WASHINGTON STATE DEPARTMENT OF
Natural Resources

Landslide Hazard Zonation Project
Priority II Assessment

Rinker, Sauk Prairie, and Upper North Stillaguamish Watersheds (and adjacent areas), Skagit and Snohomish Counties, Washington

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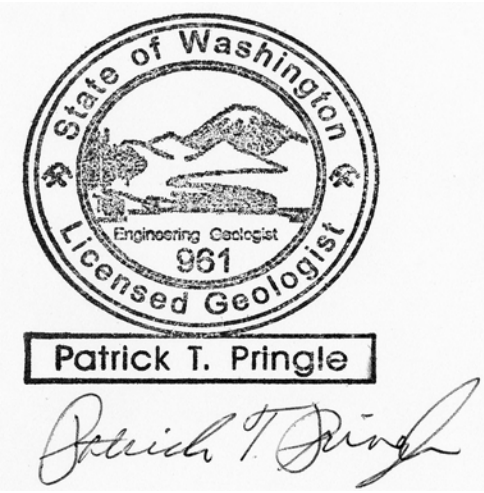

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1.0 Overview

The purpose of this assessment is to identify areas that have a moderate or high risk of mass wasting owing to the effects of natural instability and forest practices, on fee and state (non-federal) lands within the Rinker, Sauk Prairie, and Upper Stillaguamish Watershed Administrative Units (WAUs). The Upper Stillaguamish WAU includes the upper reaches of the Stillaguamish River and its tributaries. The Rinker, Sauk Prairie, and Upper Stillaguamish WAUs total 106.3 mi^2, of which 56.4 mi^2 (about 53 percent of the total) are private or state-owned lands. Changes in WAU boundaries adopted late in the project led to the assessment of additional areas.[1]

The area under evaluation includes valley floor environments of the North Fork Stillaguamish, Sauk, Suiattle, and Skagit River floodplains, adjoining terraces composed of alluvium and glacial drift (mostly outwash), and adjacent areas of moderately to steeply sloping lower valley walls composed of alluvial fan debris, mass wasting deposits, and bedrock of the North Cascades System of Tabor and others (2002), which are described below. The bedrock units include the Darrington Phyllite, Shuksan Greenschist, Slate of Rinker Ridge, Bell Pass Mélange, Yellow Aster Complex, and Chilliwack Group.

I identified 209 historic mass wasting features in the evaluated areas during my review of aerial photographs (spanning 1978 through 2001) and two site visits. There are several other mapped landslides in the area of concern—these are deep-seated landslides or landslide complexes (Tabor and others, 2002). At least 92 debris flows, 35 shallow rapid landslides, and two earthflows delivered sediment to public resources as inferred from a review of aerial photos. As a result of these investigations, I designate six mass wasting map units (MWMUs) in the assessment area.

The mass wasting methodology requires that several critical questions be answered during the analysis. These critical questions are found in Section 5.0 below.

This mass wasting assessment was conducted using aerial photographs, topographic and geologic maps, and GIS-based digital elevation data. Using this information, I evaluated evidence of past mass wasting processes and potential for future mass wasting relative to the aforementioned critical questions. A series of exercises designed to either confidently answer these critical questions, or identify more detailed information necessary to do so, is developed in this assessment. The objective of these exercises is to generate information sufficient to establish:

1. The mass wasting features and processes (e.g. shallow-rapid landslides, debris flows, and deep-seated failures) active in the basin.
2. Portions of the landscape having similar inherent physical characteristics relative to mass-movement behavior.
3. The relative potential for mass wasting impacts associated with the landscape units.

1.1 Introduction to Mass Wasting Processes and Terminology

Terminology used to describe mass wasting processes in this assessment follows the classification system established by the Washington Forest Practices Board's standard methodology for conducting watershed analysis (WFPB, 1997) and updated by the landslide compilation of Boyd and Vaugeois (2003), which places slope movement into nine types (shallow-rapid, debris flow, debris avalanche, shallow sporadic

[1] In particular, the Rinker and Sauk Prairie WAUs are now largely incorporated into the new Lower Sauk and Middle Sauk WAUs, along with all or parts of four other basins; work in this project also essentially completes the new Lower Suiattle WAU. The new information (including 16 additional landslides) is not reflected in the maps and statistics within this report, but the landslide and landform maps (A-1 and A-2) incorporate the later assessments. See Appendix 8.4 for details.

deep-seated, large persistent deep-seated, earth flow, rock topple/fall, and snow avalanche). Geomorphic analysis is aided by designating landform, slope shape, and land use associated with landsliding. Other attributes related to landslide data analysis are also collected and analyzed (see Form A-1).

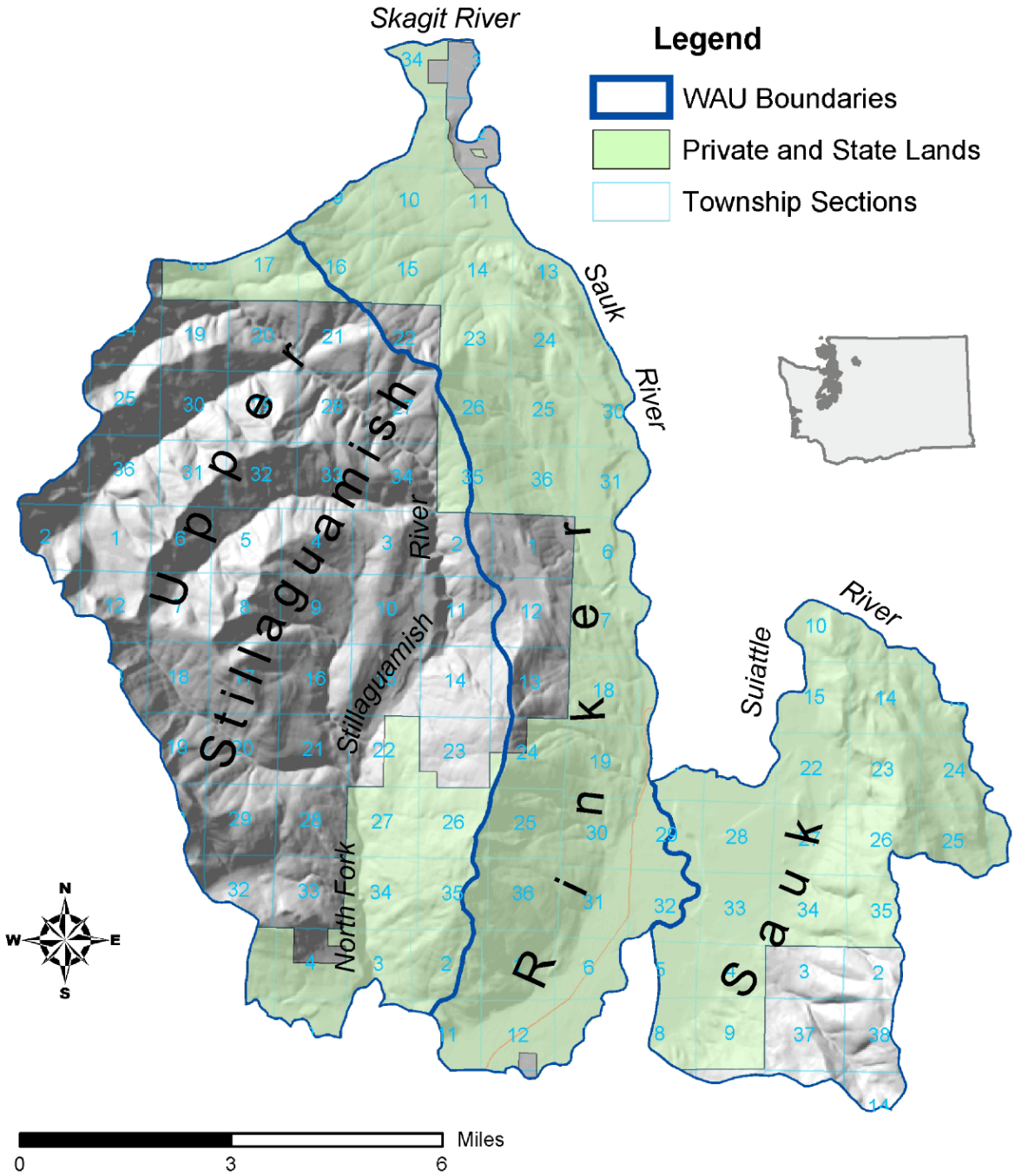

Figure 1. Map of the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs showing the location of private and state lands (green shading) reviewed during this mass wasting assessment.

2.0 Summary of Geologic and Physiographic Setting Pertinent to Mass-Wasting Interpretations

The lands reviewed in this assessment of the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs encompass six major landform types. Landforms of Quaternary age include (1) gently sloping to flat floodplain and alluvial terraces of the upper North Fork Stillaguamish, Suiattle, Sauk, and Skagit Rivers; (2) the inner gorges of the North Fork Stillaguamish and the Suiattle Rivers, and local inner gorges incised into valley walls throughout the study area; (3) moderately steep to steep valley walls along the river valleys; (4) bedrock hollows in valley walls composed of Darrington Phyllite, Slate of Rinker Ridge, Shuksan Greenschist, and Chilliwack Group metasediments (Figs. 2 and 3); (5) deep-seated landslides; and (6) terraces composed of glacial outwash and glacial till. Mass wasting has been documented along the inner gorges and on the valley walls of the North Fork Stillaguamish, Suiattle, Sauk, and Skagit Rivers and along the edges of glacial outwash terraces, as well as in bedrock hollows and on large deep-seated landslides. In many instances, this mass wasting can be associated with forest practices. Other factors that contributed to mass wasting include the steepness of the slopes, the nature of geologic materials, and aspects of precipitation including intense storm events and rain-on-snow processes.

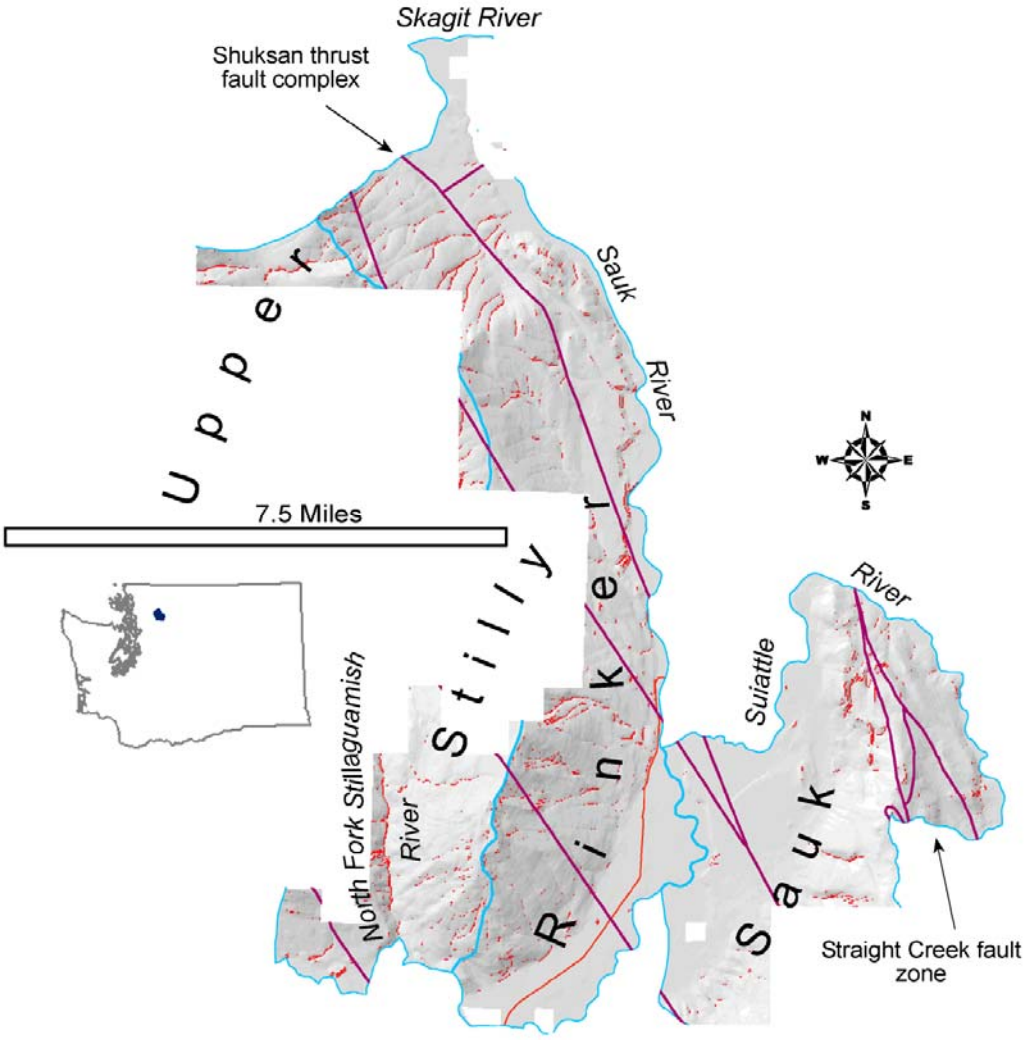

Figure 2. Map showing the areas being assessed in the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs, and slopes steeper than 60 percent (red areas) on portions of valley walls. The crimson lines are faults.

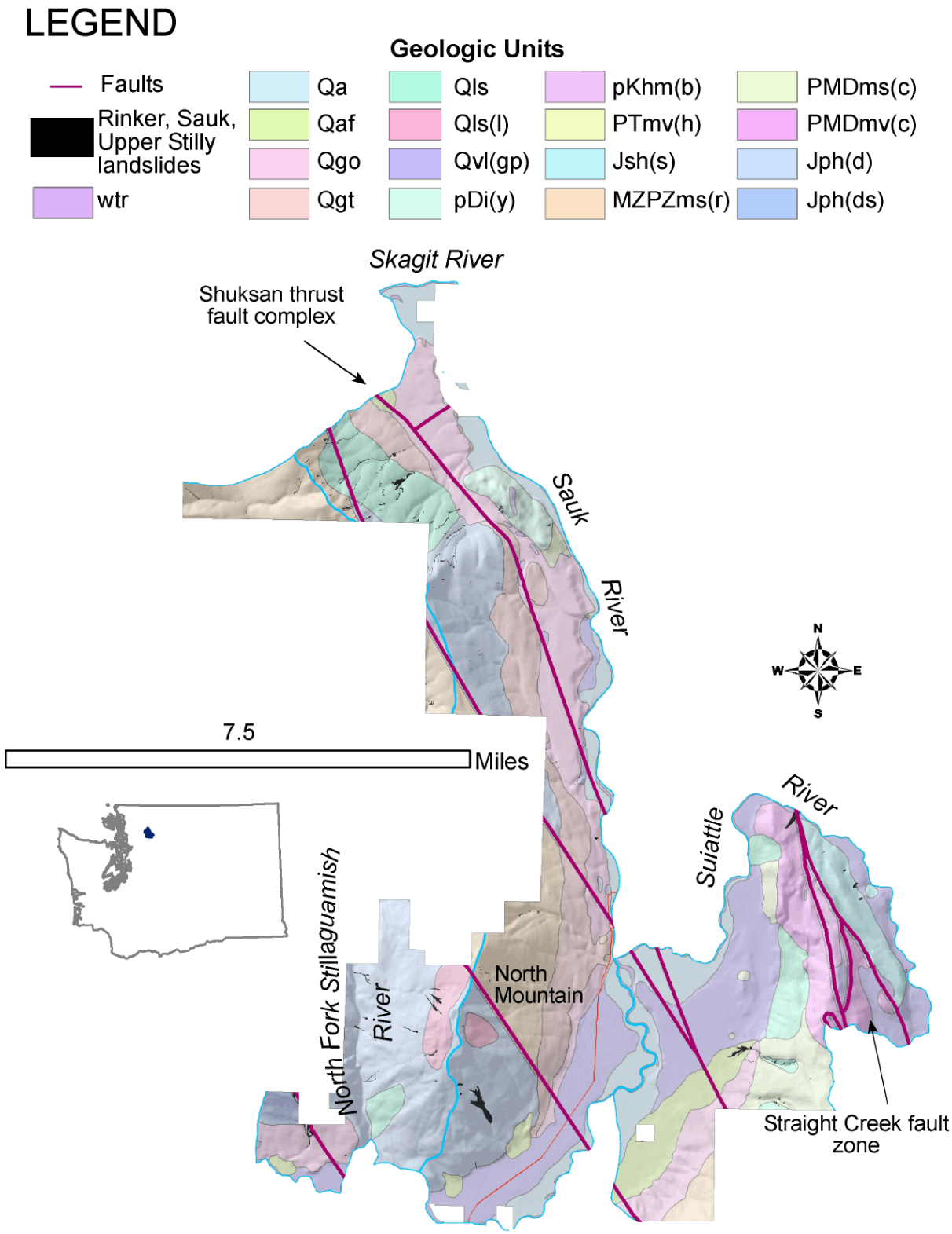

Figure 3. Map of the areas being assessed in the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs and the 209 mass wasting features (black polygons) identified during review of aerial photos. Colors show major geologic units after Dragovich and others (2002). See Table 1 (below) for geologic unit codes and names.

