Appendix A

ENGINEERING GEOLOGIC FIELD RECONNAISSANCE

DEBRIS SLIDES, DEBRIS FLOWS,
AND
AFFECTED PROPERTIES

3506, 3600, 3618, 3633, and 3652 Nelson Road
Whatcom County, Washington

Prepared for:

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Washington Department of Natural Resources
Land Management Division

May 6, 2009

TO: Jeff May
Baker District Manager
Department of Natural Resources
919 Township Street
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SUBJECT: **ENGINEERING GEOLOGIC FIELD RECONNAISSANCE**
Debris Slides, Debris Flows, and Affected Properties
3506, 3600, 3618, 3633, and 3652 Nelson Road
Whatcom County, Washington

DATE: May 6, 2009

The following Engineering Geologic Field Reconnaissance report presents our findings, a discussion, and our recommendations regarding the debris slides and debris flows that affected the residential properties at 3506, 3600, 3618, 3633, and 3652 Nelson Road in Whatcom County, Washington. This reconnaissance report addresses the following issues: 1) were the points-of-initiation of the debris slides on DNR managed lands, 2) were the points-of-initiation in areas of recent management activities, 3) did the management activities contribute to debris slide initiation, and 4) how much did management activities contribute to debris slide initiation.

If you have any questions, please call.

Respectfully submitted,

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EXECUTIVE SUMMARY

ENGINEERING GEOLOGIC FIELD RECONNAISSANCE DEBRIS SLIDES, DEBRIS FLOWS, AND AFFECTED PROPERTIES

3506, 3600, 3618, 3633, and 3652 Nelson Road Whatcom County, Washington

The early January 2009 storm triggered debris slides that mobilized into debris flows throughout much of northwest Washington. Some of these debris flows impacted to greater or lesser degrees five properties on Nelson Road in western Whatcom County (Figure 1). Three of those properties: Gantman, Fox, and Knutzen have residential structures that sustained damage along with lawn and pasture areas. The other two: Davis/Aube/ Danenger and Anderson properties, sustained damage to fields only (Figure 2).

There were six debris slide points of initiation (PI), informally named in this report from north to south: North, Middle, Sandy, South, Way South #1, and Way South #2. The North, Middle, and Sandy PIs are located in the early 1990s private timber sale named Tat. Following timber harvest of the Tat sale the land was acquired by the Department of Natural Resources (DNR). The South and Way South #1 PIs occurred in leave tree/riparian buffer zones adjacent to harvested areas of the early 2000s DNR Jack Straw Aerial Timber Sale. The Way South #2 PI occurred on DNR lands in an area that has not been managed for about 60 years. The slides that originated in the Tat sale all utilized the same drainage to reach the valley floor and impact the Davis/Aube/Danenger, Gantman, Fox, and Knutzen properties. The slides that originated in the Jack Straw sale utilized two separate drainages to reach the valley floor and impacted the Knutzen and Anderson properties. The Way South #2 slide utilized the same drainage as the Way South #1 slide with the same results.

Natural site conditions that influenced the development of the debris slides in question include the steep topography of the area; the bedrock structure and fracture patterns in the bedrock; the locally thin soils, thick glacial deposits, or deep-seated landslide debris (Figure 3); and storm induced increases in runoff and ground water. Management activities that also likely influenced the occurrence of the slides include the two timber sales and the haul road, informally named in this report the Tat Road, built for the Tat sale and later used during harvest of the Jack Straw Aerial Sale (Figure 3). However, it was the rain-on-snow conditions associated with the early January 2009 storm that was the triggering event that initiated the debris slides and associated debris flows.

The North and Middle PIs developed in landforms that under current forest practice rules would have received protection, but at the time of the Tat sale were not recognized as needing protection. These slides occurred in thin soils overlying well-fractured bedrock. The surrounding regeneration had reached about 20% hydrologic maturity; the root system may have recovered to between 40% to 70% of pre-harvest total effective strength. Based on our review of aerial photographs and our field reconnaissance it appears that earlier storms did not trigger slides at these sites, inspite of the relatively more vulnerable conditions (lower root strength levels) that would have existed at earlier times. The management activities likely had a low level of influence and the major reason for the development of these two slides was because the January storm overwhelmed material strength of the earth materials and, in effect, legacy the on-ground-conditions created by the forest practice rules at the time of the Tat sale and harvest.

The Sandy and Way South #1 PIs were influenced by other landslides in addition to local site conditions. They may also have been influenced by the cumulative effects of timber harvesting upslope of them. The Sandy PI occurred in a hillside deposit of glacial sand in the Tat sale. The slopes at the site are not particularly steep. Prior to the failure this site would not likely have received any special prescriptions under current rules, let alone the rules in effect at the time of the Tat sale and harvest. The underlying bedrock structure may likely have had some influence in directing ground water toward the PI. Cumulative effects with respect to the upslope Jack Straw sale may have also had some influence. A relatively large road cut failure likely had the effect of directing additional water to the area of the Sandy PI via a relatively small debris slide associated with the larger Tat Road slide. The water from this small slide combined with ground water from the Jack Straw sale was directed toward the site of the Sandy PI via the northward inclination of the bedrock, leading to saturation of the sand and initiating the Sandy PI slide. The Way South #1 PI occurred in landslide debris on steep slopes in inner gorge terrain in the Jack Straw Aerial Timber Sale. The slide debris is associated with an existing large deep-seated landslide that was apparently reactivated in response to the January 2009 storm. Ground cracks developed at the head of the slide and along a scarp within the slide mass. It was at the intersection of the latter scarp and associated ground cracks, and the steep slopes of the drainage that the Way South # 1 PI developed. The cumulative effects of timber harvesting up slope of the deep-seated landslide could have contributed to the reactivation of the slide. Movement of the deep-seated landslide, combined with the already weak nature of the slide debris, which is then further disturbed by the development of the slide scarp, and the steep slopes of the inner-gorge terrain, lead to a slide occurring at that location. At both PIs just discussed the long-term degradation of hillside strength and the cumulative effects of timber harvest on the stability of adjacent areas or deep-seated landslides must be considered as contributing factors in the development of the Sandy and Way South #1 PI.

The South PI occurred at in an inner-gorge setting adjacent to a harvested area the Jack Straw Aerial Timber Sale. It too occurred in landslide debris on the margin of a deep-seated landslide, but a deep-seated slide that did not appear to be reactivated by the January 2009 storm. Downed trees in the drainage at the PI confuse the interpretation of how the slide developed. It is not clear whether the in-fallen trees caused the slide or fell in as a result of the slide. At this PI it appears that the magnitude of the storm overwhelmed the site conditions and, in effect, the on-the-ground conditions created by the Watershed Analysis prescriptions. It is possible that had the storm been smaller the slide would likely not have occurred.

The Way South #2 PI does not appear to be related to any current management activities.

The January 2009 rain-on-snow event triggered the debris slides that are the subject of this engineering geologic field reconnaissance report. In the case of the North and Middle PIs management activities appear to have had a low or minor influence in the initiation of the debris slides at those locations. At the Sandy PI and the Way South #1 PI the cumulative effects of timber harvesting likely had a moderate to high level of influence with respect to those failures. At the South PI management activities likely had a low influence with respect to development of the slide that occurred at that location. Management activities had no influence on the development of the Way South #2 PI, the stand of trees at that PI were at least 60 years old.

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

TO: Jeff May
Baker District Manager
Department of Natural Resources
919 Township Street
Sedro-Woolley, Washington 98284

SUBJECT: **ENGINEERING GEOLOGIC FIELD RECONNAISSANCE**
Debris Slides, Debris Flows, and Affected Properties
3506, 3600, 3618, 3633, and 3652 Nelson Road
Whatcom County, Washington

DATE: May 6, 2009

1.0. INTRODUCTION

At your request we have completed an engineering geologic field reconnaissance of the debris slides and debris flows that affected residential properties in west-central Whatcom County. The debris slides and debris flows that are the subject of this field reconnaissance report occurred during the early January 2009 rain storm. The general area of our geologic field reconnaissance and the affected properties is shown on Figure 1. The affected properties (Owners) are located at 3506 (Anderson), 3600 (Knutzen), 3618 (Fox), 3633 (Davis/Aube/Danenger), and 3652 (Gantman) Nelson Road. The distribution of the several properties and the general configuration of debris-flow run-out areas are shown on Figure 2. The debris slides initiated in the NW¼ of Section 21 and the affected residences are located in the NE¼ of Section 20, T38N, R5E, (Willamette Base Line &Meridian) in the US Geological Survey 7½-minute Deming Quadrangle.

Initial field reconnaissance for this storm event identified and proposed to treat the debris slides and flows that affected the Anderson, Knutzen, and Fox properties in one report named Nelson Road #1 and the debris slides and flows that affected the Davis/Aube/Danenger and Gantman property separately in another report named Nelson Road #2. However, as our field reconnaissance unfolded it became apparent that the five properties were impacted to greater or lesser degrees by the same debris slides and debris flows, save for the Anderson and Knutzen property that were affected not only by the debris slides and flows that affected the three other properties, but also by two other debris slides and associated debris flows. For this reason we have decided to prepare one report for all five properties.

As shown on Figure 1, the affected properties are located at or near the base of the west side of a plateau-like topographic high known as Van Zandt Dike. The properties are situated in the Acme Watershed Administrative Unit (WAU). To date Landslide Hazard

Zonation mapping has not been undertaken for this area. However, watershed analysis for the Acme WAU was released in 1999 by Trillium Corporation. The debris slides originated in the Acme Watershed Mass Wasting Map Unit (MWMU) #7. This MWMU is described as a “conditionally high hazard” area. In this MWMU slope processes are characterized as predominately shallow landslides, small debris slides, and possibly bedrock-slab failures. The area in question is designated as Area of Resource Sensitivity Mass Wasting Unit 1 (ARS MW-1). This ARS is accompanied by an involved set of landform descriptions, resource concerns, linkages, and prescriptions. Please see the Acme Watershed Analysis for details. Save for the Davis/Aube/Danenger and Anderson properties the some or all of the other properties are located within an alluvial fan hazard zone as shown on the *Geologically Hazardous Areas* map of the Whatcom County Critical Areas Ordinance prepared in 2006 for Whatcom County Planning & Development. The Davis/Aube/Danenger property is located on alluvial terrace deposits and the Anderson property is located essentially on the valley floor.

The purpose of our geologic field reconnaissance was to locate the point-of-initiation (PI) of the debris slides, observe the site conditions at the PIs, observe the conditions along the flow tracks, and note conditions in the areas of deposition. In addition, we were asked to provide a professional opinion, based on the office data reviewed and field evidence we observed, as to the natural and, if applicable, the anthropomorphic contributory factors that influenced landslide initiation, as well as the triggering event that caused the debris slides and flows. We also provide, as appropriate, site specific recommendations intended to help reduce the potential for future debris slides and flows on DNR managed lands in the area in question.

2.0. SCOPE OF WORK

Our scope of work included the following tasks:

- Review of pertinent published and unpublished geologic reports and maps in our office files
- Review of Whatcom County hazards maps
- Review of watershed analysis reports
- Review of unpublished landslide hazards reports
- Review of pertinent data files in the DNR electronic database
- Review of pertinent LIDAR imaging in the DNR electronic database
- Review of pertinent aerial photographs in the DNR files at the Northwest Region office
- Review of available pertinent past Forest Practices Applications
- Reconnaissance of the debris-slide points-of-initiation and flow tracks
- Reconnaissance of the depositional area of the debris flows

- Photographing pertinent aspects of the debris slides, flow tracks, and depositional areas
- Review of pertinent historical rainfall and snowfall data
- Review of available rainfall and snowfall data related to the January 4 to 8, 2009 storm
- Analysis of the resulting data
- Preparation of this field reconnaissance report and accompanying illustrations

In addition there was one meeting with the Northwest Regional Manager and selected assistant Northwest Regional staff, geologists from Washington Division of Geology and Earth Resources, and geologists from the DNR Land Management Division (LMD) Earth Sciences Program in which the general nature of the proposed reports for the slides related to the January storm and estimated schedule of field work and report completion were discussed. No specific site was discussed in any detail.

