WASHINGTON STATE DEPARTMENT OF
Natural Resources

Landslide Hazard Zonation Project

Mass Wasting Assessment

Lower Finney and Miller Creek Watersheds
Skagit County, Washington

Prepared by:

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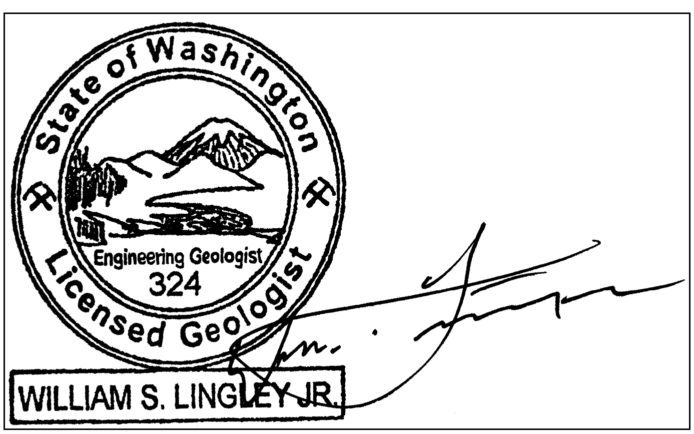

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1.0 Project Introduction

The purpose of this mass wasting assessment is to identify areas within the non-federal part of the Finney Creek and Miller Creek watershed administrative units (here called the Lower Finney–Miller WAUs[1]) that have moderate or high risk of landslides due to the effects of forest management activities (logging, roading, yarding, etc.). The Washington Forest Practices Board's *Standard Methodology for Conducting Watershed Analysis* (Version 4.0, 1997), adopted in part for use here, requires several critical questions to be answered and mass wasting map units (MWMU) to be defined, both of which help assess the risk that landslide debris could be delivered to public resources (surface waters, public roads, and other public infrastructure). This is a reconnaissance study, and its level of resolution must be kept in mind when using the document. For example, analysis of individual landslides or slopes is not an appropriate use of this report. Moreover, the report was prepared according to the strict schedule necessary to produce a statewide screening tool during a short period. For this reason, much of the information presented here has not been checked. Undoubtedly, some landslides have been accidentally omitted, some benign features may be improperly mapped as landslides, and some data have been miscoded.

This assessment was conducted using aerial photographs, various maps, and field observations. The specific objectives of the data collection were to establish:

1. A generalized characterization of mass wasting processes active in the basin;
2. General patterns of mass wasting impacts to public resources;
3. Portions of the landscape that share similar physical characteristics relating to mass-movement behavior, which are known as mass wasting map units;
4. The relative overall hazard potential for each MWMU, composed of two components, the frequency of failure and the area delivering sediment, per unit time.

This information was collected and compiled in a manner designed to respond to the critical questions or to suggest areas where more detailed information is necessary.

1.1 Mass Wasting Terminology

Terminology used to describe mass wasting processes in this assessment follows the classification system established by the Washington Forest Practices Board (1997) as modified by Boyd and Vaugeois (2003). This system groups slope movement into nine types (shallow-rapid, debris flow, debris avalanche, undifferentiated deep-seated, small sporadic deep-seated, large persistent deep-seated, earth flow, rock topple/-fall, and snow avalanche). Analysis is aided by designating landforms, slope shapes, land uses, and other observations associated with each group of landslides. (See Form A-1.) For the purposes of this study, most landslides that fail below rooting depth are categorized as deep-seated. This characterization is consistent with the Forest Practices Rules (WAC 222-16-050). However, a few deep-seated landslides that moved rapidly and clearly entered waterways are included in assessing the patterns of sediment delivery.

2.0 Physical Setting Pertinent to Mass-Wasting Interpretations

The Finney and Miller Creek WAUs cover 70 mi^2 in the west-central part of the North Cascades physiographic province, south of the town of Concrete in Skagit County. Figure 1 shows topography and some geographic features discussed in the text. Finney Creek, the largest stream, drains north-northeast in the

[1] WAU boundaries and names were revised after this report was prepared, particularly on the north edge of the project area. Miller Creek WAU, comprising the basins of several small streams flowing to the Skagit downstream of the Sauk, has been merged into the Corkindale WAU (#040531; see Lingley, 2004a) to the east. Many small streams draining north to the Skagit that were formerly part of the Finney WAU (#040532) are now included in the Grandy WAU (#040533).

mountainous southern part of the watershed (as do several of its larger tributaries), but turns abruptly westward where it encounters a prominent two-step terrace. This terrace has tread elevations between 600 and 1,100 ft and is composed of complexly layered sediments. From the terrace, Miller Creek, Aldon Creek, and many unnamed small streams flow generally northeastward to the Skagit River.

The study area includes the drainage areas of Finney and Miller Creeks, exclusive of federal ownership in the southern uplands, and the small basins north of the Finney–Skagit divide. About 40% of the land in the basins is managed by the U.S. Forest Service and not included in this study. The remaining ~33 mi^2 of fee acreage was analyzed in this project. Much of the area has been intensely managed for forest products, but some stands of dense second-growth conifers are present on fee and U.S.F.S. lands.

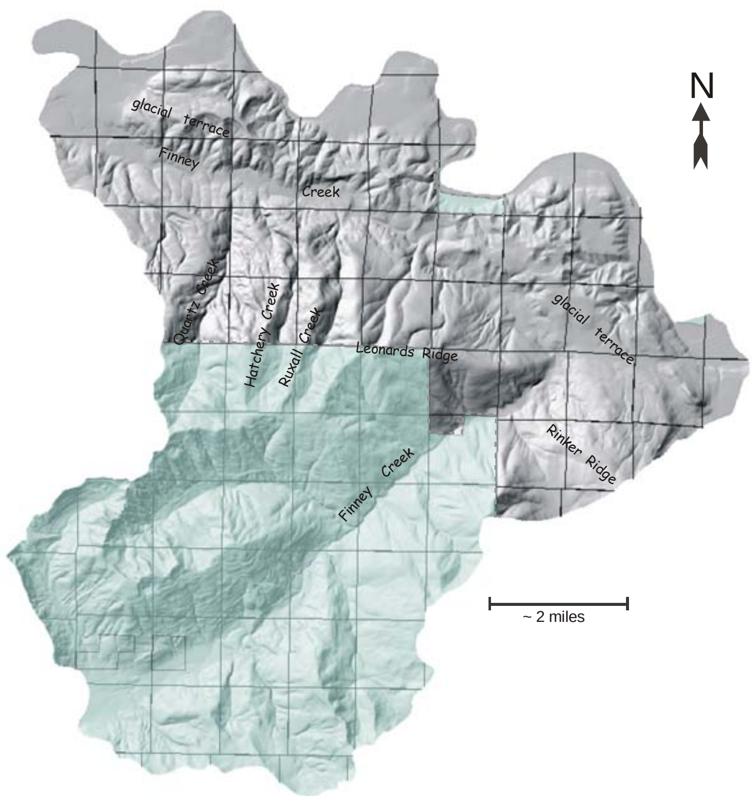

Figure 1. Topographic model for the Finney Creek and Miller Creek watersheds, showing some key geographic features. Mt. Baker–Snoqualmie National Forest lands (shown with the transparent mask) are not included in this study; see Parks (1992) for a discussion of slope stability in the main USFS block.

2.1 Topography

The Lower Finney–Miller study area occupies 20,900 acres of the 44,665-acre combined Finney and Miller Creek WAUs. The lowest elevations rise from about 122 to 200 ft above mean sea level along the banks of the Skagit River, between river miles 47.5 and 65. Within the project area, elevations range up to 3,760 ft and 3,880 ft on the summits of Rinker and Leonards Ridges, respectively; the highest points in the entire Finney Creek watershed are above 5000 ft around Finney Peak and Gee Point.[2]

[2] Based on U.S. Geological Survey topographic maps for the Finney Peak (1966), Gee Point (1989), Grandy Lake (1989), and Lake Shannon (1989) quadrangles.

The study area can be divided into five main physiographic elements: 1) planar bedrock and till slopes extending from the crests of Leonards and Rinker Ridges to Finney Creek; 2) complexly dissected gorge systems of Ruxall, Hatchery, and Quartz Creeks and other large tributaries of Finney Creek; 3) the lower Finney Creek floodplain developed along its northwest-trending reaches; 4) the glacial terraces, comprising a step at about 660 ft elevation and a second, more continuous step between 900 and 1,100 ft; and 5) the Skagit River floodplain. Slope stability in the Lower Finney–Miller watersheds is best described in terms of two broad units, the bedrock-dominated physiographic elements and the glacial-terrace physiographic elements.

The northeast-trending section of Finney Creek is characterized by a trellis drainage pattern. That is, tributaries enter Finney Creek at near 90° angles owing to the intersection of northwest-trending layering in the bedrock with the main-stem channel and other northeast-trending features. A trellis pattern is also present on the northeast faces of Leonards and Rinker Ridges. Farther west, the drainages of Ruxall, Hatchery, and Quartz Creeks are characterized by dendritic (branching) patterns and by numerous knife-edge ridges separating linear, northwest-trending sub-gorges or randomly oriented sub-gorges, both of which show evidence of rapid headward erosion. Faceted spurs[3] characterize the upper (southern) part of the Finney Creek drainage. Streams on the glacial terrace are characterized by convergent headwall basins, which gather water from first-order channels to form small second-order tributaries of Finney Creek and the Skagit River. Finney Creek and the Skagit River have moderate sinuosity and relatively narrow floodplains, which are restricted by the glacial terraces and adjacent mountainous terrain.

2.2 Geology

Bedrock

Thorough discussions of the general bedrock geology in the vicinity of the study area are presented in Tabor and others (1994, 2002) and Dragovich and others (2002); the geologic map shown in Figure 2 was taken from these sources. Bedrock in the Lower Finney–Miller Creeks area is chiefly composed of thickly layered, gray meta-sandstone and thinly layered black phyllite[4]. Both are part of the Slate of Rinker Ridge (Tabor and others, 2002), probably a sandy variation of the Darrington Phyllite, a bedrock unit that crops out in many parts of the western North Cascade Range. The black phyllite within the Slate of Rinker Ridge is essentially identical to the Darrington Phyllite (and is equally unstable, as described below). The Slate of Rinker Ridge is 180 to 144 million years old[5] and in contact with outcrops of Darrington Phyllite in the southwestern part of the study area. Phyllite in both geologic units readily weathers to thick soils whereas the meta-sandstone is resistant to erosion. Small exposures of other metamorphic rocks are also present: the Chilliwack Group, which crops out in the eastern part of the study area, and the Shuksan Greenschist, which crops out on the eastern end of Rinker Ridge. The Chilliwack Group consists of relatively weak meta-sedimentary and meta-volcanic rocks (Lingley, 2004a), whereas the Shuksan Greenschist is welded into a competent crystalline rock (Tabor and others, 1994, 2002).

Unconsolidated Sediments

Heller (1978, 1979, 1981) and Lingley (2004a) describe the geology of the glacial terraces. Soils within the study area are described in Parks (1992).

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[3] Facets are ridges that have been cut off by faults or alpine glaciers, forming planar slopes that are triangular in map view and parallel the trend of the valley.

[4] Phyllite is metamorphic rock composed of altered clay minerals, similar to slate in appearance but shinier and more thoroughly layered.

[5] Tabor and others (2002) assign unit ages on the basis of the most recent metamorphic event that affected the unit, whereas Dragovich and others (2002) assign ages on the basis of the original, unmetamorphosed rock, hence a discrepancy between geologic ages given on these maps. Both are correct.

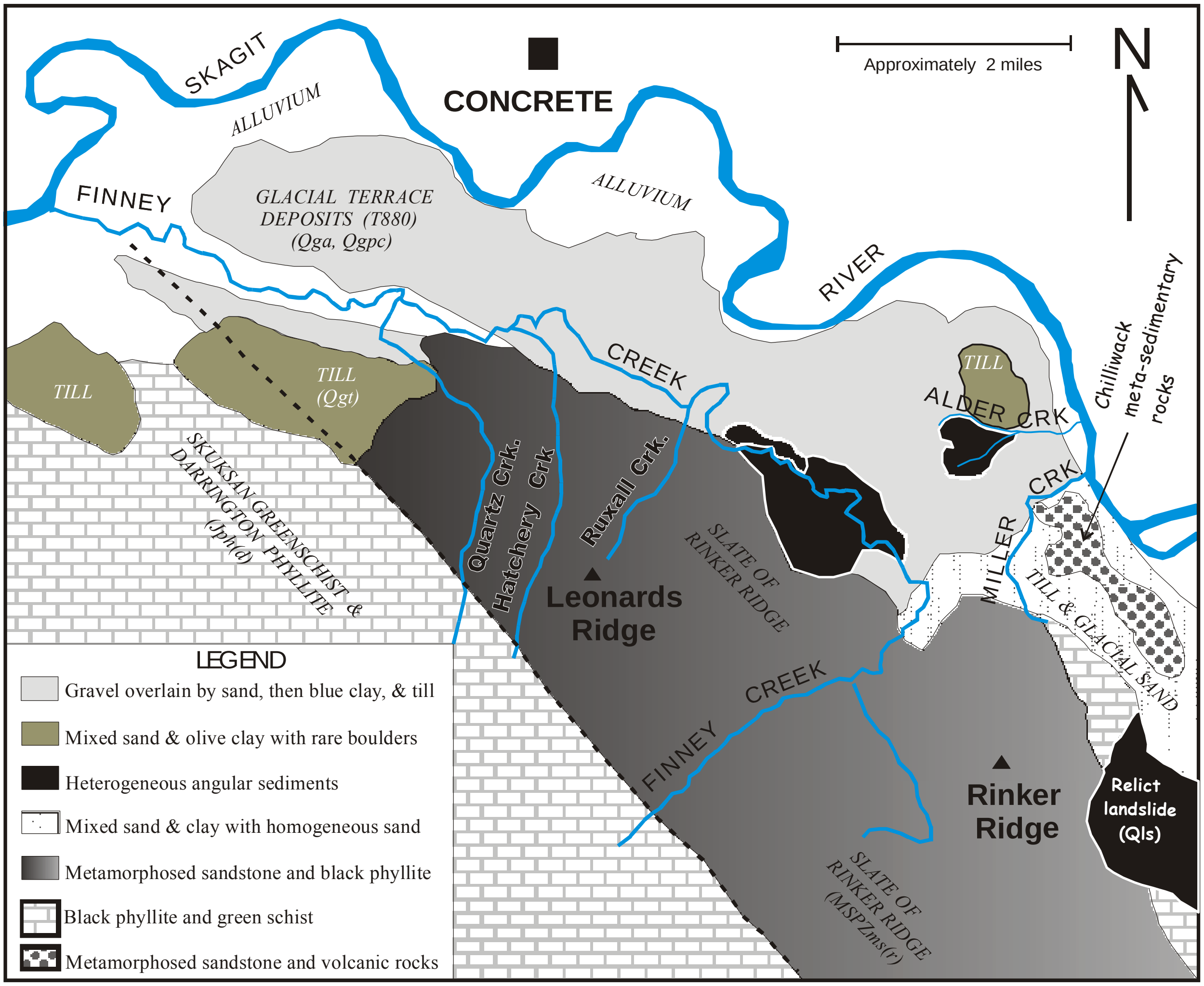

Figure 2. Simplified geologic map of the Lower Finney–Miller study area and adjacent lands (modified from Tabor and others, 1994, 2002). The dashed line is a major fault; two other large faults with the same orientation are present in the map area, but not shown for simplicity. Geologic unit codes shown in parentheses are after Dragovich and others (2002).