Table 1. Geologic symbols and mapped geologic units

Symbol	Quaternary/unconsolidated units	Symbol	Bedrock units
Qa	Alluvium	pTmv(h)	Helena Haystack Mélange
Qaf	Alluvial fan deposits	pKhm(b)	Bell Pass Melange metamorphic rocks
Qgo	Glacial outwash deposits	Jsh(s)	Shuksan Greenschist
Qgt	Glacial till	Jph(d), (ds)	Darrington Phyllite
Qls, Qls(l)	Mass wasting deposits	MzPzms(r)	Slate of Rinker Ridge
Qvl(gp)	Lahar deposits	PMDms(c)	Chilliwack Group metasediments
		PMDmv(c)	Chilliwack Group metavolcanics
		pDi(y)	Yellow Aster Complex gneiss

After Dragovich and others (2002). Figures 4, 5, and 18 show relationships among landslides and geologic materials based on the results of this assessment.

2.1 Topography

The assessed areas of the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs range in elevation from about 220 ft (67 m) in the floodplain of the Skagit River, to 3824 ft (1166 m) at North Mountain along the southern portion of the area being evaluated (southeast ¼ of section 26, T33N R9E).

2.2 Geology

The most useful geologic information and maps for this assessment were published by Tabor and others (2002) and Dragovich and others (2002). Other information was obtained in McCleary and others (1978) and Brown and others (1987). A number of geologic units are of great importance for the purposes of this assessment of landslides. They are (with their map symbols in parentheses): the Slate of Rinker Ridge (MzPzms(r)); a related unit—the Darrington Phyllite (Jph(d)); mass wasting deposits (mapped as either Qls or several mapped units of Qls(l)); Chilliwack Group metasediments (PMDms(c)); and glacial outwash deposits (Qgo). Together, these are associated with nearly 90 percent of the observed landslides (Fig. 4) and more than 97 percent of the cumulative area of those landslides inventoried (Fig. 5). Mass wasting and glacial outwash deposits consist of more or less unconsolidated fragmental debris. All of the map units are described below.

2.2.1 Deposits of Quaternary age

Quaternary alluvium (Qa) includes fluvial deposits, fan deposits, and fluvial terraces of postglacial age that are not primarily volcanic in origin, along the North Fork Stillaguamish, Suiattle, Sauk, and Skagit Rivers and tributary creeks.

Qls and Qls(l) include deposits from several large deep-seated landslides or landslide complexes. Nearly 2,773 acres (7.7 percent of the assessed area) is underlain by geologic materials that have been mapped as mass wasting deposits. The 48.8 acres of historic landslides inventoried on these mass wasting deposits during the 23-year period photo record period amounts to 1.76 percent of the area of mass wasting deposits, the third highest percentage of failures with respect to a given geologic unit for the lands being assessed. The largest landslide complex, which sits on the northeast flank of Rinker Ridge, encompasses some 1466.95 acres (2.29 mi^2). Field evaluation of this landslide complex reveals that it comprises some shallow landslides and unmapped fans and was the source for more than 30 of the slope failures identified during reconnaissance of aerial photos.

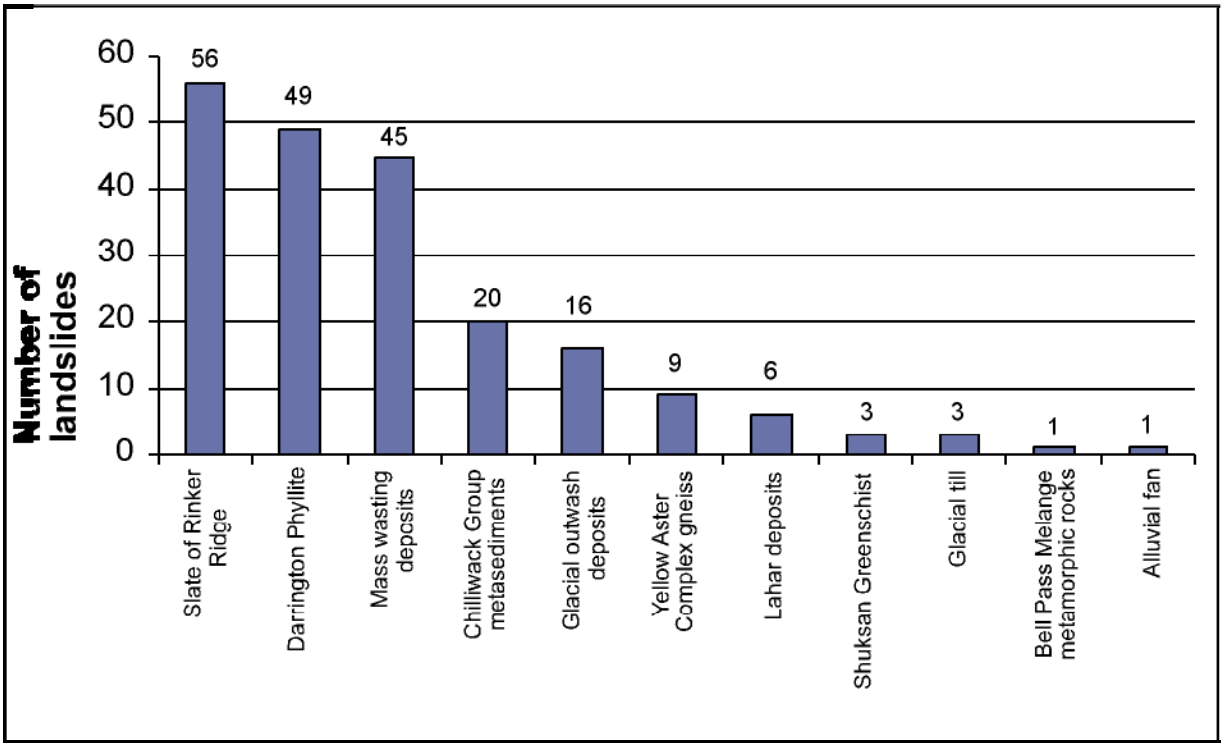

Figure 4. Graph showing the number of landslides observed within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs by geologic unit.

Debris flows and debris torrents are among the processes responsible for construction of the fans that are associated with the landslide deposits (see also Lingley, 2004). Alluvial and debris fans are of particular interest because alluvial fan deposits are defined as "sensitive sites" under the Washington Forest Practices rules (WAC 222-16-010). Some of the fan-like deposits that sit atop the Rinker Ridge landslide, or other units such as Qls(l), may be analogous to the draped fan deposits mapped by Tabor and others (2002) and described by Pringle (2004) near the mouth of Illabot Creek. Field evaluation of those features at Illabot Creek revealed that they are part of a compound landform unit that consists of mass-wasting deposits and fluvial deposits of varying ages, and that they have been modified by erosional processes.

A roadcut in the landslide on the northeast flank of Rinker Ridge, adjacent to an inner gorge and at an elevation of about 600 ft (183 m), exposes a veneer of tan, subangular pumice lapilli that is 7-15 cm in thickness. The presence of this intact fallout tephra layer (ejected volcanic particles) on top of a landslide suggests that major movement of the landslide material underlying it likely has not occurred for 2-5 millennia (Harden and others, 1982). Pringle (2004) previously described this deposit of tephra in an evaluation of the Illabot Creek watershed several miles to the east. Thus far the tephra, which is slightly oxidized, has not been linked to any particular volcano. A provisional interpretation is that the tephra layer could be as old as the pumice erupted ~5,500 yr B.P. from Glacier Peak, or as young as that erupted about 1,800 yr B.P. ("yr B.P." = radiocarbon years before AD 1950)[2].

[2] A brief description of this pumice is included because identifying it could be helpful to workers trying to assess the age of slide events or landforms in this area. Thus far the pumice lapilli have been observed locally as a veneer in locations slightly south of the Sauk–Skagit confluence (both W and E of Sauk River). Freshly broken pieces of the pumice are light orange, but unbroken lapilli may have a slightly reddish cast and the deposit as a whole has this reddish tint as well. In a quick binocular scope evaluation of crushed pumice, I provisionally identified hornblende and augite as well as plagioclase, quartz, and hypersthene, which may help in its identification.

Glacial deposits include terraces mapped as glacial outwash (Qgo) as well as more compact glacial till (Qgt). Glacial outwash makes up about 14 percent of the assessed area. The 16 landslides that headed on glacial outwash accounted for 9.95 percent of the 209 landslides identified in the assessed lands but made up only 0.37 percent of the area underlain by this unit. In other words, glacial outwash is characterized by a significant number of small landslides. Although glacial till makes up 8.2 percent of the area being assessed, the three landslides amount to 1.44 percent of the 209 identified. Note that Lingley (2004) documented tens of landslides in glacial outwash terraces directly northwest of this study area.

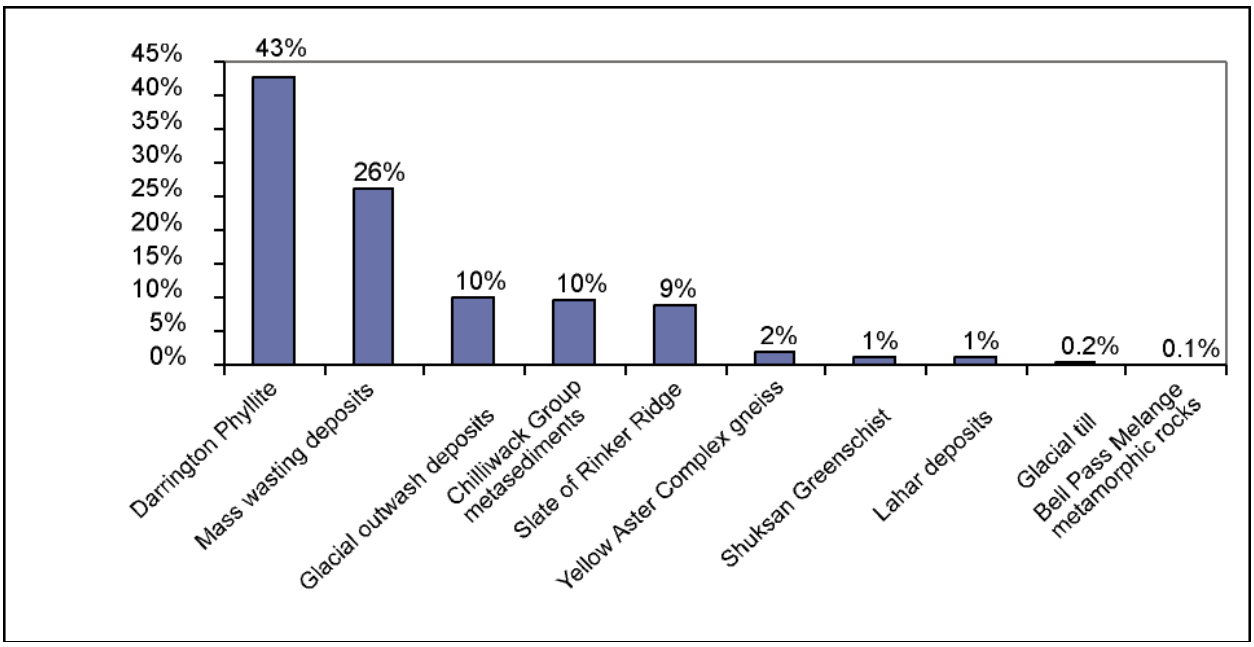

Figure 5. Graph showing proportions of landslide areas (not including deep-seated landslides) that originate from major geologic units, based on the area of all inventoried landslides.

2.2.2 Bedrock units

Most of the bedrock in the three WAUs consists of rocks of the North Cascades System of Tabor and others (2002). Formations belonging to this suite of rocks in the assessed area include the Darrington Phyllite, Slate of Rinker Ridge, Shuksan Greenschist, Bell Pass Mélange, Yellow Aster Complex, and the Chilliwack Group. These geologic units are briefly described below.

Darrington Phyllite

The Darrington Phyllite is a fine-grained, foliated metamorphic rock that is intermediate in metamorphic grade. It is predominantly phyllite (Tabor and others, 2002). In the study area, this rock unit is quite susceptible to mass wasting. Paulson (1997) noted that a significant number of slope failures, mostly of the shallow-rapid type, could be associated with this rock unit. Additionally, recent studies have shown that the Darrington Phyllite can be particularly susceptible to mass wasting depending on its structural orientation (Lingley, 2004; Dragovich, WDNR, written commun., 2004). Of the 209 landslides inventoried on the assessed lands, 49 (24 percent) originated in Darrington Phyllite.

Slate of Rinker Ridge

This unit is associated with the Easton metamorphic suite of rocks, specifically the Darrington Phyllite noted above, but has a lower metamorphic grade than that unit. Generally, this rock type is similar to the

Darrington Phyllite except that the Slate of Rinker Ridge contains more metamorphosed sandstone. Few data are available on the landslide susceptibility of this unit. However, 56 of the 209 landslides (27 percent) inventoried in the assessed lands originated in the Slate of Rinker Ridge. This unit is highly unstable in the adjacent watershed (Lingley, 2004).

Shuksan Greenschist

The Shuksan Greenschist is predominantly greenstone, weakly-to-moderately foliated. Paulson (1997) noted significantly fewer occurrences of slope failures in Shuksan Greenschist than in the Darrington Phyllite in her investigations in nearby watersheds and suggested that the two units should be considered separately in mass wasting assessments. This unit accounts for only 2.6 percent of the area of the lands being assessed herein. The three landslides identified make up only 0.24 percent of the area underlain by Shuksan Greenschist in the assessed area.