3.0. LIST OF ILLUSTRATIONS

The following illustrations are attached to the back of this report:

4.0. PHYSICAL SETTING

The area is dominated by the Van Zandt Dike and the South Fork Nooksack River Valley. The physical setting of the PIs of the debris slides, flow tracks, and the areas of deposition (all collectively referred to as the “Site”) are characterized by the topography, climate, geology, landslides, and ground water. Each of these attributes is briefly discussed below.

4.1. TOPOGRAPHY

The topography of the Site is represented by two distinctly different types of terrain (Figures 1, 2, and 3). The PIs are in an area of steep hillside topography. The affected residences are located on relatively gentle hillside topography. The west-facing slopes of Van Zandt Dike exhibit an average inclination of about 85%. However, locally bedrock cliffs characterized by essentially vertical inclinations of several tens of feet are present; locally, between the cliffs can be found narrow northwesterly-inclined benches. The bench and cliff topography create a subtle “ribbed” effect that sweeps downward across the hillside area, where the debris slides originated, and across lower slopes (Figure 3). The PIs are situated at elevations that vary from about 970 to 1,425 feet. The depositional areas and affected residences are situated on relatively gentle topography, at elevations of approximately 250 to about 370 feet. The local relief between the residences in question and the area of the PIs is high, up to approximately 1,400 feet vertical over a horizontal distance of about 2,000 feet measured from the base of the slope. Subtle benchy topography or existing landslides were observed in the area of some of the PIs (Figure 3). These benches display northwesterly inclinations. Three relatively significant drainages can be observed incised into the west-facing slopes of the Site. As shown on Figure 3, they are informally named, from north to south, the Gantman-Fox Drainage, the Bench Drainage, and the Knutzen Drainage. Locally these drainages are well incised with high, steep side-slopes, bedrock cascades, and towering water falls, but also stretches (though sometimes short) of more subdued topography were observed. The upper portions of the streams in the Site are all classified as Type-5 streams. About half way down in the Gantman-Fox and Knutzen drainages the streams are reclassified as Type-4s. In the Knutzen Drainage the stream is again re-typed, about 500 feet further downstream, as a Type-3. Inspection of the LiDAR topographic mapping and field observations revealed that two of the residences (Gantman and Fox) are located on an alluvial fan that has developed at the mouth of the Gantman-Fox Drainage (Figure 3). Alluvial fans can also be delineated at the mouths of drainages in the immediate vicinity, including the Knutzen Drainage and to a lesser extent the Bench Drainage (Figure 3).

4.2. CLIMATE

The historical climatic record and pertinent details of the recent storm are briefly presented below. Details of the recent storm are as current as possible at the time of preparation of this report. These details could change as more information becomes available.

4.2.1. Historic Record – The area of the Site 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, about 120 miles to the west. The Site is about 10½ miles southwest of the Canyon

Lake and Kenney Creek watershed and is likely subject to similar general climatic conditions as that watershed. Based on the general climatic description for the Canyon Lake and Kenney Creek watersheds it is reasonable to infer that in the area of the Site the majority of the rainfall occurs between mid-October and late February (Trillium Corporation, 1993). (Similar data was not available in the Acme Watershed Analysis.) Yearly rainfall in the Canyon Lake and Kenney Creek watershed is estimated to average about 70 inches in the lower elevations to about 100 inches/year at higher elevations.

The nearest weather recording station with a lengthy historic record is located at the Glacier Ranger Station (Western Region Climate Center (WRCC), 2008), about 13½ miles to the northeast of the Site. The Glacier recording station is some distance away but is at an elevation of approximately 1,000 feet, in the range of the elevations of the PIs (970 to 1,420 feet) of the several debris slides. In our opinion it does not appear to be unreasonable to assume that historical precipitation conditions at the PIs are at least somewhat similar to the Glacier station. The area of the PIs is in the rain-dominated zone (below 1,600 feet). The generally accepted zone of greatest or most frequent rain-on-snow influence in this portion of the Cascades is from 1,600 to 4,000 feet (Trillium Corporation, 1993).

The three periods-of-record (POR) for the Glacier Ranger Station include the following: 1949-1983, 1961-1990, and 1971-2000; in total a 51-year record. The WRCC (2008) reports the annual average rainfall at the Glacier Ranger Station varies between about 68¾ and 71 inches with a yearly standard deviation of about 12 inches. The mean annual for the 1949 to 1983 POR is 66⅔ inches of rain. The highest recorded January rainfall for the POR was 19½ in 1974; for a December it was 21 inches in 1979. The mean January and December rainfalls are 9⅓ and 10½ inches, respectively. Average daily precipitation in January and December it is about ⅓ of an inch, within a daily range that varies from about one-eight inch to five-eights inches for both months. However, the maximum one-day total in January during the POR is about 3½ inches, while in December it is about 4⅔ inches. It appears that during one very unusual December storm event the daily average rainfall was exceeded by about 1,225%. The mean average snow fall is about 51¾ inches per year over the 1948 to 1982 POR for snow fall. The greatest snowfall in January was 73¾ inches in 1954; in December, 25 inches in 1971. The monthly mean is about 17 and 8 inches for January and December, respectively. Daily average snowfall for January and December has varied from 0 to about 1¾ inches; however, during extreme events up to at least 17 inches of snow has fallen in a single day. Snow depths at the Glacier station during January average between about 1 and 6⅓ inches over the POR; in December the average for the POR is between 0 to about 1 inch. Over the POR, snow-depth extremes for January range from about 11 inches to about 37¼ inches; for December, the range is from 0 to about 11 inches.

Since 2000 (the end of the POR) the National Climatic Data Center (2009) reports that Whatcom County has experienced one heavy snow event in February 2001, three heavy snow events in January and February of 2002, one heavy rain event in October 2003, a winter-weather mix event in January 2004, heavy rains in November and December 2004, one heavy snow event followed by a flood (heavy rain?) event in January 2005, and finally a flood (heavy rain?) event in November 2006. In December 2008, the area experienced a prolonged period of severe winter weather during which snow accumulations reached about a foot-and-a-half in the low lying areas.

The January 2009 storm followed a several-week period of snow storms, prolonged freezing temperatures, and thick accumulations of snow, even at the lower elevations. We reviewed the available historic climate data to determine how often such a sequence of weather events has occurred in the area of the Site. Only the data for the years 1949 to 1983, a 34 year period, from the WRCC contained totals for monthly accumulations of snow and rain. We arbitrarily chose months where the December snow fall equaled or exceeded 10 inches, and the January rainfall equaled or exceeded 10 inches, to try to provide a minimum match to the conditions leading up to the January 2009 storm. For the time period reviewed there were only two periods that matched these criteria: December/January 1970/71 (snow 30"/rain 13", respectively) and December/January 1971/72 (snow 45"/rain 13" respectively). It should be noted that in both January's there was significant snowfall in addition to the rainfall. It should also be noted that there were several January snowfall and rainfall totals that came close or exceeded the 10-inch minimum (January 1954, '60, '68, '70, '74, '76, and '82) but because it is uncertain whether the rain followed the snow or vice-versa we could not be sure how representative these storms would be of the climatic setting leading up to the January 2009 storm.

4.2.2. January 2009 Storm – The damaging storm in question began about January 4 and continued to about January 8, 2009, and followed on the heels of the December 2008 snow storms mentioned above. No recording stations are located at the Site or immediately near it. However, interpretation of Doppler-radar imaging of the four day period of rain bracketed above (National Weather Service, 2009) suggests that the Van Zandt Dike area received about 9 to 11 inches of rain during that period. The January 4 to 8 period was preceded and followed by showers and light rain and snow so that the actual total could be somewhat greater. The time-intensity relationships are uncertain, but likely were characterized by periods of heavy rainfall interspersed with periods of lighter to no rainfall. The amount of snowfall on the Dike and slopes above the affected residences is also uncertain. However, based on anecdotal discussions with the Unit Forester at the Deming Work Center, it appears that the snow pack was about two feet, and maybe as much as three, thick. Temperature, and wind data from University of Utah TSUNA weather station east of Deming near the base of Sumas Mountain recorded almost three weeks of below or just above freezing temperatures prior to the January 4 to 8 storm. During the storm, temperatures rose over the four day period from below freezing to almost 50°F during the last couple of days of the storm. Also wind speeds between 20 to 30 mph from the SSW with sustained speeds of 15 to20 mph were recorded at the weather station during the latter days of the storm (University of Utah, 2009).

4.3. GEOLOGY

The geology of the Site is represented by the underlying Eocene age bedrock and the Quaternary age surficial deposits that overlie the bedrock. Surficial deposits include glacial sediments, soil and colluvium, landslide debris, alluvial fan deposits and alluvial/terrace deposits. A brief description and general distribution of these earth materials is presented below, their general distribution is shown on Figure 3.

4.3.1. Bedrock – The bedrock geology at the Site is represented by the Chuckanut Formation (Dragovich and others, 2000). It is composed of sandstone interbedded with lesser amounts of siltstone and shale. The sandstone varies from locally laminated to very thick bedded and exhibits a general east-west strike and a moderate (40°) to steep (70°) northerly dip. Locally the bedrock is broken by sets of generally steeply dipping northeasterly and northwesterly striking joints. The bedrock crops out in the upper reaches of the Site and is assumed to underlie the surficial deposits from the mid-slope areas downward where the bedrock is overlain by a variety of surficial deposits.

4.3.2. Surficial Deposits – The **glacial sediments** at the Site are represented by a relatively thick accumulation of sand. The lower portion of the deposit is characterized by faint “blocks” of sand in a sandy matrix. Overlying the lower layer is a couple of tens of feet of sand. The sand is relatively loose. The deposit is mapped as an isolated patch in the upper reaches of the Site (Figure 3).

Soils and colluvium are derived from the mechanical and chemical weathering of the underlying bedrock. These deposits are composed of varying amounts sand, silt, and clay intermixed with blocks of bedrock and organic debris. Soil mapping published by Goldin in 1992 classifies the soils underlying the lower portions of the Site as Chuckanut loam and those underlying the mid- and upper slopes as Andic Xerochrepts on 60% to 90% slopes. The Chuckanut loam is characterized as well drained, moderately permeable, having a high water capacity, moderate runoff, and moderate erosion hazard. The Andic Xerochrepts soil is described as a loam intermixed through the area with bedrock outcrops. The loam component is characterized as well drained, moderately permeable, having a high water capacity, moderate runoff, and moderate erosion hazard. The soils form more or less in-place; however, the colluvial deposits are formed by the accumulation of soil moved down slope in response to gravity driven processes (e.g., soil creep, etc.). Herein, colluvial deposits are considered to be soil deposits thicker than about 3 to 4 feet. The soils occur in patches and discontinuously across the upper areas of the site including the bedrock benches noted above. Colluvium blankets the mid- and lower slopes of the site, but also has accumulated locally on topographic benches.

Landslide debris is composed of a mixture of sand, silt, clay, and blocks of bedrock. The blocks of rock can be quite variable in size. Landslide debris is confined to landslides in the hillside areas, but is understood to be inter-fingered with sediments in alluvial fans and soil and colluvium on lower slope areas of the site.

Alluvial fan deposits are composed of interbedded debris-flow deposits and fluvial sediments. The debris-flow deposits, where exposed, are poorly-stratified, poorly-sorted deposits of coarse angular accumulations of bedrock debris and soil. They are mapped at the mouths of the various drainages at the Site. **Alluvial deposits and terrace deposits** are composed of stratified gravel, sand, silt, and clay. They underlie the valley floor areas of the Site, and can be interfingered with colluvial and alluvial deposits.