Mapped surficial units consist of sediments deposited by continental glaciers[6] and alluvium deposited by streams. Continental ice covered the entire study area during the last advance of the Cordilleran ice sheet, as evidenced by blankets of till at the highest elevations. Till in this area is an olive-brown random mixture of clay, sand, and gravel together with a few boulders, deposited directly by glacial ice.

The glacial terraces consist of a highly dissected terrain with many local flat summits and benches at about 900 ft elevation, covering most of the northern study area. The terrace area also includes a flat bench with an upper elevation of 660 ft, which is located north of Aldon Creek, and three higher summits (~1,100 ft) which may be cored with bedrock. The upper terrace is paired with a dissected terrace north of the Skagit River, near the mouth of Jackman Creek (Heller, 1978; Lingley, 2004a). In the study area, the terraces are mostly composed of layers of flat-lying sand, gravel, cobbles, and blue-gray silty clay. However, there is considerable lateral variation in sediment types. Age dates from similar terraces in the

[6] Sediments deposited by alpine glaciers are also likely present in the study area, but have not been mapped.

South Fork Stillaguamish River valley suggest that these sediments were deposits during the period shortly before the onset of the most recent glaciation (~35,000 yr before present) until the end of the ice age (~10,000 yr; see Dragovich and others, 2003). The clay, which is commonly exposed in the upper third of the terrace, was deposited in a pro-glacial lake(s). Interbeds of till are also mapped near the top of the terrace (Heller, 1978). South of Finney Creek, this till extends up-slope past the highest parts of the terrace system where it is exposed as a veneer of clay-rich olive gray sediment on top of bedrock.

Large debris fans have been built out at the mouths of Quartz Creek, Ruxall Creek, and other large tributaries of Finney Creek. These accumulations of gravel and boulders are indicative of rapid erosion along the upper parts of these drainages and rapid sedimentation in the debris fans. Field observation suggests that much of the sediment transport from the upper drainages to the fans resulted from debris flows, which periodically rerouted the lower parts of the tributaries.

Structures

The bedrock units are cut by three large-scale northwest-trending faults (Tabor and others, 2002). These large faults are mimicked by pervasive micro-faults known as cleavage, which also trend northwest and form scaly layering in most of the bedrock. Layering in the meta-sandstone and phyllite is generally vertical and trends northwest parallel to the large-scale faults and cleavage. Where phyllite-bearing parts of the Slate of Rinker Ridge are interlayered with more resistant meta-sandstone beds, the landscape is characterized by many small northwest-trending hollows and gorges separated by northwest-trending ridges.

The linear and faceted aspect of the northeast-trending reaches of upper Finney, Alder, and Pressentin Creeks (the latter two located adjacent to the study area) and the trellis drainage patterns suggest that the orientation of these valleys are controlled by unmapped northeast-trending, vertical faults.

2.3 Hydrology

Precipitation within the basin is high, ranging from 50–80 in/yr in lower elevation areas of the western study area to 80–100 in/yr on Rinker Ridge (WDNR, 2003; Oregon Climate Service[7]). This is substantially drier than the north side of the Skagit Valley because of a rain shadow created by the high hills southwest of the study area. Most of the annual rainfall occurs between September and June. During the winter months, elevations between 1,800 and 3,200 ft are susceptible to rain-on-snow events, which can trigger widespread mass wasting along the Cascade foothills.

Precipitation intensity and duration in the Skagit Valley are important factors that likely contribute to initiation of mass wasting (Heller, 1981; Montgomery and Dietrich, 1994). Heavier 24-hr rainfall intensities at Concrete are about 2 in/hr (Parks, 1992). Storms that produced peak flows greater than 10-yr recurrence interval[8] in the Skagit River at Concrete occurred in 1932 (twice), 1935, 1949, 1951, 1962, 1975, 1979, 1980, 1990, 1995, and 2003 (USGS, 2007).

Groundwater hydrology in the upper elevations of the watershed consists primarily of movement through forest duff or across the surface because the substrates are dominantly poorly permeable till and bedrock. Highly permeable glacial sand overlying poorly permeable till and glacial lacustrine clays probably creates active groundwater recharge for deep-seated landslides along the glacial terrace margins.

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[7] Oregon Climate Service, PRISM Group annual precipitation maps for 1971–2000; see map function at http://mistral.oce.orst.edu/www/mapserv/.

[8] The peak flow of 166,000 cfs on October 21, 2003 was the highest since the Skagit River dams were built. Recurrence intervals are calculated for regulated flows since the 1920s; earlier high flows were estimated at >200,000 cfs.

2.4 Summary of Previous Mass Wasting Investigations

Landslides within the Finney and Miller Creek WAUs have been mapped at two different scales, by four sets of investigators. Tabor and others (2002) identified two large landslides in the bedrock physiographic element and one large mass-wasting area forming the basin of Aldon Creek on the glacial terrace. Heller (1978, 1979, 1981) mapped numerous landslides on the glacial terraces. He concluded that groundwater perching at poorly permeable barriers, steep slopes, and deforestation are the most common site conditions contributing to slope failure in his study area, which also included lands farther west. Parks (1992) described some attributes of 374 landslides in the greater Finney Creek watershed and demonstrated relations among slope failure and forest management activities. In a sediment-budget study of ten Skagit sub-basins, Paulson (1997) mapped 566 landslides in the Finney Creek drainage, calculated a failure rate of about 0.1/km^2/yr (0.3/mi^2/yr) over a 33-yr photo record, and found that Finney had the second highest rate of movement and sediment delivery among the basins she surveyed.

3.0 Summary of Methods

This assessment generally follows the Level II procedures for the mass wasting module presented in the *Standard Methods for Conducting Watershed Analysis* (Version 4.0; Washington Forest Practices Board, 1997). However, the data-gathering period is shorter than many of the watershed analyses, and the synthesis and prescription phases have been omitted.

Five sets of aerial photographs acquired between 1965 and 2001 were viewed using a mirror stereoscope with 3x magnification (Table 1). Unfortunately, many key images were missing from DNR's collection in Olympia and could not be viewed. In addition, 1998 orthophoto coverage was used as a layer during GIS analysis and mapping. Note that many features identified from the orthophotos (designated NWH-98 in Appendix A) are actually relict slides and probably considerably older than the 1998 acquisition date.

Table 1. Photographic surveys used in this project.

Year	Scale	Image	Flight Number	Ref/Ownership	Comment
1965	1:62,500	black & white	WFPA65–38,39	DNR	high altitude
1978	1:12,000	black & white	NW78–81 to 88	DNR	many missing photos
1987	1:8,000	black & white	NW87–24 to 39	DNR	14 missing photos
1991	1:8,000	black & white	NW91–20 to 32	DNR	22 missing photos
1998	1:12,000	orthophotos	NWH–98	DNR	complete coverage
2001	1:8,000	color	NWC01–36, 43	DNR	eastern area missing

Nine 'questionable' to 'definite'[9] landslides were located during a reconnaissance field investigation of part of the area on February 25 and 26, 2004. Twenty-seven additional questionable to definite slides were identified during field work in April 2004.

Mapping was accomplished by digitizing the landslides on the Department of Natural Resources digital raster graphic ("drg75") topographic contours in ArcGIS as a shapefile. Many landslides, especially

[9] *Questionable* landslides include those that cannot be mapped accurately, or that have a limited number of observed landslide characteristics; e.g., an area with a distinct arcuate headscarp but no obvious toe, hummocky ground, or deranged drainage might be mapped as a questionable landslide. *Definite* landslides include those that have been field checked, and those that have multiple landslide characteristics observable on air-photos or other data.

relict[10] features, were mapped on orthophotos in ArcGIS and shifted to fit the drg75 contours. The maximum resolution of these techniques is about 10 m. A slope/convergence map (SLPSTAB; Vaugeois, 2000) and an ArcGIS slope-gradient (in percent) map derived from a USGS 10-m digital elevation model (DEM) covering the study area aided in predicting areas of potential shallow-rapid slope failure and in delineating mass wasting map units (MWMUs).

The resulting landslide coverage is displayed as Map A-1; pertinent attributes of the landslides are recorded on data sheets, summarized on Forms A-1 (Appendix A) and A-3 (Appendix C). These include: 1) the type of mass wasting process; 2) the level of certainty of the observation; 3) whether the mass wasting feature delivered sediment to surface waters or other public resources; 4) the associated land use; 5) the slope form (convergent, divergent, planar); 6) the photo-year in which the failure was initially recognizable; 7) the gradient or steepest slope increment within each landslide, and the gradient of the slope at the toe of deep-seated landslides; 8) the highest elevation on each landslide; and 9) the geologic unit in which the failure occurred. For some slides, an additional landform is designated to provide a more complete description. The movement process was recorded only where it could be rapidly determined, but most failures are lumped in "shallow rapid–undifferentiated" or "deep-seated–undifferentiated" categories.

Maximum slope gradients were determined by exploring the DEM-derived slope pixels within each landslide polygon on the Landslide shapefile. Note that the steepest slope increment corresponds to the "slope at failure" only in medium to large translational landslides. (See *angle of slide* in Jackson, 1997). The slope angle cannot be reliably determined for small or narrow landslides where accuracy is limited by the 10-m resolution of the DEM. Due to averaging, slope angles derived from DEMs are generally gentler than those measured in the field, but are less subjective than slopes casually derived from aerial photography. Conversely, the steepest slopes on rotational failures are on the failure plane and therefore steeper than the ground slope just before landslide initiation. As a result, the method of slope gradient estimation presented here is an approximation.

Once the locations of mass-wasting features were mapped and evaluated, areas of similar mass-wasting potential were grouped into MWMUs, generally following the assessment procedures of watershed analysis. These are shown on Map A-2, and described in section 5 and Forms A-2 (Appendix B).

4.0 Summary of Analysis and Results

During this review, a representative sample of 361 questionable to definite/field-confirmed landslides was inventoried using air-photos obtained between 1965 and 2001 (Table 2; see Forms A-1 and A-3). Figures 3 through 19 characterize these features. Compared to other watersheds of similar size in Washington, the landslide frequency of the Lower Finney–Miller area is moderate to high (see Tables 5 and 6; also Lingley, 2004a, b; Wegmann, 2004a, b).

Table 2. Landslide frequency rates for the Lower Finney and Miller Creek WAUs.

WAUs	Landslides (n)	Years	Study Area Acreage	Rate (n / ac / yr)
Lower Finney & Miller Creek	361	39	20,900	4.4×10^{-4}

[10] *Relict* landslides include those with rounded topographic expression or other features indicating that the slide is very old. These slides could have occurred during prehistoric wet periods such as the Little Ice Age or another wet period about 10,000 yr ago. In most cases, relict landslides appear to pre-date management activities in the forest.

Of the landslides identified during this mass wasting assessment, 62% were mapped as shallow rapid–undifferentiated failures, 14% were debris flows, 2% were debris avalanches, 9% were deep-seated–undifferentiated, 8% were large persistent deep-seated, 2% were small sporadic deep-seated, and 10% were earthflows (Fig. 3 and 4; note that most of the graphs discriminate between landslides that occurred on glacial terraces and those that occurred on bedrock slopes).

Most landslides on the glacial terraces are associated with the terrace face, but secondary landforms such as convergent headwalls, inner gorges, and sediment hollows control the location of most failures (Fig. 7). Undercutting along Finney and Miller Creek meander bends also creates many failures on the terraces. The number of landslides diminishes progressively with increasing size (Fig. 9), and undifferentiated deep-seated landslides account for most of the area affected by mass wasting (Fig. 11).

In bedrock areas, most failures are associated with rule-identified features including inner gorges, bedrock hollows, and convergent headwalls, but undercutting by Finney Creek and its tributaries is also an important mechanism for bedrock-related failures (Fig. 8). The number of landslides in the bedrock-dominated area also diminishes progressively with increasing size (Fig. 10). Undifferentiated deep-seated landslides account for most of the disturbed area, but many other processes contribute to the large total area affected by mass wasting (Fig. 12).

Slopes within the Lower Finney–Miller WAUs are most susceptible to failure following timber harvest (Fig. 5, 6). On managed lands, slides associated with clearcuts (0 to 5 yr) and young stands (5 to 15 yr) represent 64% of all recorded failures; sub-mature timber (15 to 50 yr) and road-related landslides constitute 12 and 13%, respectively. Landslides in mature stands represent a combined total of 14% of observed slope failures. Note that failures in 'mature stands' include relict/ancient landslides; natural features resulting from erosion on the outside of meanders along Finney and Miller Creeks are common and long-lived.

Both deep-seated and shallow rapid landslides in the glacial terrace sequences have initiation/headscarp slopes typically ranging from 34 to >100% (Fig. 13 and 15, Table 3). Most deep-seated and shallow rapid landslides in the bedrock terrain have initiation/headscarp slopes of 50 to 130% (Fig. 14, 16). DEM-derived initiation slopes for all landslide processes are gentler in the terrace-related physiographic element than in the bedrock-related physiographic element (Table 3). Slopes at the toes of deep-seated landslides are also much gentler in the terraces than in bedrock areas (Table 3, Fig. 19). Presumably this occurs as a result of poor cohesion in terrace landslide deposits that are dominated by free-flowing glacial-outwash sands. Most inventoried landslides occurred in concave and convergent slopes (Fig. 17, 18).

Table 3. Mean DEM-derived slopes and standard deviations (gradients in %) for various landslide components and physiographic elements in the Lower Finney–Miller Creek study area.

Failure Component	Terrace-Related Slopes Mean (Std Dev)	Bedrock-Related Slopes Mean (Std Dev)
Deep-seated initiation	71% (19%)	115% (40%)
Deep-seated toe	53% (15%)	111% (24%)
Shallow rapid initiation	72% (27%)	89% (33%)

Notes: DEM-derived slopes are commonly 10 to 20% lower than slopes measured in the field, because of the 10-m averaging effect of the DEM and because slopes may be too short to be recorded on the DEM.