Chilliwack Group metasediments

Within the study area, the Chilliwack Group consists of metasediments including possibly some volcaniclastic rock. About 3.1 percent of the assessed area is underlain by the Chilliwack Group. The 20 landslides documented for the 23-year period of photo record (9.62 percent of the 209) reviewed in this assessment accounted for 1.6 percent of the area underlain by Chilliwack Group rocks.

Bell Pass Mélange metamorphic rocks

The Bell Pass Mélange mostly consists of metasedimentary and metavolcanic units. It is a body of shattered rock containing blocks and fragments of other rock bodies (known as 'mélange'). The Bell Pass Mélange makes up only 0.7 percent of the investigated area. Only one mass-wasting feature of the 209 identified in the assessed area was identified on this geologic unit during the 23-year period.

Yellow Aster Complex gneiss

The Yellow Aster Complex consists of metamorphosed quartzose gneiss, which looks like layered granite. No information is available on the landslide susceptibility of the Yellow Aster Complex gneiss. While only 0.4 percent of the assessed area is underlain by this geologic unit (140 acres), landslides identified in this study amounted to 3.64 acres or 2.59 percent of the area for this geologic unit. This is the highest percentage for any geologic unit in this study.

Faults

The area being assessed is cut by two of the largest faults in Washington, the Straight Creek fault and Shuksan Thrust, both shown on Figure 2. Significantly, the proximity of this area to major faults suggests that the bedrock units are probably sheared in places and thus could be particularly weathered and weakened. A reconnaissance of 1991 and 1998 high-elevation aerial photos for the area revealed ridge-parallel depressions locally that resemble those associated with sackung (ridges whose tops collapse as their side slopes spread apart) at and north of North Mountain.

2.3 Hydrology

Precipitation within the Rinker, Sauk Prairie, and Upper Stillaguamish watersheds (Fig. 6) varies from 60 inches per year, near the Skagit River in the extreme north part of the area and in the North Fork Stillaguamish River in the extreme southwest part of the area; to more than 90 inches per year in the upper elevation reaches to the extreme southeast and extreme northwest (WDNR, 2003). Most of the annual rainfall occurs between October and May, with a pronounced summer dry season.

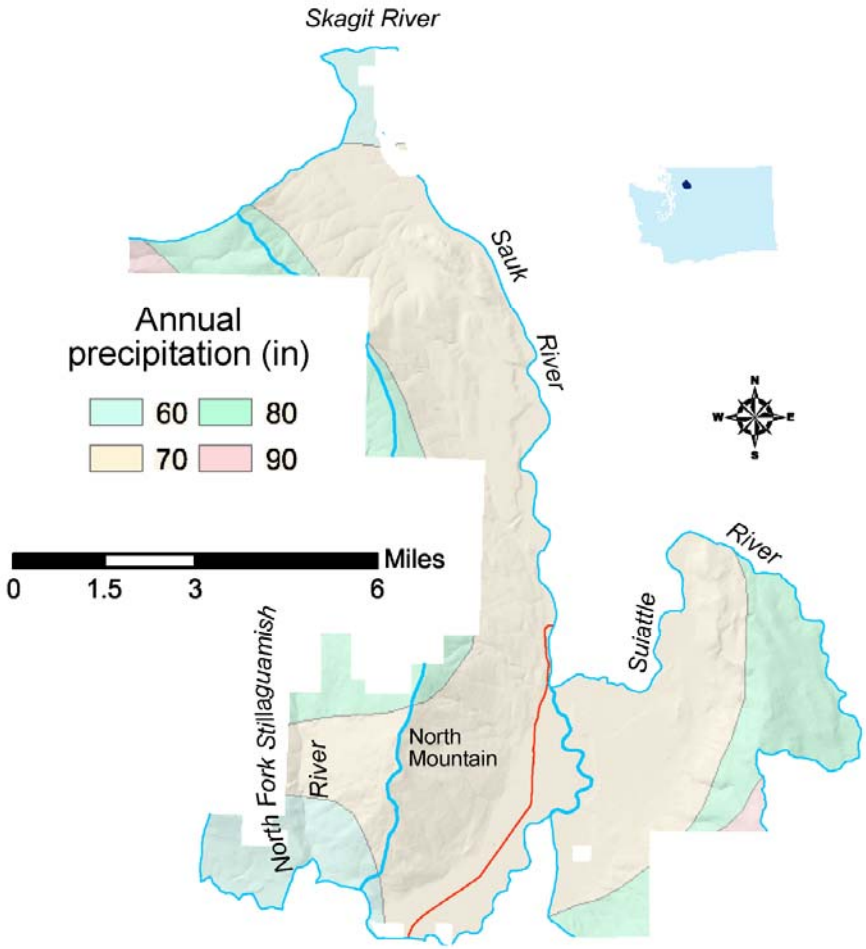

Figure 6. Map showing annual precipitation for the areas being assessed in the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs.

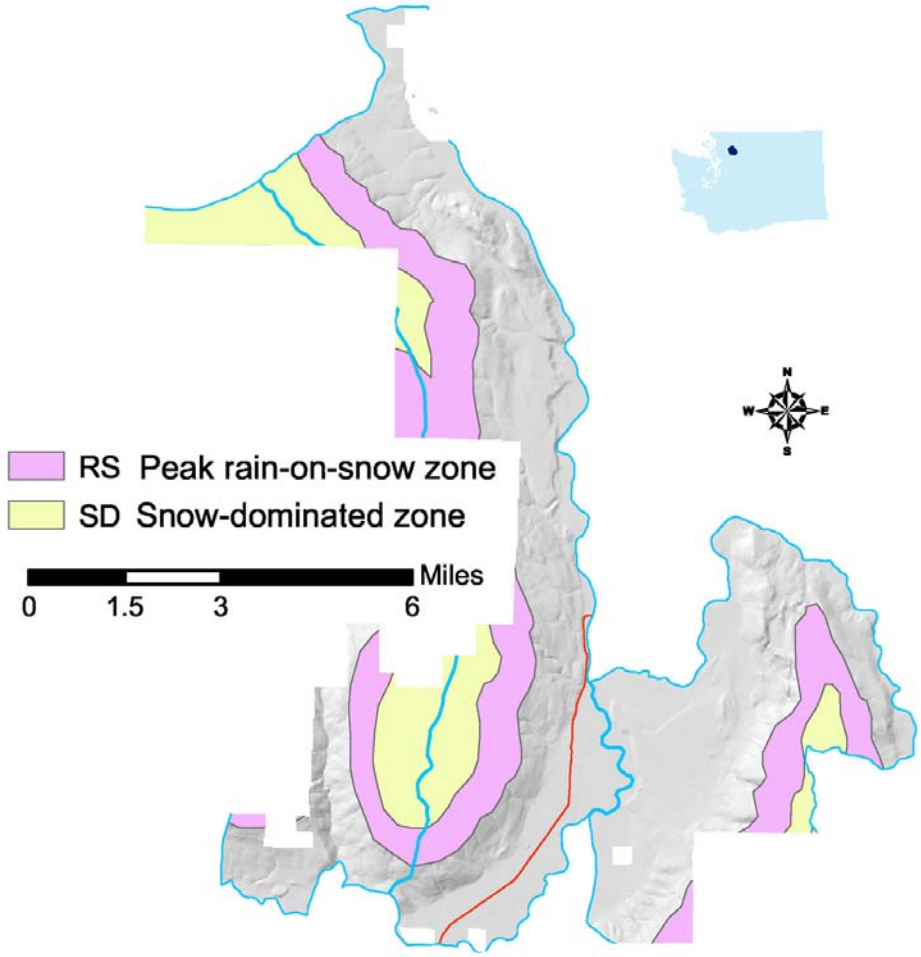

Figure 7. Map showing the areas being assessed in the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs with peak rain-on-snow zone delineated in purple (WDNR, 1991).

In the WDNR (1991) classification of precipitation zones, most of the lands assessed here are mapped as rain dominated; a substantial area is in the rain-on snow zone, and some in the snow dominated zone (Fig. 7). During winter months, elevations between about 1,000 and 3,000 feet are most susceptible to rain-on-snow hydrologic events, which, if they occur, can aggravate mass wasting along the steep valley margins. Steep slopes in and below the rain-on-snow zone are more susceptible to shallow rapid mass wasting events triggered by excess pore-water pressures.

Figure 8 shows maximum annual peak flows in the Sauk River, measured at a stream gauge near its confluence with the Skagit. The major regional floods of record since late 1928 occurred in February 1932, November 1949, February 1951, December 1975, December 1980, December 1989, November 1990, November 1995 (two storms), and October 2003 (USGS 2004; Jon Riedel, National Park Service, personal commun., 2004). Note that these all occurred in autumn to mid-winter, triggered by heavy rain augmented with snowmelt.

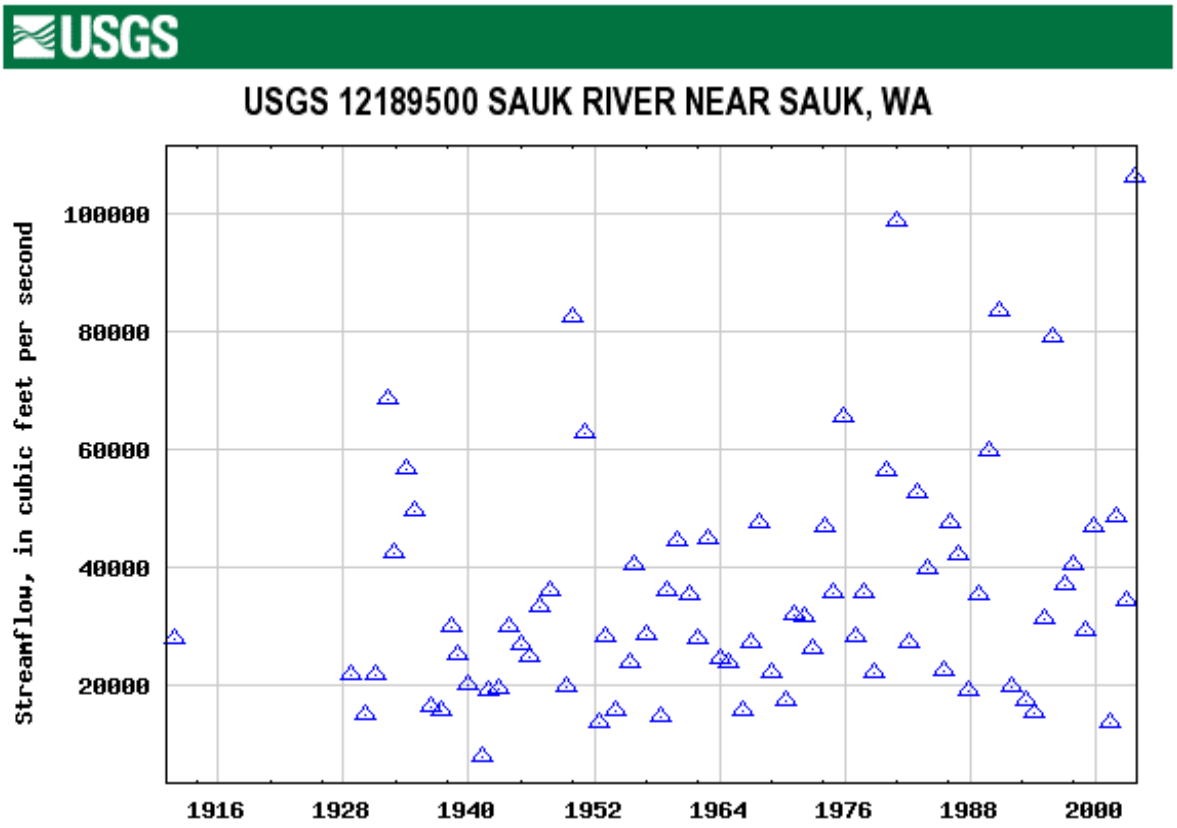

Figure 8. Plot of annual maximum instantaneous peak streamflow in the Sauk River near Sauk, Washington (USGS gauge 12189500) for water years 1912 and 1929 to 2004 (USGS, 2004).

2.4 Summary of Previous Mass Wasting Investigations

McCleary and others (1978), Tabor and others (2002), and Dragovich and others (2002) mapped landslides as well as ridge-top spreading associated with gravitational creep of a mountain (sackung features) during their geologic mapping in this general area. Nearly all their mapped landslides can be categorized as episodic and deep-seated. Paulson (1998) evaluated sediments in 10 sub-basins of the Skagit River, including the Sauk and Suiattle, in order to investigate the relative influence of geology, landforms, and land use on mass wasting and streams. However, she did not map any of the historic landslides evaluated herein. Wegmann (2004) performed a Level 2 landslide hazard zonation assessment for some areas in the southern sector of this study area; this report updates that inventory.

3.0 Summary of Methods

This assessment follows the Landslide Hazard Zonation Project protocols developed for Priority 2 watersheds. In many respects, the methods used herein are similar to those utilized for Level 2 mass wasting assessments as part of the *Standard Methods for Conducting Watershed Analysis, Version 4.0* (WFPB, 1997). Available geology, topography, soils, and hydrology information was reviewed for the assessment area, and I made a field visit to the area with a particular interest in examining the Quaternary fan deposits that had been mapped by Tabor and others (2002).

Aerial photographs acquired by WDNR in 1978 (1:12,000 black & white), 1983 (1:12,000 color), 1996 (1:12,000 black & white), 1991 (1:63,360 black & white), 1998 (1:63,360 black & white), and 2001 (1:12,000 color) were viewed in stereo using a mirror stereoscope with 3x magnification.

Landslides identified in the aerial photo review were digitized freehand utilizing 2000 DNR digital orthophotos in an ArcGIS environment (Map A-1). Pertinent attributes of the landslide features were recorded on data sheets (Form A-1). Recorded information includes: 1) the type of mass wasting process, 2) level of certainty of the observation, 3) whether the mass wasting feature delivered sediment to surface waters or public resources, 4) associated land use, 5) the slope form (convergent, planar, divergent), 6) the photo-year in which the failure was initially recognized, and 7) the gradient or steepest slope increment within each landslide polygon.

A slope/convergence map (SLPSTAB; Vaugeois, 2000) and a slope-percent map derived from a USGS 10-meter digital elevation model (DEM) of the watershed assisted the delineation of MWMUs. The slope angle cannot be reliably determined for small or narrow landslides where accuracy is limited by the 10-meter resolution of the DEM, which was derived from 1:24,000-scale topographic mapping. Dragovich and others (1993), for example, observed that field-measured slopes for landslides were 5–10 degrees steeper than mapped. Conversely, the steepest slopes on rotational failures are on the failure plane and therefore steeper than the slope of the ground just before landslide initiation. As a result, the method of slope estimation presented is an approximation.

