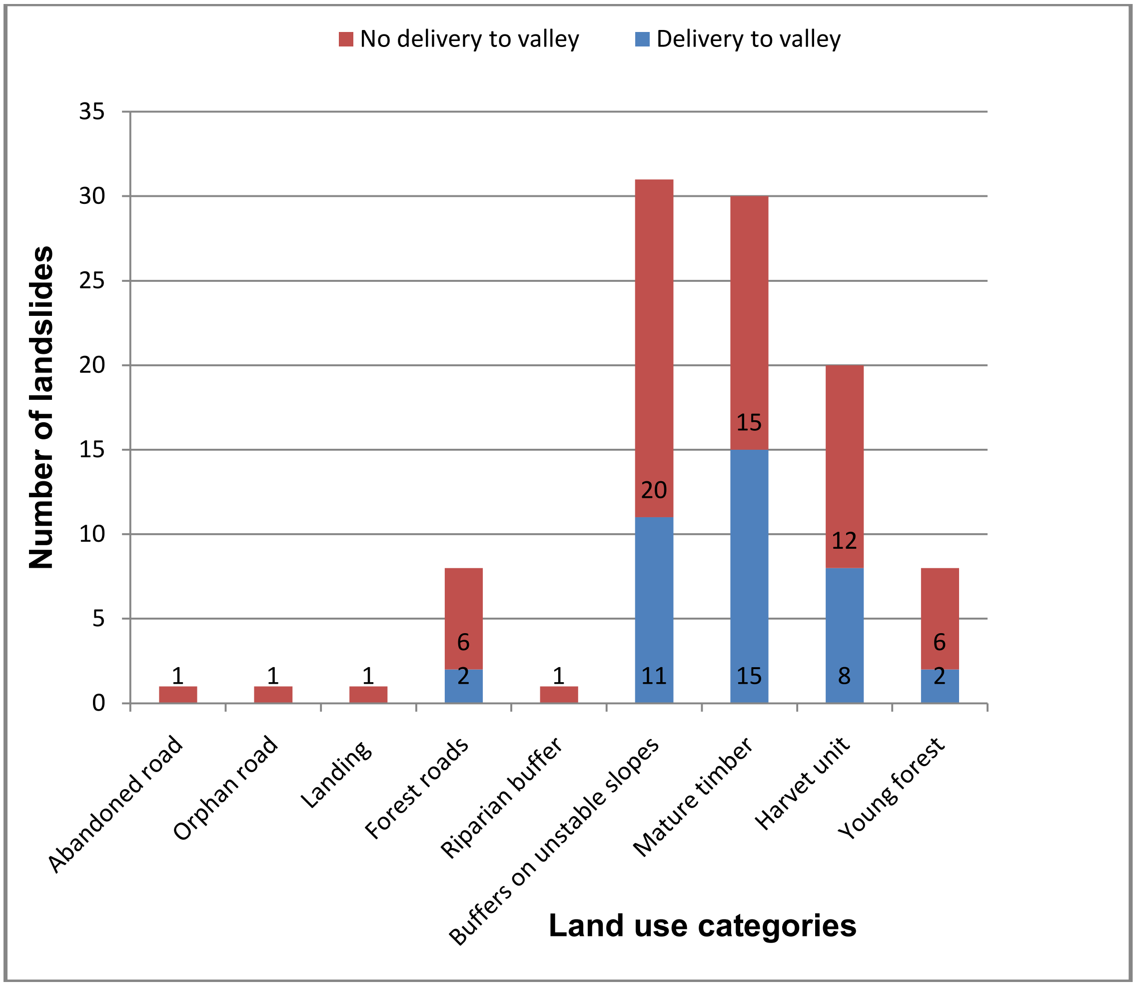


Figure 14. Land use associated with landslides that delivered to the South Fork Nooksack Valley.

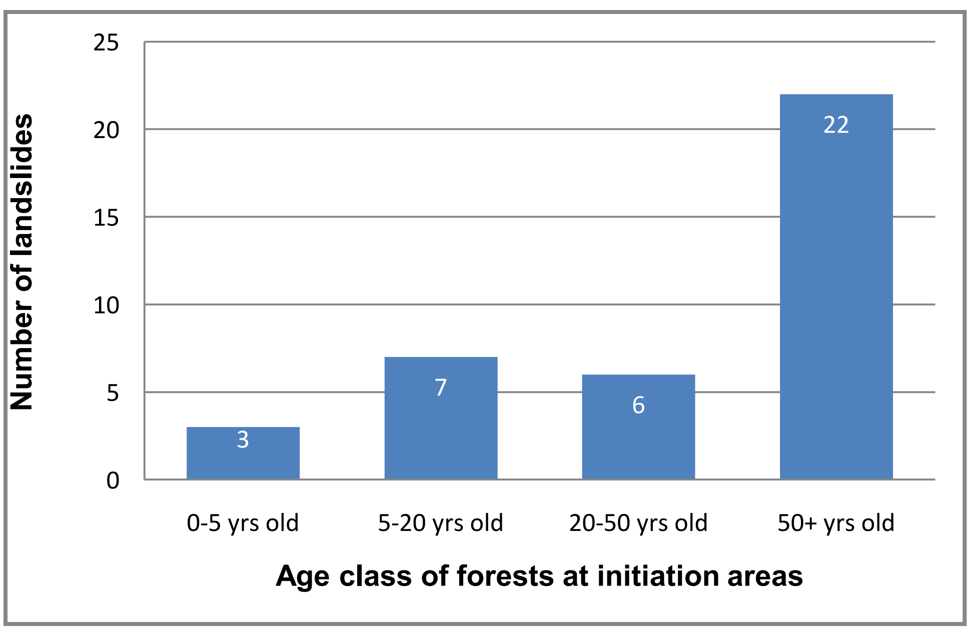


Figure 15. Age class at the initiation area of landslides that reached the South Fork Nooksack Valley.

Review of the Acme Watershed Analysis Mass Wasting Map Units

Prescriptions associated with MWMUs are the basis of unstable-slope related forest management regulation in the Acme Watershed. Mass Wasting Map Units (MWMUs) used during the Watershed Analysis process (Washington Forest Practices Chapter WAC 222-22, 1997) characterize potential for management-related instability by developing a landslide map and inventory. MWMUs are based on the frequency of landslides and their relation to landforms, topography, slope gradient, geologic units and structures, slope hydrology, and natural vegetation types.

Ten MWMUs are delineated in the Acme Watershed Analysis. These are based on landslides mapped from aerial photography compiled at a 1:24,000 map scale with field verification (Benda and Coho, 1999 In Crown Pacific Ltd Partnership, 1999). The data have been digitized to produce layers currently housed in the DNR GIS database (Vaugeois and Boyd, 2007). See Appendix B, Acme Watershed MWMUs for detailed descriptions and maps of MWMUs.

Some Acme Watershed Analysis MWMUs have only subtle differences among their physical attributes and associated landforms. This can create confusion when assigning a specific location on the ground to the appropriate MWMU. For example, MWMU #7 contains parts of MWMUs #1, #2, and #6 and MWMU #6 “probably contains other map units” (Benda and Coho, 1999 *In* Crown Pacific Ltd Partnership, 1999).

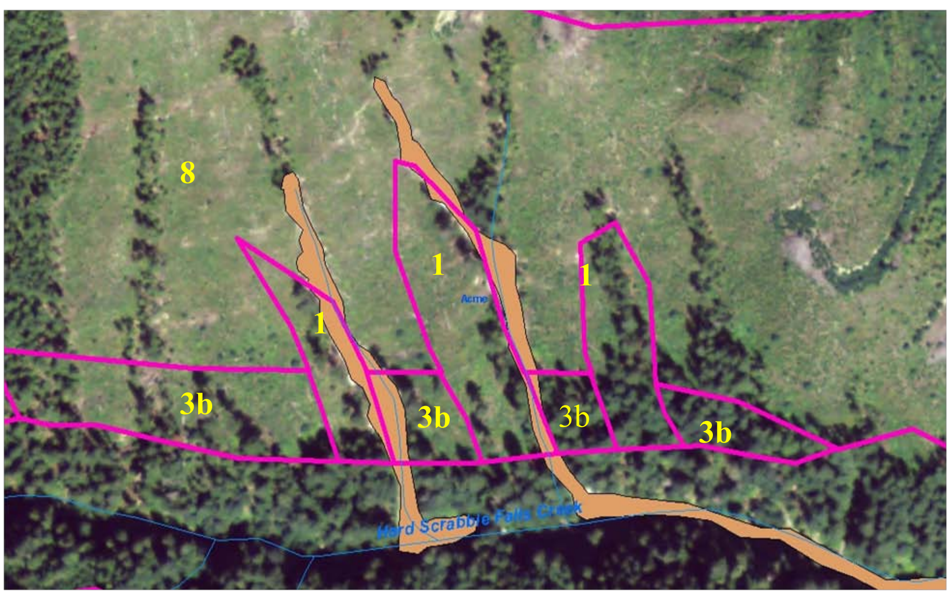


Figure 16. Acme Watershed MWMUs (magenta polygons with yellow labels) overlain on 2009 NAIP orthophoto imagery. Two debris flows that probably occurred in 2009 are shown in orange.

Some MWMU boundaries do not correspond with current digital information, orthophotography, and/or lidar imagery. Some MWMUs defined by Benda and Coho can be mapped with greater accuracy using this current technology (Fig. 16). For example, the buffered area for MWMU #1, shown by strips of timber in obvious bedrock hollows meets the goal of the MWMU #1 prescriptions, but does not correspond to the MWMU boundary as taken from the DNR database. The initiation areas of these landslides would have been tallied in MWMU #8, which suggests that land sliding should be rare or non-existent. However, we determined these two landslides are actually MWMU #1. Apparently in the example above, the layout of harvest units left on the ground by foresters correctly match MWMUs as described by Benda and Coho. This underscores the importance of field verification.

Landslides in MWMUs fell into these categories:

- Forty-nine landslides are assigned to the correct MWMU as determined using the DNR GIS data; these are moderate to high hazard areas.
- Twenty-nine landslides were outside the correct MWMUs, but are in other MWMUs properly assigned moderate to high hazard.
- Twenty landslides initiated in a MWMU defined as an area that landslide activity is *rare to non-existent and no delivery directly to streams of any order…the area contains steeper, more unstable ground but that do not deliver to any water or public resources* (Benda and Coho, 1999). Of these twenty landslides, 12 delivered to a public resource and four delivered debris to the South Fork Nooksack Valley.
- The initiation area of three landslides in the Radonski Creek area could not be determined

Appendix B contains more detailed information on MWMUs along with MWMU maps and the 2009 likely landslides in this report.