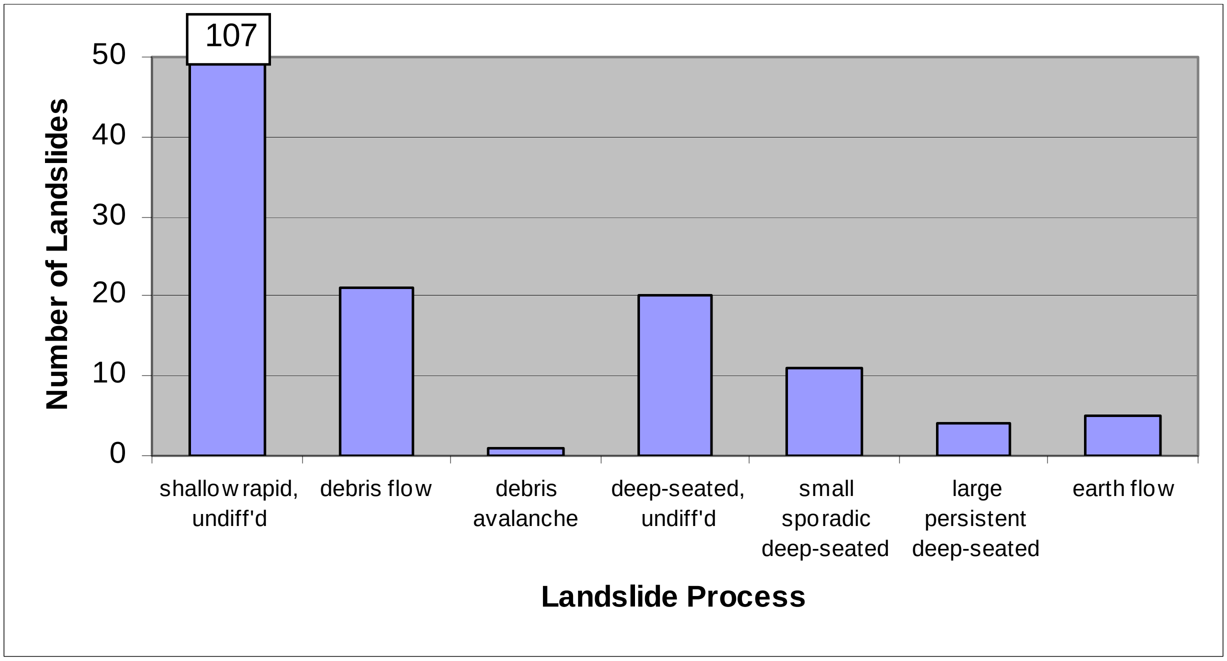

Figure 3. Number of landslides observed within glacial terrace sequences of the Lower Finney and Miller Creek study area by mass wasting process. In this and other graphs, a number in a box indicates a bar value beyond the range of the y-axis.

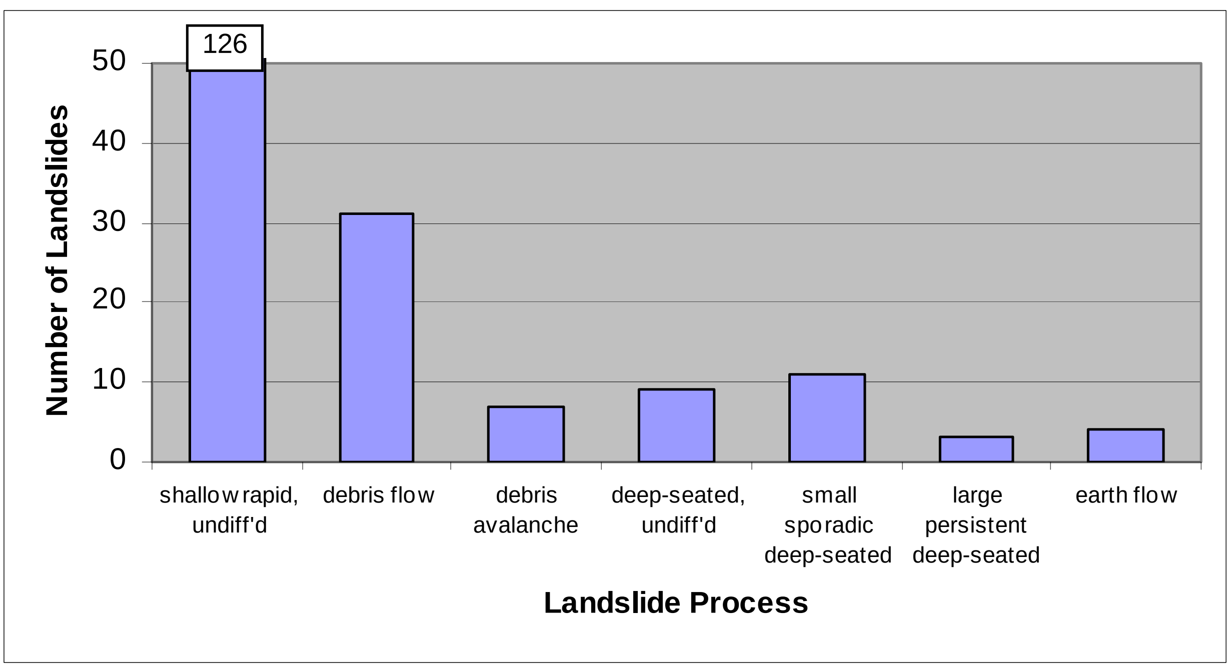

Figure 4. Number of landslides observed within bedrock-related sequences of the Lower Finney–Miller study area by mass wasting process.

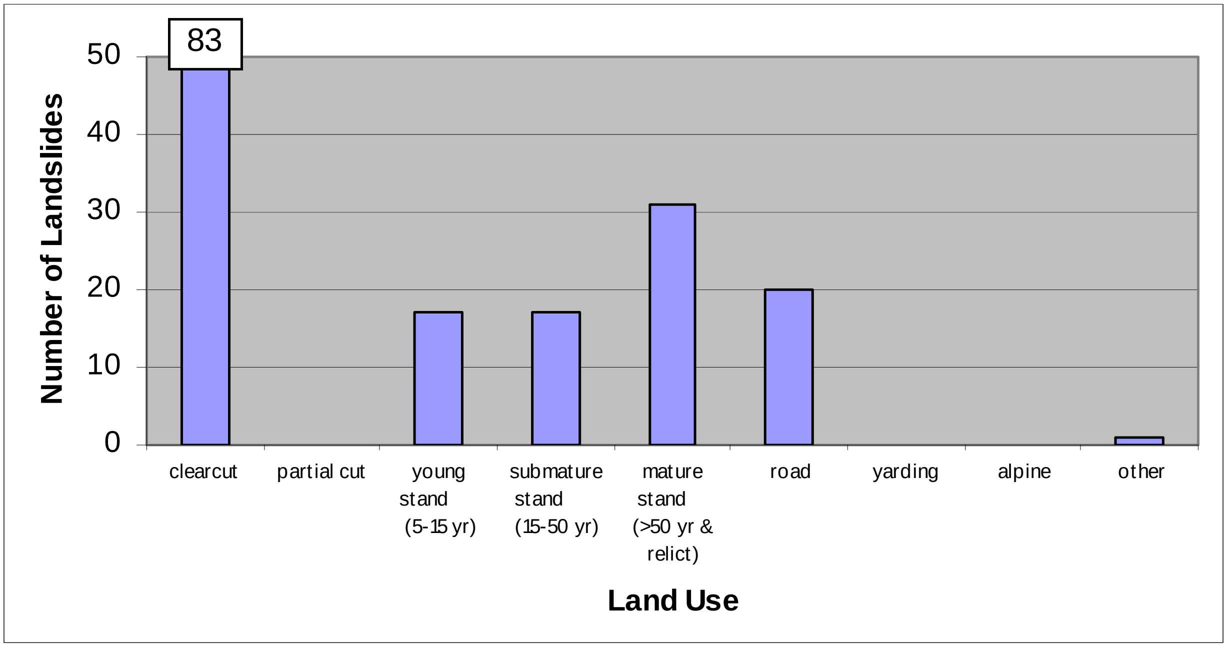

Figure 5. Number of landslides observed within glacial terrace sequences of the Lower Finney–Miller study area by land use association.

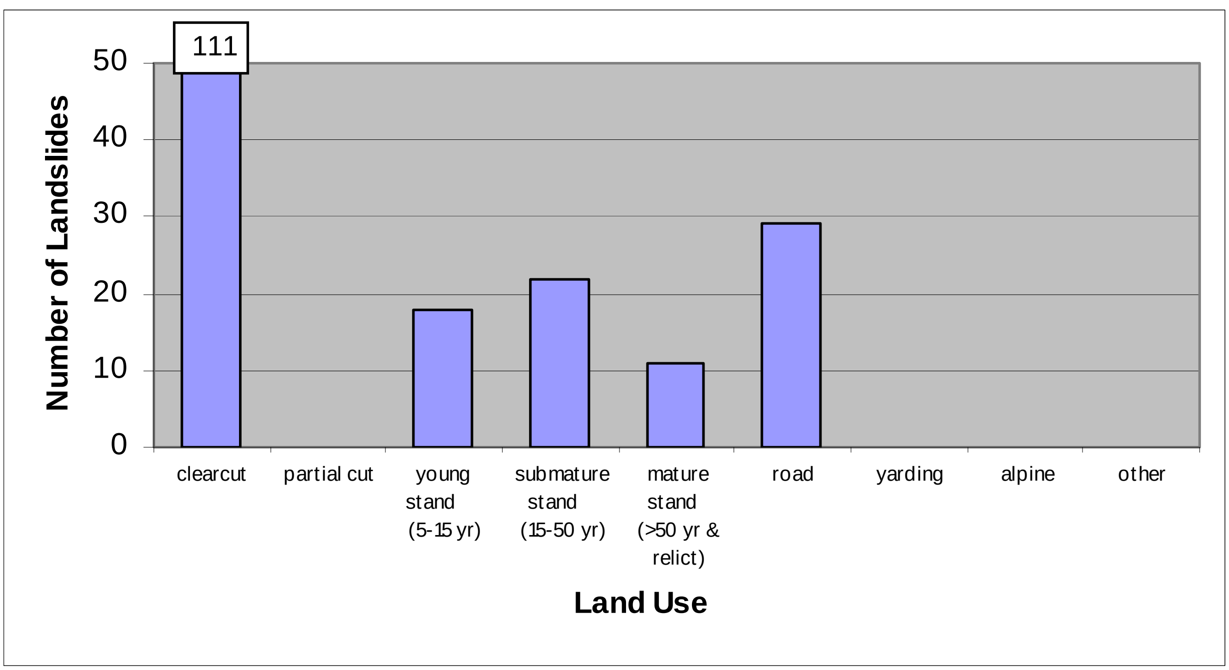

Figure 6. Number of landslides observed within bedrock-related sequences of the Lower Finney–Miller study area by land use association.

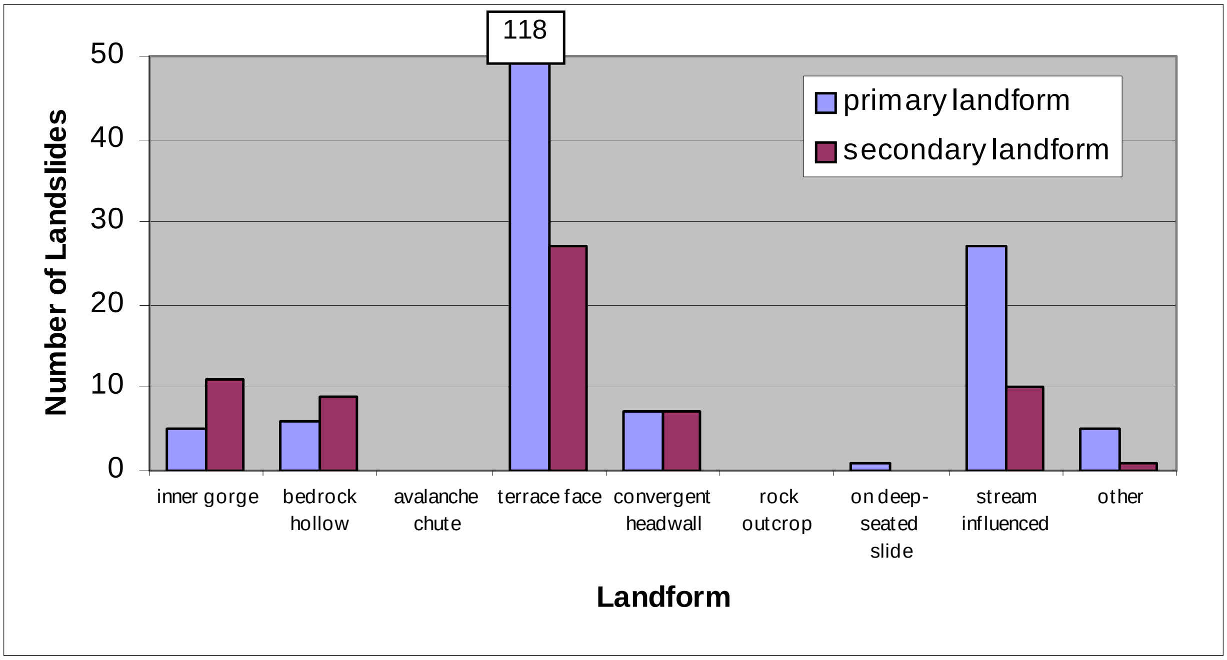

Figure 7. Number of landslides observed within glacial terrace sequences of the Lower Finney–Miller study area by landform association. Primary landforms are those that have the strongest correlation with slope failure in any given area; secondary landforms include smaller-scale landforms. For example, terrace margins (primary landforms) commonly fail in superimposed inner gorges (secondary landform).

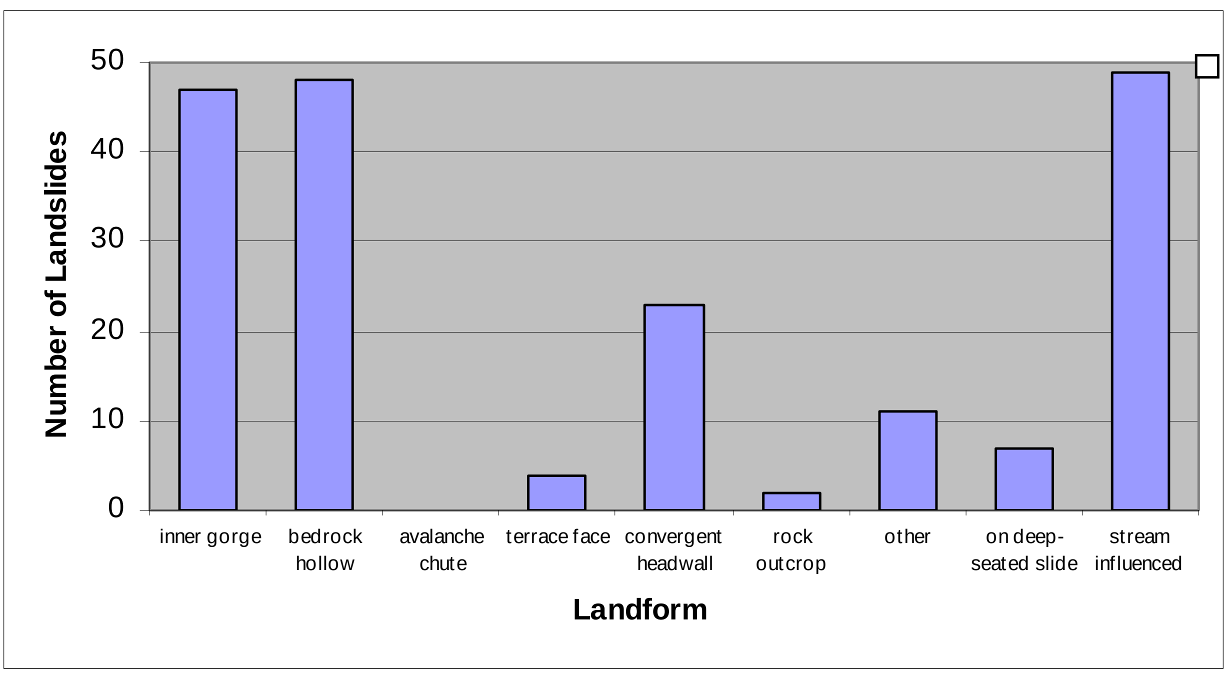

Figure 8. Number of landslides observed within bedrock-related sequences of the Lower Finney–Miller study area by landform association.