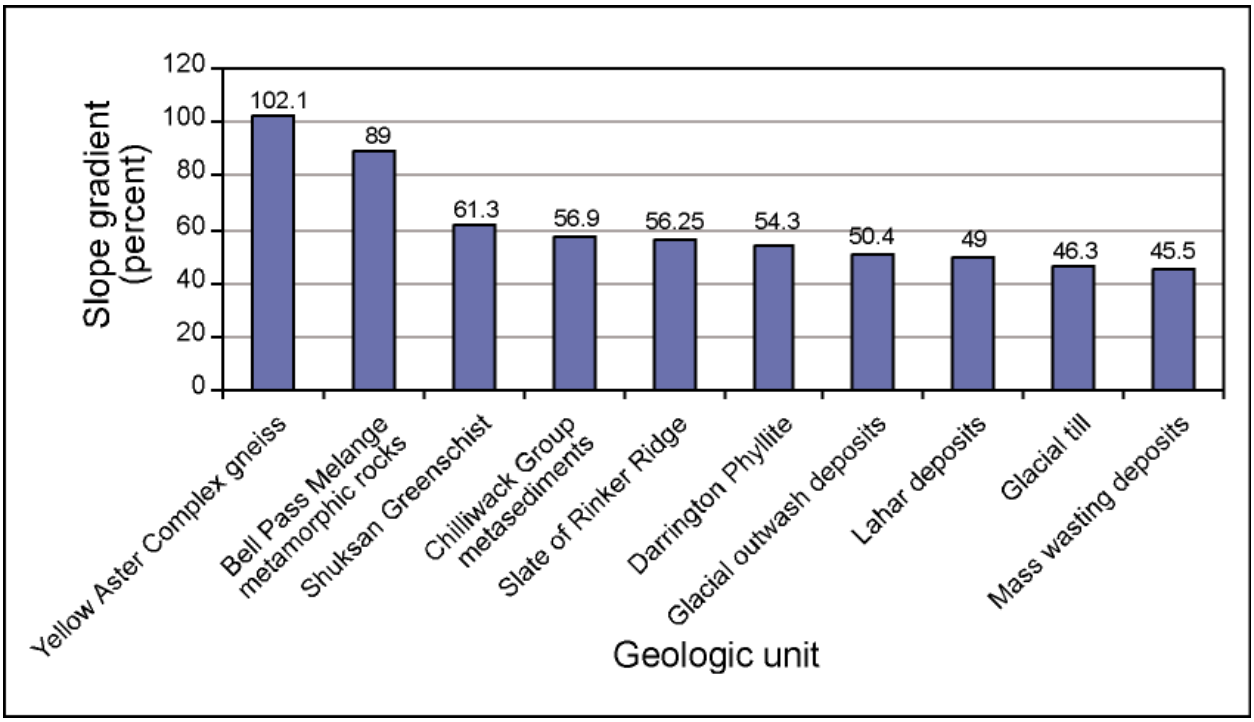

Figure 9. Average slope gradient (percent) of failure for all inventoried landslides of a given geologic unit within the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs. The value for each rock type was used as a threshold for the delineation of MWMUs 1, 2, and 3

4.0 Summary of Analysis and Results

During this review, a representative sample of 209 'questionable' to 'definite', field-confirmed landslides were inventoried using data obtained between 1976 and 2001.[3] The features identified in the landslide inventory are listed in Forms A-1 (Appendix 8.2), and shown on Map A-1. Many of the characteristics of these slope failures are illustrated by the graphs in Figures 5 and 9 through 20.

Once the locations of mass wasting features were mapped and evaluated with respect to geology, land-form and slope, areas interpreted to have a similar mass-wasting potential were grouped into one of six different mass wasting map units (MWMUs). The MWMUs for the fee and state lands of the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs are listed in Table 2, and described in more detail in Forms A-2 (Appendix 8.3); they are shown on Map A-2.

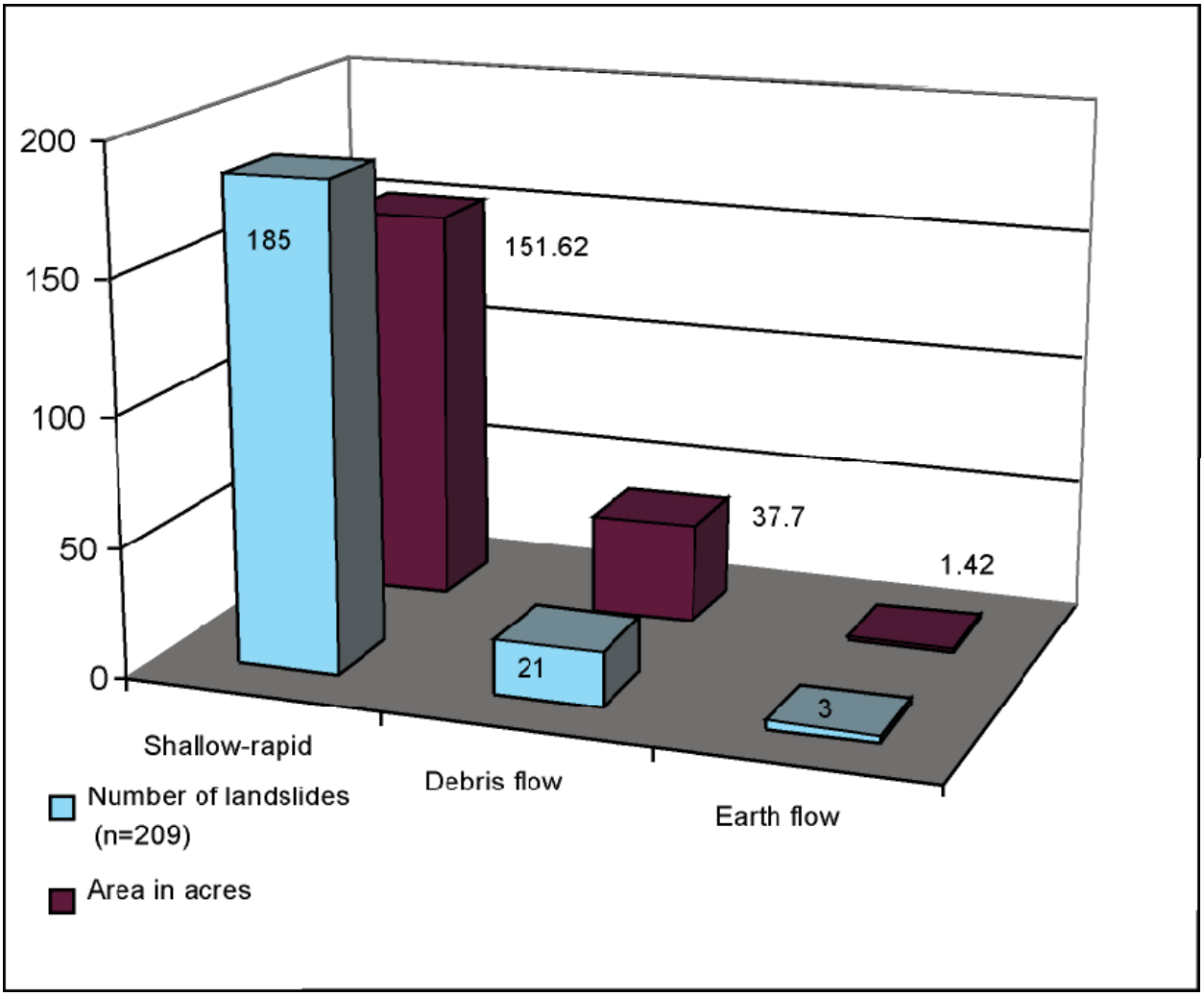

Figure 10. Number and cumulative area of landslides observed within the assessed lands in the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs by mass wasting process. Previously mapped deep-seated landslides were not included in the calculations.

[3] Note again that an additional 16 features were identified in 2005 in areas added to this assessment. These slides are included in the landslide inventory and map (Forms and Map A-1), but not reflected in the graphs.

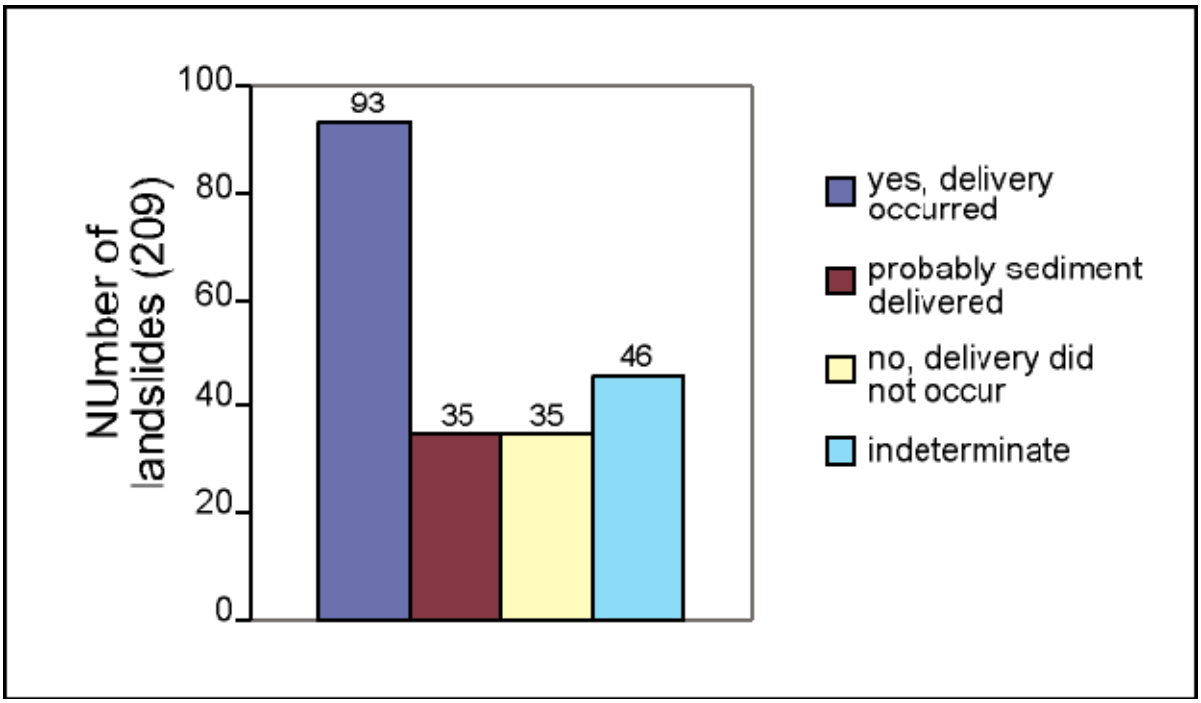

Figure 11. Distribution of delivery categories for landslides in the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs. Previously mapped deep-seated landslides were not included in the calculations.

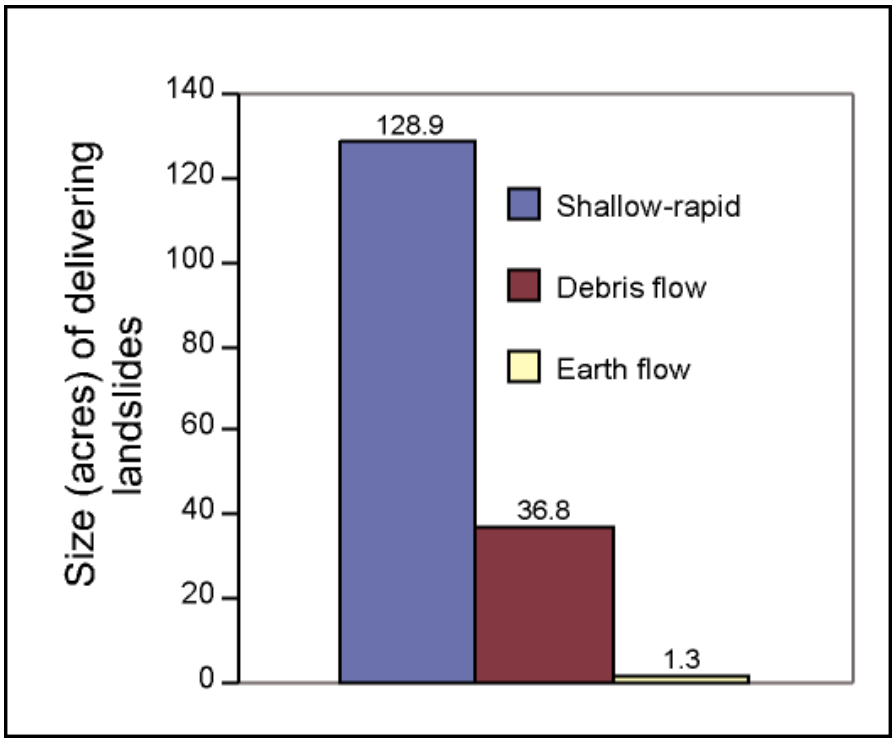

Figure 12. Area of delivering landslides within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs. Area of delivering landslides is used as a proxy for the volume of sediment delivered to surface waters via different landslide processes. Both 'yes' and 'probable' values for delivery were counted in this analysis (Form A-1).

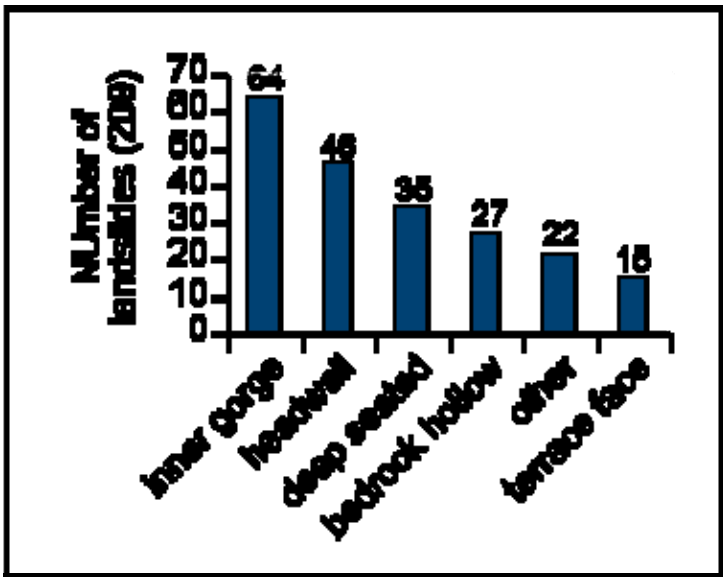

Figure 13. Number of landslides observed within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs by landform association.

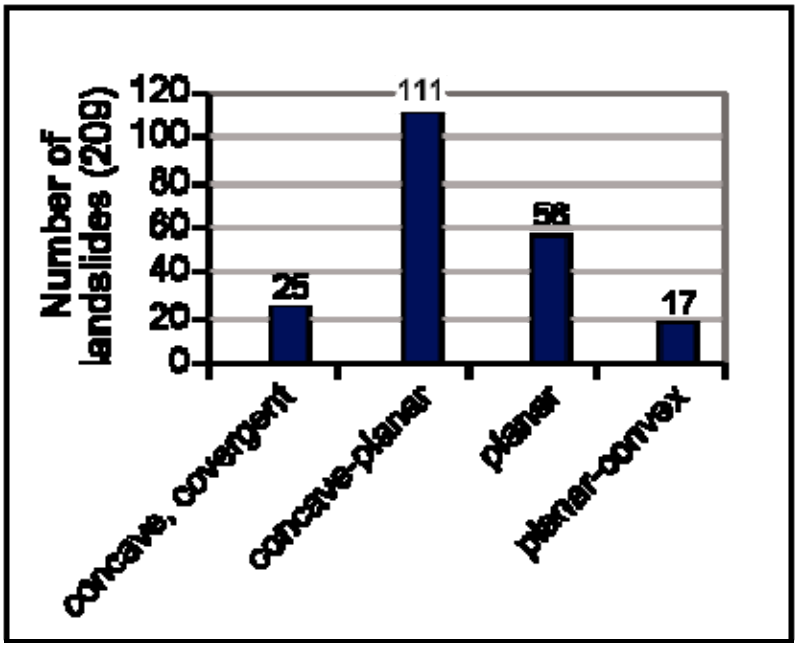

Figure 14. Distribution of landslides by slope shape for landslides observed within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs.