Landslides and Forest Practices rule-identified landforms

Forest management in the Acme watershed is regulated with specific prescriptions in the Acme Watershed Analysis (Crown Pacific Limited Partnership, 1999). However, it is informative to compare landslides from the 2009 storm with potentially unstable slopes and landforms as defined in the Forest Practices rules. These rules define slopes and landforms that are potentially unstable (WAC 222-16-050 (1) (d)). The definitions are designed to avoid impacts to public resources and threats to public safety and are based on an examination of landslides described in 55 watershed analyses, which were used to determine common physical characteristics associated with slope failure on forest lands. Rule identified landforms must be field verified by the Department. Nonetheless, we have considerable confidence in our landslide determinations and their relation to apparent rule-identified landforms.

Figure 17 shows the relation of apparent rule identified landforms and inventoried landslides. The category, "No Rule Identified Landforms", contains slopes regulated under WAC 222-16-050 (1) (d) (E), which states that *areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes*" are also rule-identified. We have less confidence in these determinations. Future field review may reveal contributing factors for the initiation of these landslides (e.g., seeps, springs, old roads or skid trails, or channeled water).

Twenty-five landslides are not associated with apparent rule-identified landforms. While the sample set is too small to draw meaningful conclusions, we have the following observations:

- These landslides are of particular concern because of the difficulty in predicting such instability with conventional remote sensing tools (e.g., lidar and aerial photography).
- Five landslides occurred on land that is not regulated by the DNR Forest Practices Rules.
- Road or landing failures accounted for eight landslides.
- Six landslides occur on slopes less than 70%.
- Initiation areas of three landslides in the Radonski Creek area were not determined due to steep topography and shadows even though parts of the landslide tracks were visible.

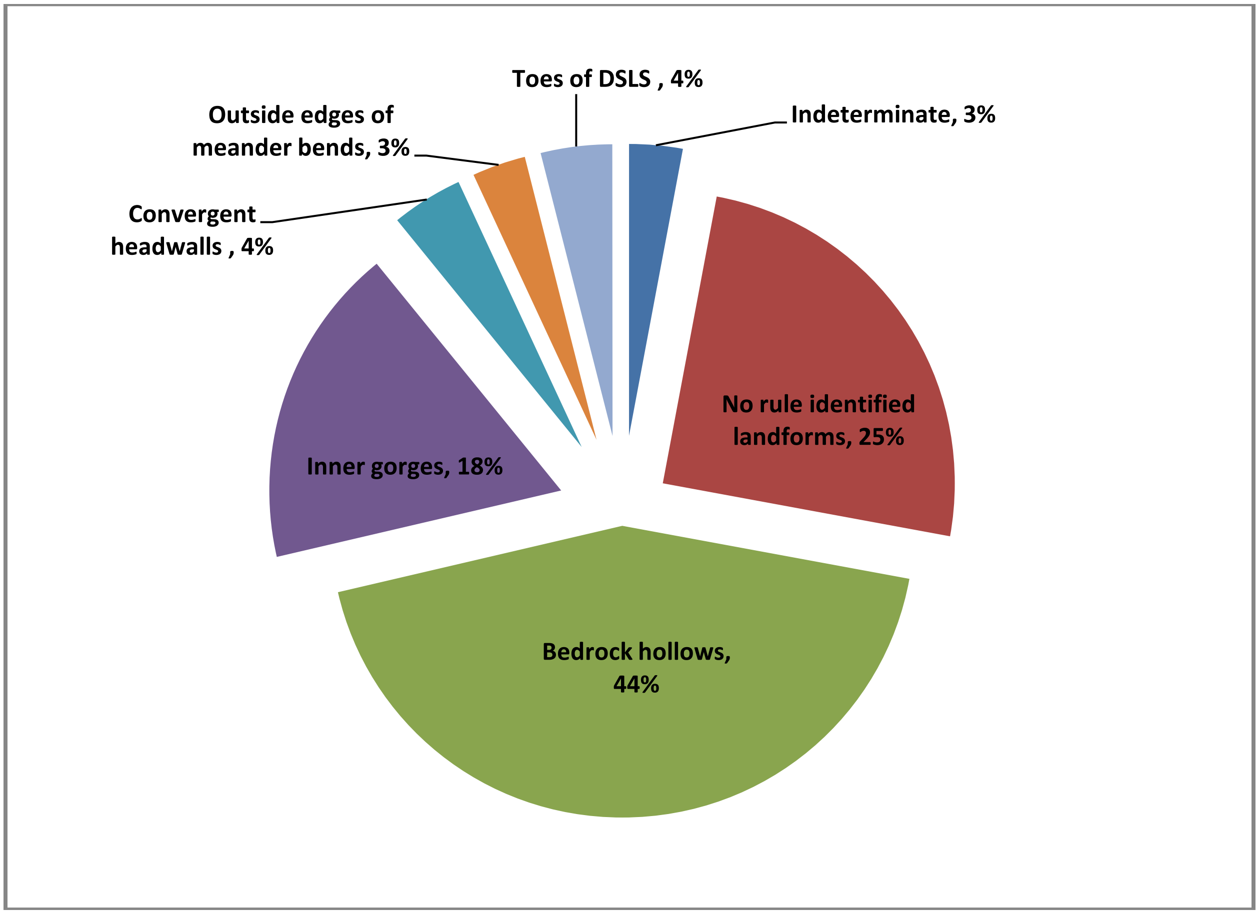


Figure 17. A total of 101 landslides and their correlation to apparent Forest Practices rule-identified landforms.

Conclusions

This is a reconnaissance study based solely on remote sensing. However, techniques used during this investigation provide a sufficient population of landslides to allow us to draw some general conclusions about the relationships between landslides, landforms, and land use in the Acme WAU. Eighty-two percent of the landslides are assigned a "high" (i.e., *definite*) level of certainty, meaning that we have considerable confidence in our interpretations.

The Acme Watershed has had a long history of landslides (Kovanen and Slaymaker 2007; Orme 1990) and the January 2009 storm, while rare, is the type of event that produces widespread mass wasting and associated impacts. Landslides that occurred in this storm are generally associated with known unstable landforms (78 of 101 landslides occur in moderate and high hazard MWMUs as defined in Acme Watershed Analysis prescriptions). At least 73 of the landslides occurred on apparent rule-identified high-hazard unstable landforms as defined in the Forest Practices Rules. This suggests that both the Acme Watershed Analysis and the current Forest Practices Rules (WAC 222-16-050) are effective at identifying areas prone to shallow landsliding.

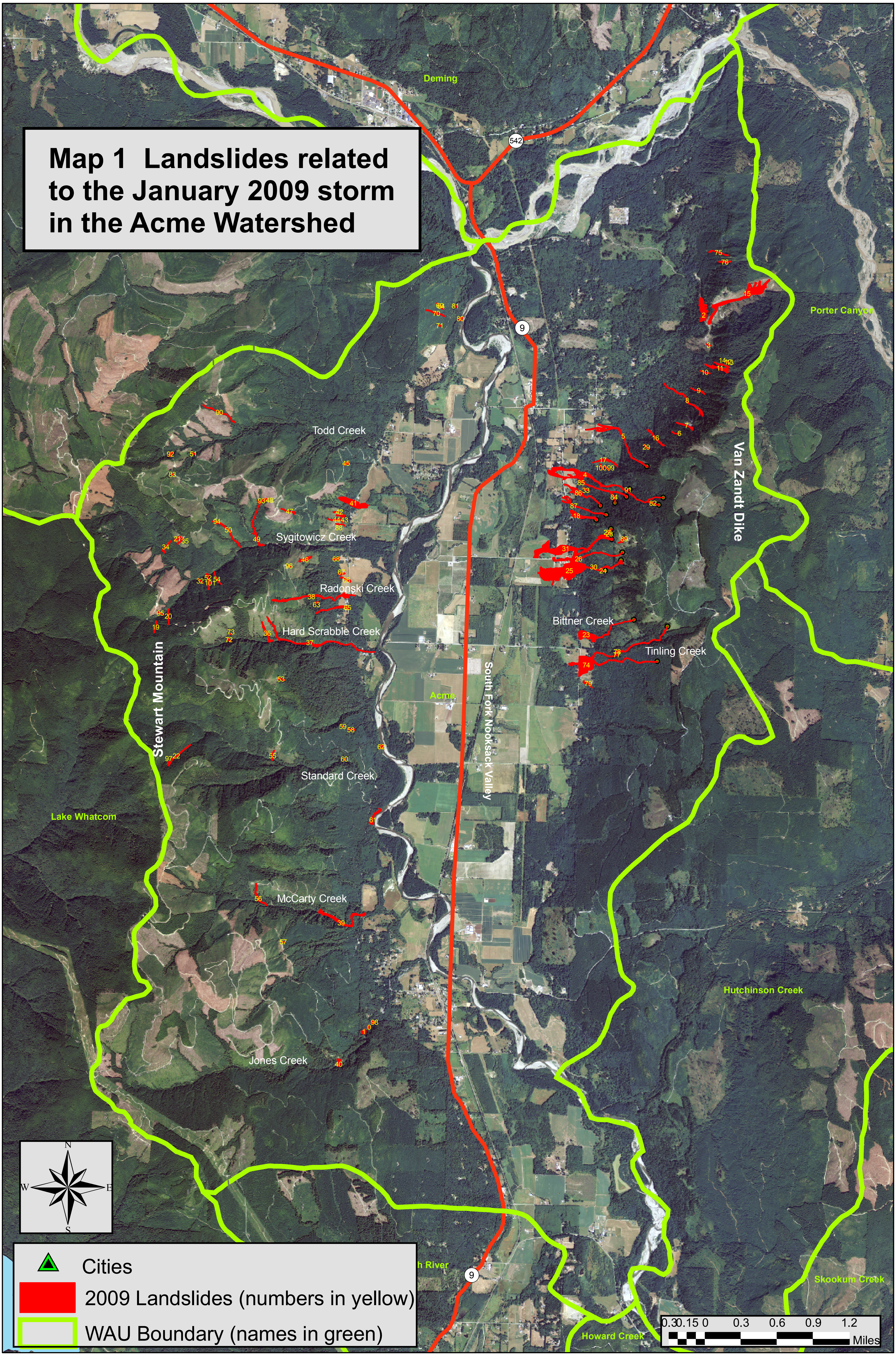
Eighty-seven of the landslides occurred on slopes greater than 71% and of these, 64 had apparent initiation gradients greater than 81%. Only 11 landslides appear to have initiation slope gradients less than 71%. This implies that the slope gradients defined as one of the factors of instability for the Acme Mass Wasting Hazard Units and the standard forest practices rules would have applied to most of these landslide initiation areas.