4.4. LANDSLIDES

Landslide processes in the area of the Site can be classified into two broad categories: 1) More-or-less intact rotational or translational slides of widely varying size and thickness and 2) debris slides and associated debris flows. In this report we utilize the flow-type landslide-classification system suggested by Hungr and others (2001). Rock fall processes likely also occur at the Site, but are probably very rare and relatively small in scale, though the collapse of the entire hillside, as happened to the north (Devils Slide area), can not go unnoticed (Brunengo, 2001).

Rotational and translational slides were observed at several locations at the Site (Figure 3). These slides vary in length from a couple of hundred feet up to 1,500 feet, and in width to 300 feet. These slides exhibit subdued topographic expression suggesting they are relatively stable. Reactivation of a modest-size translational slide was observed in the upper reaches of the Knutzen Drainage (Figure 3). In this reconnaissance report this slide is informally referred to as South Side Landslide. This slide is discussed in more detail in section **6.4. OTHER SLIDES AND POINTS OF INTREST.**

Topographic evidence (e.g., bedrock hollows, convergent topography, and alluvial fans) suggesting past debris slide activity is apparent at many locations (Figure 3) in the area of the Site. Our field observations and interpretations of the LiDAR topography suggest that the base of the rock cliffs can be a point-of-initiation for some of these slides. Elsewhere they are clearly related to the steep side-slopes of the drainage channels or initiate at the heads of the drainages, leading to gradual upslope propagation and deepening of the drainage channels. Bedrock hollows are also a source area and double as evidence for past debris slide activity. Debris flows carry the earth materials and organic debris derived from the point-of-initiation and scoured from the sides and bottom of the channel in which the slides are confined, rapidly down the channel to the valley floor. They can attain speeds from 1-foot/minute to 10-feet or more/second (Cruden and Varnes, 1996) and because of the relatively dense nature of the slurry that is the flows, the flows can carry quite large size rocks and other debris. At the valley floor the flows begin to deposit earth materials and organic debris they are carrying. Where this deposition occurs alluvial fans are developed. The flows can carry the entrained materials quite some distance from the mouth of the drainage, which is essentially the apex of the alluvial fan. It should be noted that less dramatic stream processes can also add to development of alluvial fans. Debris slides and associated debris flows related to the January storm are discussed in some detail in section **6.0. RECONNAISSANCE OBSERVATIONS**

The Whatcom County Critical Areas Ordinance – Geologically Hazardous Areas map, prepared in 2006, shows that the locations of the residential structures of the properties in question (save for the Andersons and Davis, Aube, Danenger,) are in an area of alluvial fan hazards (GHA3 area on the Geologically Hazardous Area map noted above).

4.5. GROUND WATER

Evidence for shallow ground-water at the time of failure or afterwards was noted in the scarps and scars at some of the debris slides (the PIs) and locally at some isolated locations around the Site. The evidence at the PIs included piping, subdued channeling, springs, and flowing water. Indirect evidence for the presence of shallow ground water was fractured bedrock. With respect to the deeper ground-water system, of particular interest is the possible influence of the bedrock structure upon the directivity of deeper ground-water flow. During our field reconnaissance we observed that locally, the sandstone bedrock is characterized by areas of relatively well-fractured bedrock, making the rock mass somewhat permeable. Elsewhere, we noted the spacing of fractures can be quite wide, thus making the rock mass fairly impermeable. It would not be unreasonable to expect that where ground water, as it percolates through the subsurface, encounters bedrock with widely-spaced fractures, to migrate northward and laterally along the bedding for some distance, at least until an area of well-fractured rock is encountered. In the area of well-fractured rock the downward (cross-bedding) migration could occur until less-fractured rock is encountered and the process of flow parallel to bedding, or parallel-to-strike, starts again. This directivity could help to concentrate ground water in some locations, such as bedrock benches and also direct the ground water toward cliff areas.

An important factor affecting ground water, especially at the time of the failures, was the January 2009 storm and the associated phenomenon commonly known as rain-on-snow (ROS) precipitation. It should be noted that the PIs of the debris slides in question were all below the 1,600 foot elevation that is often considered to be the lower elevation of the ROS zone. However, portions of the harvest areas out of which the slides originated extend up into the ROS zone, and the upper areas of the Site, including the PIs, were covered by snow prior at the time of the January 2009 rain storm.

The change in peak flows in harvested areas verses un-harvested areas in the Acme WAU was analyzed by Beschta (1995) for that watershed analysis. Part of that analysis focused on the Van Zandt Dike area, referred to in that analysis as the Eastern SubWAU. Beschta determined peak flow for the subWAU (not individual streams in it) under fully-forested conditions and subsequent increases in peak flow under then current conditions (about 33% of the subWAU forested with hydrologically immature (<25yrs old) stands), and clear-cut conditions. Though the analysis was for the entire Dike and not a relatively small specific area of the Dike, in our opinion, some generalized relationships can be drawn from the aforementioned analysis. Beschta (1995) showed that there was an approximately 3% increase in peak flow under then current conditions and that there would be an 11% increase in peak flow if the entire sub-basin were clear cut. Stated another way, the magnitude of a peak-flow with a 10-year recurrence interval under fully-forested conditions would increase to that of a 14-year storm event under clear-cut conditions (Beschta, 1995). As part of Beschta (1995) analysis of the Acme Watershed, in addition to the Eastern SubWAU, he also recognized a Western SubWAU. One important difference between the two subWAUs is that the Western SubWAU is characterized with more land at higher elevations than the Eastern SubWAU. Thus, the results of the same analysis show that the peak flows in the Western SubWAU would be about twice that of the Eastern SubWAU. In this report we have assumed that an increase in stream flow would also suggest a somewhat like-magnitude increase in ground water.

We understand that the sub-basin is not uniform and that projection of the results from basin-wide to a localized hillside setting needs to be done with some caution. However, the results of the Beschta analysis suggests the change in the hydrologic regime (peak flows and, by association, ground water) at the Site following the clear cut of the latest timber harvest (the Jack Straw Aerial Timber Sale noted below in Section 5.2.1) would not be extremely large. An older harvest known informally as the Tat sale (see Section 5.2.1) is adjacent to the north and west of the Jack Straw Aerial Timber Sale. After the Tat Sale was harvested, DNR acquired the property and it is now referred to as the West Side Dike management unit. Based on hydrological maturity data presented by Beschta (1995), the Tat sale had probably reached 10% to 15% recovery of the hydrologic maturity at the time of the January 2009 storm. This low percent recovery does not equate to a significant improvement of the ground-water setting of the Tat sale over current conditions of the Jack Straw sale.

5.0. HISTORICAL SETTING

The historical setting of the Site is briefly summarized below. This includes the past landslide history and past forest practices and adjacent land-use history. Interpretation of stereoscopic aerial photography was relied upon for preparation of this section. For a complete list of aerial photography reviewed please see **AERIAL PHOTOGRAPHS REVIEWED** in the back of this report.

5.1. LANDSLIDE HISTORY

Review of 12 sets of aerial photographs dating from 1947 to 2001 revealed only a few small debris slides originating on slopes in the Site during that time period. The 1947 aerial photographs showed minor debris-slide activity on slopes to the north and south of the Site. The 1955 photos revealed one small slide on a mid-slope area of the Site. The 1961 photos showed a couple of debris-slide scars on the side slopes of the Knutzen Drainage. Review of the 1970 coverage suggested some slope disturbance on the lower slopes surrounding the Knutzen Drainage, but the exact cause of the disturbance was difficult to discern. The 1976 photos showed two debris slides on the lower steep slopes just north of the site. It appears that at least one of these slides may have flowed down to the valley floor. Only one very small slide, occurring on steep slopes just north of the Site, was observed on the 1978 photos. The 1983 aerial coverage showed one debris slide occurring on the steep lower slopes just north of the Site. No slides were noted on the 1988 photographs. In 1995 a debris slide reoccurred in one of debris slides sites noted on the 1970 photos. The 2001 coverage did not show any evidence of recent (to the time of the photographs) debris slide activity. It should be noted that evidence for movement of large, seep-seated landslides was not observed on the photographs reviewed. This should not be construed to suggest that movement has or has not occurred; only that such movement may have been too small to be detectable on 1:12,000 scale aerial photographs.

5.2. FOREST PRACTICES AND LAND-USE HISTORY

The following discussions are based on review of vertical, stereographic aerial photographs dating back to 1947, review of relevant forest practices applications, and discussions with home owners of the affected residences.

5.2.1. Forest Practices – The 1947 aerial photographs show that by that time a large area of the “top” of Van Zandt Dike had been clear cut. Based on the appearance of the regeneration, the clear cut may date to 10 to 20 years earlier. The lower slopes and On the 1947 aerial photographs the lower slopes are in very dark shadows and it is very difficult to see any details and only vague suggestions of any activity in the area of the site. The 1955 aerial photographs show harvest activity on slopes in the southwest area of the Site. Based on the appearance of the revegetation the harvest activity may date to the late 1940s. However, it appears that prior to 1955 the great majority of the harvest activity was apparently confined to the flat and gentle slopes of the Dike, except for two harvest areas that extended down two hillside-ridge areas (north and south) within the Site. The 1970 aerial photographs show a couple of small harvest areas on the lower slopes behind the current location of the Gantman and Fox residences. The 1976 photographs show a small harvest on the southern hillside-ridge area noted on the 1947 coverage. By 1978 another area had been cut. This area straddled an east-west ridge that flanks the northern margin of the Site. To that date it appears that no protection was afforded streams or areas of potential instability. Review of the 1995 photo coverage shows the Tat timber harvest had occurred. The actual time of the Tat harvest was 1994 to 1995 (FPA 30-074490). This harvest included part of a hillside-ridge area cut earlier in 1947. Construction of the road and landing for that sale occurred prior to that harvest in 1994. (In this report the road and landing are referred to as the Tat Road and the Tat Landing.) The above noted harvests apparently all occurred on DNR managed lands except for the Tat harvest, which occurred on privately held lands that shortly thereafter were acquired by DNR. The 2001 aerial photographs show that the flat and gently sloping areas along the southeast margin at the top of the Site were reentered for the DNR Dike Dutchman Timber Sale. An area lower on the west-facing slope and flanking the south side of the Site was also cut by 2001. Later, significant portions of the upper area of the Site were included as part of the DNR Jack Straw Aerial Timber Sale (FPA 30-074490, 2003) that was subsequently cut in 2004 and 2005 (Pers. comm., Doug Hooks, 2009). For the Jack Straw harvest the Tat road was utilized, but then abandoned in the fall of 2005 following the harvest (Pers. Comm., Doug Hooks, 2009). Both the Tat and Jack Straw sales were clear cut harvests with clumps and scattered leave-trees. The Jack Straw Timber Sale was laid out to comply with the Acme Watershed Analysis prescriptions (Crown Pacific Limited Partnership, 1999). Stream inner-gorges, bedrock hollows, and other areas of instability were excluded from the sale as per the watershed prescriptions. In some areas, apparently including some places around Type-5 streams, harvest boundaries were delineated to exceed the requirements of the Acme Watershed Analysis prescriptions (Wolff, 2003). By the time of the January storm a moderately- well developed Douglas-fir plantation and associated understory along with some hardwoods had regenerated in the Tat sale. The Jack Straw Aerial sale had been replanted and the seedlings growing.

5.2.2. Land-Use History – Nelson Road is present on the 1947 aerial photographs. Its configuration is essentially the same as today with the 90° turn that directs the road west to its intersection with Washington State Route 9, about 1¼ miles south of Van Zandt (Figure 1). North of the 90° turn, Nelson Road is characterized by three relatively gentle bends. After the northernmost of these bends the road continues straight northward to a “T”-intersection with Potter Road, which extends eastward from Van Zandt.