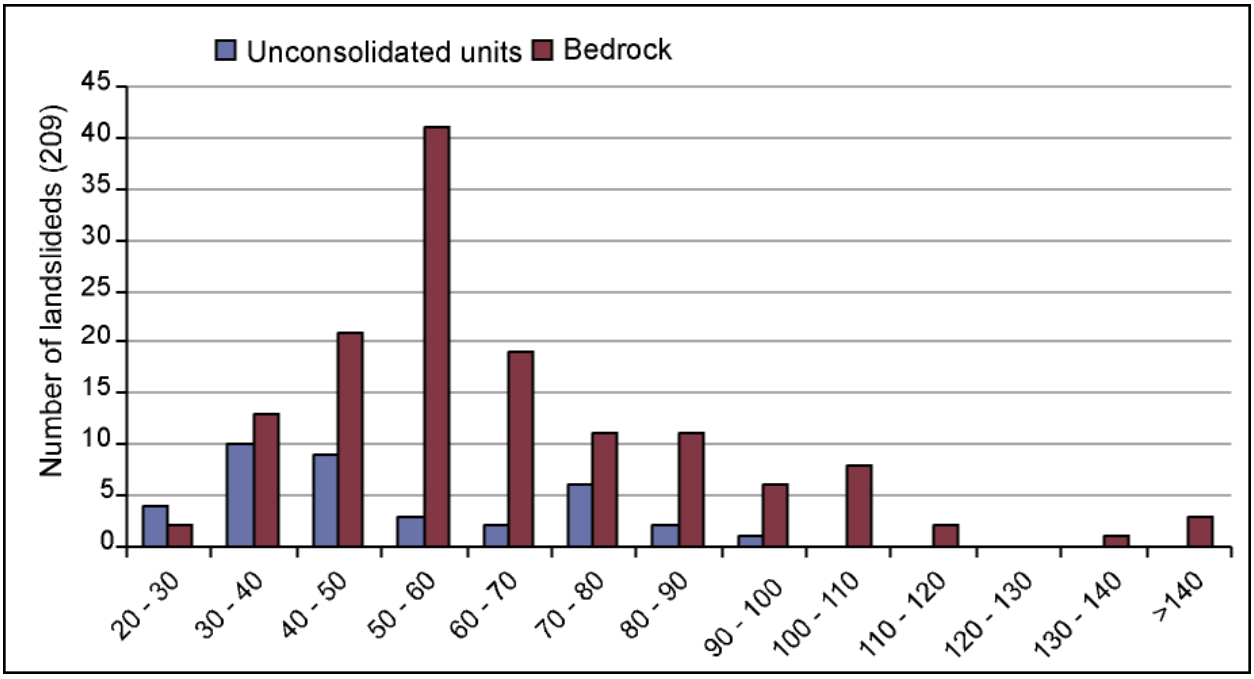

Figure 15. Slope angles (percent) at which landslides initiated within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs. The mean slope for landslide initiation is 45 and 59 percent for landslides in unconsolidated deposits and bedrock, respectively. The methods used for determining slope are an approximation, as noted in section 3.0.

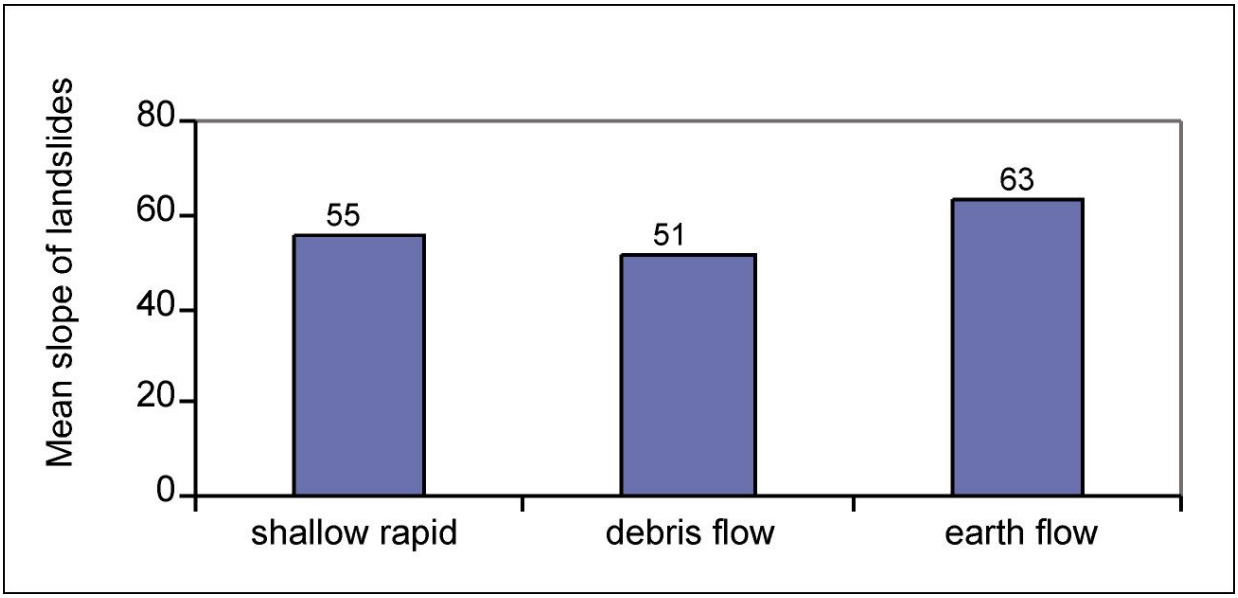

Figure 16. Mean slope (percent) of failures by landslide process for identified landslides within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs. The methods used for determining slope are an approximation, as noted in section 3.0.

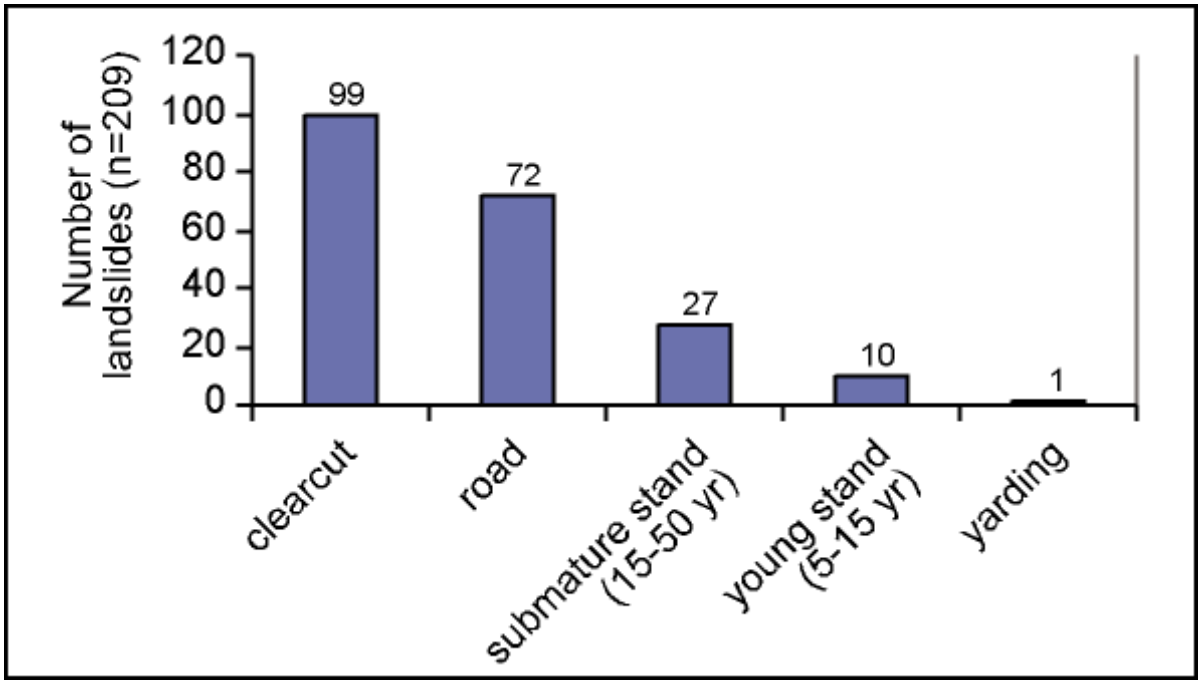

Figure 17. Number of landslides observed within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs by land use association.

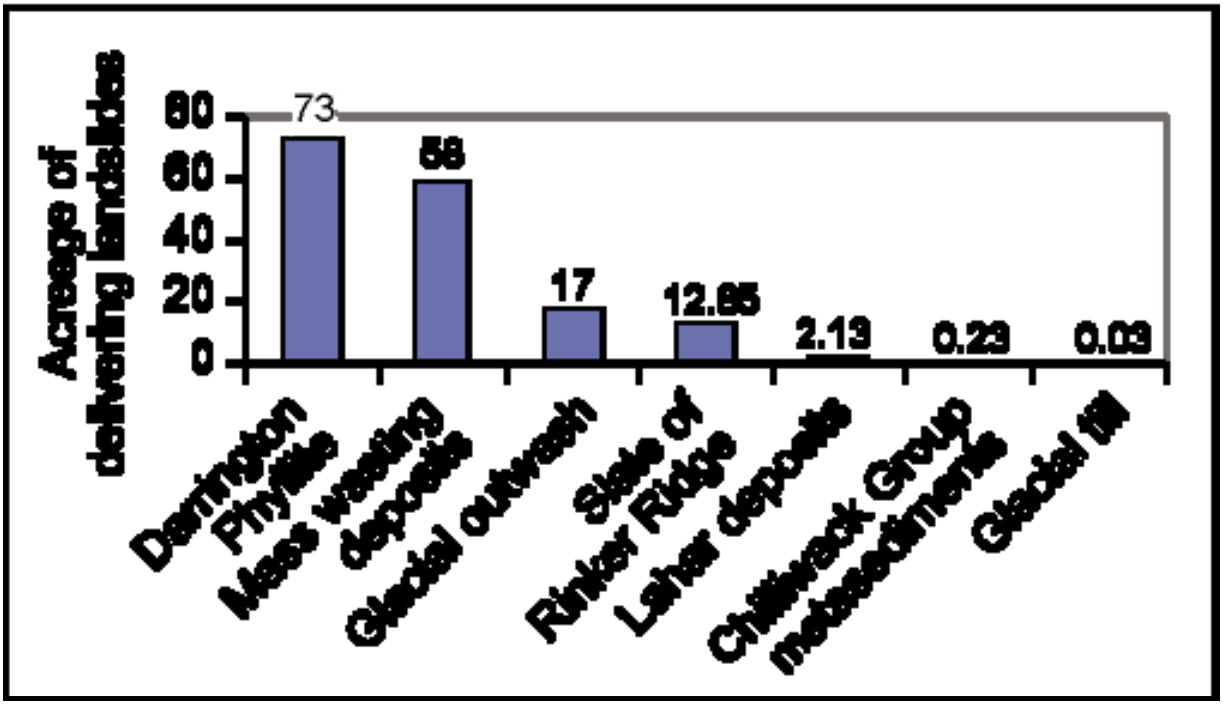

Figure 18. Acreage of delivering landslides observed within the assessed lands in Rinker, Sauk Prairie, and Upper Stillaguamish WAUs by geologic unit.

Table 2. Mass wasting map units in the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs

MWMU #	Mass wasting map unit	Slope threshold	Area (acres)	Hazard Rating
1	Low hazard areas	≤ 5 %	8539	low
2	Other upland areas	< 60 %	17139	moderate
3	Moderately steep to steep slopes of glacial terrace deposits	35–115 %	813	high
4	Inner gorges, stream-adjacent slopes, convergent headwalls, bedrock hollows	≥ 50 %	1328	high
5	Inner gorges, stream-adjacent slopes, convergent headwalls, bedrock hollows, on deep-seated landslides or other unstable materials	≥ 45 %	374	very high
6	Areas of deep-seated landslides and their headscarps	variable	4121	variable

5.0 Summary of Critical Questions

In order to explicitly address the critical questions posed by the *Standard Methods for Conducting Watershed Analysis*, the following summaries are included:

What evidence is present for mass wasting or mass wasting potential in the watershed?

A total of 209 mass wasting features were identified during this assessment of fee and state lands. Based on this evidence and the nature of geologic materials composing the evaluated landforms, six mass wasting map units were assigned because of the inferred potential for future mass wasting on these lands.

What mass wasting processes are active?

Shallow-rapid slides, debris flows, and earthflows have been documented in the area under assessment (Maps A-1 and A-2, Form A-1).

How are mass wasting features distributed throughout the landscape?

The 209 recent mass wasting features were noted in a review of air-photos taken over 23 years. These identified features show close correlation with areas delineated as potentially unstable by a slope/convergence map (SLPSTAB; Vaugeois, 2000) and a slope-percent map derived from a USGS 10-meter DEM.

Do landslides deliver sediment to stream channels or other waters, or threaten public works or safety?

Yes, at least 60 percent of identified features delivered sediment/debris.

How do forest management activities create or contribute to instability?

Management activities such as clearcutting, roading, and yarding likely contributed to 99, 72, and 10 mass wasting features, respectively, of the 209 landslides observed on the assessed lands over the period of photo analysis.

What areas of the landscape are susceptible to slope instability?

Six different mass wasting map units can be delineated for the lands being assessed; these are shown on Map A-2 and described on Forms A-2. Of these, three have hazard potential that is moderate (covering 17,139 acres), high (2,141 acres) or very high (374 acres).

6.0 Confidence in Work Products

The overall confidence in this mass wasting assessment for the limited fee and state land portions of the Rinker, Sauk Prairie, and Upper Stillaguamish WAUs is high. This confidence is due to the large number of mass wasting features (209) identified during review of aerial photographs over a 23-year period.

7.0 Disclaimer

Care was used during this project to ensure accuracy. However, due to changes in ownership and the need to rely on outside information, the Department of Natural Resources cannot accept responsibility for errors or omissions on these maps and therefore, there are no warranties which accompany this material. Neither the State of Washington, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the State of Washington or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the State of Washington or any agency thereof.