This study shows that conditions relating to forest roads have changed in the WAU since the Acme Watershed Analysis. The percentage of road-related landslides decreased from 43% to 12% of the total. This may be due to improvements made in the road system after it was extensively damaged by a similar storm event in 1983. After the 1983 storm, damaged stream crossings from road related landslides were rebuilt to withstand future debris flows. New roads have been constructed and maintained to the 2001 Forest Practices rule standards.

The uplands portion of this watershed contains large areas of steep, unstable topography. Thirty of the 101 landslides initiated from forest lands that have not been harvested for at least 50 years, but are steep and at higher elevation. Many landslides (31 of 101) initiated in areas that had been buffered out of timber harvest units because of potentially unstable slopes indentified during the Watershed Analysis. Therefore, 61% of the January 2009 storm-related landslides originated from areas with high natural landslide vulnerability and many of these occurred without any forest management activities.

Thirty-eight landslides deposited sediment or debris to the South Fork Nooksack Valley. Two of these were from forest roads and five landslides initiated from areas that had been harvested since implementation of the Acme Watershed Analysis mass wasting prescriptions in 2000. A majority of the landslides (71 of 101) initiated in areas harvested under earlier Forest Practices regulatory frameworks that afforded less protection to unstable slopes or landforms.

Map 1 Landslides related to the January 2009 storm in the Acme Watershed



Landslide #	Location	Level of uncertainty	Landslide Type	Present on 2009 NAIP (from the 2009 storm)	Present on 2006 NAIP	Land use (2009 at initiation zone)	Age Class of trees (2009 at initiation zone)	LiDAR-derived slope (%) at initiation zone	Delivery to a public resource	Delivery debris to "valley bottom"	Acme WA Landslide Inventory ID # (present ca 1993)	Landslide initiation areas verified as **within** MWMUs from the DNR GIS screening tool	Landslide initiation areas verified as **outside** MWMUs from the DNR GIS screening tool (per this inventory)	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050?	Comments*
0	122.218111 48.713899	Definite	DS	Yes	Yes 20%	Buffers on unstable slopes	50+	63	Yes	Questionable	9973	2	2	Yes	Toe of DSLS *	The average of the slope is less than 65%, however, slopes within polygon can reach 102%; Reactivation of landslides at the toe of DSLS (#9973) along Jones Cr inner gorge
1	122.219023 48.713358	Definite	DS	Yes	Yes 20%	Buffers on unstable slopes	50+	74	Yes	Questionable	12421	9	9	Yes	Toe of DSLS	Reactivation of landslides at the toe of DSLS along Jones Cr inner gorge
2	122.159159 48.801148	Definite	DA	Yes	No	Mature timber	50+	92	No	No	None	999	8	No	N/A	cutslope failures on the Williams Lake Road
3	122.158393 48.797011	Questionable	DA	No	No	Harvest unit	0-5	77	No	No	49736	6	6	No	N/A	Near spur rd off the Williams Lake Rd
4	122.166411 48.778537	Definite	DF	Yes	No	Young forest	20-50	71	Yes	Yes	None	7	7	Yes	BH	North Creek drainage; North Upper IP detailed in State Trust Lands Report App I, Landslide impacted homes along Nelson Rd
5	122.169503 48.782282	Definite	DF	Yes	No	Mature timber	50+	95	Yes	Yes	197, 192	6	6	Yes	BH	State lands report App H; landslide in cliff area at head of steep drainage west face Van Zandt Dike
6	122.163763 48.786336	Questionable	DF	No	No	Mature timber	50+	103	Yes	No	381	6	6	Yes	BH	cliff area in steep drainage west face Van Zandt Dike
7	122.161412 48.786987	Definite	DS/DF	No	Yes 50%	Mature timber	50+	87	Yes	Questionable	9961	6	6	Yes	CH	Reactivation landslide in cliff area at head of steep drainage west face Van Zandt Dike
8Ch	122.159632 48.788612	Definite	DF	Yes	No	Mature timber	50+	95	Yes	No	166	6	6	Yes	CH	Reactivation landslide in cliff area at head of steep drainage west face Van Zandt Dike. LSI # 166 is just above (north) of DNR # 8
9	122.159321 48.791178	Probable	DF	Yes	Yes 5%	Mature timber	50+	83	Yes	No	None	6	6	Yes	IG	Steep drainage west face Van Zandt Dike
10	122.158461 48.793684	Probable	DF	Yes	No	Mature timber	50+	87	Yes	No	None	6	6	Yes	BH	Steep drainage west face Van Zandt Dike
11	122.155236 48.794102	Definite	DA/DF	Yes	Yes 5%	Mature timber	50+	94	Yes	No	9960	6	6	Yes	BH	Reactivation landslide in cliff area at head of steep drainage west face Van Zandt Dike
12	122.155014 48.795078	Probable	DS	No (shadow)	Yes 80%	Mature timber	50+	122	Yes	No	None	6	6	Yes	CH	Reactivation landslide in cliff area at head of steep drainage west face Van Zandt Dike
13	122.155369 48.794984	Probable	DS	No (shadow)	Yes 80%	Mature timber	50+	139	Yes	No	None	6	6	Yes	CH	Reactivation landslide in cliff area at head of steep drainage west face Van Zandt Dike
14	122.155149 48.794543	Probable	DS/DF	No (shadow)	Yes 80%	Mature timber	50+	107	Yes	No	None	6	6	Yes	BH	Reactivation landslide in cliff area at head of steep drainage west face Van Zandt Dike
15	122.149660 48.804702	Definite	DA/DF	Yes	No	Harvest unit	0-5	90	No	No	None	6	6	No	N/A	recent clear cut harvest in large bedrock hollow or convergent headwall at top of Van Zandt Dike Ridge
16	122.166595 48.784858	Definite	DF	Yes	No	Mature timber	50+	85	Yes	No	None	6	6	Yes	IG	Landslide started in old harvest unit and flowed into more recent harvest unit
17	122.174993 48.782263	Definite	DF	Yes	No	Harvest unit	0-5	88	No	No	None	7	7	Yes	BH	Landslides initiated along the edge of 5 yr old harvest unit low on the slope of Van Zandt Dike in a bedrock hollow
18	122.178521 48.775771	Definite	DF	Yes	No	Mature timber	50+	90	Yes	Yes	None	7	7	Yes	BH	Landslide described in State Trust Lands Report App B, possible initiating from a shallow bedrock hollow
19	122.258756 48.760977	Definite	DF	Yes	No	Young forest	20-50	83	Yes	No	269	1	1	Yes	BH	Head of south fork Sygatowicz, 2007 landslide onto main haul road
20	122.256174 48.762287	Definite	DF	Yes	Yes 20%	Young forest	20-50	114	Yes	No	2393	3a	1	Yes	IG	Head of south fork Sygatowicz, 2007 landslide below the main haul road
21	122.254494 48.772562	Definite	DA	Yes	No	Forest road	5-20	91	No	No	None	3b	3b	No	N/A	Road sidecast failure along the Sygatowicz Mainline
22	122.171321 48.763731	Definite	DS	Yes	Yes 50%	Young forest	20-50	96	Yes	No	None	999	1	Yes	Toe of DSLS	Minor reactivation of a small portion of a large deep-seated at the head of Standard Creek, the landslide visible on black & white orthos; the slide is reported as extending >1000' down the mainstem, visible on obliques. The same slide track is visible in 2004, partly revegeated (?) in 2006.
23	122.171303 48.763741	Definite	DF	Yes	No	Buffers on unstable slopes	20-50	77	Yes	Yes	None	999	7	Yes	IG	Landslide detailed in State Trust Lands Report App F; Bitter Creek PI: >70% slope at initiation point
24	122.176706 48.769538	Definite	DF	No	No	Buffers on unstable slopes	50+	39	Yes	Yes	None	7	7	Yes	IG	Landslide detailed in State Trust Lands Report App A; Knutzen Drainage; Landslide "Way South #2 PI", App A reports 50-70% slope