Review of the 1947 photography shows no residential structures, or any other structures, east of Nelson Road from the 90° turn and through the "bendy" segment; however, structures are observed north of the "bendy" segment, though the Anderson residence is present. In 1947 land use was solely agricultural, and arguably some timber production along the lower slopes of the Dike. By 1955 some of the structures at the Knutzen site are present at the 90° turn. No other structures are present along the "bendy" road segment of Nelson Road. Review of the 1983 photographs shows the Fox residence is present, indicating it was built between 1978 and 1983 (1982 according to Whatcom County Assessors database, 2009). The Gantman residence first appears on the 2001 coverage, indicating it was built about 19988 (Whatcom County Assessors database, 2009). The Davis/Aube/Danenger structures were constructed in 2006 (Whatcom County Assessors database, 2009).

6.0. RECONNAISSANCE OBSERVATIONS

The debris slides that affected the Anderson, Gantman, Davis/Aube/Danenger, Fox, and Knutzen properties are reported to have begun around midnight January 6th and continued sporadically until mid afternoon January 7th (Pers. comm, Doug Hooks, 2009). The following discussion presents salient field observations regarding the debris slides that impacted the several residences. The discussion proceeds from the PI downslope to the areas of deposition. Resulting damage to private property is summarized in the Areas of Deposition discussion. Other slides and points of interest are also presented.

As shown on Figure 3 there were six PIs in the Site distributed across the hillside in a generally north-south orientation. Herein they are referred to, from north to south, as North PI, Middle PI, Sandy PI, South PI, Way South #1 PI, and Way South #2 PI (Figure 3). The debris slides generated at the northern three PIs followed the Gantman-Fox Drainage and impacted the Gantman, Davis/Aube/Danenger, Fox, Knutzen, and Anderson properties. The southern three debris slides followed different drainages, the Bench and Knutzen, but impacted only the Knutzen and Anderson properties. The PIs, flow tracks, and deposition areas are discussed below from north to south. The PIs of the debris slides and subsequent debris flows that caused damage, and are discussed below, are all located on DNR-managed lands.

6.1. POINTS OF INITIATION (PI)

The **North PI** is at an elevation of about 1,425 feet in the Tat sale (Figure 3). It is in the upper portion of a somewhat subtle draw characterized by steep (70%) slopes and broad convergent topography in the upper reaches of the Gantman-Fox Drainage (Figure 4). The slide scar is estimated to be about 35 feet wide and 3 to 5 feet deep. The sandstone bedrock exposed is well jointed and fractured. The slide failed on an essentially planar soil/bedrock contact. Root depth as exposed in the slide scarp is about 2 feet, and there is no evidence that roots penetrated into the underlying bedrock. Regenerating Douglas-fir is estimated to be about 10 to 15 years old, with a well-developed understory. At the time of our reconnaissance the scarp area of the scar was dry; however, erosion channels ½- to 1¼-feet deep that developed after the failure are present suggesting running water. A seep was observed in the scar about 20 feet downslope from the scarp. No evidence for channelized overland flow was observed above the scarp.

The **Middle PI** is at an elevation of about 1,370 feet in the Tat sale (Figure 3). It is located in the upper stretch of a well-defined narrow swale characterized by an 80 to 90% slope in the upper reaches of the Gantman-Fox Drainage (Figures 4 and 5). The slide scar is estimated to be about 25-feet wide and about 3-feet deep. Well-fractured sandstone bedrock is exposed and overlain by about 1 to 3 feet of soil. The slide apparently occurred on the soil/bedrock contact in pre-existing bedrock-hollow topography. Root depth is confined to the soil and there is no evidence that roots penetrated into the underlying bedrock. Regenerating Douglas fir is estimated to be about 10 to 15 years old, with a well-developed understory. At the time of our reconnaissance, the bedrock surface exposed in the hollow had water on flowing across it with an erosion channel present in the debris slide track. About 50 feet upslope of the scar slopes become planar.

The scarp of the **Sandy PI** is at an elevation of about 1,390 feet in the Tat sale (Figure 3). It is located in the upper reaches of the Gantman-Fox Drainage. The scarp is about 100 feet wide and is estimated to be about 35 feet tall (Figure 5). The slide scar is estimated to be about 10- to 15-feet deep (measured perpendicular to the ground surface). The slide occurred in an area of broadly convergent to planar topography characterized by slope inclinations of 40 to 60% locally; however, along the north side of the scarp and up slope of the scarp, slope inclinations are upwards of 70 to 90%. The slide occurred in a deposit of sand, the origin of which is uncertain, but is likely glacial. Roots penetrated about 4 to 5 feet into the sand deposit. Regenerating Douglas fir and big leaf maple is estimated to be about 10 to 15 years old, with a well developed understory. At the time of our reconnaissance, we noted several small erosion channels within the slide scar indicating locally channelized post-failure flow. These channels were generally less than 2 feet wide and ranged from approximately ½- to 3-feet deep. No water was observed in the erosion channels in this area during our reconnaissance.

The **South PI** is at an elevation of about 1,400 feet in the Jack Straw Timber Sale (Figure 3). It is located in the upper reaches of the Bench Drainage on the south side of a steep-walled section of that drainage. The PI at this location is a stream-side landslide (Figure 6). The scar is estimated to be about 20-feet long, 40-feet wide, and 5-feet deep. The debris from this slide may have been augmented by some debris from a relatively small channel disturbance about 100 feet upstream. At the time of our field reconnaissance a seep was noted at the head of the slide scar. The original side slope apparently was about 10- to 15-feet high with inclinations from about 55 to

60%, though the LiDAR imaging suggest slopes of 73%) The slide occurred in landslide debris related to a relatively large deep-seated landslide that underlies the hillside terrain to the south of this area of the Bench Drainage. The slide occurred in a riparian buffer and several down mature firs were observed at the site of the slide. Whether they were blown down into the drainage or fell in after the slide occurred is uncertain.

The **Way South #1 PI** is at an elevation of 1,280 feet (Figure 3). It is located in the upper reaches of the Knutzen Drainage. The PI at this location is a stream-side landslide (Figure 8). The slide scar is estimated to be about 25-feet long, 15-feet wide, and 5-feet deep. At the time of our field reconnaissance no subsurface water was observed issuing from the slide scar. The original side slope apparently was about 10- to 15-feet high with inclinations greater than about 73% (LiDAR imaging). The slide occurred at the intersection of one of the scarps of the active deep-seated South Side Landslide and the Knutzen Drainage, and may have been triggered by movement of the South Side slide. However, it should be noted that the slide occurred in a riparian buffer and several down trees were observed in the drainage at the site of the slide. Whether they were blown down into the drainage or fell in after the slide occurred is uncertain. In our opinion the deep-seated landslide was likely reactivated in response to the January storm. Movement of the deep-seated landslide may also have been a factor in initiation of the debris slide at this site.

The **Way South #2 PI** is at an elevation of about 970 feet (Figure 3). It is located in the upper reaches of a short tributary in the lower portion of Knutzen Drainage. The debris slide is in a Forest Practice Rule defined bedrock hollow (Figure 9). The scar is estimated to be about 40-feet long, 20-feet wide, and 6-feet deep. At the time of our field reconnaissance no subsurface water was observed issuing from the slide scar. The original side slope apparently was about 5- to 10-feet high with inclinations from about 50 to 70%. The slide occurred in an area that, at least for the last 60 years or so, has not been subjected to timber harvest activities.

6.2. DEBRIS-FLOW TRACKS

In the **Gantman-Fox Drainage** the debris slides from each PI (North, Middle, and Sandy) initially occupied separate debris flow tracks (Figures 2 and 3). However, after traveling a relatively short distance they came to occupy the same flow track beginning at an approximate elevation of 1,150 feet (Figure 3). Above this junction the debris slides from North and Middle PI scoured a relatively narrow channel to bedrock. From the Sandy PI to the 1,150 foot junction the debris flow from the Sandy PI scoured a relatively wide path across the hillside, removing several feet of soil but leaving tree stumps supported by the root structures of the stumps. A relatively small volume of debris "jumped" a subdued ridge on the southwest margin of the Sandy flow track and traveled downslope joining the main track a short distance down slope of the 1,150 foot junction. Just below the junction a relatively small bedrock slide was observed. The debris from this slide likely contributed to the mass of the debris flows. From the 1,150 foot junction the debris flows were essentially confined to the channel of the Gantman-Fox Drainage until the deposit reached a waterfall and a sharp, almost 90°, bend between about 800- to 700-foot elevation (Figure 10). At this area portions of the debris ran over the low bank on the north side of the 90° turn, and then back down into the drainage. Presumably at the same time other portions of the flow went over the waterfall and then a portion of that debris shot up the southerly side of the drainage and over a relatively low ridge (Figure 10) that delineates the top of the south bank and then down the planar slope below that ridge, ultimately impacting the Fox trailer on the Fox property (Figure 11). Meanwhile the remaining majority of the debris flow continued down to the mouth of the drainage. There, due presumably to topography and the volume of debris, the debris flow bifurcated; some was directed toward the Fox residence and down the fan surface toward the Knutzen structures and Anderson property with presumably a small amount crossing Nelson Road and going on the Davis/Aube/Danenger property; a larger percentage was directed toward the Gantman residence, across that property, across Nelson Road, and then also onto the Davis/Aube/Danenger property to the west of Nelson Road (Figure 2). It is important to remember that all the PIs did not fail at one time in one event. It is reported that several pulses of debris swept down the drainage during the about one-half day the process was active. We suspect that the flow from the Sandy PI likely caused the greatest damage.

In the **Bench Drainage** the debris flow from the South PI was confined, save for a stretch from about 1,250- down to 1,000-foot elevation, to a relatively narrow channel. Between 1,250 and 1,000 feet the channel becomes much less pronounced as the drainage essentially flows down the surface of a bench created by a bedding plane in the Chuckanut Sandstone. Where not flowing on the bench, the debris flow was confined to the channel, resulting in scour of the channel, removing soil, rock, and organic debris. When the debris flow reached the upper end of the bench it was less confined and relatively small portions of the flow spilled out and travelled for short distances across the relatively planar, inclined ground surface of the bench. Some of the debris rejoined the main flow in the channel on the bench. On the bench the debris flow created a channel up to about 3- to 5-feet wide, locally a bit wider and scoured the soil and vegetative cover to bedrock, a depth of about four feet. At the mouth of the drainage debris was deposited on the Knutzen property continuing down the alluvial fan and onto the Anderson property, traveling about 2,000 feet from the mouth of Bench Drainage (Figure 2).

In the **Knutzen Drainage** the channel was scoured to bedrock along most of the channel. Debris from the flow was deposited on the Knutzen property and ran out on to the Anderson property (Figures 2 and 3). Several smaller channel side slope failures were present along the Knutzen Drainage that included developing soils as well as large blocks of rock; likely failures controlled by bedding and joint patterns in the underlying bedrock. These side slope failures were likely the result of undercutting by the large debris flow that originated at Way South #1 PI. One of the larger side slope failures came from the north side of the drainage. It is located at the first bedrock cliff and associated waterfall from the toe of the slope, at about elevation 780 feet. The evacuated hollow is approximately 30-feet wide, 50-feet long, and 10-feet deep. Rocks and debris from this side-channel failure did not likely run out very far due to the relatively short distance it travelled from the initiation point to the toe of the steep slope.