8.0 Appendices

Appendix 8.1 References

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Appendix 8.2 Form A-1, Landslide Inventory

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Landslide size (acres)	Landform	Slp_shp	Gradient	Delivery	Land use	Init_elev	Geologic unit	Photo_number
1	1	d	1978	3	0.16	7	3	70	i	5	1000	Jsh(s)	nw78 97 d9-11
2	1	q	1978	4	0.60	7	4	60	i	5	1000	Jsh(s)	nw78 97 d9-11
3	1	q	1978	5	2.23	7	4	30	i	5	1040	Jsh(s)	nw78 97 d9-11
4	1	d	1978	5	1.17	2	1	60	y	5	1200	Qvl(gp)	mw78 96e 9-10
5	1	p	1987	5	14.73	1	1	60	y	3	1800	PMDms(c)	nw87 34 81 137-8
6	1	p	1996	3	0.13	1	2	80	y	3	760	Qvl(gp)	nw96 67 84 223-4
7	1	p	1996	3	0.33	1	2	80	y	3	760	Qvl(gp)	nw96 67 84 223-4
8	1	p	1996	3	0.34	1	2	80	y	3	860	Qvl(gp)	nw96 67 84 223-4
9	1	d	1996	2	0.06	1	2	47	y	3	2080	Qls	nw96 67 82 127-8
10	1	d	1996	3	0.19	8	2	100	y	3	2080	Qls	nw96 67 82 127-8
11	1	d	1996	2	0.05	8	2	45	y	3	2080	Qls	nw96 67 82 127-8
12	1	d	1996	3	0.19	8	3	40	I	3	1000	pKhm(b)	nw96 67 82 133-4
13	1	d	1996	3	0.21	1	2	60	y	3	1800	PMDms(c)	nw96 63 81 45-6
14	1	d	1996	4	0.86	8	2	80	y	5	1900	PMDms(c)	nw96 63 81 45-6
15	1	d	1996	3	0.36	1	2	25	y	5	1200	PMDms(c)	nw96 63 81 45-6
16	1	d	1996	1	0.02	8	2	60	y	3	1640	PMDms(c)	nw96 63 81 45-6
17	1	d	1996	1	0.00	1	2	70	y	3	1450	PMDms(c)	nw96 63 81 45-6
18	1	d	1996	2	0.03	1	2	60	y	3	1700	PMDms(c)	nw96 63 81 45-6
19	1	d	1996	2	0.02	1	2	60	y	3	1650	Qgo	nw96 63 81 45-6
20	1	n	1996	3	0.15	7	2	70	n	1	950	Qgo	nw96 63 81 45-6
21	1	n	1996	2	0.03	7	2	50	n	1	840	Qls	nw96 63 81 45-6
22	2	n	1996	3	0.24	8	2	100	y	1	2180	Qls	nw96 63 81 45-6
23	1	n	1996	3	0.35	8	2	135	y	1	1400	Qls	nw96 63 81 45-6
24	2	n	1996	5	15.04	8	2	100	y	1	1680	Qgo	nw96 63 81 45-6
25	2	n	1996	4	0.43	1	2	50	n	1	890	PMDms(c)	nw96 63 81 45-6
26	1	q	1996	2	0.08	1	2	50	y	5	2650	PMDms(c)	nw96 63 81 45-6
27	1	q	1996	2	0.04	1	2	50	y	1	2400	PMDms(c)	nw96 63 81 45-6
28	2	d	1996	2	0.06	7	2	50	n	5	1000	PMDms(c)	nw96 63 81 45-6
29	2	p	1996	1	0.02	7	2	50	n	1	1150	PMDms(c)	nw96 63 81 45-6
30	2	p	1996	1	0.01	7	2	50	n	1	1120	PMDms(c)	nw96 63 81 45-6
31	2	p	1996	1	0.01	7	2	50	n	1	1340	PMDms(c)	nw96 63 81 45-6
32	1	d	1996	2	0.09	1	1	69	y	3	900	Qls	nw96 63 81 46-7
33	1	d	1996	1	0.01	1	2	85	n	3	1020	PMDms(c)	nw96 63 81 46-7
34	1	d	2001	4	0.43	1	2	95	y	3	1760	PMDms(c)	nwc01 47 82 22-3
35	1	d	2001	3	0.16	1	2	75	y	3	1700	PMDms(c)	nwc01 51 81 200-1
36	1	d	2001	2	0.05	1	3	80	y	3	900	PMDms(c)	nwc01 47 82 22-3
37	1	d	1978	3	0.17	1	2	35	y	3	460	Qgo	nw-78 87d-12
38	1	q	1978	4	0.44	7	3	38	i	3	480	Qgo	nw-78 87d-12
39	1	d	1978	5	18.67	2	1	40	y	5	2200	Jph(d)	nw-78 87d-14
40	1	d	1983	3	0.32	2	2	38	y	7	3040	Mzpzms(r)	nwc83 22-72-220
41	1	d	1983	4	0.91	2	1	38	y	1	3380	Mzpzms(r)	nwc83 22-72-220
42	1	d	1983	3	0.13	5	2	54	y	1	3040	Mzpzms(r)	nwc83 22-72-220
43	1	d	1983	1	0.02	1	2	55	Y	1	2820	Mzpzms(r)	nwc83 22-72-220
44	1	d	1983	2	0.03	1	2	43	y	1	2700	Mzpzms(r)	nwc83 22-72-220
45	1	d	1983	3	0.19	1	2	41	y	1	2930	Mzpzms(r)	nwc83 22-72-220
46	1	d	1983	2	0.05	1	2	41	y	1	2550	Mzpzms(r)	nwc83 22-72-220

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Landslide size (acres)	Landform	Slp_shp	Gradient	Delivery	Land use	Init_elev	Geologic unit	Photo_number
47	1	d	1983	2	0.03	1	1	40	y	1	2390	Mzpzms(r)	nwc83 22-72-220
48	1	d	1983	2	0.03	1	1	40	y	1	2550	Mzpzms(r)	nwc83 22-72-220
49	1	d	1983	2	0.03	1	1	40	y	1	2320	Mzpzms(r)	nwc83 22-72-220
50	1	d	1983	2	0.02	1	1	40	y	1	2320	Mzpzms(r)	nwc83 22-72-220
51	1	d	1983	3	0.20	1	1	40	y	1	2240	Mzpzms(r)	nwc83 22-72-220
52	2	d	1983	4	0.78	2	1	39	y	1	3320	Mzpzms(r)	nwc83 22-73-281
53	1	d	1983	3	0.23	2	1	39	y	1	3380	Mzpzms(r)	nwc83 22-73-281
54	1	d	1983	3	0.19	2	1	37	y	1	3330	Mzpzms(r)	nwc83 22-73-281
55	1	d	1983	3	0.11	1	2	58	y	1	2720	Mzpzms(r)	nwc83 22-73-281
56	1	d	1983	2	0.06	1	2	58	y	1	2640	Mzpzms(r)	nwc83 22-73-281
57	1	d	1983	2	0.05	1	2	53	y	1	2620	Mzpzms(r)	nwc83 22-73-281
58	1	d	1983	2	0.05	1	2	80	y	1	2560	Mzpzms(r)	nwc83 22-73-281
59	1	d	1983	3	0.24	5	2	77	p	5	3180	Mzpzms(r)	nwc83 21-74-37
60	1	d	1983	5	1.20	5	2	70	p	1	2960	Jph(d)	nwc83 21-74-37
61	2	d	1983	5	1.96	5	2	91	p	1	3280	Mzpzms(r)	nwc83 21-74-37
62	2	d	1983	3	0.39	5	2	86	p	1	3180	Mzpzms(r)	nwc83 21-74-37
63	2	d	1983	5	1.28	5	1	63	p	1	2880	Mzpzms(r)	nwc83 21-74-38
64	2	d	1983	5	4.41	8	1	37	y	1	2560	Qls	nwc83 21-74-38
65	1	d	1983	3	0.35	8	4	80	p	5	2680	Qls	nwc83 21-74-38
66	1	d	1983	4	0.89	5	2	70	i	5	2720	Mzpzms(r)	nwc83 21-74-39
67	2	d	1983	5	1.90	8	4	37	y	5	2160	Qls	nwc83 21-74-39
68	1	d	1983	3	0.39	8	4	37	y	5	2150	Qls	nwc83 21-74-39
69	1	d	1983	2	0.05	5	3	63	i	5	3160	Mzpzms(r)	nwc83 21-74-39
70	1	d	1983	2	0.08	7	4	77	i	5	2240	Qls	nwc83 21-74-39
71	1	d	1983	2	0.10	5	2	77	i	5	2250	Jph(d)	nwc83 21-74-39
72	1	d	1983	4	0.73	5	3	109	i	5	2360	Jph(d)	nwc83 21-74-39
73	1	p	1983	5	2.01	1	1	34	p	5	2920	Jph(d)	nwc83 21-75-89
74	1	p	1983	4	1.03	1	1	47	p	3	1000	Jph(d)	nwc83 21-75-89
75	1	p	1983	2	0.09	1	3	63	p	3	900	Jph(d)	nwc83 21-75-89
76	1	p	1983	4	0.84	1	2	75	p	3	1200	Jph(d)	nwc83 21-75-90
77	1	p	1983	4	0.93	5	2	50	p	5	1480	Jph(d)	nwc83 21-75-90
78	1	p	1983	3	0.40	5	2	82	p	5	1340	Jph(d)	nwc83 21-75-90
79	1	p	1983	5	2.01	1	2	29	i	5	3340	Qls(l)	nwc83 21-75-89
80	1	p	1983	5	3.57	5	2	34	p	2	3200	Qls(l)	nwc83 21-75-90
81	1	p	1983	5	5.27	5	2	34	p	2	3220	Qls(l)	nwc83 21-75-90
82	1	p	1983	5	1.67	7	2	31	p	2	3020	Qls(l)	nwc83 21-75-90
83	1	p	1983	5	1.96	7	2	41	p	5	1450	Jph(d)	nwc83 21-75-90
84	1	p	1983	5	1.79	8	2	43	p	5	1450	Jph(d)	nwc83 21-75-90
85	1	y	1983	3	0.15	8	3	34	i	1	2280	Qls	nwc83 21-75-103
86	1	y	1983	3	0.37	8	2	102	p	1	2200	Qls	nwc83 21-75-103
87	1	y	1983	4	0.46	8	2	58	p	1	2180	Qls	nwc83 21-75-103
88	1	y	1983	3	0.36	8	3	102	i	1	2010	Qls	nwc83 21-75-103
89	1	y	1983	4	0.70	8	3	102	i	1	1950	Qls	nwc83 21-75-103
90	1	y	1983	5	1.05	8	3	148	y	1	1750	Qls	nwc83 21-75-103
91	1	y	1983	5	1.09	8	3	126	y	1	1480	Qls	nwc83 21-75-103
92	1	y	1983	5	1.51	8	2	158	y	1	1640	Qls	nwc83 21-75-103
93	1	y	1983	4	0.64	8	3	84	y	1	1640	Qls	nwc83 21-75-103
94	1	y	1983	3	0.29	8	3	100	i	1	1360	Qls	nwc83 21-75-103
95	1	y	1983	4	0.56	8	2	130	i	1	1500	Qls	nwc83 21-75-104
96	1	y	1983	3	0.26	8	3	67	i	5	1800	Qls	nwc83 21-75-104

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Landslide size (acres)	Landform	Slp_shp	Gradient	Delivery	Land use	Init_elev	Geologic unit	Photo_number
97	1	y	1983	3	0.20	8	3	220	i	5	1800	Qls	nwc83 21-75-104
98	2	y	1983	5	1.78	8	2	130	y	5	1730	Qls	nwc83 21-75-104
99	1	y	1983	3	0.15	8	2	74	y	1	1760	Qls	nwc83 21-75-104
100	1	y	1983	3	0.21	8	3	110	y	5	1720	Qls	nwc83 21-75-104
101	1	y	1983	3	0.12	8	2	74	y	1	1570	Qls	nwc83 21-75-104
102	1	y	1983	2	0.06	1	3	74	y	1	1520	Qls	nwc83 21-75-104
103	1	y	1983	4	0.51	1	3	36	y	1	1200	Qls	nwc83 21-75-104
104	1	y	1983	5	1.45	1	3	47	y	1	1080	Qls	nwc83 21-75-104
105	1	y	1983	3	0.13	1	3	47	y	1	1020	Qls	nwc83 21-75-104
106	1	y	1983	5	10.14	8	2	170	y	1	1600	Qls	nwc83 21-75-104
107	1	y	1983	5	1.66	5	2	200	y	1	1020	Qls	nwc83 21-75-104
108	1	p	1983	4	0.41	1	2	60	n	1	3120	Jph(d)	nwc83 21-76-144
109	1	p	1983	5	1.97	2	2	65	p	5	3040	Jph(d)	nwc83 21-76-144
110	1	p	1983	4	0.59	7	3	42	n	5	2800	Jph(d)	nwc83 21-76-144
111	2	p	1983	3	0.37	2	2	38	p	1	3420	Qls	nwc83 21-76-145
112	1	p	1983	3	0.23	2	2	164	i	5	3950	Jph(d)	nwc83 21-76-146
113	2	p	1983	2	0.06	5	3	56	i	1	3430	Qls	nwc83 21-76-146
114	1	p	1983	3	0.17	5	3	45	i	5	3540	Mzpzms(r)	nwc83 21-76-146
115	1	p	1983	3	0.13	1	3	45	i	5	3580	Mzpzms(r)	nwc83 21-76-146
116	1	d	1983	4	0.74	1	2	39	y	1	1580	Mzpzms(r)	nwc83 21-76-154
117	1	d	1983	3	0.18	1	1	80	y	1	1400	Mzpzms(r)	nwc83 21-76-154
118	1	d	1983	3	0.20	7	3	65	n	5	2740	Jph(d)	nwc83 21-76-158
119	1	d	1983	2	0.04	7	3	67	n	5	3120	Jph(d)	nwc83 21-76-158
120	1	p	1983	2	0.05	5	3	67	n	1	3160	Jph(d)	nwc83 21-76-158
121	1	d	1983	4	0.53	5	3	100	i	1	3000	Jph(d)	nwc83 21-76-158
122	1	d	1983	3	0.28	2	2	54	i	1	2780	Jph(d)	nwc83 21-76-158
123	1	d	1983	2	0.10	2	2	51	i	1	2320	Jph(d)	nwc83 21-76-158
124	1	d	1983	5	1.04	2	1	51	i	1	2480	Jph(d)	nwc83 21-76-158
125	1	d	1983	4	0.74	2	2	65	p	1	2440	Jph(d)	nwc83 21-76-158
126	2	d	1983	5	1.54	1	1	37	p	5	1820	Jph(d)	nwc83 21-76-159
127	2	d	1983	5	1.58	1	1	58	y	5	2250	Jph(d)	nwc83 21-76-159
128	1	d	1983	4	0.55	1	1	47	y	5	2160	Jph(d)	nwc83 21-76-159
129	1	d	1983	4	0.60	1	2	33	y	5	2140	Jph(d)	nwc83 21-76-159
130	2	d	1983	5	1.30	1	1	55	y	5	1600	Jph(d)	nwc83 21-76-159
131	1	p	1983	3	0.21	8	3	46	y	5	1600	Qls	nwc83 21-76-159
132	1	d	1983	3	0.29	8	2	51	y	5	1450	Qls	nwc83 21-76-159
133	2	d	1983	5	3.36	8	3	34	y	5	1560	Qls	nwc83 21-76-159
134	1	q	1983	5	34.59	1	2	41	p	1	2400	Jph(d)	nwc83 21-77-193
135	1	p	1983	2	0.08	5	3	59	p	5	3640	Jph(d)	nwc83 21-77-196
136	1	p	1983	3	0.20	5	3	59	p	5	3450	Jph(d)	nwc83 21-77-196
137	1	p	1983	3	0.22	7	3	59	p	1	3380	Mzpzms(r)	nwc83 21-77-196
138	1	p	1983	3	0.28	5	3	60	i	1	3160	Mzpzms(r)	nwc83 21-77-196
139	1	p	1983	2	0.10	5	3	48	i	1	3480	Mzpzms(r)	nwc83 21-77-197
140	1	p	1983	4	0.50	5	2	64	i	1	3300	Mzpzms(r)	nwc83 21-77-197
141	1	d	1983	3	0.17	1	4	84	y	5	2360	Mzpzms(r)	nwc83 21-77-198
142	1	p	1983	3	0.25	1	2	84	p	5	2420	Mzpzms(r)	nwc83 21-77-198
143	1	d	1983	3	0.22	1	2	77	y	5	2320	Mzpzms(r)	nwc83 21-77-198
144	1	d	1983	3	0.11	1	2	100	y	1	2000	Mzpzms(r)	nwc83 21-77-198
145	1	d	1983	3	0.24	1	4	76	y	1	1880	Mzpzms(r)	nwc83 21-77-198
146	1	d	1983	3	0.28	1	2	94	y	1	1720	Mzpzms(r)	nwc83 21-77-198