Landslide #	Location	Level of uncertainty	Landslide Type	Present on 2009 NAIP (from the 2009 storm)	Present on 2006 NAIP	Land use (2009 at initiation zone)	Age Class of trees (2009 at initiation zone)	LiDAR-derived slope (%) at initiation zone	Delivery to a public resource	Delivery debris to "valley bottom"	Acme WA Landslide Inventory ID # (present ca 1993)	Landslide initiation areas verified as **within** MWMUs from the DNR GIS screening tool	Landslide initiation areas verified as **outside** MWMUs from the DNR GIS screening tool (per this inventory)	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050?	Comments*
25	122.173859 48.770446	Definite	DSLS/DF	Yes	No	Buffers on unstable slopes	50+	84	Yes	Yes	None	7	7	Yes	BH	Landslide detailed in State Trust Lands Report App A; Knutzen Drainage; Landslide "Way South #1 PI", App A reports >73 slope; Small deep-seated landslide initiating on planar slopes buffer; flowed into an inner gorge and produced a 2,300 ft debris flow which impacted homes
26	122.173549 48.771869	Definite	DF	Yes	No	Buffers on unstable slopes	50+	72	Yes	Yes	234	7	7	Yes	IG	Landslide detailed in State Trust Lands Report App A; Landslide "South PI", App A reports 55-60% slope w/ 73% lidar slopes; Bench Drainage; Streamside landslide; Debris flow in 40yr old buffer next to a 4(?) old harvest unit;
27	122.175798 48.774515	Definite	DS/DF	Yes	No	Harvest unit	5-20	73	Yes	Yes	None	7	7	Yes	BH	Landslide detailed in State Trust Lands Report App A; Landslide "North PI", App A reports 70% slope; Gantman-Fox Drainage, "TAT" timber sale harvested 1992,
28	122.175726 48.774020	Definite	DS/DF	No	No	Harvest unit	5-20	71	Yes	Yes	None	7	7	Yes	BH	Landslide detailed in State Trust Lands Report App A; Landslide "Middle PI", App A reports 80-90% slope; Gantman-Fox Drainage; Shallow bedrock hollow; "TAT" timber sale harvested 1992
29	122.169262 48.784399	Probable	DS/DF	No	No	Mature timber	50+	122	Yes	No	None	6	6	Yes	BH	Steep drainage west face Van Zandt Dike,
30	122.178619 48.770086	Definite	DS/DF	Yes	No	Mature timber	50+	96	Yes	Yes	None	7	7	Yes	BH	Landslide shown on State Trust Lands' Report App A Figure 2 but not described in text
31	122.175792 48.773313	Definite	DA/DF	Yes	No	Harvest unit	5-20	75	Yes	Yes	None	7	7	No	N/A	Landslide detailed in State Trust Lands Report App A; Landslide "Sandy PI", App A reports 70% slope; Gantman-Fox Drainage; Broadly convergent to planar landform (not a defined RIL); "TAT" timber sale harvested 1992
32	122.250197 48.767049	Probable	DF	No	No	Young forest	20-50	94	Yes	No	254	3b	1	Yes	IG	Inner gorge failure along upper Sygatowicz Creek; Below orphans road
33	122.180007 48.779280	Definite	DA	Yes	No	Mature timber	50+	87	No	Yes	None	999	7	No	N/A	Debris avalanche on the slope above Nelson Rd, close to houses but no apparent delivery
34	122.256180 48.772015	Definite	DF	Yes	Yes 5%	Young forest	20-50	83	Yes	No	224	3b	8	Yes	BH	Debris flow initiating in old landslide channel; delivered to North Fork Sygatowicz Creek.
35	122.254103 48.772378	Definite	DA	Yes	No	Forest Road	5-20	82	No	No	None	3b	8	No	N/A	Debris avalanche initiating from a road fill failure; Landslide flowed across a steep recent harvest unit and stopped against 30+ year old harvest unit
36	122.239153 48.762391	Definite	DF	Yes	Yes 70%	Buffers on unstable slopes	20-50	80	Yes	Yes	None	8	1	Yes	BH	Debris flow formed in bedrock hollow in unstable buffer leave area. Much of the buffer had blown down by 2006; Landslide delivered to Hardscrabble Creek
37	122.238204 48.763064	Definite	DF	Yes	Yes 5%	Buffers on unstable slopes	20-50	88	Yes	Yes	None	8	1	Yes	BH	Debris flow formed in bedrock hollow leave area. Much of the buffer had blown down by 2006; Landslide delivered to Hardscrabble Creek and damaged a private road in the valley bottom
38	122.237501 48.765139	Definite	DF	Yes	No	Harvest unit	5-20	60	Yes	Yes	None	8	8	No	N/A	Radonski Creek; water could have been channeled by old harvest road; Debris flow that imitated on a planner slope with only the very head of the landslide on slope >70%; The DF flowed down the stream between Hardscrabble and Sygatowicz and across the county road;
39	122.227339 48.727722	Definite	DS/DF	Yes	No	Buffers on unstable slopes	50+	122	Yes	Yes	346	2	2	Yes	IG	Debris slide which may have resulted in a small dam break flood . Possibly part of LSI # 346.
40	122.223655 48.709919	Definite	DS	Yes	Yes 40%	Buffers on unstable slopes	50+	77	Yes	Questionable	9976	9	9	Yes	Toe of DSLS	Debris Slide at the toe of Jones Creek Landslide; The debris slide has increased in size since 2006 photo; Slide reportedly moved considerably in 2007-8, pushing creek into RB--movement may not be related to 09 storm--check with Paul Pittman.
41	122.225377 48.777595	Definite	DA	Yes	No	Harvest unit	5-20	77	Yes	Yes	None	3a	3b	No	N/A	Massive avalanche that crossed Hillside Road; Slide initiated in 10(?) year old harvest unit; Headscarp of landslide is now a series of cliff bands: thin soils failed off a bedrock surface that was harvested ~10 yrs ago
42	122.226021 48.775574	Definite	DF	Yes	No	Harvest unit	0-5	89	No	Yes	None	1	3b	Yes	BH	One of three debris flows on planar slope in 2005 clear cut between Sygatowicz and Todd Creek

Landslide #	Location	Level of uncertainty	Landslide Type	Present on 2009 NAIP (from the 2009 storm)	Present on 2006 NAIP	Land use (2009 at initiation zone)	Age Class of trees (2009 at initiation zone)	LiDAR-derived slope (%) at initiation zone	Delivery to a public resource	Delivery debris to "valley bottom"	Acme WA Landslide Inventory ID # (present ca 1993)	Landslide initiation areas verified as within MWMUs from the DNR GIS screening tool	Landslide initiation areas verified as outside MWMUs from the DNR GIS screening tool (per this inventory)	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050?	Comments*
43	122.226581 48.775943	Definite	DF	Yes	No	Harvest unit	0-5	95	No	Yes	None	3a	3b	Yes	BH	One of three debris flows on planner slope in recent clear cut between Sygatowicz and Todd Creek
44	122.227560 48.775116	Definite	DF	Yes	No	Buffers on unstable slopes	50+	99	No	Yes	None	3a	1	Yes	IG	Debris flow initiated and traveled through unstable slope buffer left when the unit was harvested ~5 yrs ago; inner gorge between Sygatowicz and Todd Creek
45	122.224855 48.781754	Definite	DA	Yes	No	Forest road	5-20	55	No	No	None	8	8	No	N/A	Debris avalanche from apparent road fill failure; head of failure area also has slopes ranging from 71 to 106 %
46	122.232512 48.769999	Definite	DA	Yes	No	Buffers on unstable slopes	50+	132	No	No	None	999	1	Yes	BH	Debris avalanche initiating in an unstable slope buffer area surrounded by recent timber harvested. The buffer contains a bedrock hollow developed in a deep-seated landslide headscarp; This landform was recognized as unstable during the FPA review, however it has determined if this bedrock hollow failed it would not deliver; south Sygatowicz Creek
47	122.236158 48.776207	Definite	DF	Yes	No	Harvest unit	5-20	81	Yes	No	None	8	8	No	N/A	Debris slide triggered a debris flow. The debris slide initiated in a ~10(?) harvest unit and traveled 200 ft to a buffered stream channel than 425 ft down to stream channel.
48	122.238794 48.777353	Definite	DF	Yes	No	Harvest unit	0-5	85	no	No	None	8	8	Yes	BH	Debris slide triggered a small debris flow that probably reached a tributary of Sygatowicz Creek. The debris slide initiated in a shallow convergent area (not defined enough to be a RIL bedrock hollow)
49	122.240485 48.777198	Definite	DS/DF	Yes	No	Buffers on unstable slopes	50+	77	Yes	No	None	2	1	Yes	BH	The DF traveled 2200 ft to Sygatowicz
50	122.247916 48.774313	Definite	DS/DF	Yes	No	Abandoned Road	5-20	65	Yes	No	215	1	8	Yes	BH	Debris slide initiated from fill slope of an abandoned road; Calls made on Lidar contours which shows a planner slope therefore the landslide initiated outside MWMU #1; The DF traveled 1700 ft to Sygatowicz; initiation site has areas with slopes from 55 to 96%. Possibly triggered by water from LS 94 captured by orphan road.
51	122.252506 48.782658	Definite	DS	Yes	No	Buffers on unstable slopes	20-50	74	Yes	No	180	3b	2	Yes	IG	Debris slide initiating in the inner gorge buffer along Todd Creek
52	122.249012 48.766319	Definite	DF	Yes	No	Orphan road	20-50	73	Yes	No	252	1	1	Yes	IG	Debris flow from orphan road south side Sygatowicz creek; verified by field forester
53	122.235998 48.755689	Definite	DS	Yes	No	Buffers on unstable slopes	50+	86	Yes	No	285	8	1	Yes	BH	Debris flow below orphan road south side Sygatowicz creek; verified by field forester
54	122.246743 48.766925	Probable	DF	No	Yes (5%)	Buffers on unstable slopes	20-50	106	Yes	No	12386	999	1	Yes	BH	Debris flow developed in a shallow bedrock in 10 (?) yr old harvest unit that delivered to Standard Creek. LSI #313 is 225 feet southeast of DNR landslide #55. Extensive blowdown prior to 2006.
55	122.236488 48.746960	Definite	DS/DF	Yes	No	Buffers on unstable slopes	50+	83	Yes	No	313	8	1	Yes	BH	Debris flow developed in a shallow bedrock in 10 (?) yr old harvest unit that delivered to Standard Creek. LSI #313 is 225 feet southeast of DNR landslide #55
56	122.239207 48.730825	Definite	DS/DF	Yes	No	Forest road	5-20	74	Yes	Yes	None	8	8	No	N/A	Debris slide initiated from a fill slope failure from a forest road. The resulting debris flow delivered to McCarty Creek.
57	122.234177 48.723906	Definite	DS	Yes	No	Forest road	5-20	89	No	No	None	8	8	No	N/A	small debris slide from a fill slope of on spur road above and cut slope of spur road below the landslide; Spur road part of Jones Creek Road system
58	122.223001 48.749773	Definite	DS/DF	Yes	No	Landing	5-20	85	Yes	No	291	8	1	Yes	BH	Debris slide initiated from edge of old landing (10+ yrs old); Delivered to head of small drainage between Standard and Hardscrabble Creek. LSI landslide # 60 is 650 feet upstream of LSI # 291.
59	122.224079 48.750073	Definite	DS	Yes	No	Harvest unit	5-20	88	No	No	None	8	1	No	N/A	Small debris slide on slope south Hardscrabble Creek in old (20+ yr old) plantation
60	122.223428 48.746243	Definite	DS	Yes	No	Buffers on unstable slopes	50+	196	Yes	No	None	2	2	Yes	IG	Small debris slide in buffered area of Standard Creek inner gorge
61	122.218014 48.739515	Definite	DS	Yes	Yes (70%)	Buffers on unstable slopes	50+	90	Yes	N/A	None	8	2	Yes	Outside Meander	Reactivation outside meander bend west bank Nooksack River; just up stream Standard Creek confluence
62	122.217152 48.747716	Definite	DS	Yes	Yes (80%)	Buffers on unstable slopes	50+	98	Yes	N/A	None	8	2	Yes	Outside Meander	Reactivation outside meander bend; west bank Nooksack River; just down stream Standard Creek confluence