6.3. AREAS OF DEPOSITION

Deposition of the debris flow that came out of the **Gantman-Fox Drainage** damaged to the garage of the Gantman home, vehicles in the garage, and damage was also incurred to the inside of the home itself. Large amounts of earth materials and organic debris (logs and stumps) were piled against the house and deposited across the parking and lawn areas of the Gantman property, all the way to Nelson Road, across Nelson Road, and onto the Davis/Aube/Danenger property, spreading sediment and organic debris across fields of that property and damaging recently planted vegetation (Initial Incident Report, 2009a). Figure 2 shows the generalized pattern of the run-out and debris deposition. The Fox residence apparently suffered relatively less damage; however, at least one vehicle was destroyed and earth materials and organic debris (logs and stumps) were deposited against the house and across parking and lawn areas. As noted above the mobile home to the southeast of the Fox residence was almost up-ended and debris spread across the parking and lawn area there too. Some of the mud slurry from the Gantman-Fox debris slide ran down the driveway and onto the Knutzen property, and flooded the Knutzen house first floor and basement and did some damage to out buildings on the Knutzen property (Initial Incident Report, 2009b). Though most of the large debris was deposited to the east of Nelson Road, water carried smaller organic debris and sediment across Nelson Road and deposited finer-grained sediment and small organic debris on fields of the Davis/Aube/Danenger property, west of Nelson Road, and the fields of the Anderson property (Figure 2); a distance of at least 1,800 feet from the mouth of the drainage. In addition, the water supply for the Fox and Knutzen properties was disrupted.

The debris flow from the **Bench Drainage** deposited earth materials and organic debris on pasture areas of the Knutzen and Anderson properties (Figure 2). It does not appear that any structures were seriously impacted. Debris from the Bench Drainage joined the Knutzen Drainage debris plume. The water intake for the Knutzen residence was also destroyed.

The debris flow from the **Knutzen Drainage** deposited earth materials and organic debris on pasture areas of the Knutzen and Anderson properties (Figure 2). Debris deposited at the base of the steep slope included approximately 2- to 3-foot diameter trees along with large boulders approximately 4 feet long by 4 feet wide by 4 feet thick. Rocks and debris deposited on the gently sloping pasture areas were generally smaller in size until mostly silt and small organic debris were present at the distal end of the run-out. It appears that most of the coarser debris was deposited on the Knutzen property; water carried smaller organic debris and fine-grained sediment into fields of the Anderson property, about 2,000 feet from the mouth of the Knutzen Drainage (Figure 2). It does not appear that any structures were impacted, however; a water-supply intake fro the Knutzen property was destroyed.

6.4. OTHER SLIDES AND POINTS-OF-INTEREST

Two landslides were observed in the cut slopes along the Tat Road and a ground crack was noted in a portion of the side-cast road fill (Figure 3) and at two locations in the fill of the Tat Landing. One of the slides is relatively large and located slightly southeast of the Tat landing, while the other is a relatively small slide about 200 feet east of the larger slide. The larger slide is about 80-feet wide at the road and about 40-feet long. The essentially vertical scarp is up to about 5-feet high. It occurred in near vertical cuts about 8-to 9-feet high in sandstone bedrock. The slope above the slide exhibits 65% inclinations and is traversed by a brush-covered road just above the scarp. Only a minor amount of the slide deposit trickled over the outside edge of the road. Some of the slide deposit ran down the road to a water bar and then, presumably combined with water captured by the water bar, formed a minor debris flow. The debris flow ran down the fill slope and then down slope in a small drainage to a point about 600 feet from the outfall of the water bar. There the flow appeared to stop and deposit debris (Figure 3). No debris could be observed further down slope of the area of deposition.

The smaller slide occurred as a thin soil-slip about 3-feet thick in an area that apparently suffered an earlier failure. The 2001 aerial photographs show a slide scar that appears to be at the same location as the current one. There is no suggestion of a slide at this location on the 1995 photographs. The crown of the slide is about 50 to 55 feet above the road, and the slide is about 12-feet wide. The slide debris was deposited on the road.

A ground crack was observed in the road fill along the outside edge of the Tat Road. The west end of this crack is about 100-feet east of the small slide just discussed (Figure 3). The crack is about 90-feet long and about 4 to 6 feet from the outside edge of the road. It exhibits scarps up to about 10-inches high and is about 18-inches deep. The site of this crack is above a well-defined swale that ultimately leads into the Bench Drainage. A ground crack was also observed in the side-cast fill of the Tat Landing (Figure 3). It is about 15-feet long and open about 3 to 6 inches. It was followed into a deck of logs. No evidence for any significant amounts runoff flowing over the side-cast fill was observed. Runoff was directed toward the Tat Road.

Evidence for reactivation of the South Side Slide was observed at the head of the slide and in the middle areas of the slide mass. This slide is in the Jack Straw Aerial

Timber Sale. Portions of this slide are in riparian management zones and were excluded from the timber sale and retained some timber. The slide is about 450-feet long and about 350-feet wide. It is characterized by a system of fresh ground cracks 4- to 6-inches wide and scarps to about 3-feet high along the head of the slide, which is, in part, at the base of a rock cliff, and internal scarps 3- to 5-feet high further downslope within the slide mass. The Way South #1 PI occurred at the intersection of the channel side-slope and this internal scarp and ground cracks (Figure 3). The reactivation of this deep-seated slide clearly suggests that though these large slides can appear to be relatively stable, all or portions can become reactivated.

7.0. DISCUSSION

As part of our charge we were asked to determine the following:

1) Were the PIs of the debris slides on DNR managed lands?
2) Were the PIs in areas of recent management activities?
3) Did the management activity contribute to debris slide initiation?
4) How much did management activities contribute to debris slide initiation?

In this section we provide our observations and opinions with respect to these questions. Section 7.1. provides our observations and conclusions with respect to items 1 and 2 above. Sections 7.2. to 7.4. address items 3 and 4. Section 7.2. provides a discussion concerning the likely influence that the January 2009 storm and accompanying rain-on-snow (ROS) conditions might have had on slope stability in and adjacent to the Tat and Jack Straw sales. Section 7.3. summarizes the likely influence that the two timber sales had on root strength and slope stability. Section 7.4 provides a brief site-specific discussion of the conditions that likely influenced slope failure at each PI, and our opinion as to the degree of causal influence the management activities may have had in development of the debris slides.

7.1. DETERMINATION OF POINTS 1 AND 2

All six debris slides initiated on DNR-managed lands. Five of the six PIs occurred in or adjacent to timber sales that had been harvested in the last 15 years. Three PIs: North, Middle, and Sandy occurred in the 15-year old Tat sale (a tract of land acquired by DNR after it had been logged), while two: South and Way South #1 occurred adjacent to harvested areas of the 4-year old DNR Jack Straw Aerial Timber Sale. One PI, Way South #2, occurred in an area that had not been subjected to harvest activity for at least about 60 years, and the tree stand is essentially mature.

7.2. STORM AND ROS INFLUENCES

The January 2009 storm followed a several-week period of rain, snow, and near freezing to freezing temperatures. A snow pack of up to at least a couple of feet blanketed the PIs prior to arrival of the rains and accompanying winds and warmer temperatures. The PIs are located in the upper portion of the generally accepted rain-dominated zone; however, a classic ROS situation developed anyway. Though not an entirely accurate portrayal of the current forest conditions of the Tat and Jack Straw sales, in this discussion we will treat both sales as recent clear cuts with no regeneration at the time of the storm. We assume this because, at this time, it would be difficult to apportion the adjacency influences that one partially regenerated area and a recently replanted sale might have on one another, and that this assumption presents a worst-case scenario. As noted by Beschta (1995) the 15- to 20-year old regeneration in the Tat sale would have reached only about 20% of hydrologic recovery, thus making the hydrologic setting of the Tat sale not markedly different than the Jack Straw sale. Under such conditions Beschta (1995) estimates that the increase in peak flows and, by assumption on our part, the increase in available ground water would be about 11%; this equates to changing the magnitude of a 10-year peak flow to that of a 14-year peak flow (Beschta, 1995); in our opinion a modest increase, at best. (However, as stated in section **4.5 Ground Water**, caution needs to be exercised when projecting Beschta’s (1995) estimates of basin wide hydrologic changes to localized areas.)

During the January 2009 storm a ROS condition existed over the entire hillslope; it was not limited to slopes above the 1,600-foot elevation mark considered to be the lower elevation of the ROS zone. This additional snow pack may have resulted in a greater increase in peak stream flow and available ground water than estimated by Beschta (1995). The Western SubWAU within the Acme WAU has a greater percent of its area in elevations above 1,600 feet, reflecting a greater area within the ROS zone. The Western SubWAU is predicted to have a 20% increase in peak flows during storm events in clear cut conditions compared with mature forest canopy (Beschta, 1995). Because the January 2009 storm produced ROS conditions at elevations lower than predicted, it would be reasonable to assume resulting peak flows would be greater than those presented by Beschta (1995). Such an increase could be considered significant. The potential for frozen ground to increase runoff could complicate the calculations and we have not tried to account for this condition in this discussion, largely because we do not know if this condition actually existed at the time of the storm. We suspect it not likely. This discussion is further complicated by work of Coffin and Harr (1992). They showed increased out flow from plantation sites in ROS events was somewhat variable and did not always exceed forested sites. Thus it is very difficult to accurately know exactly how much additional ground water was actually added to the area of the Jack Straw and Tat sales as a result of the January storm and associated ROS conditions.

The area of the Site has experienced at least two similar weather events in 1970/71 and 1971/72 during a record of 34 years (an approximately 9 or 17-year average recurrence interval, depending on assumptions about whether a storm might have occurred in the year just before and the year just after the POR). Review of the 1976 aerial photographs show debris slides occurred on slopes just north of the Site. Review of the 1995 and 2001 aerial photographs, a time when the sale would have been particularly vulnerable, did not reveal debris slides in the Tat sale. During our field reconnaissance of the Tat and Jack Straw harvest areas we did not observe evidence for earlier (pre-2009) significant debris sides, this in spite of the fact that at least eleven significant storms (ten since the Tat harvest) have passed through the county, some of which certainly passed over the Site since the Tat harvest.

7.3. MANAGEMENT AND REVEGETATION INFLUENCES

As noted above, all the PIs, save one (the Way South #2), occurred in or adjacent to recent harvest units. The North, Middle, and Sandy PIs developed in the Tat sale, a regenerating stand of Douglas-fir estimated to be about 10 to 15 years old. The South and Way South #1 PIs developed in riparian-buffer zones adjacent to harvested areas of the Jack Straw Aerial Timber Sale. By today's standards the topography of the North and Middle PIs in the Tat sale would likely be classified as Class IV-Special (potentially unstable) terrain, which would require evaluation by a qualified expert prior to management activity, following guidelines and criteria discussed in the Washington State Forest Practices Rules (WAC 222-16-050) and Board Manual Section 16. However, when the Tat sale was prepared the current Watershed Analysis and Forest Practice rules (with respect to unstable slopes) were not in effect, thus those sites were not protected. The thick sandy nature of the Sandy PI would likely not have been recognized under the current (2009) standards of practice and care. In our opinion, the topography of the Sandy PI site would not likely have been identified as potentially unstable and likely would likely not have required any particular protection under current forest practice rules. And without the LiDAR imaging now available the influence of the bedrock structure and benches, and thus the potential for directivity of the ground water flow, would also likely not have been recognized. The South and Way South #1 PIs, as noted earlier, occurred in inner-gorge, or inner-gorge-like, terrain adjacent to harvested areas of the Jack Straw sale. In both cases the gorge was protected by a riparian buffer.

The intent of retaining leave trees in steep, convergent and inner-gorge topography is to maintain root strength. In such areas, ground water is often concentrated and usually becomes channelized surface-water down slope. With a few exceptions, field observations indicated tree roots were shallow and did not penetrate the underlying bedrock in all tree-stands, from newly regenerated to mature unmanaged forest. This indicates that at the sites in question the tree roots did not anchor the soil to the slope, however some soil strength is likely added from lateral tree-root systems growing together with adjacent lateral tree-root systems. O'Loughlin and Ziemer (1982) point out that root strength, particularly smaller roots, is in a strong phase of recovery during the 10- to 15- year period following harvest activities. During this initial 10- to 15-year period root strength recovery and reinforcement can quickly increase from to 40% to 70% of total effective pre-harvest values. Also, in adjacent areas to the north, we observed that along the lateral margins of landslides originating in mature timber stands, tree root strength was overcome, and roots were broken by the destabilizing forces of landslide processes. It appears that the extreme quantity of water produced by the rain-on-snow event overwhelmed the root strength on the slopes of the west side of the Van Zandt Dike, resulting in landslides originating in all timber stand ages.