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Landslide size (acres)	Landform	Slp_shp	Gradient	Delivery	Land use	Init_elev	Geologic unit	Photo_number
147	1	d	1983	3	0.14	1	2	58	y	1	1640	Mzpzms(r)	nwc83 21-77-198
148	7	d	1983	5	1.14	4	3	100	y	1	500	Qgo	nwc83 28-78-104
149	1	d	1983	3	0.29	4	2	50	y	1	380	Qgo	nwc83 28-78-105
150	7	d	1983	2	0.10	4	2	61	y	3	380	Qvl(gp)	nwc83 28-78-105
151	7	d	1983	3	0.18	4	3	84	i	3	560	Qgo	nwc83 28-78-107
152	1	p	1983	2	0.06	4	3	60	p	3	500	Qvl(gp)	nwc83 24-79-95
153	1	d	1996	4	0.53	2	2	58	n	1	850	Jph(d)	nw91 23-76-199
154	1	p	1996	3	0.11	5	2	50	n	1	2100	Jph(d)	nw-96-62-74-80
155	1	d	1996	5	1.83	5	2	57	p	1	3280	Mzpzms(r)	nw-96-62-74-80
156	1	d	1996	3	0.14	5	2	60	i	5	3950	Mzpzms(r)	nw-96-62-74-80
157	1	d	1996	3	0.22	5	2	97	i	1	3400	Mzpzms(r)	nw-96-62-74-80
158	1	d	1996	2	0.09	5	4	97	i	1	3280	Mzpzms(r)	nw-96-62-74-80
159	1	d	1996	3	0.14	5	4	64	i	1	3120	Mzpzms(r)	nw-96-62-74-80
160	1	d	1996	2	0.05	5	2	100	i	1	3600	Mzpzms(r)	nw-96-62-74-80
161	1	d	1996	2	0.04	5	2	100	i	1	3400	Mzpzms(r)	nw-96-62-74-80
162	1	d	1996	3	0.22	5	3	56	i	1	3250	Mzpzms(r)	nw-96-62-74-80
163	1	d	1996	2	0.07	5	2	74	i	1	3400	Mzpzms(r)	nw-96-62-74-81
164	1	d	1996	3	0.10	5	2	64	i	1	3140	Mzpzms(r)	nw-96-62-74-81
165	1	d	1996	4	0.74	5	2	54	i	5	3440	Mzpzms(r)	nw-96-62-74-81
166	1	d	1996	2	0.06	2	2	70	i	1	2440	Qls	nw-96-62-74-81
167	2	p	1996	4	0.84	1	1	38	p	5	1560	Jph(d)	nw-96-64-75-175
168	1	d	1996	4	0.42	1	2	51	y	1	1560	Mzpzms(r)	nw-96-62-75-113
169	1	d	1996	4	0.45	1	2	51	y	1	1550	Mzpzms(r)	nw-96-62-75-113
170	1	d	1996	2	0.04	1	2	44	y	1	1200	Qls	nw-96-62-75-119
171	1	d	1996	2	0.10	2	3	31	i	5	1920	Jph(d)	nw-96-64-76-152
172	1	d	1996	3	0.17	4	3	69	y	5	540	Qgo	nw-96-64-77-256
173	1	d	1996	3	0.14	4	2	67	y	3	520	Qgo	nw-96-62-78-220
174	1	d	1996	2	0.09	4	3	45	y	5	540	Qgo	nw-96-62-78-221
175	1	d	1996	3	0.17	4	3	45	y	5	540	Qgo	nw-96-62-78-221
176	1	d	1996	2	0.06	4	4	45	y	5	520	Qgo	nw-96-62-78-221
177	1	d	1996	3	0.20	4	3	45	y	5	520	Qgo	nw-96-62-78-221
178	1	d	1996	3	0.17	4	2	114	y	2	500	Qgo	nw-96-62-78-223
179	1	d	1996	3	0.16	4	4	60	y	1	380	PMDms(c)	nw-96-62-78-226
180	1	d	1996	2	0.07	4	4	60	y	1	380	PMDms(c)	nw-96-62-78-226
181	1	d	1996	2	0.07	4	4	34	i	5	520	Qgo	nw-96-62-78-226
182	1	d	2001	2	0.03	5	3	35	i	5	1350	Jph(d)	nwc-01-41-77-37
183	1	d	2001	3	0.22	1	3	81	i	1	1240	Qgt	nwc-01-41-77-37
184	1	d	2001	4	0.76	2	2	61	i	5	760	pDi(y)	nwc-01-41-77-39
185	1	p	2001	3	0.14	7	4	90	n	5	880	pDi(y)	nwc-01-41-77-39
186	1	p	2001	2	0.10	5	1	150	n	1	840	pDi(y)	nwc-01-41-77-39
187	1	p	2001	3	0.21	5	3	145	n	5	1020	pDi(y)	nwc-01-41-77-39
188	1	p	2001	3	0.26	5	3	107	n	1	940	pDi(y)	nwc-01-41-77-39
189	1	p	2001	4	0.80	5	3	114	n	1	100	pDi(y)	nwc-01-41-77-39
190	1	p	2001	3	0.20	5	2	109	n	1	1020	pDi(y)	nwc-01-41-77-39
191	1	p	2001	5	1.10	2	2	112	n	1	1050	pDi(y)	nwc-01-41-77-39
192	1	q	2001	3	0.14	7	3	43	n	5	640	Qgt	nwc-01-40-75-196
193	1	p	2001	2	0.03	2	2	64	n	2	3500	Jph(d)	nwc-01-40-76-247
194	1	p	2001	2	0.05	2	2	64	n	2	3520	Jph(d)	nwc-01-40-76-247
195	1	p	2001	3	0.15	2	2	80	n	2	3480	Jph(d)	nwc-01-40-76-247
196	1	p	2001	2	0.02	2	2	137	n	5	3740	Jph(d)	nwc-01-40-76-248

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Landslide size (acres)	Landform	Slp_shp	Gradient	Delivery	Land use	Init_elev	Geologic unit	Photo_number
197	1	p	2001	1	0.02	2	2	101	p	2	1420	Mzpzms(r)	nwc-01-40-76-257
198	1	p	2001	2	0.09	7	3	58	n	5	2000	Jph(d)	nwc-01-40-76-257
199	1	p	2001	2	0.07	7	3	72	n	1	1520	Jph(d)	nwc-01-40-76-257
200	1	p	2001	3	0.14	2	2	40	n	5	2000	Jph(d)	nwc-01-40-76-257
201	1	p	2001	3	0.17	2	2	75	n	5	1640	Jph(d)	nwc-01-40-76-257
202	1	p	2001	3	0.16	2	3	75	n	5	1680	Jph(d)	nwc-01-40-76-257
203	1	p	2001	2	0.08	2	2	86	p	2	1580	Mzpzms(r)	nwc-01-40-76-257
204	1	p	2001	3	0.20	5	4	44	p	2	1620	Mzpzms(r)	nwc-01-40-76-257
205	1	p	2001	2	0.10	7	3	65	n	5	3150	Jph(d)	nwc-01-40-76-259
206	1	p	2001	3	0.14	5	4	34	n	5	1400	Jph(d)	nwc-01-40-76-259
207	1	p	2001	3	0.10	5	2	76	y	5	1300	Jph(d)	nwc-01-40-76-259
208	1	p	2001	2	0.03	1	2	98	p	1	1240	Qgt	nwc-01-40-76-259
209	1	p	2001	2	0.07	5	3	54	n	5	1040	pDi(y)	nwc-01-40-76-261
210	1	d	1978	1	3.32	7	4	147	y	5	719	Jsh(s)	nw78-90d-29
211	1	d	1978	1	0.06	1	3	39	y	2	446	Jsh(s)	nw78-90d-29
212	1	d	1978	1	5.22	2	2	60	y	2	2251	Jmt(em)	nw78-96E-12
213	1	d	1978	1	0.09	1	4	60	p	2	2637	Jph(d)	nw78-95E-13
214	1	d	1978	1	0.16	1	2	102	y	2	2753	Jph(d)	nw78-95E-13
215	1	d	1978	1	0.22	1	2	135	p	2	1953	Jph(d)	nw78-95E-13
216	1	d	1978	1	0.19	1	1	67	y	2	2986	Jph(d)	nw78-95E-13
217	1	d	1978	1	0.07	7	4	82	p	2	2627	Jph(d)	nw78-95E-13
218	1	d	1978	1	1.37	7	1	67	p	5	2625	Jmt(em)	nw78-97-11
219	1	d	1978	1	0.21	7	1	49	I	5	2915	Jmt(em)	nw78-97-12
220	1	p	2001	1	0.02	1	3	76	y	3	2243	Jph(d)	nwc01-51-81-207
221	1	d	2001	1	0.18	1	2	86	y	3	2917	Jph(d)	nwc01-51-81-207
222	2	d	2001	1	4.67	7	3	56	y	5	3149	Jsh(s)	nwc01-51-81-207
223	1	d	2001	1	0.33	2	1	68	p	2	2665	Jsh(s)	nwc01-51-81-207
224	2	d	2001	1	1.71	1	2	72	p	2	2241	Jsh(s)	nwc01-51-81-207
225	1	d	1987	1	0.67	8	3	44	p	1	1130	Qls	nw87-24-77-122

Note: Source document for all geologic units is Dragovich and others (2002).

Appendix 8.3 Form A-2 Descriptions of Mass Wasting Map Units

Note: Due to mapping scale, some MWMU polygons include areas that do not meet the criteria of the MWMU descriptions. Conversely, some specific land areas outside the mapped limits of a MWMU's polygons do meet the criteria. In either case, the titles and descriptions of a MWMU constitute the ruling definition, superseding the maps if there is a conflict.

MWMU Number: 1 — Low hazard areas

Description: Gently sloping to flat floodplains and alluvial terraces of the North Fork Stillaguamish, Suiattle, Sauk, and Skagit Rivers (220 to about 600 ft elev.), and low gradient areas of ridge tops and valley sides at intermediate elevations (600 to 2,240 ft elev.).

Materials: Low hazard areas include alluvial deposits of the North Fork Stillaguamish, Suiattle, Sauk and Skagit Rivers, low gradient surfaces of glacial outwash deposits of Vashon age and of lahar (volcanic debris flow) deposits—all composed of unconsolidated silt, sand, cobbles, and boulders, either stratified or massive. Other low hazard areas include local low-gradient bedrock benches or ridgetops composed of Chilliwack Formation, Bell Pass Melange, Yellow Aster Complex intrusive rocks, and Shuksan Green-schist.

Landform: Low-to-moderate gradient valley floors, terraces, bedrock benches, and gently sloping ridge tops.

Slope (Determined via DEM):	Min: flat	Max: 5 percent.
Elevation (Determined via DEM):	Min: 220 ft	Max: 2,240 ft
Total Area:	8,539 acres; 26.4 percent of the total (32,301 acres)	

MW Processes: None observed or predicted.

Total Number of Landslides:	0
Number of Delivering Landslides:	0

Forest Practice Sensitivity: Not applicable because there were no mass wasting features in this area.

Mass Wasting Potential: Low

Delivery Potential: Low

Delivery Criteria Used: Proximity and direction of visible landslide scars in relation to surface water features.

Hazard Potential Rating: Low

Trigger Mechanisms: None

Confidence: High

MWMU Number: 2 — Other upland areas —moderate hazard

Description: Low- to moderate-angle hillslopes, moderate gradient planar valley walls, gently sloping to moderately sloping terraces composed of glacial till, and alluvial fans; all having slope gradients gentler than 60 percent.

Materials: Includes glacial outwash deposits of Vashon age and alluvial fans that consist of silt, sand, cobbles, and boulders; and foliated metamorphic rocks of the Darrington Phyllite, Slate of Rinker Ridge, Shuksan Greenschist, and Chilliwack Group metasediments.

Landform: Low- to moderate- gradient planar valley sidewalls and alluvial fans.

Slope (Determined via DEM):	Min: 5 percent	Max: 60 percent.
Elevation (Determined via DEM):	Min: 280 ft	Max: 3,800 ft.
Total Area:	17139 acres; 53.1 percent of the total (32301 acres)	

MW Processes: Predominantly shallow rapid landslides (46/54) and debris flows (8/54).

Total Number of Landslides:	54
Number of Delivering Landslides:	33 (49 percent of the total for this MWMU)

Forest Practice Sensitivity: Moderate to high sensitivity for harvest (about 28 landslides in this MWMU were related to harvesting, 22 to roads, and 1 to yarding); moderate to high sensitivity for road construction, especially where sidecast or end-hauled material is placed above convergent topography and where adequate road drainage is not designed or maintained.

Mass Wasting Potential: Moderate

Delivery Potential: Moderate

Delivery Criteria Used: Proximity and orientation of convergent topography in relation to public resources including surface water features.

Hazard Potential Rating: Moderate

Trigger Mechanisms: High intensity rainfall, thick soil accumulations, loss of root strength owing to clear-cutting, which results in a reduction of the effective soil cohesion, and road construction.

Confidence: High

MWMU Number: 3 — Moderately steep to steep (35–115 percent) slopes of glacial terrace deposits — high hazard

Description: Moderate to steep marginal scarps and incised slopes of prominent glacial terraces (tread elevations of about 440 and 760 feet, flat to gently sloping surfaces) that skirt the bases of hillsides along the North Fork Stillaguamish, Sauk, Suiattle, and Skagit Rivers (see Map A-2). Outwash material on the slopes above the higher terrace has gradients locally exceeding 70 percent but does not form terraces.

Materials: Predominantly consists of stratified sand and gravel and silty sand to silty clay; stratified and massive. Includes minor poorly sorted deposits of volcanic debris. Mostly composed of outwash deposits of Vashon age (Tabor and others, 2002).

Landform: Consists of terraces inset against the valley wall along the North Fork Stillaguamish, Sauk, Suiattle, and Skagit Rivers as well as deposits plastered on the valley walls. The margins of the terraces have been modified by local incision.

Slope (determined via DEM):	Min: 35 percent	Max: 115 percent
Elevation (determined via DEM):	Min: 240 ft	Max: 1,100 ft
Total Area (determined via DEM):	813 acres; 2.5 percent of the total (32,301 acres)	

MW Processes: Inferred shallow rapid failures (Maps A-1 and A-2). Fourteen shallow landslides initiating from the slopes of glacial outwash terraces were recognized during this assessment. Lingley (2004) identified shallow landslides and debris flows initiating on a similar terrace landform in the Finney Miller WAU to the north.

Total Number of Landslides:	16
Number of Delivering Landslides:	12

Forest Practice Sensitivity: High sensitivity to roads and clearcuts. Six of the 16 inventoried landslides in glacial outwash deposits were associated with roads, four with clearcuts, and the remainder with sub-mature (15-50 years old) or young (5 to 15 years old) timber stands.