Landslide #	Location	Level of uncertainty	Landslide Type	Present on 2009 NAIP (from the 2009 storm)	Present on 2006 NAIP	Land use (2009 at initiation zone)	Age Class of trees (2009 at initiation zone)	LiDAR-derived slope (%) at initiation zone	Delivery to a public resource	Delivery debris to "valley bottom"	Acme WA Landslide Inventory ID # (present ca 1993)	Landslide initiation areas verified as **within** MWMUs from the DNR GIS screening tool	Landslide initiation areas verified as **outside** MWMUs from the DNR GIS screening tool (per this inventory)	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050?	Comments*
63	122.229511 48.765010	Probable	DS	Yes	No	Mature timber	50+	144	Yes	Yes	262	1	1	Yes	IG	Small debris slide in channel South Fork Radonski Creek
64	122.207747 48.801162	Definite	DA	Yes	Yes (50%)	Harvest unit	5-20	100	No	No	None	999	Tribal lands	No	N/A	Small debris flow in harvest unit (10-12 year old) just south of the confluence of the N & S Fork of the Nooksack; This landslide on the Stewart Mtn side of the valley
65	122.229303 48.763703	Definite	DF	Yes	No	Mature timber	50+	79	Yes	Yes	None	3a	1	Yes	BH	Debris flow south of Radonski Creek that reached the Hillside Rode
66	122.224910 48.768069	Definite	DF	Yes	No	Mature timber	50+	N/A	Yes	Yes	19461	Indeterminate	N/A	Indeterminate	N/A	Debris flow north of Radonski Creek that reached the valley bottom, however, the initiation point was not determined
67	122.225398 48.768531	Definite	DF	Yes	No	Mature timber	50+	N/A	No	Yes	19461	Indeterminate	N/A	Indeterminate	N/A	Debris flow north of Radonski Creek that reached the valley bottom, however, the initiation point was not determined
68	122.226387 48.770276	Definite	DF	Yes	No	Mature timber	50+	N/A	No	Yes	19461	Indeterminate	NA	Indeterminate	N/A	Debris flow north of Radonski Creek that reached the valley bottom, however, the initiation point was not determined
69	122.208548 48.801435	Definite	DS/DF	Yes	NO	Harvest unit	5-20	59	No	No	None	999	Tribal lands	No	N/A	Small debris flow in harvest unit (10-12 year old) just south of the confluence of the N & S Fork of the Nooksack; This landslide on the Stewart Mtn side of the valley
70	122.210270 48.800567	Definite	DS/DF	Yes	Yes (5%)	Forest road	5-20	54	No	No	None	999	Tribal lands	No	N/A	Small debris flow just below a forest road, Not sure if road contributed to the imitation of this landslide; south of the confluence of the N & S Fork of the Nooksack; This landslide on the Stewart Mtn side of the valley;
71	122.208079 48.798793	Definite	DA	Yes	No	Harvest unit	5-20	82	No	No	None	999	Tribal lands	No	N/A	Small debris avalanche in harvest unit (10-12 year old) just south of the confluence of the N & S Fork of the Nooksack; This landslide on the Stewart Mtn side of the valley
72	122.245331 48.760449	Definite	DS	Yes	Yes 10%	Buffers on unstable slopes	20-50	126	Yes	Yes	None	3b	2	Yes	IG	Small debris slide along the inner gorge of Hardscrabble Creek (left bank). Landslide is inside the unstable slope buffer; forester notes that slide possibly occurred between 9/06 & 12/08
73	122.244830 48.760992	Definite	DS	Yes	No	Buffers on unstable slopes	20-50	117	No	No	272	3b	1	Yes	BH	Small debris slide along the inner gorge of Hardscrabble Creek (left bank). Landslide is inside the unstable slope buffer. Very close to LSI # 272
74	122.166740 48.758824	Definite	DF	Yes	No	Young forest	20-50	64	Yes	Yes	None	999	2	Yes	IG	Landslide detailed App. G State lands report; Debris flow in Stavik Creek with impacted homes, 85% initiation slopes
75	122.155548 48.807978	Probable	DF	Yes	Yes 5%	Mature timber	50+	92	Yes	No	9959, 30823	7	7	Yes	BH	Poorly visible DF just north of Devil Slide. Jack use the LSI # to be consistent!
76	122.155153 48.807222	Probable	DS/DF	Yes	No	Mature timber	50+	78	Yes	No	151	7	7	Yes	BH	Visible on Nov 4th flight; poorly visible 2009 ortho: reactivation of steep rock chute just north of Devils Slide. DNR #76 is just south of LSI # 30823
77	122.174209 48.759460	Definite	DSLS	Yes	No	Buffers on unstable slopes	50+	77	Yes	Yes	None	2	2	Yes	IG	Deep-seated slide on the edge of a large Tinling Creek debris flow that damaged homes at the valley bottom; State Trust Lands Report App G; Slide in Glacial Sediments
78	122.165201 48.763017	Definite	DS/DF	Yes	No	Buffers on unstable slopes	50+	64	Yes	Yes	None	999	8	No	N/A	Landslide described in State lands report App G . Reported 85% slope initiation
79	122.178157 48.755406	Definite	DF	Yes	Yes 10%	Mature timber	50+	87	Yes	Yes	None	999	8	Yes	BH	The initiation for this landslide is not visible, It could have initiated up slope
80	122.204289 48.799627	Definite	DSLS	Yes	Yes 30%	Riparian Buffer	50+	94	Yes	N/A	None	999	8	Yes	Outside Meander	Deep-seated slide on the outside of Meander of Nooksack
81	122.204289 48.799627	Definite	DS	Yes	No	Forest road	5-20	99	No	Yes	None	999	Tribal lands	No	N/A	Reactivation of headscarp of large deep-seated
82	122.167351 48.777655	Definite	DS/DF	No	No	Mature timber	50+	62	Yes	Yes	None	999	7	Yes	BH	See State Trust Lands Report App I describes this landslide as the North Middle PI that initiated on slopes of 70 - 75% and was a debris slide in colluvium that generated down slope debris flood that impacted several Clipper Road properties
83	122.256177 48.779986	Probable	DS	No	No	Buffers on unstable slopes	20-50	80	Yes	No	None	1	1	Yes	BH	A small debris slide was reported by a field forester which started about 150' above the mainline in a buffered hollow in the upper reach of the southern fork of Todd Creek. MMWU 1. It delivered, though most of the material deposited on the road. It did not evolve into a debris flow.
84	122.175198 48.777820	Definite	DS/DF	No	No	Mature timber	50+	81	Yes	Yes	None	7	7	Yes	BH	State Trust Lands Report App I details landslide "South Slope PI" as a debris slide formed in colluvium from the left bank tributary to drainage that generated Slide # 85 and impacted Moceri/Porter; App I reports initiation slopes of 75%
85	122.173401 48.778684	Definite	DS/DF	No	No	Mature timber	50+	85	Yes	Yes	None	7	7	Yes	IG	Landslide described in State Trust Lands Report App I describes landslide "South Upper PI" as a debris slide in main stem South Creek generated debris flow from a colluvium exposed in scarp with initiation slopes of 85%

Landslide #	Location	Level of uncertainty	Landslide Type	Present on 2009 NAIP (from the 2009 storm)	Present on 2006 NAIP	Land use (2009 at initiation zone)	Age Class of trees (2009 at initiation zone)	LiDAR-derived slope (%) at initiation zone	Delivery to a public resource	Delivery debris to "valley bottom"	Acme WA Landslide Inventory ID # (present ca 1993)	Landslide initiation areas verified as **within** MWMUs from the DNR GIS screening tool	Landslide initiation areas verified as **outside** MWMUs from the DNR GIS screening tool (per this inventory)	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050	Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050?	Comments*
86	122.177840 48.777455	Definite	DS/DF	No	No	Mature timber	50+	89	Yes	Yes	None	7	7	Yes	BH	State Trust Lands Report (App H) mapped this landslide as "3830 NR PI" with initiation slopes of 80-85% and note that bedrock, colluvium and glacial cobbles exposed in debris slide scarp
87	122.176875 48.776268	Definite	DS/DF	No	No	Mature timber	50+	90	Yes	Yes	None	7	7	Yes	BH	State Trust Lands Report App H describes landslide "3810 NR PI" as having colluvium and glacial cobbles exposed in scarp with initiation slope 85-90
88	122.226087 48.774542	Definite	DS/DF	Yes	No	Harvest unit	0-5	94	No	Yes	None	1	3b	Yes	BH	Small Debris flow in recent clear cut just north of Sygatowicz Cr near Hillside Road
89	122.173207 48.773582	Questionable	DA	Yes	Yes 5%	Forest Road	5-20	103	No	No	None	7	7	No	N/A	Tat Road failure in the Gartman-Fox drainage near the end Tat Road; State Trust Lands report (App A) reports it initiating in a nearly vertical cutslope
90	122.250751 48.788548	Definite	DF	Yes	No	Buffers on unstable slopes	20-50	91	Yes	No	12363, 376	1	1	Yes	BH	Sizable debris flow in upper Todd Creek
91	122.172622 48.779469	Probable	DF	No	No	Young forest	20-50	72	Yes	Questionable	None	7	7	Yes	BH	State Trust Lands report App I mapped but did not describe this landslide
92	122.256700 48.782283	Probable	DA	Yes	No	Buffers on unstable slopes	20-50	117	Yes	No	Near 12372	2	2	Yes	BH	Small debris avalanche in upper Todd Creek just below the haul road
93	122.239398 48.777359	Probable	DF	No	NO	Buffers on unstable slopes	20-50	77	Yes	No	None	999	1	Yes	BH	Small debris flow high up on a left bank tribe of Sygatowicz Cr
94	122.248636 48.774503	Probable	DF	No	NO	Mature timber	50+	84	Yes	No	None	999	8	No	N/A	Small debris flow which flowed into a larger debris flow that started from a road failure (Landslide reported by field forester) Also visible in obliques.
95	122.258110 48.763402	Probable	DF	No	NO	Buffers on unstable slopes	20-50	167	No	No	None	2	2	Yes	BH	Small debris flow head waters of Sygatowicz Cr; reported and mapped by field forester
96	122.234718 48.769353	Definite	DA	Yes	No	Harvest unit	0-5	70	No	No	None	999	8	No	N/A	Small debris avalanche below a landing (Cats Eye)
98	122.217492 48.714540	Definite	DS	Yes	Yes 10%	Buffers on unstable slopes	50+	86	Yes	Questionable	None	2	2	Yes	IG	Small debris side along Jones Creek
99	122.176558 48.781761	Definite	DA	No	No	Harvest unit	0-5	92	No	No	None	7	7	No	N/A	Small debris avalanche from edge of ~ 10 year old harvest unit; visible only on winter flight photos
100	122.177592 48.781849	Definite	DA	No	No	Harvest unit	0-5	76	No	No	None	7	7	No	N/A	Small debris avalanche from edge of ~ 10 year old harvest unit; visible only on winter flight photos
101	122.248639 48.766985	Probable	DF	No	No	Buffers on unstable slopes	20-50	73	Yes	Questionable	251	3b	1	Yes	BH	Debris flow from slope below orphan road south side Sygatowicz creek; verified by field forester

Appendix A: Landslide inventory explanations for attribute

Header	Input Variable	Description of the inputs
Landslide #	Integer	Derived by user selected from air reconnaissance flight
Location	Latitude and longitude in decimal degrees	Location taken from the center of the initiation area location on lidar. These coordinates are taken from the average elevation of the original evacuation area
Confidence	Definite, questionable, probable	Confidence in the ability to identify and map the landslide as definite, questionable, or probable. This is a subjective determination, however, all landslides were identified with two to four geologists.
Landslide Type	DS, DF, DA, DSLS	DS=debris slide, DF=debris flow, DA=debris avalanche, DSLS = deep seated landslide
Present on 2009 NAIP (from the 2009 storm)	Yes/No	Could the landslide be seen on the 2009 NAIP photography
Present 2006	No/ Yes (%)	Was the landslide visible on the 2006 NAIP photography. If yes, a percentage of the 2009 NAIP imagery.
Land use (2009 at initiation area)	Harvest unit, Mature timber, Young forest, Forest road, Orphaned road, Abandoned road, Landing, Buffer on unstable slope, Riparian buffer	Harvest unit If the initiation location was on or obviously from a road or unstable buffer.
Age Class of trees (2009 at initiation zone)	0-5, 5-20, 20-50, and 50+ years	In order to be uniform throughout the watershed, we used these age classes. Ambiguity associated with the duplication of ages between classes was deliberate; we do not know all specific age classes. Some definitive age classes from Sierra Pacific were used to cross-check our estimates.
Lidar-derived slope (%) at initiation zone	Gradient in percent	A polygon was created at the initiation of landslide. The gradient in this area was averaged using a GIS application created by SE Region technical staff for this project.
Delivery to a public resource	Yes/ No	Delivery to a public resource, usually a stream, but could also be public infrastructure.