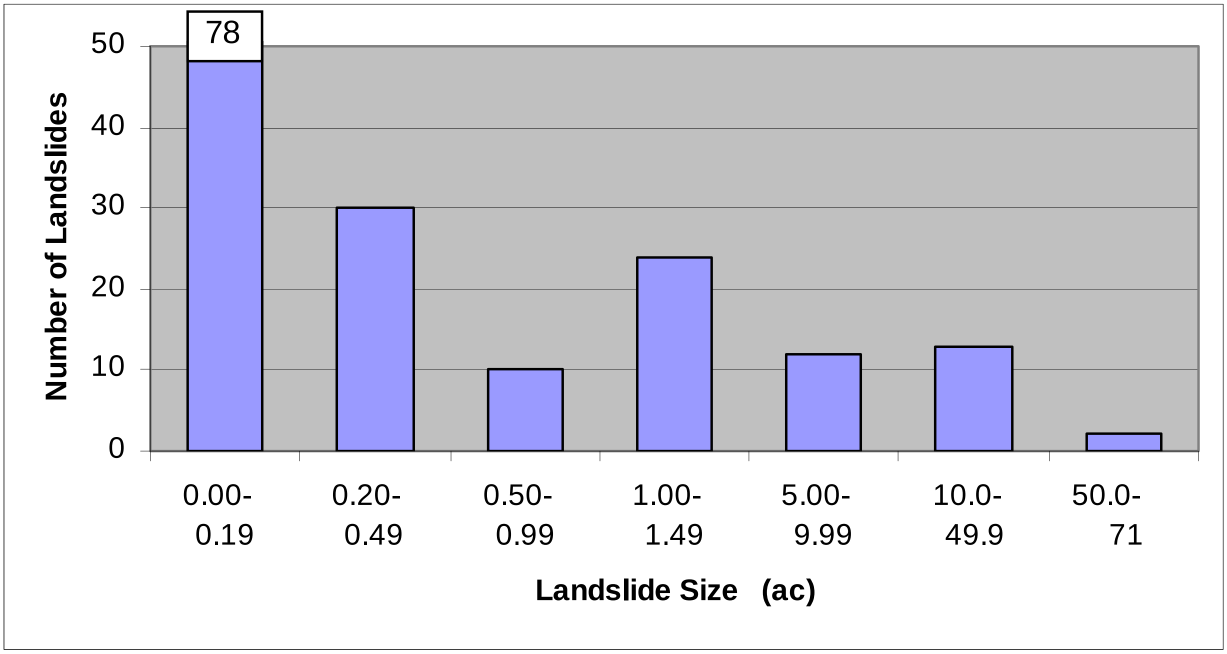

Figure 9. Size distribution of landslides within glacial terrace sequences of the Lower Finney–Miller study area.

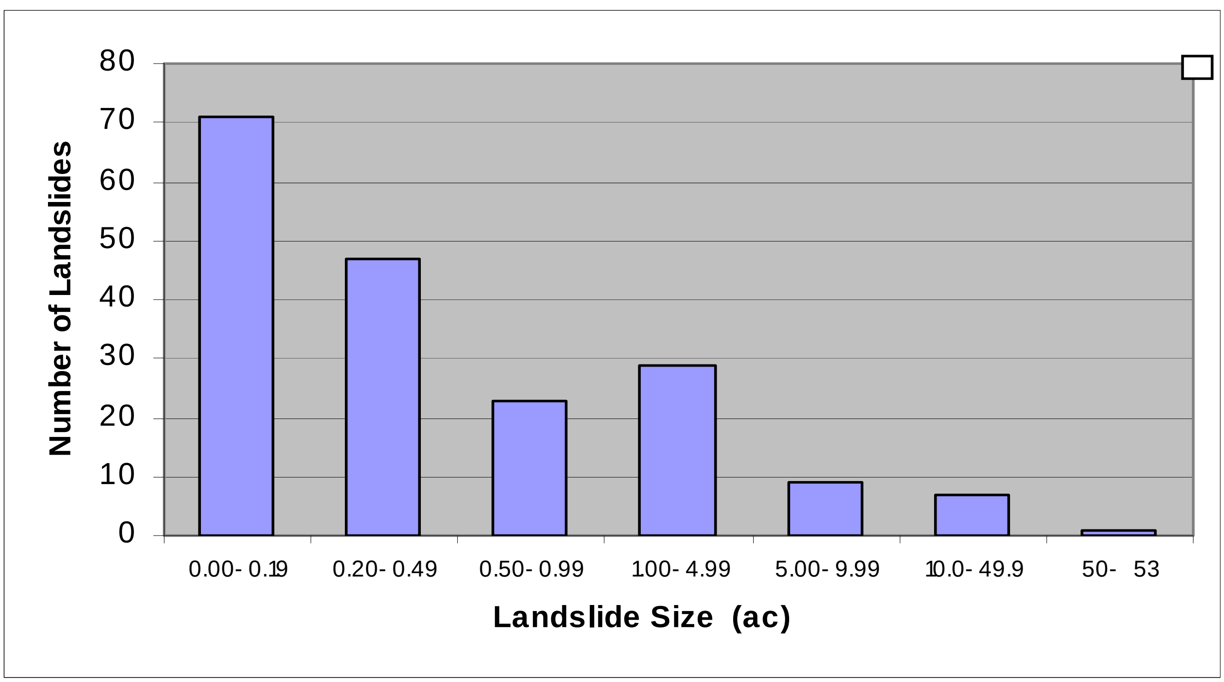

Figure 10. Size distribution of landslides within bedrock-related sequences of the Lower Finney–Miller study area.

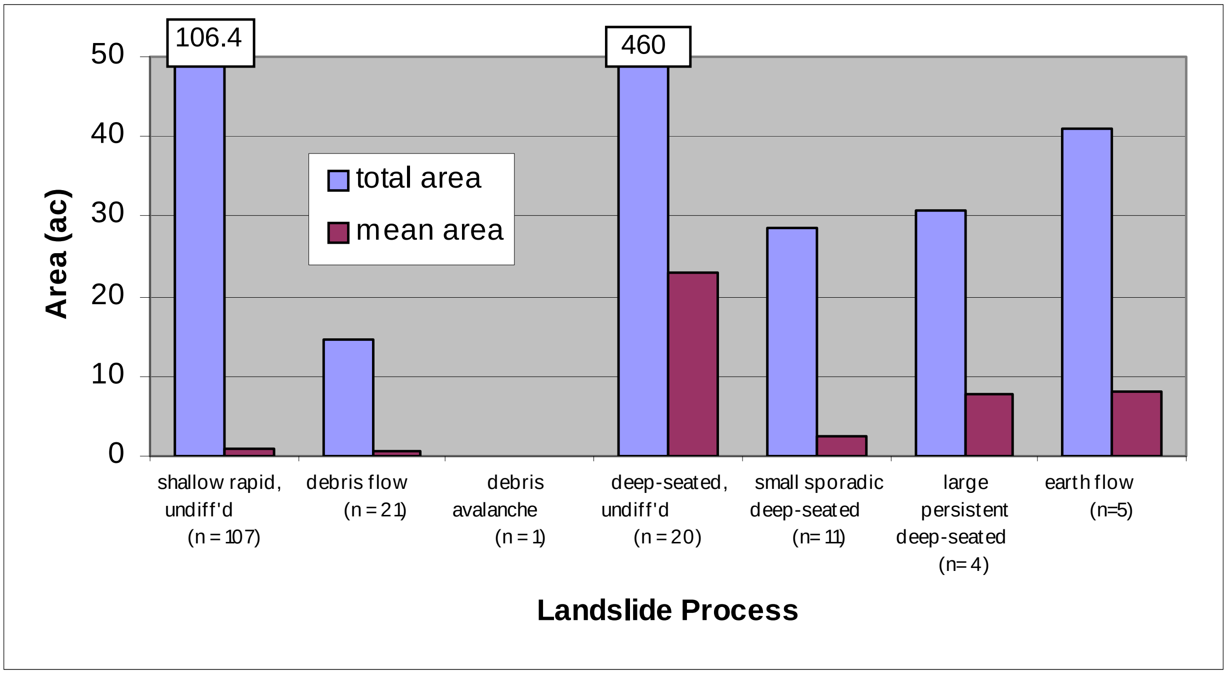

Figure 11. Cumulative area of landslides by landslide process within glacial terrace sequences of the Lower Finney–Miller study area.

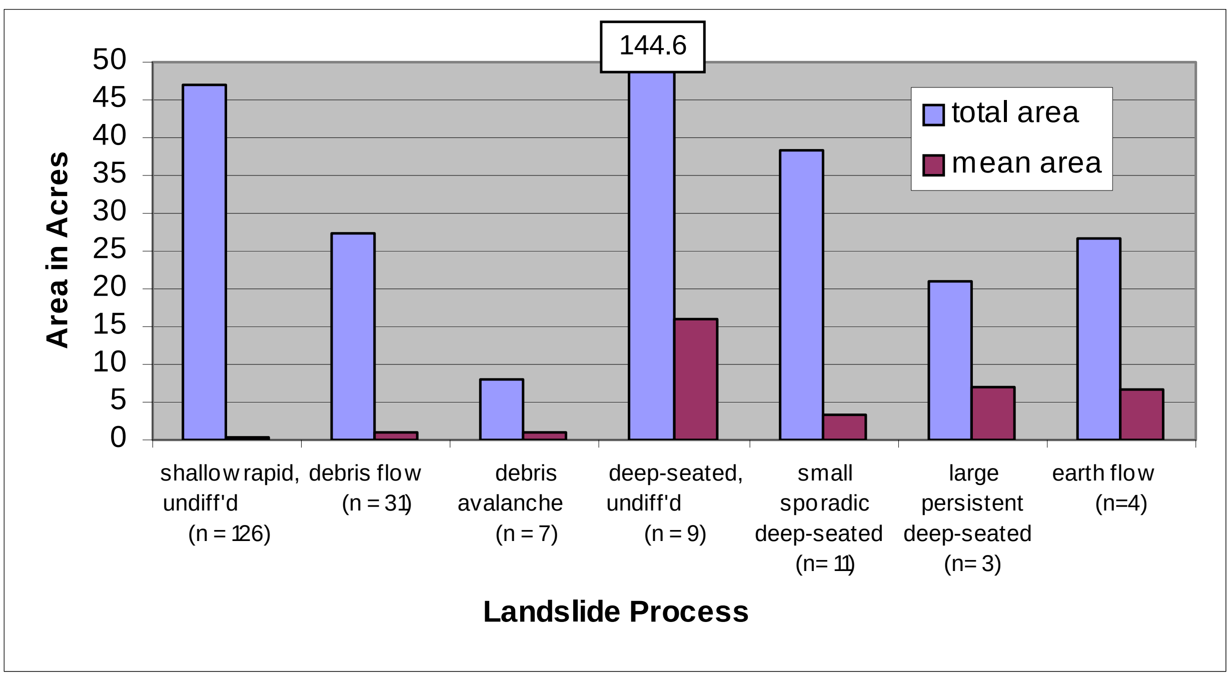

Figure 12. Cumulative area of landslides by landslide process within bedrock-related sequences of the Lower Finney–Miller study area.

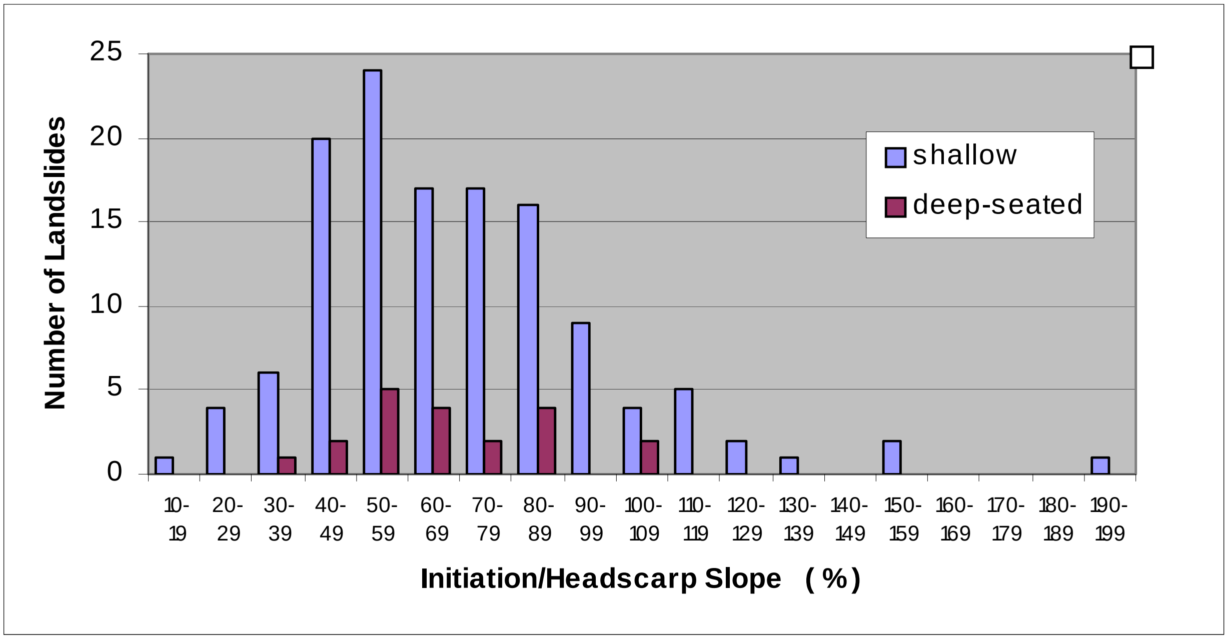

Figure 13. Distribution of all landslides by initiation/headscarp slope for glacial terrace sequences of the Lower Finney–Miller study area.