Mass Wasting Potential: Moderate to high

Delivery Potential: High. At least 75 percent (12 of 16) of inventoried landslides delivered to stream channels. The sediment delivery potential is highest where streams or standing water exist at the base of the terrace scarp landforms, and decreases with increasing distance between the terrace scarp base and surficial waters.

Delivery Criteria Used: Proximity and orientation of failure scars toward public resources including stream channels; historical delivery observed.

Hazard Potential Rating: High. About 70 percent of MWMU3 is adjacent to surface waters.

Trigger Mechanisms: High sensitivity to roads and clear cutting. Clear cutting on terrace margins reduces the effective soil cohesion contributed by tree-root strength on hillslopes in heads of convergent channel environments. The likely superposition of permeable glacial sand over less permeable silty-clay in similar units has encouraged saturation and build-up of pore-water pressures (via groundwater recharge of glacial materials) that contribute to slope failures.

Confidence: High. These terrace deposits are probably genetically related to terraces in the Stillaguamish River valley and Finney Creek that have been associated with shallow rapid failures and with several large, active deep-seated landslides (Lingley, 2004).

MWMU Number: 4 — Inner gorges, steep stream-adjacent slopes, convergent headwalls, and bedrock hollows, having slopes steeper than 50 percent — high hazard

Description: Generally short and moderately to very steep inner gorges, steep planar to concave stream-adjacent slopes, local steep areas of alluvial fans, as well as the inner gorges of the Suiattle River and the North Fork Stillaguamish River. The latter inner gorge extends north for about 2.8 mi (4.5 km) upstream from where the river debouches from the mountains southwest of North Mountain (see Map A-2). This MWMU is generally underlain by thin colluvial soils and metamorphic bedrock except for the alluvial fan deposits, which are chiefly fragmental in nature. Note, as explained above in section 3.0 (Summary of Methods), the DEM-delineated slopes mapped here likely do not represent all the areas of critical slope angle defined by this map unit.

Materials: Inner gorges and bedrock hollows generally have soil derived from bedrock, including strongly foliated (thinly laminated) Darrington Phyllite, Slate of Rinker Ridge, Shuksan Greenschist, and Chilliwack Group metasediments, as well as minor glacial outwash terrace deposits and local alluvial fan deposits (Tabor and others, 2002; Dragovich and others, 2002; see also Figs. 2 and 3).

Landform: Generally planar to concave hillslopes and stream-adjacent inner gorge slopes formed in alluvial fan, glacial, and bedrock units. The uppermost portion of mapped inner gorges locally transition into bedrock hollows at channel heads.

Slope (determined via DEM):	Min: 50 percent	Max: 164 percent
Elevation (determined via DEM):	Min: 360 ft	Max: 3,840 ft
Total Area (determined via DEM):	1,328 acres; 4.1 percent of the total (32,301 acres)	

MW Processes: Shallow-rapid failures dominated (85 of 91). Some merged with debris flows (5 of 91) —most probably during intense precipitation events.

Total Number of Landslides:	91
Number of Delivering Landslides:	About 49 (54 percent of the total for this MWMU)

Forest Practice Sensitivity: High sensitivity to clear-cutting. The source failures of the inventoried landslides were situated within inner gorges that had been recently clear-cut.

Mass Wasting Potential: High

Delivery Potential: High where slopes are oriented so that moving material could enter directly into streams or affect rule-identified infrastructure; most of the areas in this MWMU are directly upslope of and tributary to streams or rivers.

Delivery Criteria Used: Proximity and direction of failure scars toward stream channels.

Hazard Potential Rating: High

Trigger Mechanisms: Clear-cutting of steep slopes (> 50 percent) reduces the effective soil cohesion contributed by tree-root strength on hillslopes in convergent channel head environments. The loss of effective soil cohesion increases the likelihood of shallow-rapid hillslope failure.

Confidence: High

MWMU Number: 5 — Inner gorges, steep stream-adjacent slopes, convergent headwalls, and bedrock hollows, with slopes steeper than 45 percent, situated on deep-seated landslide bodies or headwalls or other unstable materials — very high hazard

Description: Generally short and moderately to very steep inner gorges and steep planar to concave stream-adjacent slopes (see Map A-2). This MWMU is underlain by deep-seated landslides or deep-seated landslide complexes, or by thin colluvial soils and metamorphic bedrock. Note, as explained above in section 3.0 (Summary of Methods), the DEM-delineated slopes mapped here likely do not represent all the areas of critical slope angle defined by this map unit.

Materials: Inner gorges and bedrock hollows generally have soil parent material derived from older landslide debris and bedrock, including strongly foliated (thinly laminated) Darrington Phyllite, Slate of Rinker Ridge, Shuksan Greenschist, and Chilliwack Group metasediments, as well as minor glacial outwash terrace deposits and local alluvial fan deposits (Tabor and others, 2002; Dragovich and others, 2002; see also Figs. 2 and 3). Many of these landforms exhibit not only a rich history of past slope failures, as demonstrated in this investigation, but also geological characteristics that demonstrate susceptibility to future mass wasting. These characteristics include irregular terrain, saturated soils, ground cracks, tilted and misshapen conifer trees, flow levees, and other evidence of recent ground movements.

Landform: Generally planar to concave hillslopes and stream-adjacent inner gorge slopes formed on landslide deposits or on steep headwalls or bedrock hollows in thin colluvial soils and metamorphic bedrock that are situated above deep-seated landslides. The uppermost portion of mapped inner gorges locally transition into bedrock hollows at channel heads.

Slope (determined via DEM):	Min: 45 percent	Max: 200 percent
Elevation (determined via DEM):	Min: 360 ft	Max: 3,800 ft
Total Area (determined via DEM):	374 acres; 1.2 percent of the total (32,301 acres)	

MW Processes: Shallow-rapid failures commonly merged and flowed to the valley bottom as debris flows—most probably during intense precipitation events.

Total Number of Landslides:	27 (of the 45 total on unit Qls)
Number of Delivering Landslides:	About 25 (>90 percent), from review of air-photos

Forest Practice Sensitivity: High sensitivity to clear cutting. The source failures of the inventoried landslides were situated within inner gorges that had been recently clear-cut.

Mass Wasting Potential: High

Delivery Potential: High. Nearly all of the areas in this MWMU are upslope of and tributary to streams or rivers, and all are developed on a landform that shows profound evidence of instability.

Delivery Criteria Used: Proximity and direction of failure scars toward stream channels.

Hazard Potential Rating: Very high

Trigger Mechanisms: Road building and operation, especially as these apply to water management, may initiate slide movement. Clear-cutting of steep slopes reduces the effective soil cohesion contributed by tree-root strength on hillslopes in convergent channel head environments. The loss of effective soil cohesion increases the likelihood of shallow-rapid hillslope failure and resulting debris-flow deposition of water, wood and sediment from steep stream adjacent slopes/inner gorges into the headwater reaches of 1st, 2nd, and 3rd order streams.

Confidence: High

MWMU Number: 6 — Areas of deep-seated landslides and their headscarps — variable hazard

Description: Bodies of deep-seated landslides and landslide complexes (translational, rotational, earthflow, sackung), characterized by disrupted terrain; plus their headscarp slopes; other than areas included in other MWMUs. Note, not all deep-seated landslides may be delineated on Map A-1.

Materials: Locally derived bedrock and unconsolidated units; slightly to intensely broken, deformed, mixed, and weathered into downslope-moving colluvium.

Landform: Hummocky or irregular ground surfaces, commonly with deranged drainage patterns, some containing internally drained basins or sag ponds. Arcuate headscarps commonly present. Deranged vegetation (tilted and pistol-butted trees) can provide signs of past slope movement.

Slope (determined via DEM):	Min: 15 percent	Max: 200 percent
Elevation:	Min: 460 ft	Max: 3,340 ft
Total Area:	4,121 acres 12.8 percent of the total (32,301 acres)	

MW Processes: Large deep-seated landslides and earthflow complexes and their headscarps host abundant surficial shallow-rapid landslides and debris flows, but are also capable of large-scale movement.

Total Number of Landslides:	18 (of the 45 total associated with unit Qls)
Number of Delivering Landslides:	About 5

Forest Practice Sensitivity: Variable. Large portions of these deep-seated landslides and landslide complexes likely have minimal response to management activities; however, there may be smaller areas, especially along inner gorges and stream-adjacent slopes transecting or adjacent to the slide masses, that are particularly susceptible to mass wasting.

Mass Wasting Potential: Variable

Delivery Potential: High where slopes are oriented so that moving material could enter directly into streams or affect rule-identified infrastructure. Six of the seven inventoried deep-seated landslides abut one or more streams (streams along marginal edges of landslide deposits) and/or have streams that cross landslide deposits. It is uncertain if these deep-seated landslides are presently introducing sediment into streams, but certainly the potential exists for sediment delivery during any future reactivation.

Delivery Criteria Used: Proximity to flowing water.

Hazard Potential Rating: Variable. Site-specific geotechnical review should be required due to the landform complexity and potential for sediment delivery via reactivation of these features.

Trigger Mechanisms: Natural climatic variations and changes in slope hydrology, near-source earthquakes, and human-induced modifications of natural slopes and hydrology.

Confidence: High as pertains to location; low as pertains to behavior of landslides related to forest practices activities.

Appendix 8.4 Maps A-1, A-2 *in separate files*

Appendix 8.5 Addendum to assessment after revision of watershed boundaries

The watershed boundaries for the Rinker, Sauk Prairie, Upper NF Stillaguamish, and adjacent WAUs were revised in August 2004, and most of them were renamed, after the initial submittal of this report and landslide inventory. Table 3 shows the revised WAU names and major changes, and Figure 19 shows the areas that were newly added to the previous WAUs and subsequently evaluated. The smallest adjustment extended the Upper North Stillaguamish boundary slightly to the southwest. The northern two-thirds of the Rinker WAU was included in the new Lower Sauk WAU, along with the old Hilt and westernmost Tenas WAUs. The new Middle Sauk WAU comprises the southern parts of the old Rinker and Sauk Prairie basins, along with slopes and valley flats near Darrington, which had been part of the old Clear Creek and Dan Creek WAUs. The northern part of the Sauk Prairie WAU is now in the Lower Suiattle WAU, along with most of the old Tenas and the north end of the old Lime Creek WAUs.

Some of the new work performed late in this project built on the mapping of Wegmann (2004) in the Clear, Dan and Lime watersheds; landform mapping that is more conservative (i.e., higher hazard ratings) will be adopted in these areas. New work on the north valley wall and up the Suiattle River has essentially completed mapping on the non-federal lands in this WAU.

Table 3. Old and revised WAU names for evaluation areas

Revised WAU name (number)	WAUs evaluated in first phase: old name (number)	Additions/changes: old name (number)
Upper N Fk Stillaguamish (050202)	Upper NF Stillaguamish (050202)	small expansion to SW
Lower Sauk (040322)	N end of Rinker (040321)	Hilt (040322) W end of Tenas (040319)
Middle Sauk (040320)	S half of Sauk Prairie (040320) S end of Rinker (040321)	NW corner of Dan Ck (040317) N end of Clear Ck (040316)
Lower Suiattle (040319)	N half of Sauk Prairie (040320)	N end of Lime Ck (040318) Most of Tenas (040319)

See Figure 19.

The topographic and geomorphic characteristics of the newly added areas are not significantly different from those already evaluated in this report. Likewise, the geologic units in the areas newly added to the previous WAUs are the same as those noted above, with the exception of the addition of one area of unit Jmt(em), which consists of metasedimentary and metavolcanic rocks associated with the Shuksan Schist. Three of the 16 newly mapped landslides originated in this unit. The 16 additional landslides were added to the landslide inventory (Form A-1), but these data were not included in the statistical evaluation owing to the abovementioned landscape similarities; and because, although unit Jmt(em) apparently has higher mass wasting potential than the other Shuksan units, it makes up a relatively small portion of the newly evaluated area (along the northeast valley wall of the Suiattle River). Approximately 400 additional MWMU areas were delineated in the newly added watershed areas using the above MWMU classification scheme (A-2). Most of the area underlain by geologic unit Jmt(em) has been included in MWMU 4.

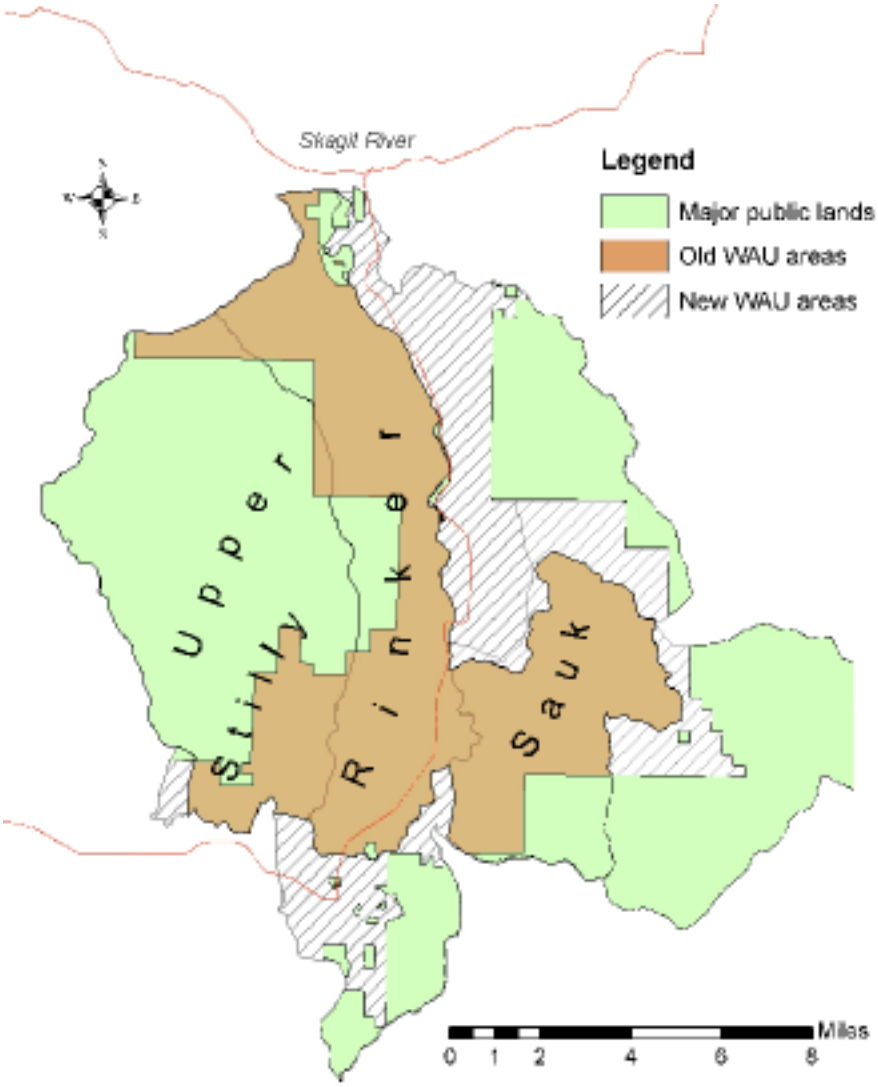

Figure 19. Location map showing areas that were evaluated (hachured) after revision of the Rinker, Sauk, and Upper Stillaguamish watershed boundaries in August 2004.