Header	Input Variable	Description of the inputs
Delivery of debris to valley bottom	Yes/ No	('Valley bottom' as used in this report includes flatter terrain below the valley walls comprising alluvial surfaces, alluvial fans, peat, landslide deposits, and glacial deposits, which form the valley floor
Acme WA Landslide Inventory ID # (present ca 1993)	Number	Landslide number form the DNR GIS landslide inventory; these landslides are part of the watershed analysis inventory
Landslide initiation areas verified as **within** MWMUs from the DNR GIS screening tool	MWMU number, indeterminate	Based on the MWMU descriptions, we determined which MWMU would apply to the area of the initiation location of the landslide. Indeterminate if unable to verify initiation areas.
Landslide initiation areas verified as **outside** MWMUs from the DNR GIS screening tool (per this inventory)	MWMU number, Tribal land	Based on the MWMU descriptions, we determined which MWMU would apply to the area of the initiation location of the landslide; landslide is within areas not regulated by the FP rules or the Acme Watershed analysis MWMUs.
Is the landslide associated with an apparent "Rule Identified Landform" as listed in WAC 22-16-050?	Yes/No/ Non FP Rules Land	Based on the MWMU descriptions, we determined which MWMU would apply to the area of the initiation location of the landslide; Tribal land indicates that the landslide is within areas not regulated by the FP rules or the Acme Watershed analysis MWMUs
Type of "Rule Identified Landform"	IG, BH, CH, Toes of DSLS, Outside Meander, Other	Inner gorges, bedrock hollows and convergent headwalls 70% gradient or more, toes of deep seated landslides with slopes 65% or greater, and outside edges of meander bends along high terraces or valley walls. Inner gorges, bedrock hollows and convergent headwalls 70% gradient or more, toes of deep seated landslides with slopes 65% or greater, and outside edges of meander bends along high terraces or valley walls."Other" includes any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes" WAC 222-16-050.
Comment	Narrative	Information may include descriptions of landslide mechanisms, references to State Land report and appendices.

Appendix B Acme Watershed Mass Wasting Map Units

Table 1 shows the number of landslides that are within MWMUs in the DNR hazard mapping GIS database. The landslides that were outside the MWMU were then assigned to the correct MWMU. Maps B 1, B 2, and B 3 show the MWMUs for the entire, northeast, and northwest, Acme Watershed, respectively. Landslides identified for this report are included.

Numbers highlighted in yellow represent the number of landslides that occurred on areas with low potential for landslide occurrence.

Acme Watershed Analysis MWMUs as mapped in the DNR GIS database	Landslides verified as **within** MWMUs from the DNR GIS screening tool	Landslides verified as **outside** MWMUs from the DNR GIS screening tool	The correct MWMU assignment for those landslides outside MWMUs from the DNR GIS screening tool
MWMU #1	5	3	1 in MWMU #8
			2 in MWMU #3b
MWMU #2	**7**	**1**	1 in MWMU #1
MWMU #3a	**0**	**5**	3 in MWMU #1
			2 in MWMU #3b
MWMU #3b	**1**	**7**	3 in MWMU #1
			2 in MWMU #2
			2 in MWMU #8
MWMU #6	**14**	**0**	Correct as mapped
MWMU #7	**20**	**0**	Correct as mapped
MWMU # 8	**12**	**21**	10 in MWMU #1
			3 in MUMW #2
			3 in MWMU #7
			5 in MWMU #8
MWMU#9	**2**	**0**	Correct as mapped

The following **hazard ratings** are from the Mass Wasting assessment in the Acme Watershed Analysis (Benda and Coho, 1999)

MWMU #1: High hazard because of the combination of unstable landforms convergent areas and high potential for sediment delivery to streams, public works or occupied fans and a high sensitivity to forestry activities. > 73 %

MWMU #2: High hazard because of the natural susceptibility of landslides, its sensitivity to forestry activities and the delivery of sedi ment directly to low gradient streams with fish and public works. >73 percent convergent slopes and > 84% on convergent topography.

MWMU #3a: High or moderate hazard, Non convergent slopes between 31 and 39 degrees (XX %) Bedrock hollows between 60% and 70% are moderate hazards and >73% are high hazards.

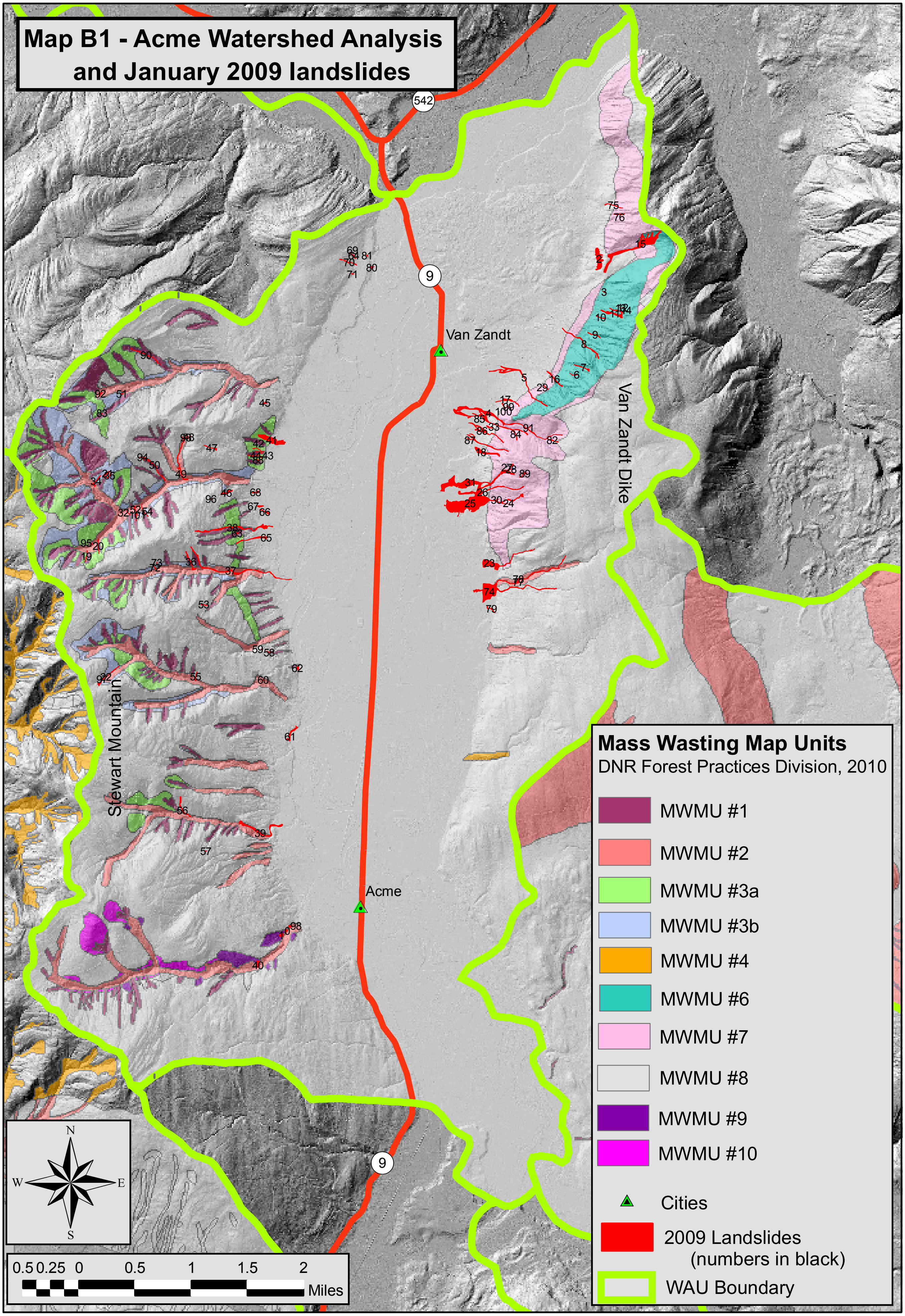
MWMU# # 6: When associated with delivery to public works and streams it is a high hazard with respect to road construction, and a moderate hazard with respect to timber harvest alone . With no delivery to water it is an low hazard.