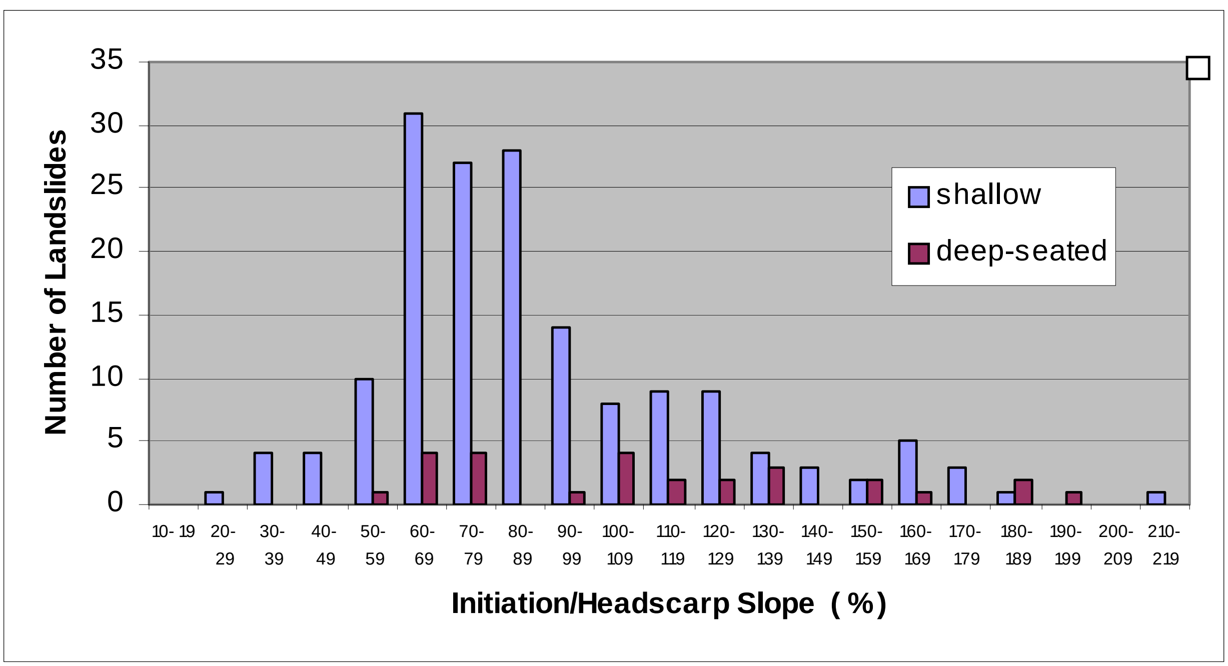

Figure 14. Distribution of all landslides by initiation/headscarp slope process for bedrock-related sequences of the Lower Finney–Miller study area.

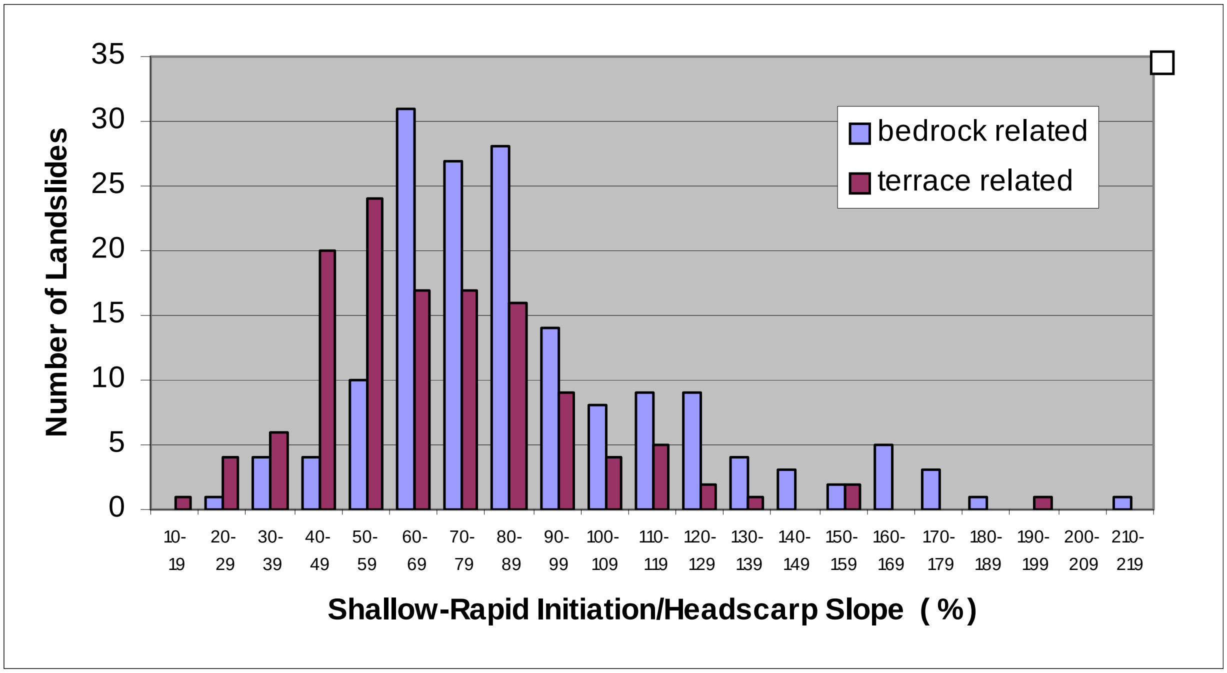

Figure 15. Distribution of failures by initiation/headscarp slope for all shallow-rapid landslide processes in the Lower Finney–Miller study area.

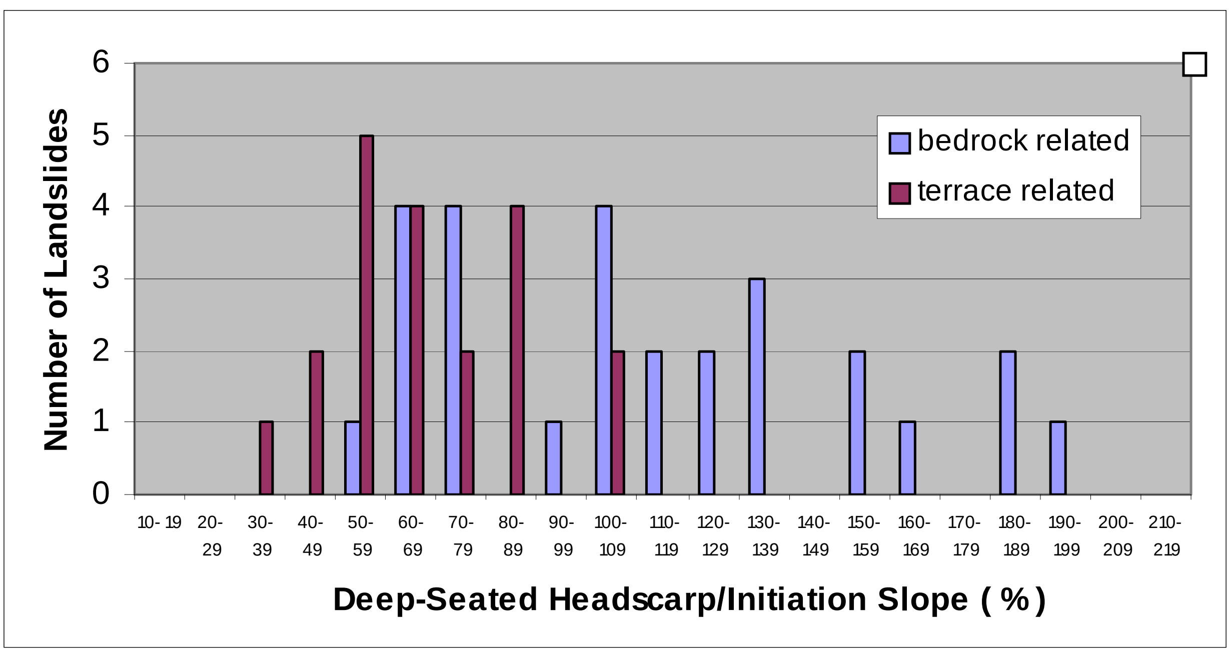

Figure 16. Distribution of failures by initiation/headscarp slope for all deep-seated landslide processes in the Lower Finney–Miller study area.

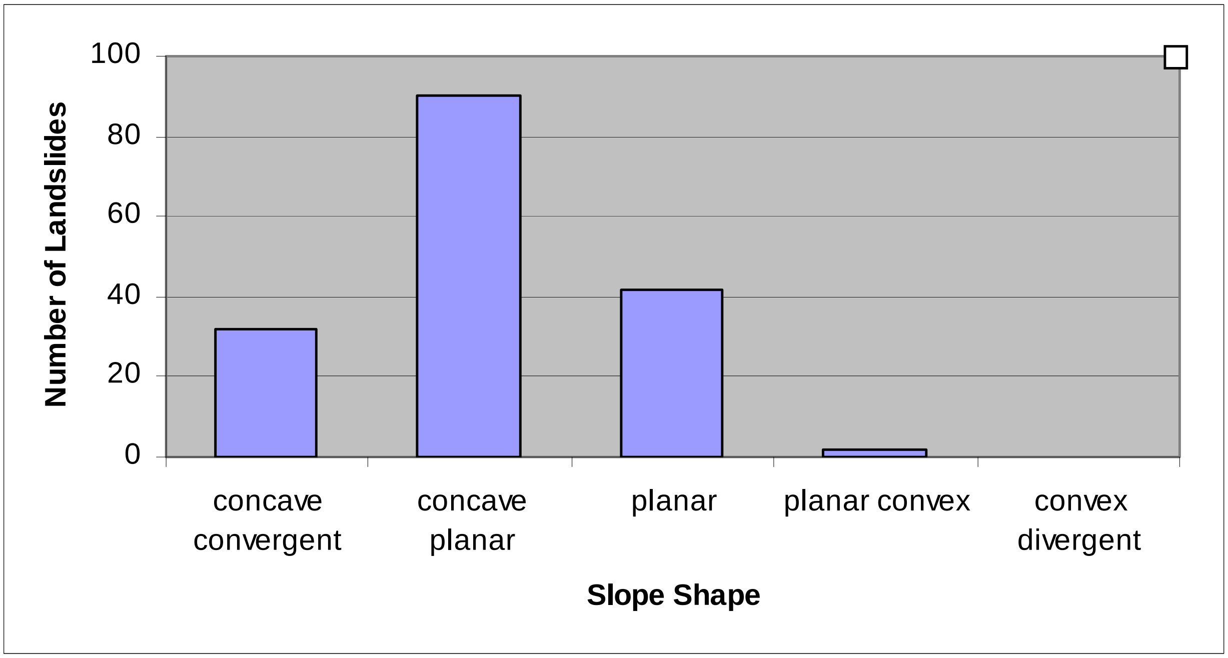

Figure 17. Distribution of landslides by slope shape for glacial terrace sequences of the Lower Finney–Miller study area.

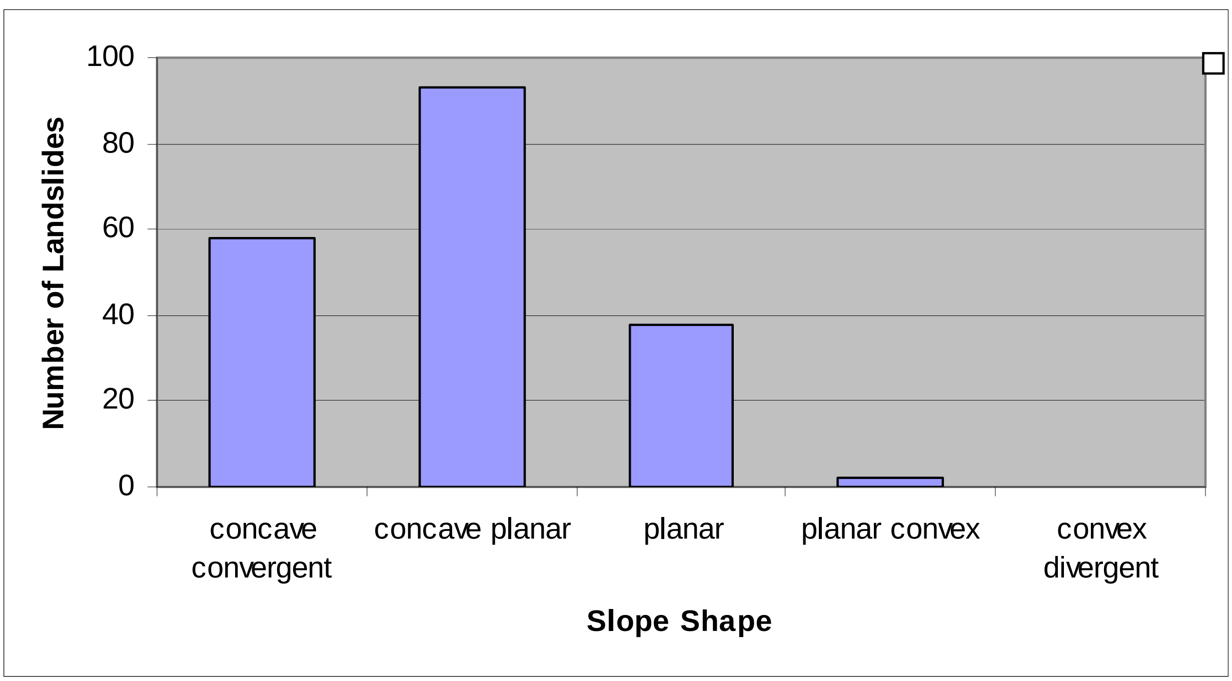

Figure 18. Distribution of landslides by slope shape within bedrock-related sequences of the Lower Finney–Miller study area.