In our opinion, it would be unreasonable to suggest the Tat harvest and the more recent Jack Straw Aerial harvest had no effect on the landslides that originated within the sale areas. Due to the lack of a mature tree canopy, snow accumulation on the ground was likely greater in these areas. When the heavy rainfall began and temperatures increased relatively quickly, the melting snow likely contributed additional surface runoff as well as some increase in soil saturation. In addition, as stated above, the landforms where the North and Middle PIs are located would likely qualify under current Watershed Analysis or Forest Practices Rules as potentially unstable landforms and would receive some kind of leave-tree protection under current management practices. However, as noted above the imprecise results of research and contradicting research results make it difficult to draw a conclusive cause-and-effect relationship between management activities and initiation of a specific slide.

Conversely, it is also our opinion that it is not reasonable to suggest that the landslides originating in the Tat sale and the Jack Straw Aerial Timber Sale would not have occurred if the area was unmanaged. This was evidenced during the last storm in nearby areas where landslides originated in mature unmanaged-timber and in the essentially mature-timber site of the Way South #2 PI. In addition, the existing hollows, convergent hillside topography, and the alluvial fans at the base of the steep slopes indicate that landslides have occurred periodically in these drainages since the end of the most recent continental glaciation (about 10,000 yrs. BP) to about 150 to 100 years ago, about the time timber harvesting began in the area.

7.4. SITE SPECIFIC DISCUSSIONS

At each PI there were several contributory factors to the initiation of the debris slides that are the subject of this reconnaissance. These factors include the topography, geology, ground-water conditions, and harvest history. The set of contributory factors are not necessarily the same for each PI. Of course the triggering factor was the January 4th to 8th storm. It should be noted that all the slides that are the subject of this reconnaissance occurred in surficial deposits, not in the underlying sandstone bedrock. The high elevations and steep slopes at the PIs and the steep gradients of the drainage channels provided a conducive environment for rapid down-slope movement once the slides developed. At the North and Middle PIs it appears that the fractured nature of the bedrock combined with the topography of the PIs (either the swale or draw) to localize concentrations of ground water. At the Sandy PI, the steep topography and possible directivity of runoff, due to bedrock structure, along with the potential for saturation of the sand could have been likely factors contributing to the failure at that site. In addition, the large cut slope failure that occurred on the Tat Road and the associated small debris slide that terminated just to the south of the Sandy PI, and the water associated with that slide, may also have had an influence. This influence would have manifested itself as delivering additional concentrations of water to the area of the Sandy PI due to the orientation of the bedrock dip toward the Sandy PI area. At South and Way South #1 PIs the inner-gorge nature of the PIs was a likely topographic factor in development of the slides at those locations. The slides developed in older landslide debris. The presence of the up-rooted trees found in the channels at the PIs and the coincidence of the Way South #1 PI with the slide scarp in the South Side Slide may have complicated the sequence of events at those sites, making for explanations with different possible “paths” to failure. At Way South #2 PI, it appears that the large quantity of water delivered during the ROS event saturated the soil at the head of a tributary stream channel, initiating a slump and delivering sediment and debris, via the tributary, to the mainstem Knutzen Drainage.

In our judgment the development of the debris slides from the **North** and **Middle PIs** were likely influenced in some part by the cumulative effects of timber harvest activities on the slopes at and above those two PIs. That being said it must also be realized that inspite of significant storms following the Tat harvest and heavy rains in November 2006 (following the Jack Straw Aerial harvest) no debris slides developed. If the January 2009 storm had been a smaller magnitude storm, it is a real probability that these two debris slides might not have developed. It should be noted that it does not appear that any runoff of any significant amount from the Tat Landing was delivered to the slopes above the North and Middle PIs. Thus, with respect to these two slides, and considering the size of the storm, the forest practice activities may have had a low level of influence in the development of the debris slides associated with the North and Middle PIs. The major reason for the development of the debris slides may have been the magnitude of the January 2009 storm and the ROS contribution of that weather event to peak flow and ground water. The January storm being of a magnitude that exceeded the climatic conditions that were factored into the development of the forest practice rules that were in effect at the time of the Tat sale and harvest.

The influence of forest practices on the development of the debris slide at **South PI** is very difficult to assess. Though it happened in an inner-gorge setting in the Jack Straw Aerial sale, the inner gorge was surrounded by a leave-tree buffer zone as required by Watershed prescriptions. In addition, the slide developed on the margin of a deep-seated landslide. It is not clear whether the fallen trees could have caused the slide, falling over due to wind and rain-soaked soil, or the trees fell in as the slope failed. In any event our observations suggest that here again the storm likely overwhelmed the topographic conditions and management prescriptions at the PI. If the storm had been a smaller magnitude storm it is possible that the slide might not have occurred.

The debris slides that originated at the **Sandy PI** and the **Way South #1 PI** may have developed, in part, in response to the cumulative effects of timber harvesting on the slope stability adjacent to and above the PIs. These sites appear to have remained relatively stable inspite of past severe storm activity and management activity in the area surrounding the debris slide PIs. However, based on our observations, it could be reasonably argued that movement of larger landslides influenced the development of debris slides at the Sandy and Way South #1 PIs. In the case of the Sandy PI, the larger cut-slope failure on the Tat Road, along with the northward inclination of the bedding in the bedrock resulted in delivery of additional water to the area of the Sandy PI, helping to saturate that area. At the Way South #1 PI harvesting upslope of the South Side Landslide may have contributed to reactivation of that deep-seated slide. Movement of the South Side Landslide created landslide scarps and, in effect, zones of concentrated disturbance and weakness. We do not think it is just coincidence that the Way South #1 PI developed at the intersection of one of the internal slide scarps, a location of concentrated ground disturbance, and the south side-slope of Knutzen Drainage. At that point of intersection the slide mass was further weakened and the debris slide occurred. In both of these cases the combination of the effects of the long-term degradation of hillside strength and the cumulative effects of timber harvesting on the development of deep-seated landslides or the stability of existing deep-seated landslides must be taken into account as a contributing factor in the development of the Sandy and Way South #1 PIs.

Way South PI #2 occurred in a slope where it appears it has been at least 60 years since the area of the PI was subjected to forest management activities. The PI is either distant from, not down bedrock dip of any recent forest-management activities, or separated from any harvest activities by drainage divides. The area of the PI had reached 100% hydrologic recovery (Beschta, 1995) and the root strength had essentially fully recovered (O'Loughlin and Ziemer, 1982). For this reason it is our opinion that past timber harvest activities did not contribute to the initiation of the debris slide at Way South #2. Failure occurred as a result of natural causes.

The January 4th to 9th rain-on-snow storm that triggered these landslides appears to have been a relatively extreme weather event compared to that discussed in the Acme Watershed Analysis. It is our opinion that at some of the PIs the volume of water from heavy precipitation and rapid snowmelt overwhelmed the site conditions and watershed analysis prescriptions that were intended to reduce the potential for development of management-related shallow-rapid slope-failures (e.g. debris slides and associated flows) discussed in this reconnaissance report.

8.0. REDUCING FUTURE LANDSLIDE POTENTIAL AT THE SITE

The following mitigation measures are offered as a means of reducing the potential for further debris slide and debris flow occurrences. Recommendation #1 should be acted upon this dry season. Recommendation #2 and #3 should be incorporated, as appropriate, into future road abandonment plans in the Van Zandt Dike area; especially in light of current discussions regarding the apparent increase in the frequency of extreme rain-storm events (Dulière and others, 2008, and Madsen and Figdor, 2007).

1. **Pull Back of Side-Cast Fill –** The sliver of failing road fill on Tat Road and failing side-cast fill on Tat Landing should be removed and disposed of either on site by placement against the cut slope, uniformly spreading it across the existing road surface, or wasting it at some other approved site. This work should be done under the supervision of the forest engineer and the region engineering geologist.

2. **Road Abandonment –** Where road abandonment is planned, the fills associated with road or landing construction should be pulled where failure of such fills could be directed into swales that ultimately connect with the drainages that deliver to the valley floor.

3. **Bedrock Structure and Ground-Water Flow –** The potential for the bedrock structure to direct ground water from management areas to adjacent areas should be taken into consideration during the geologic evaluation of a timber sale in areas underlain by Chuckanut Formation.

9.0. RECONNAISSANCE LIMITATIONS

This reconnaissance report presents a qualitative assessment of the debris slides and associated debris flows that impacted the properties located at 3506, 3600, 3618, 3633, and 3652 Nelson Road in Whatcom County as a result of the early January 2009 storm. The charge of this reconnaissance was to develop an opinion with respect to the following questions:

1) Were the PIs of the debris slides on DNR managed lands?
2) Were the PIs in areas of recent management activities?
3) Did the management activities contribute to initiation of debris slides?
4) How much did the management activities contribute to debris slide initiation?

In this reconnaissance report we provide our observations and opinions, with respect to these questions, based on our field reconnaissance and review of office derived data. If new information should be become available, our geologic interpretations, and thus, our discussion and subsequently recommendations could require modification.

The signatures and stamp for this engineering geologic field reconnaissance report are on the cover letter that accompanies this report; just behind the title page. This report, or any copy, shall not be considered complete without the cover letter signed with original signatures and stamp or authorized facsimiles of the same.

END

REFERENCES

Beschta, R. L., 1995, Rain-on-snow hydrologic analysis: Acme Watershed Administrative unit, in Acme Watershed Analysis, Section 5.0 Hydrologic change, Appendix 5-1: Crown Pacific Limited Partnership, 1999 (original date 1995?), Acme Watershed Analysis: Unpublished report prepared for Department of Natural Resources, Olympia, Washington, report revised 1999.

Brunengo, M.J., 2001, Part 2. The Van Zandt Dike Landslide and a medley of other mass-movement features in the Samish – south Nooksack trough; in Northwest Geological Society Field Trip – June 2-3, 2001 field trip guidebook: Northwest Geological Society.

Canyon Lake Creek and Kenny Creek Watershed Assessment, 1993, Prepared for Trillium Corporation, preparer unknown, Bellingham, Washington, dated February 1993.

Coffin, B.A., and Harr, R.D., 1992, Effects of forest cover on volume of water delivery to soil during rain-on snow, Final report for Project SH (Rain-On-Snow Field Study), (Originally PROJECT 18): Timber, Fish, & Wildlife series, Sediment, Hydrology, and Mass Wasting Steering Committee.

Crown Pacific Limited Partnership, 1999 (original date 1995?), Acme Watershed Analysis: Unpublished report prepared for Department of Natural Resources, Olympia, Washington, report revised 1999.

Cruden, D.M. and Varnes, D.J., 1996, Landslide types and processes, in Turner, A.K. and Schuster, R.L., Landslides – Investigation and mitigation: Transportation Research Board, National Research Council, National Academy Press, Washington, D.C.

Dragovich, J.D., Norman, D.K., Haugerud, R.A., and Pringle, P.T., 1997, Geologic map and interpreted geologic history of the Kendall and Deming 7.5-minute Quadrangles, western Whatcom County, Washington: Washington Division of Geology and Earth Resources Open File Report 97-2, scale 1:24,000.

Dulière, Valérie, Mote, Philip, Salathé, Eric, Mault, and Elsner, M.M., 2008, Are extreme rain events becoming more frequent?: presentation of the Climate Impacts Group, University of Washington at the 2008 Pacific Northwest Weather Workshop.

Fox, Steve, De Chant, Jennie, and Raines, Mary, 1992, Whatcom County critical areas inventory report, Alluvial fan hazard areas: Unpublished report presumably prepared for County of Whatcom, Washington, dated August 1992.