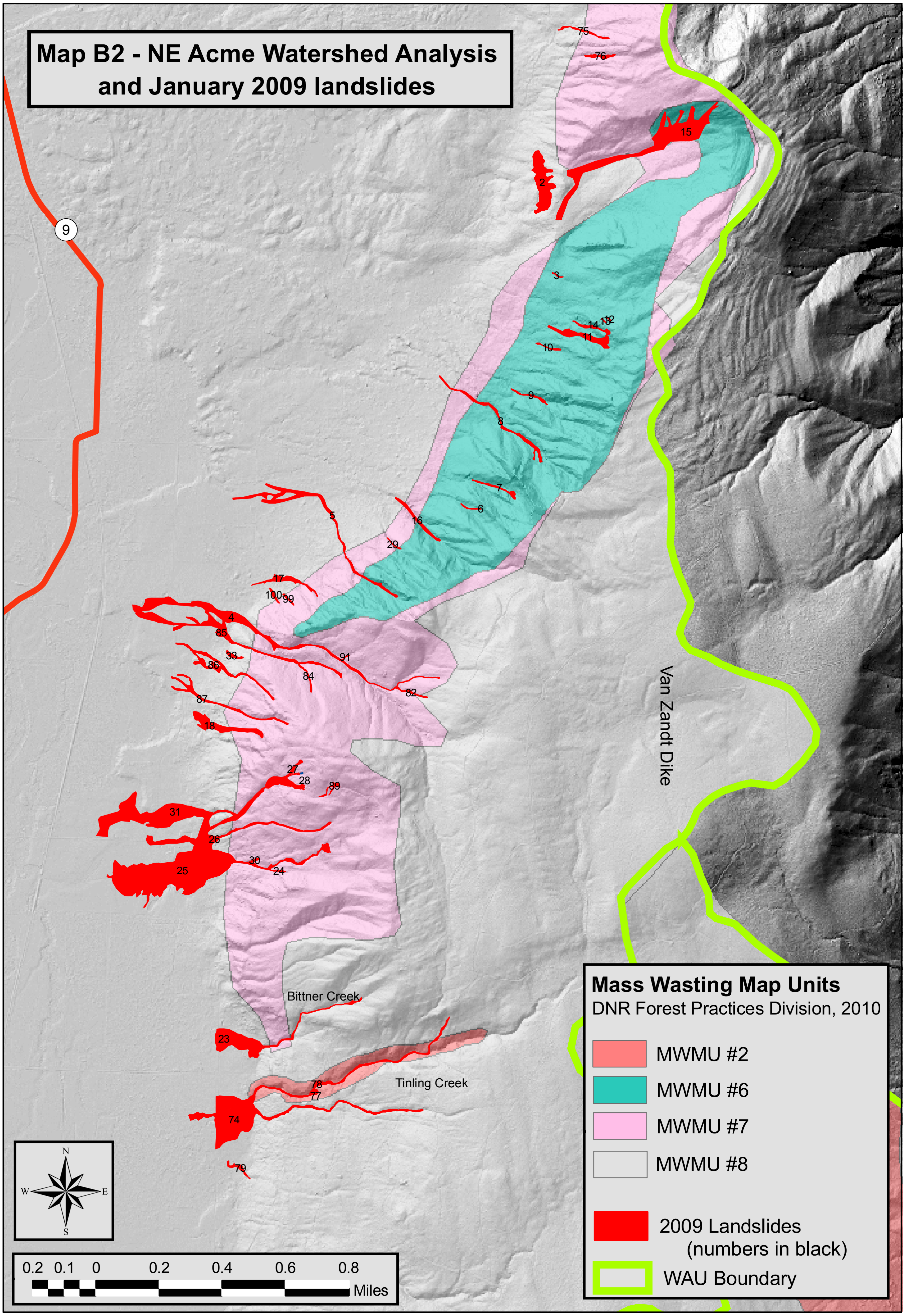
MWMU #7: Conditionally high hazard because it contains map units #1, #2, #3, and possibly #6 (with delivery) and the areas were unmapped due to the forest canopy precluded their identification using aerial photography. There are inclusions of low hazard areas which need to be located in the field.

MWMU #8: Ranked a low hazard either because there is no direct sediment delivery to channels of any order, or because landforms have limited landsliding because of low gradients.

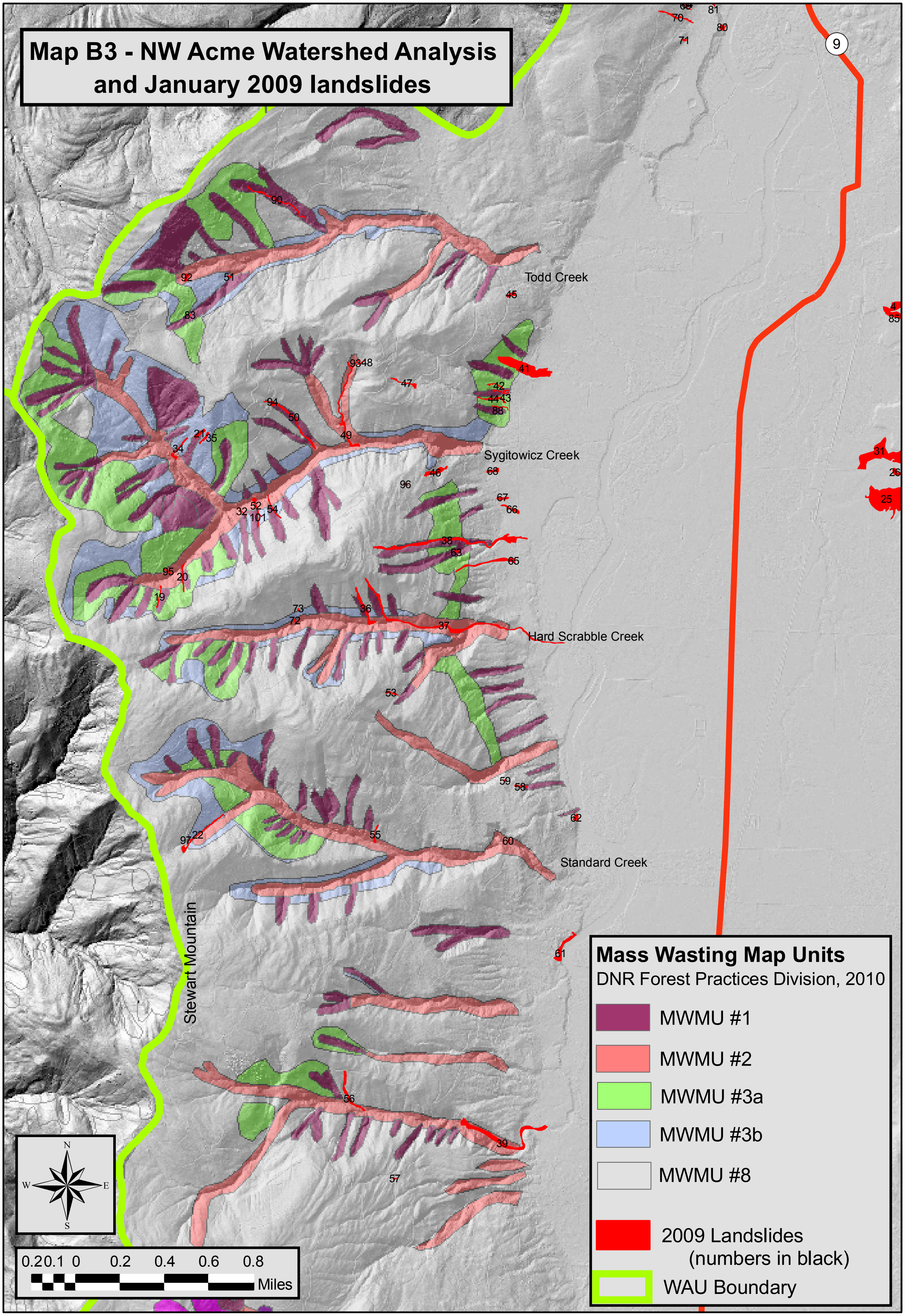
MWMU #9: High hazard if individual deep seated landslides show signs of recent activity that deliver to public resources If the landslides are dormant are ranked low with respect to harvest and high hazard with respect to high hazard road construction where blasting or large removal of sediment on the slide is anticipated.

MWMU descriptions are sometimes redundant; field verification is the key to determine which MWMU prescription will be pertinent at the site.


Map B1 - Acme Watershed Analysis
and January 2009 landslides
542
9
Van Zandt
Van Zandt Dike
Stewart Mountain
Acme
Mass Wasting Map Units
DNR Forest Practices Division, 2010
MWMU #1
MWMU #2
MWMU #3a
MWMU #3b
MWMU #4
MWMU #6
MWMU #7
MWMU #8
MWMU #9
MWMU #10
Cities
2009 Landslides
(numbers in black)
WAU Boundary
N
W
E
S
0.5 0.25 0 0.5 1 1.5 2
Miles



Map B2 - NE Acme Watershed Analysis
and January 2009 landslides
9
Van Zandt Dike
Bittner Creek
Tinling Creek
Mass Wasting Map Units
DNR Forest Practices Division, 2010
MWMU #2
MWMU #6
MWMU #7
MWMU #8
2009 Landslides
(numbers in black)
WAU Boundary
N
S
E
W
0.2 0.1 0 0.2 0.4 0.6 0.8
Miles


Map B3 - NW Acme Watershed Analysis
and January 2009 landslides
Todd Creek
Sygitowicz Creek
Hard Scrabble Creek
Standard Creek
Stewart Mountain
9
Mass Wasting Map Units
DNR Forest Practices Division, 2010
MWMU #1
MWMU #2
MWMU #3a
MWMU #3b
MWMU #8
2009 Landslides
(numbers in black)
WAU Boundary
N
S
E
W
0.20.1 0 0.2 0.4 0.6 0.8
Miles

The following insert is from the Acme Watershed Analysis, Mass Wasting Assessment (Benda and Coho, 1999)

Table 3-3 A summary of slope stability map unit descriptions for the Acme WAU. (See DNR form A-2 for further details.) .

MWMU #1: Initiation sites of shallow landslides and debris flows. Debris deposits may trigger dam-break floods. Map unit is defined as convergent topography (bedrock hollows) of slope gradient > = 36 degrees and generally first-order inner gorges. Area may also contain more shallow bedrock depressions, referred to as wedges (see text). Delivery to fish-bearing channels and/or occupied fans. Map unit #1 is a variable-width zone (see prescriptions). The unstable zone may be locally wider or narrower for short distances depending on local topography.

MWMU #2: Initiation sites of shallow landslides and debris flows. Debris deposits may trigger dam-break floods. Unit is defined as inner gorges of second-through higher-order channels with landslide-prone planar and divergent slopes having gradients in excess of 40°. Hollows in close proximity to stream channels, although located in inner gorges, are defined by a slope gradient threshold of > == *36°* similar to map unit # 1. The map unit contains all slope forms with convergent and planar being the most potentially unstable. Delivery to fish-bearing channels and/or occupied alluvial/debris fans, particularly by dam-break floods.

MWMU #3: Initiation sites of shallow landslides and debris flows. Debris deposits may trigger dam-break floods. Predominantly non-convergent hillslopes greater than or equal to 31 degrees of all slope forms. Map unit contains numerous unmapped convergent areas which should be steeper than surrounding planar slopes (i.e., MWMU #1). Delivery to fish-bearing channels and/or occupied alluvial/debris fans. Convergent areas between 31 and 35 degrees are susceptible to failure but at a lower rate compared to hollows > =36 degrees. Planar slopes > == 40 degrees are also susceptible to failure but less than convergent areas. Planar, 36 -40 degree slopes have a lower likelihood of failure compared to steeper areas. Broadly mapped as two areas: map unit 3A contains predominantly > = 36° slopes (including hollows) and map unit 38 contains 31 to 35° slopes (including hollows). Map unit requires field identification of slope gradients and slope forms.