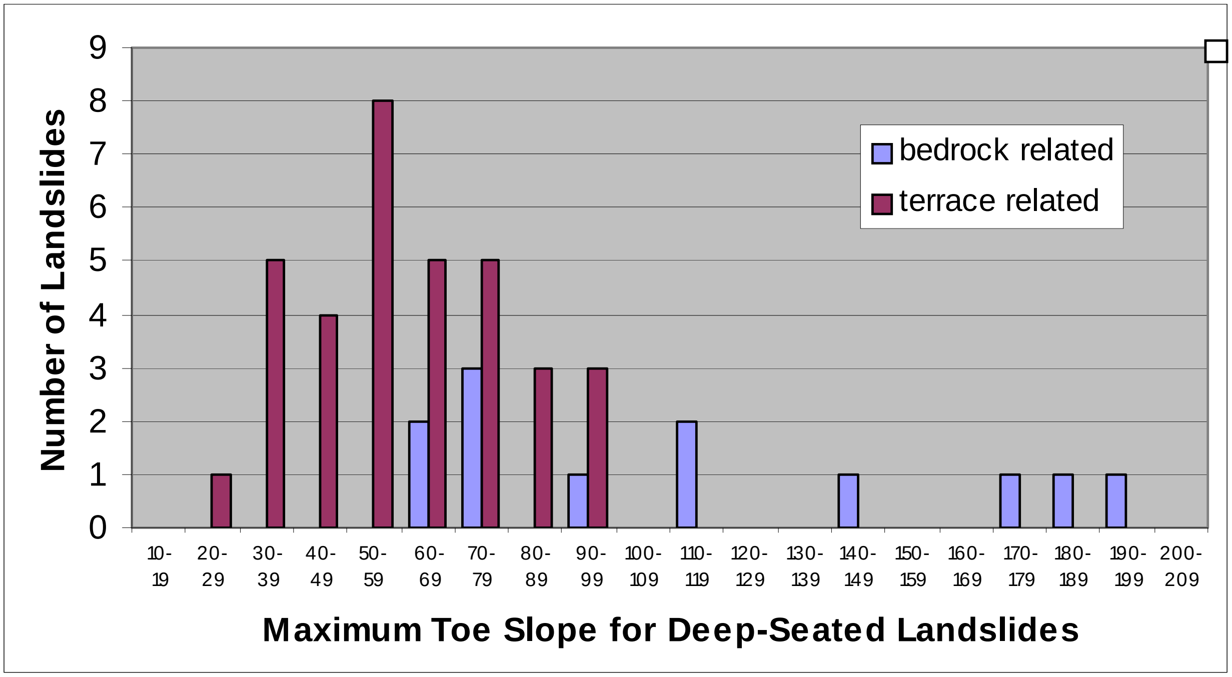

Figure 19. Distribution of landslides by slope angle at the toe of each landslide for bedrock- and glacial-terrace related sequences of the Lower Finney–Miller study area.

5.0 Mass Wasting Map Units

The distribution and extents of nine mass wasting map units (MWMUs) for the Lower Finney and Miller Creek study area are shown on Map A-2; they are described in Forms A-2 (Appendix B), with additional summary information in Table 4 and Appendix C. The MWMUs have been delineated to depict areas having similar potential for mass wasting and delivery of sediment and debris to public resources. Mass wasting potential is based mainly on landslide process, failure density, lithology, hydrology, geomorphology, and topography. Slope thresholds for field identification were based on statistics of the gradients of inventoried landslides (see Appendix B). The following sections briefly describe the characteristics of each MWMU. Sediment delivery is discussed in a following section.

The whole study area (comprising all nine mass wasting map units) is rated as moderate hazard, but the eight MWMUs with high hazard cover almost 30% of it. Among a sampling of watersheds that have been analyzed during the Landslide Hazard Zonation Project thus far, only the Jackman Creek and Corkindale Creek watersheds (Lingley, 2004a) are less stable.

5.1 Mass Wasting Map Units Related to Bedrock

MWMU1 – Rapidly Eroding Gorge Systems in Bedrock (≥60% slope) – High Hazard

The major tributaries of Finney Creek in bedrock are characterized by headwalls and knife-edged ridges sculpted by many landslides. This action results in steep gorge systems that are highly unstable, especially within a decade of harvest as observed here. Most of the landslides in MWMU1 involve the Darrington Phyllite (geologic unit Jph(d)) and essentially identical black phyllite within the Slate of Rinker Ridge (unit MZPZms(r); see Fig. 2). These geologic units weather and form thick soils more rapidly than many other rock types in the North Cascade Range because they are intensely layered on a scale of millimeters and composed of weak clay minerals.[11] Commonly, first- and second-order streams in these systems are oriented parallel with the weak northwest-trending layers in the bedrock resulting in a higher potential for failure. MWMU1 is rated as high for overall hazard.

MWMU2 – Other Gorges, Headwalls & Hollows in Bedrock (≥40% slope) – High Hazard

MWMU2 is similar to MWMU1, except that large gorge systems have not developed, possibly because erosion has not proceeded as far as the adjacent gorge systems or because these areas are underlain by more resistant metamorphosed sandstone. MWMU2 consists of lower relief inner gorges, hollows, and convergent headwalls that have a high overall hazard rating.

MWMU3 – Steep Bedrock Slopes above Finney Creek & Skagit River (≥55% slope) – High Hazard

MWMU3 consists of areas along Finney Creek and the Skagit River with slopes in bedrock, commonly exceeding 100% gradient and generally undercut by river erosion. Any soil that accumulates on these steep slopes tends to fail immediately creating frequent shallow rapid landslides, especially during storms when floodwaters impinge on the base of the bedrock slopes. MWMU3 is rated as high overall hazard owing to the low rate of soil accumulation on these slopes.

MWMU4 – Deep-Seated Slides on Bedrock Slopes (≥65% slope) – High Hazard

MWMU4 consists of the area of several large deep-seated landslides on steep bedrock slopes. Many shallow-rapid landslides are superimposed on these deep-seated failures. Analogy with deep-seated landslides in the Jackman Creek watershed (Lingley, 2004a) suggests that the relict deep-seated landslides in this study area are unstable as a result of the sheared and disrupted bedrock blocks that compose these landslides. The hazard rating for MWMU4 is high.

5.2 Mass Wasting Map Units Related to Glacial Terraces

MWMU5 – Steep Slopes in Glacial Terrace Deposits above Roads & Rivers (≥50% slope) – High Hazard

MWMU5 is similar to MWMU3 except that the steep slopes eroded by the Skagit River and Finney Creek are cut in glacial terrace sediments. MWMU5 is rated as high hazard owing to fairly continuous raveling where vegetation has been removed by earlier landslides or road building.

MWMU6 – Rapidly Eroding Basins in Glacial Terrace Deposits (≥45% slope) – High Hazard

MWMU6 includes several large (~300 acre) convergent basins consisting of actively eroding headwalls in glacial terrace sediments. These generally have poorly developed first-order streams and zero-order hollows that coalesce to form a single outlet stream. The headwalls and hollows are sites of many landslides including varied shallow-rapid processes on gentle to moderate slopes, and earthflows and slumps on low-angle slopes. The underlying cause of these landslides is interlayering of poorly permeable sediments including till and glacial-lacustrine clay with highly permeable and very poorly consolidated

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[11] The Landslide Hazard Zonation Project as well as the current Washington Forest Practices Rules (WAC222-050) are based on recognition of unstable landforms. However, many forest managers recognize the Darrington Phyllite and similar black phyllite in the Slate of Rinker Ridge and the semischist of Mt. Josephine (Tabor and others, 1994) as regionally unstable rock types (S. Bratz, Crown Pacific Corporation, 2004 verbal commun.). Harvest units that are oriented perpendicular to the dominant NW-trending geologic structure (layering, cleavage, and faults) in the phyllite (typically north 50° east) will likely be more stable.

glacial outwash sand. More specifically, failures occur in response to deep groundwater recharge and/or sapping[12] mechanisms. Slope stability in MWMU6 is highly susceptible to forest management, and the overall hazard is rated as high.

MWMU7 – Other Gorges, Headwalls & Hollows in Glacial Terrace Deposits (≥45% slope)–High Hazard

MWMU7 consists of typical unstable landforms found throughout forested areas in Washington, but in this study area, these landforms commonly fail at lower slope angles than most rule-identified equivalents elsewhere. (See WAC 222-16-050.)

MWMU8–Deep-Seated Slides in Glacial Terrace Deposits & Adjacent Lands (≥55% slope)–High Hazard

MWMU8 includes 17 large deep-seated landslides within glacial terraces deposits. Loss of cohesion within the bodies of deep-seated failures has resulted in 18 shallow-rapid slides that have formed on top of these large older features. The hazard rating for MWMU8 is high.

5.3 Mass Wasting in Other Parts of the Study Area

MWMU9 – Other Hills and Floodplains – Low Hazard

The remaining 71% of the study area (14,393 acres) contains 13 landslides, only four of which are proven to have delivered sediment to streams. These are randomly dispersed across the landscape, precluding classification within a more precise MWMU.

Table 4. Landslide summary for the Lower Finney–Miller Creek WAUs.

Mass Wasting Map Unit	Number of Delivering Landslides	Total Landslides	Area of Delivering Shallow Rapid Failures (acres)	Area of All Shallow Rapid Failures (acres)	Area of Delivering Deep-Seated Failures (acres)	Area of All Deep-Seated Failures (acres)	Total Area of All Failures (acres)
1	110	138	69.7	75.1	28.1	191.5	266.6
2	13	16	4.0	5.1	0.7	0.7	5.8
3	16	20	5.8	7.5	3	4.9	12.4
4	12	15	3.0	4.7	0	100.6	105.3
5	10	10	3.9	3.9	0.6	0.6	4.5
6	15	37	3.8	6.5	13.6	48.2	54.7
7	22	50	5.5	10.4	9.3	19.2	29.6
8	26	62	15.8	17.7	146.6	573.9	591.6
9	4	13	0.5	0.9	0	3.5	4.4
Total	**228**	**361**	**112.0**	**131.8**	**201.9**	**943.1**	**1074.9**

[12] *Sapping* is the process whereby groundwater flow erodes tunnels in unconsolidated sediments, commonly above a poorly permeable layer, causing collapse of overlying material and headward erosion of small rills and hollows.

6.0 Delivery

In this report, the ***Landslide Area Rate for Delivery (LAR)*** is used to help quantify the ratings for potential hazard of delivery of sediment to public resources, combining mass wasting potential and delivery potential (as outlined in Table A-2 of Washington Forest Practices Board, 1997). The LAR is simply the area of delivering landslides normalized for the area of each MWMU and the period of study; these values are multiplied by one million to produce whole numbers.

Data used to calculate the LARs for the nine MWMUs in the Lower Finney–Miller WAUs are presented in Table 5. In the 39-yr study period, 228 inventoried landslides delivered sediment and debris to streams and other public resources; the total area of those delivering landslides is approximately 313 acres (0.5 mi^2). LAR values range from 1 for MWMU9, to 3940 for the entire MWMU8; most map units have values of 350 to 600, with MWMU1 higher at 1306. The entire study area has LAR of 205 or 384, depending on whether or not all slides in MWMU8 are counted.

Table 5. Annualized rate of landslides that deliver to public resources in terms of landslide frequency and delivery area rates during the 39-year study period.

Mass Wasting Map Unit	MWMU 1	MWMU 2	MWMU 3	MWMU 4	MWMU 5	MWMU 6	MWMU 7	MWMU8 All	MWMU8 SR	MWMU9	Study Area
Area of MWMU (acres)	1919.4	320.7	442.4	216.2	241.4	1094.1	669.7	1057		14939.1	20900
Number of 'delivering' landslides	110	13	16	12	10	15	22	26	18	4	228 220
Frequency of delivery (no. of delivering landslides / area / 39 yr) x 10^6	1469	1039	927	1423	1062	352	842	631	437	7	280 270
Area of 'delivering' landslides (acres)	97.8	4.7	8.8	3.0	3.9	17.4	14.8	162.4	15.8	0.5	313.3 166.7
Landslide area rate for delivery (area of delivering landslides / area / 39 yr) x 10^6	1306	376	510	356	414	408	567	3940	383	1	384 205

Notes: For this analysis, 'delivering landslides' include those that move rapidly and have a 'probable' or 'yes' delivery rating. Delivering landslides do not include deep-seated failures, except slides on very steep slopes of MWMUs 1 and 2, and deep slumps on glacial terraces demonstrated to have entered Finney Creek. (See Form A-1.) Values for the entire study area are calculated using all delivering slides of MWMU8, and just shallow-rapid slides.

Table 6 shows a comparison of LAR indices for a range of landform types, in four other studies as well and the Lower Finney–Miller project. Limited application suggests that areas with LAR less than 100 might be considered low hazard, rates between 100 and 250 are probably moderate, and rates greater than 250 appear to be high hazard. Note that higher LAR values can be achieved by reducing the size of the mass wasting map unit. While this may appear to be 'data gerrymandering', it has a favorable effect, which is to help limit the area of high-hazard units to those areas that are actually demonstrated to have high hazard. The LARs for the Lower Finney–Miller watershed are higher than those for corresponding MWMUs in most other watersheds studied to date (2004), but comparable to those in the nearby Jackman Creek and Corkindale Creek watersheds.

Table 6. Comparison of Landslide Area Rates for Delivery for MWMUs in five LHZ projects.

Project Basins	General Type of Mass Wasting Map Unit										WAU or Study Area
	Gorges, Headwalls, Hollows	Inner Gorges	Bedrock Hollows	Convergent Headwalls	Superimposed on Relict Landslides	Cliff-Dominated Slopes	Lower Hazard Hills	Incised Rivers	Glacial Outwash Terraces	Valley Floors	
Lower Calawah Valley (Lingley, 2004b)	404						24	405		37	68
Jackman Corkindale (Lingley, 2004a)	1167 1142				1217	213	24 10		35 19		461
Nookachamps (Wegmann, 2004a)		273	173	384					31		11
Lime and Dan Creeks (Wegmann, 2004b)	119										4
Finney Miller (this study)	*1306*	*376*			*356* *383*	*510* *414*	*1*		*567* *408*		*384* *205*
Averages	**828**	**325**	**173**	**384**	**652**	**379**	**15**	**405**	**408**	**37**	**168**

Note: LAR for delivery is called vulnerability factor in some studies (e.g., Jackman–Corkindale). The MWMU categories tabulated include all such features regardless of the angle of the contained slope (i.e., rule-identified unstable slopes and gentler features are both included). Two ratings are for two MWMUs in the same general category.

7.0 Summary of Critical Questions

In order to address the critical questions posed by the *Standard Methods for Conducting Watershed Analysis*, which have been adopted as part of the Landslide Hazard Zonation Project protocols, the following summaries are included:

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

During this review of the Lower Finney and Miller Creek WAUs, a total 361 landslides were identified over a 39-year photo history, including a wide variety of shallow-rapid and deep-seated landslide processes. Of these, 36 were confirmed by field observation; unstable conditions involving stratigraphic and structural aspects of the rocks were also observed in the field. In addition, Heller (1978), Parks (1992), Paulson (1997), and Tabor and others (2002) located numerous landslides in the study area. Nine mass wasting map units were defined on the basis of similarities in landform, slopes, landslide frequency, geology, and other factors. Eight MWMUs are identified as having high mass wasting potential, many of them higher than those of comparable landforms in other watersheds in the Cascades and Olympics (e.g., Lingley, 1998, 2002; Parks, 2000; Lingley, 2004a, b; Wegmann, 2004a, b). However, more than 70% of the Lower Finney–Miller study area is rated as low hazard, making the basin hazard rating moderate.

What mass wasting processes are active?

Essentially all mass-wasting processes except rock topples, rock wedge failures, and liquefaction failures have been observed in the study area. This wide variety of movement types reflects the steep slopes, varied and weak rocks and unconsolidated sediments, locally unfavorable hydrology, and structural geology, all of which can be conducive to slope failure.

How are mass wasting features distributed throughout the landscape?

See Map A-1. A preponderance of the landslides inventoried in this assessment can be assigned to two broad physiographic associations: 1) bedrock related failures, and 2) glacial-terrace related failures.

MWMUs 1 through 4 are located within unstable landforms in bedrock, and are sensitive to forest practices (as defined in WAC 222-16-050). MWMUs 5 through 8 are located within unstable landforms in glacial terrace sediments and are also sensitive to forest practice management activities. However, landslides involving glacial terraces can initiate on slopes that are gentler than rule-identified thresholds.