FPA 30-074490, 2003, Jack Straw Aerial Timber Sale: Timber Sale prepared by Northwest Region, files available at Northwest Regional Office.

Goldin, Alan, 1992, Soil survey of Whatcom County area, Washington: U.S. Department of Agriculture, Soil Conservation Service.

Hungr, Oldrich, Evans, S.G., Bovis, M.J., and Hutchinson, J.N., 2001, A review of the classification of landslides of the flow type: Environmental & Engineering Geoscience, v. VII, no. 3.

Initial Incident Report, 2009a, Damage report for 3633 and 3652 Nelson Road on file at Land Management Division Northwest Region District office, dated February 24, 2009.

Initial Incident Report, 2009b, Damage report for 3600 and 3618 Nelson Road on file at Land Management Division Northwest Region District office, dated February 18, 2009.

Madsen, Travis, and Figdor, Emily, 2007, When it rains, it pours, Global warming and the rising frequency of extreme precipitation in the United States: Environment Washington Research & Policy Center, dated December 2007.

National Climatic Data Center, 2009, Storm total precipitation, Radar precip est from 6:22 AM PST Sun Jan 04 2009 to 6:42 AM PST Thu Jan 06 2009; National Weather Service, Seattle/Tacoma, WA.

O'Loughlin, Colin, and Ziemer, R.R., 1982, The importance of root strength and deterioration rates upon edaphic stability in steepland forests: Proceedings of I.U.F.R.O. Workshop, P.1.07-00 Ecology of Subalpine Ecosystems as a Key to Management; Corvallis, Oregon; Oregon State University, Corvallis, Oregon; August 2-3, 1982.

University of Utah, 2009, climate data from TSUMA recording station web site: www.met.utah.edu/cgi-bin/droman/time_mesowest.cgi?stn=TSUMA&unit=0&yime=...

WAC 222-16, 2002, Guidelines for evaluating potentially unstable slopes and landforms, in Forest Practices Board Manual.

Western Regional Climate Center, 2008, Glacier Ranger Station, Washington: http://www.wrcc.

Whatcom County Planning & Development, 2006, Whatcom County critical areas ordinance – Geologically hazardous areas: Unpublished map prepared for Whatcom County Planning & Development, dated February, 2006; scale 1:83,000.

Wolff, Noel, 2003, Jackstraw Timber Sale: unpublished memo, dated July 7, 2003.

AERIAL PHOTOGRAPHY REVIEWED

Date	Flight Line/Frames	Approx. Scale	Medium
8/24/47	BBK – 5B – 101 to 103	1:24,000	B/W
8/6/55	BBK – 2P – 167, 168	1:24,000	B/W
7/8/61	F.35 – 18 to 21, 23, 24	1:12,000	B/W
6/5/70	NW-69 228 49C-27 to -31	1:12,000	B/W
6/5/70	NW-69 228 50B-30 to -32	1:12,000	B/W
7/14/71	NW-H-71 351 – 11B – 13, 14	1:80,000 (?)	B/W
7/15/76	NW-C 76-25-129 to -132	1:24,000	Color
6-3-78	NW-78 62A-229 to -233	1:12,000	B/W
6-3-78	NW-78 63C-46 to -51	1:12,000	B/W
5/23/83	NW-C-83 13-49 379 to 384	1:12,000	Color
5/23/83	NW-C-83 13-50 418 to 422	1:12,000	Color
6/26/87	NW87 11-50-71 to -73	1:13,400	B/W
8/22/88	NW87 39-51-52 to -55	1:13,600	B/W
5/26/95	NW-95 27-49-128 to -133	1:12,000	B/W
5/26/95	NW-95 30-50-41 to -42	1:12,000	B/W
8/26/01	NW-C-01 13-49-147, -148	1:12,000	Color
8/26/01	NW-C-01 58-50-40, -1, -43 to -45	1:12,000	Color

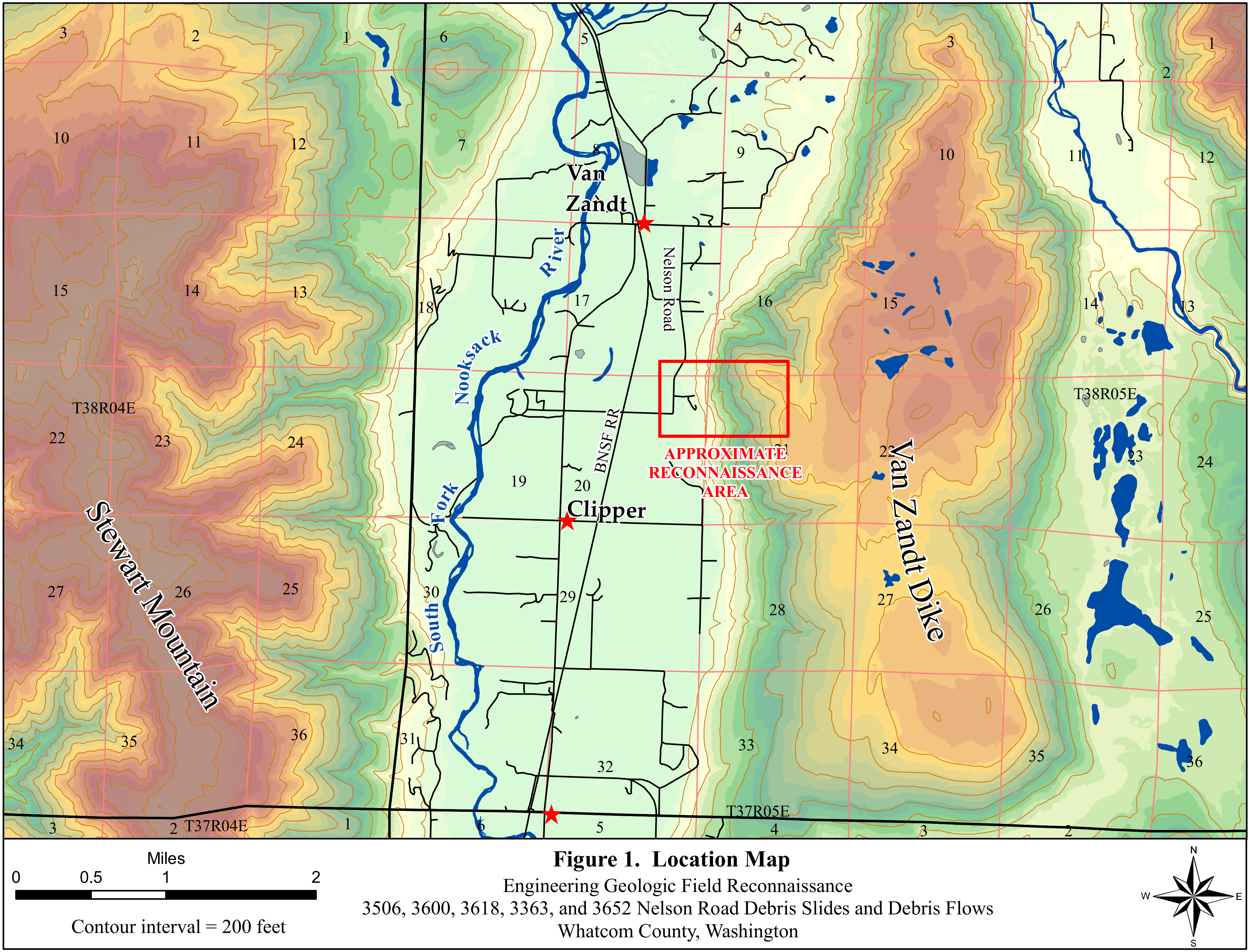


Figure 1. Location Map

Engineering Geologic Field Reconnaissance

3506, 3600, 3618, 3363, and 3652 Nelson Road Debris Slides and Debris Flows

Whatcom County, Washington

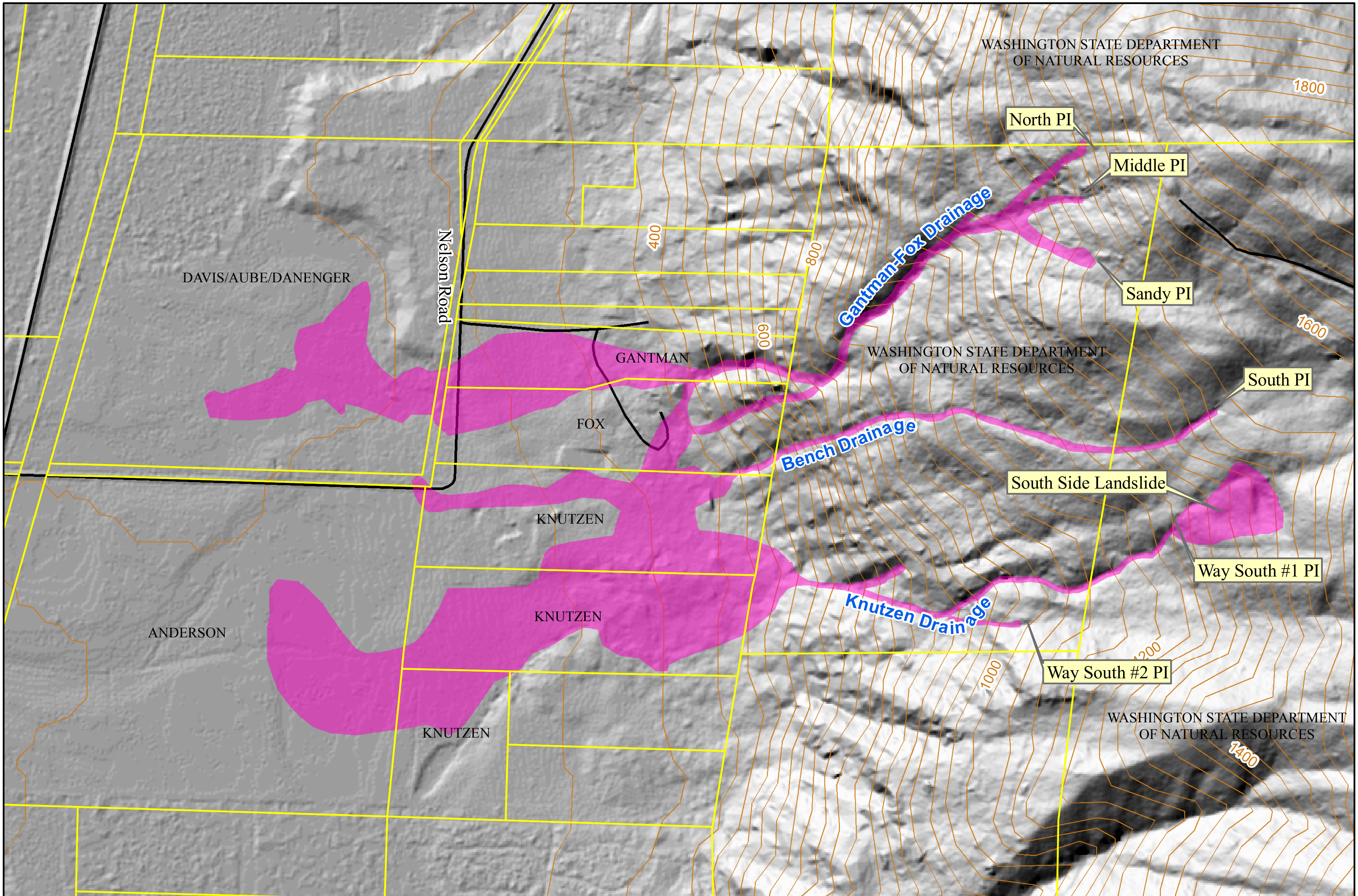
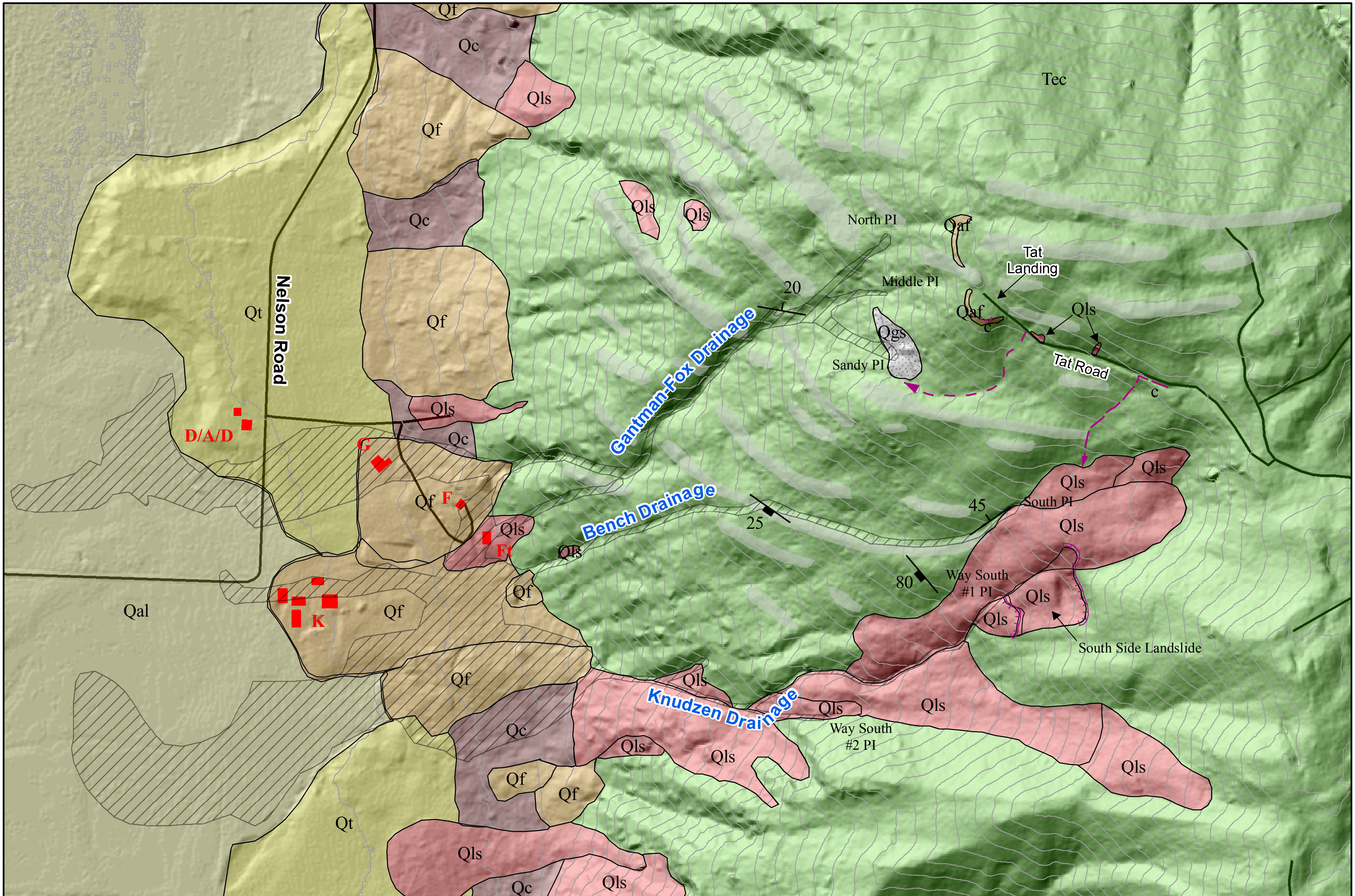