MWMU #4: Same as map unit #2 but long runout debris flows through fish-bearing waters do not occur. Landslide-derived sediments are transported into fish-bearing reaches by fluvial processes.

MWMU #5: Same as map unit #1 but long runout debris flows through fish-bearing waters do not occur. Landslide-derived sediments are transported into fish-bearing reaches by fluvial processes.

MWMU #6: Devils slide area. Failures of bedrock slabs. Delivery to base of cliffs. Broadly mapped as one unit and landforms and delivery need to be determined in the field on a site specific basis. Map unit may extend into MWMU #7. Individual bedrock fractures and detached slabs not inventoried. Slope gradients > = 30 degrees and all slope forms. Probably contains other map units.

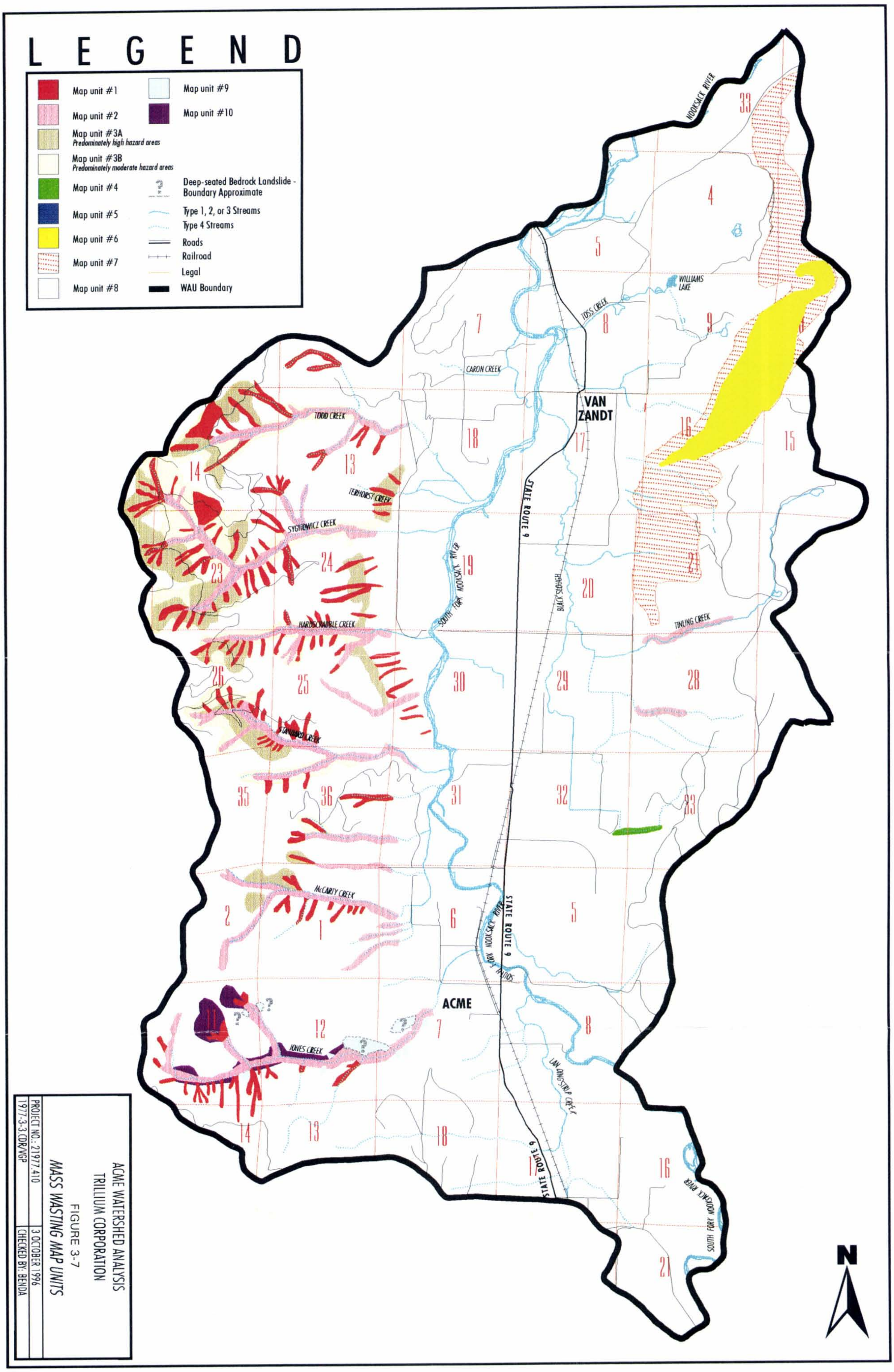
MWMU #7: Shallow landslides and small debris flows and possibly bedrock slab failures. General map unit contains areas that range from approximately 30 degrees to greater than 40 degrees and contains all slope forms including numerous unmapped bedrock hollows and small inner gorges. May also contain a part of the Devils slide area (map unit #6). Unit also contains stable areas such as ridges and lower gradient landforms. Broadly mapped as one unit: landform and delivery need to be determined in the field on a site specific basis. Canopy cover precluded mapping of individual landslide areas. Map unit #7 contains the map units 1, 2, and 6.

MWMU #8: Landslide activity is rare to nonexistent, and/or no landslide delivery directly to streams of any order. Includes landforms such as hillslopes, valley floors, and ridges. Slope gradients less than or equal to 30 degrees. May contain small, localized deep-seated/earth flow areas, located primarily south of McCarty Cr. basin. Inclusions of less stable areas need to be identified with site specific field surveys. Area contains steeper, more unstable ground but that do not deliver to any water or other public resources.

MWMU #9: Active and dormant deep-seated landslide terrain. Sliding along rotational failure planes but shallow landsliding along over-steepened toes is likely. Failures into Jones Creek may trigger dam-break floods. Dormant areas characterized by hummocky topography and evidence of past failures. In some cases, tipped and deformed trees and small tension cracks (centimeters) indicate slow deformation. Active areas characterized by large ground ruptures (meters) and recent displacement of soil blocks or groups of blocks. In addition, active failures may be recognized by fresh slide scarps and downed trees Slope gradients generally greater than 20 degrees. Landslides generally most active near toes along channels and immediately upslope. Deep-seated landslides may also be located in map unit 2 in the Jones Creek basin, and in some cases they are unmapped. The deep-seated landslides may be the largest sediment source for the Jones Creek fan. High sediment delivery ratio.

MWMU #10: Shallow (landsliding and debris flows, and to a lesser extent small, sporadic deep-seated failures. Landsliding is generally uncommon in this unit, although the possibility exists for failure. Slope gradients generally between 31 and 35 degrees. The unit may contain unmapped inclusions of map unit #1 but this should not be common. Mostly planar topography with some broadly convergent areas.

The following insert is the original MWMU map from the Acme Watershed Analysis. Note that there no MWMU #5 polygons, and only one MWMU #4 polygon as these are to be verified in the field if needed.


LEGEND
Map unit #1
Map unit #2
Map unit #3A
Predominately high hazard areas
Map unit #3B
Predominately moderate hazard areas
Map unit #4
Map unit #5
Map unit #6
Map unit #7
Map unit #8
Map unit #9
Map unit #10
Deep-seated Bedrock Landslide - Boundary Approximate
Type 1, 2, or 3 Streams
Type 4 Streams
Roads
Railroad
Legal
WAU Boundary
NOOKSACK RIVER
WILLIAMS LAKE
TOSS CREEK
CARON CREEK
VAN ZANDT
TODD CREEK
TERHORST CREEK
SYGITOWICZ CREEK
STATE ROUTE 9
SOUTH FORK NOOKSACK RIVER
BLACK SLOUGH
HARDSCRABBLE CREEK
TINLING CREEK
STANDARD CREEK
McCARTY CREEK
ACME
JONES CREEK
LAND-STRIP CREEK
N
ACME WATERSHED ANALYSIS
TRILLIUM CORPORATION
FIGURE 3-7
MASS WASTING MAP UNITS
PROJECT NO.: 21977.410
3 OCTOBER 1996
1977-3-3.CDR/VGP
CHECKED BY: BENDA

Appendix C: Forest Practices Potentially Unstable Slopes

Landslides and the Forest Practices rule identified landforms. The Forest Practices rules for unstable slopes contain landforms that are identified as being potentially unstable. These landforms were determined as a result of the commonalities among 55 watershed analyses that identified potentially unstable slopes. Forest practices applications for timber harvest or associated activities such as roads, landings and rock pits on or adjacent to these landforms will require a qualified expert report to address the potential to deliver sediment or debris to a public resource or that has the potential to threaten public safety. (WAC 222-16-050 (1)(d). These applications will be classified as a Class IV special application except when "the proposed forest practice is located within a Watershed Administrative Unit (WAU) that is subject to an approved watershed analysis and in accordance with approved prescriptions with some other provisions" as seen in WAC 222-16-050 (1) (d) (iii) (A,B,C).

Forest Practices rule identified landform descriptions below are from *Forest Practices Board Manual 16* for unstable slopes (Forest Practices Board, 2001):

Bedrock hollows are (colluvium-filled bedrock hollows, or hollows; also referred to as zero-order basins, swales, or bedrock depressions) means landforms that are commonly spoon-shaped areas of convergent topography within unchannelled valleys on hillslopes with slopes steeper than thirty-five degrees (seventy percent). (See board manual section 16 for identification criteria.)

Inner gorges are canyons created by a combination of the down-cutting action of a stream and mass movement on the slope walls; they commonly show evidence of recent movement, such as obvious landslides, vertical tracks of disturbance vegetation, or areas that are concave in contour and/or profile with slopes steeper than thirty-five degrees (seventy percent). (See board manual section 16 for identification criteria.)

Convergent headwalls (or headwalls) are teardrop-shaped landforms, broad at the ridge top and terminating where headwaters converge into a single channel; they are broadly concave both longitudinally and across the slope, but may contain sharp ridges separating the headwater channels with slopes steeper than thirty-five degrees (seventy percent). (See board manual section 16 for identification criteria.)

Toes of deep-seated landslides are toes of deep-seated landslides, with slopes steeper than thirty-three degrees (sixty-five percent)

Outer edges of meander bends are the outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream;

'Other indicators of instability' includes any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes" (WAC 222-16-050 (1) (d) (E)).

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