In addition, there are four smaller-scale landform groups associated with failures in the Lower Finney and Miller Creek study area, and these are present in both of the broad physiographic associations. These secondary landform groups are:

1. Convergent, rapidly-eroding gorge systems and basins, which are particularly unstable. In fact, the bedrock-related gorge systems are the least stable mass wasting map unit identified during the Landslide Hazard Inventory project to date (2004). Knife-edge ridges, steep headwalls, and limited areas of convex topography characterize the gorge systems and basins. This landform group includes MWMU1 and MWMU6.
2. All other inner gorges and hollows, both in bedrock and in sediments. These are sites of frequent failure and include MWMU2 and MWMU7.
3. Steep slopes directly above and eroded by Finney Creek and the Skagit River. These are unstable and prone to failure by raveling and shallow rapid processes. This landform group includes MWMU3 and MWMU5.
4. Large, relict, deep-seated landslides are sites of common shallow-rapid landsliding. This landform group includes MWMU4 and MWMU8.

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

Yes. About 63% of landslides observed in the Lower Finney–Miller study area probably or definitely delivered sediment to stream channels or other waters (Form A-1). Damage to other public resources has also occurred as a result of slope failure above South Skagit Road in MWMU3 and MWMU5. Landslides starting in bedrock-related MWMUs have a higher proportion of delivery (~80%) than those from glacial-terrace-related MWMUs (~45%). This discrepancy results from several factors. Commonly, landslides in glacial terrace deposits are located in highly permeable sand, which may limit down-slope travel. Because this sand is very unstable, some failures occur in mid-slope positions that do not connect to drainage systems. Many slides in the glacial terraces result from deep groundwater recharge mechanisms, whereby flat-lying poorly permeable glacio-lacustrine clay arrests downward movement of groundwater through overlying porous sand. Landslides can form anywhere across the landscape under this mechanism, and thus are not limited to convergent topographic elements.

How do forest management activities create or contribute to instability?

Of the observed mass wasting features in the Lower Finney–Miller WAUs, 78% are associated with forestry-related land uses: over the record period, 53% of all landslides inventoried occurred in recent clearcuts (≤5 yr old), another 10% in young stands (to 15 yr old), and 15% were associated with roads.

What areas of the landscape are susceptible to slope instability?

Most landslides are associated with rapidly eroding gorge systems in bedrock and rapidly eroding basins in glacial terrace deposits. These landforms are evolving rapidly in response to sculpting by landslides. Particularly unstable ground is present in areas underlain by Darrington Phyllite and similar black phyllite in the Slate of Rinker Ridge. Gorge systems in the Rinker Ridge slates have the highest Landslide Area Rate for Delivery of any MWMU identified in the Landslide Hazard Zonation Project to date (2004). In addition, rule-identified landforms (including steep convergent headwalls, inner gorges, bedrock hollows, and glacial deep-seated features) are prone to frequent movement. Commonly, smaller slides are superimposed on large relict landslides in both bedrock and glacial sediments. Finally, steep slopes above the Skagit River and Finney Creek are prone to failure, mainly as a result of undercutting during floods.

8.0 Confidence in Work Products

The confidence in this mass wasting assessment is moderate. This rating results because the Landslide Hazard Zonation Project is designed to provide a watershed-scale overview of slope instability throughout the state in the shortest reasonable time; it is to be used as a screening tool only. As a consequence, fieldwork and the number of air-photo sets examined are held to reasonable minima and the work is performed rapidly with little time given to cross-checking results. **This assessment would be entirely insufficient and misleading if used as a stand-alone document for protecting private and public resources or for land-use planning. Keep in mind that some landslides may have been accidentally omitted, and some benign features may be improperly mapped as landslides**.

This assessment was conducted primarily using aerial photographs. As a result, there is a high likelihood that errors of omission occurred, primarily in areas covered by mature forest canopies at any given time. The scarcity of mass wasting features identified under mature canopy conditions is not necessarily an indication of the relative stability of these slopes.

Because many deep-seated landslide features are quite large, remain heavily vegetated during movement, and may not have obvious scars visible through the vegetation canopy, misinterpretation is more likely. A recent detailed study in Cowlitz County, Washington, suggests that up to 25% of inferred deep-seated landslides identified from air-photo analysis are misinterpreted (Wegmann, 2003). Therefore, confidence in work products related to classification of landslide process is low to moderate.

Another important source of potential error in this assessment is in the accuracy and precision of measurements of mass wasting features. Because very few landslides were actually visited in the field, it is not possible to report the degree to which location and measurement error in the GIS environment compares to on-the-ground field measurements. Similarly, measurements of slope angle from digital elevation models typically misrepresent the true hillslope angle. Given these sources of error, the confidence in the precise location and accuracy of measurements of individual landslides is considered moderate.

9.0 Acknowledgements

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11.0 Appendix A – Form A-1: Landslide Inventory

Form A-1 Mass Wasting Inventory Data for the Lower Finney and Miller Creek Valley WAUs

Codes for this table are presented on the DNR Forest Practices website.

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1001	2	D	1998	5	2003	5	1	1	106		Y	3	2271	NWH_98	1	5.15		MZPZms(r)
1002	1	P	1998	3			2	1	92		Y	3	1341	NWH_98	1	0.12		MZPZms(r)
1003	2	P	1998	3			1	1	63		Y	3	1350	NWH_98	1	0.20		MZPZms(r)
1004	2	Q	2001	5			8	1	69		N	3	1502	NWH_98	1	3.09		MZPZms(r)
1005	1	Q	1998	3			1	1	61		Y	2	3349	NWH_98	2	0.22		MZPZms(r)
1006	2	D	1998	5	2003	5	1	1	65		Y	3	2080	NWH_98	1	8.52		MZPZms(r)
1007	1	P	1998	4			1	2	40		Y	3	1912	NWH_98	1	0.56		MZPZms(r)
1008	5	D	1998	5	2003	5	1	2	67		Y	3	1893	NWH_98	1	2.63		MZPZms(r)
1009	5	P	1998	5	2003	5	1	2	73	67	Y	3	2154	NWH_98	1	11.04		MZPZms(r)
1010	2	D	1998	3			1	2	82		Y	3	1432	NWH_98	1	0.39		MZPZms(r)
1011	1	P	1998	5			1	2	63		Y	3	1090	NWH_98	1	1.14		MZPZms(r)
1012	6	P	1998	5	2003	5	2	2	75	71	Y	3	2097	NWH_98	1	13.09		MZPZms(r)
1013	1	D	1998	4			2	2	71		Y	3	934	NWH_98	2	0.67		MZPZms(r)
1014	5	P	1978	5	2003	4	5	2	69		Y	1	1218	NW78_84D_26	3	1.05		MZPZms(r)
1015	2	P	1978	3	2003	3	5	1	74		Y	1	1239	Field	3	0.32		MZPZms(r)
1016	5	P	2003	5			5	2	63		Y	1	1243	NW78_84D_26	3	1.94		MZPZms(r)
1017	7	Q	1965	5	2003	5	4	2	49	21	N	4	819	WFPA65_39_36	8	12.50		Qga
1018	1	P	2003	3			1	1	76		Y	4	814	Field	8	0.19		Qga
1019	6	Q	2003	5			4	4	80	57	Y	2	866	Field	8	26.74		Qga
1020	1	P	1998	4	2003	4	4	2	52		P	1	894	NWH_98	7	0.48		Qga
1021	6	P	1965	5			4	1	78		N	4	865	WFPA65_39_36	8	1.83	5	Qga
1022	6	P	1965	5			4	2	81		N	4	942	WFPA65_39_36	8	1.88	5	Qga
1023	5	Q	2003	5			4	2	65		N	3	760	Field	6	2.36		Qga
1024	1	D	1998	3	2003	4	4	3	45		Y	2	732	1998	6	0.19		Qga
1025	1	D	1998	3	2003	3	4	4	54		N	1	479	NWH_98	7	0.16		Qga
1026	5	P	1998	3			4	3	63		N	1	465	NWH_98	6	0.40		Qga
1027	1	P	2001	2			4	1	91		Y	1	703	NWH_98	6	0.07	1	Qga
1028	2	P	1998	3			4	1	76		Y	1	657	NWH_98	6	0.15	1	Qga
1029	1	P	1998	3			4	2	99		Y	1	671	NWH_98	6	0.12	5	Qga
1030	1	Q	1998	2			2	2	86		I	1	2492	NWH_98	1	0.07		MZPZms(r)
1031	1	Q	1998	3			2	2	94		Y	1	2470	NWH_98	1	0.19		Jph(d)
1032	2	D	1978	3	2001	5	8	1	102		Y	3	577	NWH_98	7	0.17		Qgt
1033	1	Q	1965	3	2001	5	4	3	103		Y	7	712	NWH_98	7	0.22		Qga
1034	3	P	1978	3	2001	5	8	2	98		Y	3	715	NWH_98	7	0.12		Qga
1035	1	Q	2001	2			2	1	103		Y	1	2166	NWH_98	1	0.05		MZPZms(r)

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1036	1	Q	1998	3			2	2	111		Y	1	2273	NWH_98	1	0.17		MZPZms(r)
1037	1	Q	1998	3			2	2	107		Y	1	2298	NWH_98	1	0.27		MZPZms(r)
1038	1	Q	1998	2			2	2	116		Y	1	2057	NWH_98	1	0.02		MZPZms(r)
1039	1	P	1998	3			2	2	181		Y	1	1876	NWH_98	1	0.36		MZPZms(r)
1040	1	P	1998	2			2	2	136		Y	1	1610	NWH_98	1	0.04		MZPZms(r)
1041	1	P	1998	3			2	2	141		Y	1	1409	NWH_98	1	0.17		MZPZms(r)
1042	1	Q	2003	3			2	2	70		I	2	1043	Field	2	0.35		MZPZms(r)
1043	5	D	1965	4			4	1	45	192	Y	1	576	WFPA65_38_36	5	0.55	1	Qga
1044	2	P	1965	5			7	3	111		Y	5	627	WFPA65_38_36	8	3.41		Qga
1045	1	P	1965	5			5	3	80	96	Y	1	1064	WFPA65_38_36	8	3.83	4	Qga
1046	4	Q	1965	5			5	2	75	69	N	4	1137	WFPA65_38_36	8	20.70	4	Qga
1047	5	Q	1965	5			2	2	185	184	Y	2	2201	WFPA65_38_36	1	5.61		MZPZms(r)
1048	5	Q	1965	5			2	2	112		N	2	1887	WFPA65_38_36	1	2.05		MZPZms(r)
1049	5	Q	1965	5			2	2	190	190	Y	2	1741	WFPA65_38_36	1	8.10		MZPZms(r)
1050	1	Q	1965	3			9	1	104		Y	2	2366	WFPA65_38_36	1	0.13		MZPZms(r)
1051	1	Q	1965	5			5	2	102		Y	3	3301	WFPA65_38_36	1	1.08		MZPZms(r)
1052	1	Q	1965	4			7	3	95		Y	1	653	WFPA65_38_36	1	0.74		MZPZms(r)
1053	1	D	1965	3			6	3	72		I	5	1391	WFPA65_39_35	1	0.25		MZPZms(r)
1054	1	D	1965	5			6	2	66		N	5	987	WFPA65_39_35	3	1.33		MZPZms(r)
1055	2	D	1965	5	1978	2	1	1	82		Y	1	1961	WFPA65_39_35	2	1.21		MZPZms(r)
1056	2	D	1965	4			1	1	61		Y	5	2176	WFPA65_39_35	2	0.85		MZPZms(r)
1057	1	P	1965	3			9	3	41		Y	2	553	WFPA65_39_35	5	0.27		Qgo
1058	4	Q	1965	5			4	2	88	56	Y	4	954	WFPA65_39_36	8	38.93		Qga
1059	4	Q	1965	5			4	2	96		N	4	807	WFPA65_39_36	6	7.27		Qga
1060	2	P	1965	4			4	1	89		P	5	548	WFPA65_39_36	6	0.78		Qga
1061	3	D	1978	5			9	2	146		Y	3	1572	NW78_80C_37	1	3.22		Jph(d)
1062	3	D	1978	5			9	3	137		Y	3	974	NW78_80C_37	1	1.87		Qgt
1063	3	D	1978	4			9	3	123		Y	3	711	NW78_80C_37	1	0.82		Qgt
1064	3	P	1998	3			9	3	63		Y	3	719	NWH_98	1	0.12		Qgt
1065	2	Q	1978	3			1	1	111		Y	5	914	NW78_80C_37	1	0.33		Qgt
1066	1	Q	1978	3			4	2	75		Y	3	485	NW78_80C_39	7	0.17		Qga
1067	5	Q	1978	5			4	2	105	78	Y	3	949	NW78_80C_39	8	7.41	5	Qga
1068	1	Q	1978	2			4	3	38		N	1	669	NW78_80C_39	8	0.03		Qga
1069	4	Q	1978	5	1987	4	4	2	114	79	Y	4	1124	NW78_80C_41	9	70.00		Qga
1070	2	D	1978	3			8	1	99		N	5	969	NW78_80C_41	8	0.29	4	Qga
1071	2	D	1978	3			8	1	112		N	5	728	NW78_80C_41	8	0.13	4	Qga
1072	2	D	1978	3			8	1	106		N	5	923	NW78_80C_41	8	0.25	4	Qga
1073	1	D	1978	2			8	2	75		Y	5	753	NW78_80C_41	8	0.05	4	Qga
1074	1	D	1978	2			8	2	50		N	5	735	NW78_80C_41	8	0.07	4	Qga
1075	2	P	1978	3			4	1	99		Y	2	1016	NW78_80C_41	8	0.25		Qgt
1076	5	D	1978	5			4	2	97	97	Y	2	1011	NW78_80C_41	8	1.26		Qga