Figure 2. Simplified Map Showing Property Owners, Debris Flow Tracks, and Approximate Depositional Areas.

Property lines and landowners from DNR database. Ownership verified on Whatcom County Assessor's website, April 2009. Depositional areas mapped from aerial photography and field observations. Depositional patterns should only be considered an approximation.



0 250 500 1,000
Feet
Contour Interval = 40 feet

Figure 3. Geologic Site Map
3506, 3600, 3618, 3363, and 3652 Nelson Road
See Figure 3A for explaination.

N
W E
S

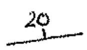
Geology mapped from field observations and interpretation of DNR LiDAR database.

EARTH MATERIALS

Qaf	Artificial fill
Qal	Alluvium
Qc	Colluvium
Qf	Alluvial fan deposits
Qls	Landslide debris
Qt	Alluvial terrace deposits
Qgs	Glacial sand deposit
Tec	Chuckanut Formation

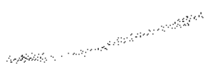
MAP SYMBOLS

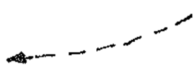

Geologic contact, locally approximate to uncertain



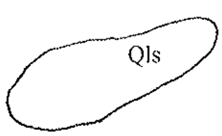
Strike and dip of bedding

Strike and dip of joints

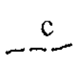

Bedrock “rib”. See Section 4.1. for discussion


Debris-slide track, arrow shows end of track from Tat Road

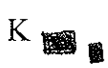

Debris slide IP and flow track. At bottom of slope diagonal-lined area shows general coverage of debris-flow deposit as it spread out across alluvial fan/valley floor.



Landslide, arrows show direction of movement



Ground crack in Tat Road or Tat Landing side-cast fill



Residence or out building: G – Gantman, D/A/D – Davis/Aube/Danenger (location approx.), F – Fox, Ft – Fox trailer, K – Knutzen house & out buildings

FIGURE 3A. Explanation for Figure 3. Geologic Site Map

Engineering Geologic Field Reconnaissance
3506, 3600, 3618, 3633, and 3652 Nelson Road
Whatcom County, Washington

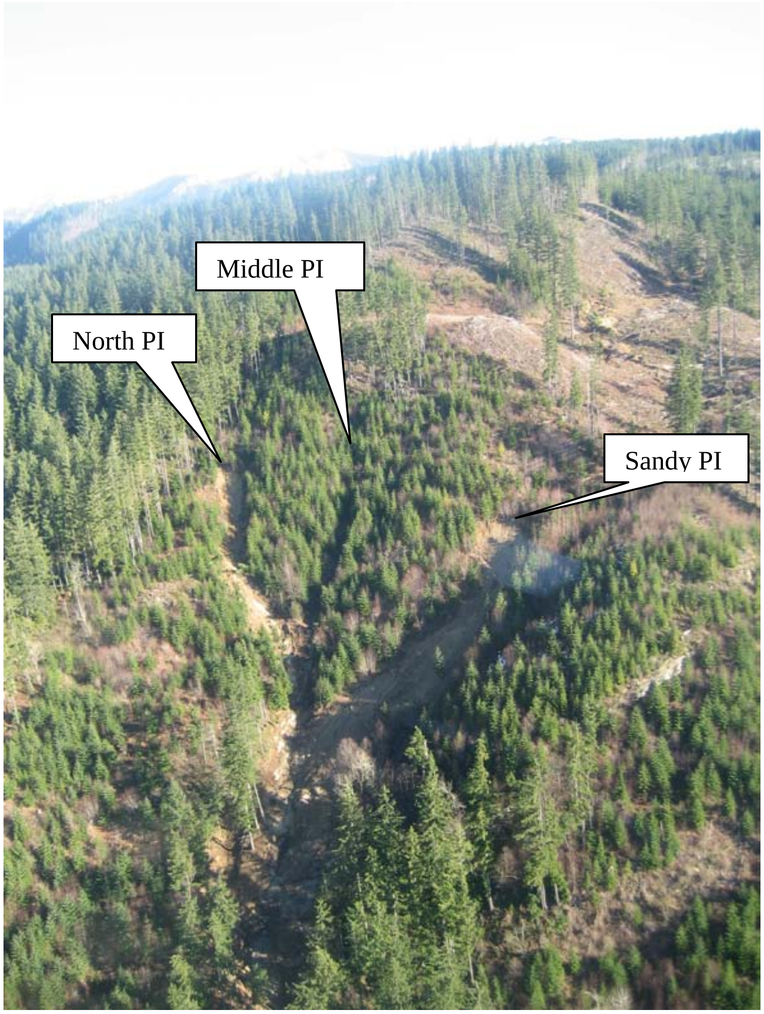


Figure 4. Helicopter Photograph of the North, Middle, and Sandy PIs. View looking east.
(Photo by Doug Hooks, 2009)

Figure 5. Middle PI Scar. View looking down slope to west.
(Photo by John Coyle, 2009).

Figure 6. Sandy PI Scar. View looking southeast.
(Photo by John Coyle, 2009)

Figure 7. South PI Scar. View looking east.
(Photo by John Coyle, 2009)

Figure 8. Way South #1 PI Scar. View looking south.
(Photo by Casey Hanell, 2009)

Figure 9. Way South #2 PI. View looking southeast.
(Photo by Casey Hanell, 2009)

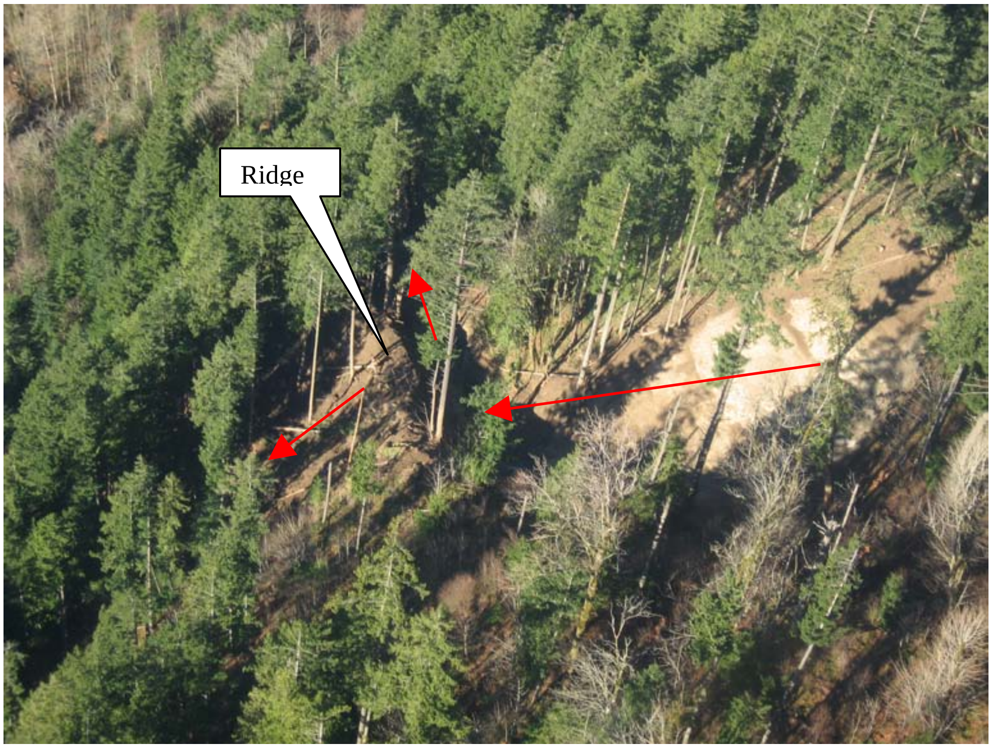


Figure 10. Helicopter Photograph of 90° Turn in Gantman-Fox Drainage. Ridge that debris ran up, over, and down to the base of the slope is labeled. Red arrows indicate the directions the debris travelled. View looking northwest. (Photo by Doug Hooks, 2009)

Figure 11. View Down Flow Track to Fox Trailer. Debris track from ridge in Figure 6 flowed down to trailer at the base of the slope. View looking west. (Photo by Casey Hanell, 2009)