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1077	1	D	1978	2	1987	3	5	2	86		Y	2	9566	NW78_80C_41	8	0.08		Qga
1078	1	D	1978	1	1987	3	5	2	121		N	2	953	NW78_80C_41	8	0.01		Qgt
1079	1	Q	1978	4			1	1	70		Y	5	2062	NW78_83E_32	1	0.93		MZPZms(r)
1080	1	P	1978	3			2	1	94		Y	1	1855	NW78_83E_33	1	0.23		MZPZms(r)
1081	2	Q	1978	3			1	1	54		Y	1	1634	NW78_83E_32	1	0.36		MZPZms(r)
1082	1	P	1978	4			1	1	63		Y	5	2315	NW78_83E_33	1	0.72		MZPZms(r)
1083	5	Q	1978	3			8	2	50		N	4	2383	NW78_83E_33	9	0.36		MZPZms(r)
1084	1	D	1978	4			2	2	112		I	5	2489	NW78_83E_33	2	0.67		MZPZms(r)
1085	1	P	1978	3			2	2	75		I	5	1131	NW78_83E_33	1	0.37		MZPZms(r)
1086	1	D	1978	3			2	2	62		I	5	1105	NW78_83E_33	1	0.28		MZPZms(r)
1087	5	P	1978	5			4	2	100		Y	5	776	NW78_83E_35	3	1.92		MZPZms(r)
1088	1	P	1978	5			4	2	131		Y	5	808	NW78_83E_35	3	1.61		MZPZms(r)
1089	1	P	1978	3			4	2	93		Y	5	816	NW78_83E_35	3	0.29		MZPZms(r)
1090	1	P	1978	4			4	2	122		Y	5	743	NW78_83E_35	3	0.84		MZPZms(r)
1091	2	D	1978	3			4	1	88		Y	1	605	NW78_83E_35	5	0.22		Qga
1092	1	Q	1978	3			4	1	25		Y	1	371	NW78_83E_35	9	0.24		Qga
1093	1	P	1978	3			2	1	80		I	1	2636	NW78_83E_34	1	0.15		MZPZms(r)
1094	2	P	1978	3			4	1	87		Y	5	539	NW78_83E_35	5	0.26		Qga
1095	1	D	1978	3			9	2	70		Y	1	1052	NW78_84D_23	1	0.10		MZPZms(r)
1096	1	D	1978	2			9	2	77		Y	1	981	NW78_84D_23	1	0.03		MZPZms(r)
1097	1	D	1978	1			9	2	73		Y	1	921	NW78_84D_23	1	0.01		MZPZms(r)
1098	1	D	1978	2			9	2	54		Y	1	1048	NW78_84D_26	3	0.05		Qls(m)
1099	2	D	1978	3			1	1	58		N	1	903	NW78_84D_26	3	0.30		Qls(m)
1100	1	D	1978	2			7	4	38		N	1	883	NW78_84D_26	3	0.03		Qls(m)
1101	1	Q	1978	4			1	1	68		Y	5	1123	NW78_84D_26	3	0.54		Qls(m)
1102	2	D	1978	3			1	1	61		Y	5	1249	NW78_84D_26	3	0.23		Qls(m)
1103	2	P	1978	3			1	1	53		Y	5	1114	NW78_84D_26	2	0.23		Qls(m)
1104	1	Q	1978	3			9	2	54		Y	3	511	NW78_84D_26	8	0.27	8	Qga
1105	1	D	1978	2			4	3	50		N	1	676	NW78_85B_32	7	0.09		Qga
1106	1	P	1978	3			1	1	61		Y	1	2181	NW78_85B_32	1	0.40		MZPZms(r)
1107	2	P	1978	3			1	2	65		Y	1	2106	NW78_85B_32	1	0.35		MZPZms(r)
1108	1	D	1978	3			1	2	73		Y	1	2015	NW78_85B_32	1	0.25		MZPZms(r)
1109	1	D	1978	3			1	2	70		Y	1	1513	NW78_85B_32	1	0.18		MZPZms(r)
1110	2	D	1978	2			1	1	72		Y	1	1453	NW78_85B_32	1	0.06		MZPZms(r)
1111	1	D	1978	4			1	2	64		Y	1	1416	NW78_85B_32	1	0.49		MZPZms(r)
1112	1	D	1978	4			1	2	66		Y	1	1393	NW78_85B_32	1	0.93		MZPZms(r)
1113	2	P	1978	3			1	1	67		Y	1	1299	NW78_85B_32	1	0.39		MZPZms(r)
1114	1	D	1978	2			9	2	54		Y	1	1160	NW78_85B_32	1	0.08		MZPZms(r)
1115	1	D	1978	4			2	3	78		I	5	2328	NW78_86E_8	4	0.76		Jph(d)
1116	1	P	1978	2			2	3	60		Y	3	1701	NW78_86E_8	2	0.10		Jph(d)
1117	1	Q	1978	2			2	3	31		Y	3	1754	NW78_86E_8	2	0.04		Jph(d)

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1118	1	P	1978	3			1	1	39		Y	5	1603	NW78_86E_8	2	0.11		MZPZms(r)
1119	1	P	1978	2			2	2	40		Y	5	2517	NW78_88B_31	2	0.03		MZPZms(r)
1120	1	P	1978	2			2	2	43		Y	5	2531	NW78_88B_31	2	0.07		MZPZms(r)
1121	1	Q	1978	2			1	1	62		I	5	2832	NW78_88B_31	2	0.03		MZPZms(r)
1121	5	P	1978	5			9	2	134		N	3	2063	NW78_81E_35	9	3.10		MZPZms(r)
1122	1	Q	1998	4			7	3	33		N	5	2470	NWH_98	4	1.01		MZPZms(r)
1123	2	Q	2001	3			5	1	45		Y	2	652	NWC01_43_65_171	1	0.21		MZPZms(r)
1124	1	Q	2001	2			2	1	55		Y	1	3130	NWC01_36_69_125	7	0.08		Qgo
1125	1	P	2001	2			2	1	58		I	1	3104	NWC01_36_69_125	1	0.04		MZPZms(r)
1126	2	P	2001	4			7	1	65		Y	1	3030	NWC01_36_69_125	1	0.50	9	MZPZms(r)
1127	1	D	2001	4			7	2	66		Y	1	3037	NWC01_36_69_125	1	0.65	9	MZPZms(r)
1128	3	Q	2001	4			2	2	77		Y	1	2935	NWC01_36_69_125	1	0.69	9	MZPZms(r)
1129	3	D	2001	2			9	1	77		Y	1	2413	NWC01_36_69_125	1	0.09		MZPZms(r)
1130	1	P	2001	4			7	1	65		Y	1	3058	NWC01_36_69_125	1	0.47		MZPZms(r)
1131	3	D	2001	5			7	3	77		Y	1	3582	NWC01_36_69_125	1	1.13		MZPZms(r)
1132	1	D	2001	2			9	3	64		Y	1	3600	NWC01_36_69_125	1	0.06		MZPZms(r)
1133	1	P	2001	3			2	2	70		Y	1	3606	NWC01_36_69_125	1	0.16		MZPZms(r)
1134	1	P	2001	2			2	2	74		Y	1	3498	NWC01_36_69_125	1	0.07		MZPZms(r)
1135	1	P	2001	3			2	2	61		Y	1	3056	NWC01_36_69_125	1	0.18		MZPZms(r)
1136	1	D	2001	5			9	3	85		Y	3	3480	NWC01_36_69_125	1	1.11		MZPZms(r)
1137	1	P	2001	4			9	3	126		Y	1	2988	NWC01_36_69_125	1	0.48		MZPZms(r)
1138	1	D	2001	3			9	3	84		Y	1	3043	NWC01_36_69_125	1	0.15		MZPZms(r)
1139	1	D	2001	2			9	3	123		Y	1	2923	NWC01_36_69_125	1	0.06		MZPZms(r)
1141	2	D	1998	4	2001	4	7	4	77		Y	3	2514	NWH_98	1	0.46		MZPZms(r)
1142	1	D	2001	2			2	2	59		Y	5	3587	NWH_98	1	0.04		MZPZms(r)
1143	4	Q	1998	5			5	2	189		N	4	2589	NWH_98	1	10.05		MZPZms(r)
1144	1	P	2001	4			8	3	143		Y	1	2230	NWH_98	1	0.43		MZPZms(r)
1145	4	Q	1998	5			5	2	103		N	4	2866	NWH_98	1	5.65		MZPZms(r)
1146	1	P	2001	3			8	1	82		I	1	2806	NWC01_36_69_126	1	0.18		MZPZms(r)
1147	4	Q	1998	5			5	2	159		N	4	2587	NWH_98	1	3.08		MZPZms(r)
1148	2	D	1998	3	2001	4	1	1	162		Y	1	2046	NWH_98	1	0.30		MZPZms(r)
1149	1	P	1998	3	2001	3	2	1	125		P	1	1950	NWH_98	1	0.13		MZPZms(r)
1150	4	Q	1998	5			5	2	103	141	Y	4	3312	NWH_98	1	17.08		MZPZms(r)
1151	4	Q	1998	5			5	2	131	173	Y	4	2980	NWH_98	1	8.52		MZPZms(r)
1152	1	Q	1998	4	2001	1	2	2	85		P	2	3535	NWH_98	1	0.66		MZPZms(r)
1153	1	Q	1998	3	2001	1	2	2	82		P	2	3596	NWH_98	1	0.32		MZPZms(r)
1154	1	Q	2001	3			7	2	85		N	2	2568	NWC01_36_69_126	1	0.16		MZPZms(r)
1155	1	Q	2001	3			2	2	79		I	2	2406	NWC01_36_69_126	1	0.16		MZPZms(r)
1156	4	Q	1998	5			5	2	119	113	Y	4	2198	NWH_98	1	23.34		MZPZms(r)
1157	1	P	1998	3	2001	4	2	1	85		P	1	2707	NWH_98	1	0.15		MZPZms(r)
1158	1	P	1998	2	2001	3	2	1	99		P	1	2656	NWH_98	1	0.08		MZPZms(r)

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1159	2	D	2001	2			8	1	87		Y	1	1117	NWC01_36_69_128	1	0.08		MZPZms(r)
1160	1	P	1998	5	2001	4	7	2	165		P	2	1309	NWH_98	1	1.42		MZPZms(r)
1161	1	D	1998	4			9	2	218		Y	1	1379	NWC01_36_69_128	1	0.87		MZPZms(r)
1162	1	D	1998	3	2001	4	9	3	75		Y	1	1759	NWH_98	1	0.11		MZPZms(r)
1163	1	D	1998	3	2001	4	9	3	71		Y	1	1719	NWH_98	1	0.12		MZPZms(r)
1164	1	D	1998	3	2001	4	9	3	84		Y	1	1609	NWH_98	1	0.21		MZPZms(r)
1165	1	D	1998	3	2001	3	9	3	85		Y	1	1541	NWH_98	4	0.12	8	MZPZms(r)
1166	1	D	1998	2	2001	3	9	3	50		Y	1	1501	NWH_98	4	0.04	8	MZPZms(r)
1167	1	D	1998	3	2001	5	9	3	129		Y	1	1416	NWH_98	4	0.40	8	MZPZms(r)
1168	1	D	1998	2	2001	3	9	3	177		Y	1	1366	NWH_98	4	0.08	8	MZPZms(r)
1169	1	D	1998	3	2001	5	9	3	121		Y	1	1253	NWH_98	4	0.38	8	MZPZms(r)
1170	1	D	1998	2	2001	3	9	3	152		Y	1	1238	NWH_98	4	0.02	8	MZPZms(r)
1171	1	D	1998	2	2001	3	9	3	102		Y	1	1202	NWH_98	4	0.05	8	MZPZms(r)
1172	1	D	1998	3	2001	4	9	3	171		Y	1	1006	NWH_98	1	0.14	8	MZPZms(r)
1173	4	Q	1998	5	2001	5	9	3	100		N	4	1703	NWH_98	4	20.10		MZPZms(r)
1174	1	P	1998	2	2001	3	2	2	89		N	2	2203	NWH_98	1	0.05		MZPZms(r)
1175	1	D	1998	3	2001	5	9	3	77		Y	1	2223	NWH_98	1	0.37		MZPZms(r)
1176	1	D	1998	3	2001	5	9	3	89		Y	1	2178	NWH_98	1	0.18		MZPZms(r)
1177	1	D	2001	2			9	3	84		Y	1	1447	NWC01_36_69_128	4	0.03	8	MZPZms(r)
1178	1	P	1998	1	2001	3	2	2	22		N	2	570	NWH_98	9	0.01		Qga
1179	1	P	1998	2	2001	3	2	2	58		N	2	611	NWH_98	7	0.03		Qga
1180	1	P	1998	2	2001	3	2	2	40		N	2	859	NWH_98	9	0.04		Qga
1181	1	P	1998	5	2001	5	4	3	155		Y	5	330	NWH_98	5	1.35		Qga
1182	1	P	2001	3			9	2	80		Y	2	3025	NWC01_36_70_42	1	0.26		MZPZms(r)
1183	1	P	2001	3			9	3	111		Y	2	454	NWC01_36_70_43	3	0.31	4	MZPZms(r)
1184	1	P	2001	3			9	3	58		Y	2	448	NWC01_36_70_43	3	0.13	4	MZPZms(r)
1185	1	P	2001	3			9	3	66		Y	2	533	NWC01_36_70_43	3	0.20	4	MZPZms(r)
1186	2	Q	1987	4			4	1	192		Y	3	638	NWC01_36_70_47	5	0.46	9	Qga
1187	1	P	1987	2			4	2	48		N	1	489	NW87_26_66_269	7	0.06		Qga
1188	1	P	1987	2			4	2	44		N	1	508	NW87_26_66_269	7	0.03		Qga
1189	1	P	1987	2			4	2	57		N	1	534	NW87_26_66_269	7	0.04		Qga
1190	1	P	1987	1			4	2	47		N	1	547	NW87_26_66_269	7	0.01		Qga
1191	1	P	1987	2			4	2	47		N	1	454	NW87_26_66_268	9	0.05		Qga
1192	5	Q	1987	5			4	2	51	47	Y	4	356	NW87_26_66_268	7	2.53		Qga
1193	1	Q	1987	3			4	1	53		P	1	378	NW87_26_66_268	7	0.39		Qga
1194	2	D	1987	5			8	1	114		Y	5	988	NW87_30_68_40	8	3.06	4	Qga
1195	1	Q	1987	2			8	1	63		P	2	951	NW87_30_68_40	8	0.02		Qga
1196	1	D	1987	4			8	2	80		P	1	917	NW87_30_68_40	8	0.65	4	Qga
1197	1	P	1987	2			8	2	66		P	1	835	NW87_30_68_40	8	0.08	4	Qga
1198	1	P	1987	2			8	2	59		P	1	822	NW87_30_68_40	8	0.03	4	Qga
1199	1	P	1987	2			8	2	86		P	1	905	NW87_30_68_40	8	0.08	4	Qga

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1200	1	P	1987	1			8	2	67		P	1	867	NW87_30_68_40	8	0.01	4	Qga
1201	1	P	1987	1			8	2	64		P	1	798	NW87_30_68_40	8	0.02	4	Qga
1202	1	P	1987	1			8	2	63	57	P	1	799	NW87_30_68_40	8	0.01	4	Qga
1203	4	Q	1987	5			4	2	91		N	4	920	NW87_30_68_40	8	9.65		Qga
1204	1	Q	1987	4			1	1	108		Y	1	1560	NW87_30_68_36	4	0.62		MZPZms(r)
1205	1	Q	1987	2			1	1	118		Y	1	1310	NW87_30_68_36	1	0.06		MZPZms(r)
1206	1	P	1987	3			2	2	161		I	1	1007	NW87_30_68_36	1	0.40		MZPZms(r)
1207	5	Q	1987	5			2	2	169	117	Y	5	2604	NW87_24_67_33	1	3.81		MZPZms(r)
1208	2	P	1987	5			1	1	179		Y	1	2190	NW87_24_67_33	4	1.09		MZPZms(r)
1209	1	Q	1987	3			1	1	135		Y	1	2058	NW87_24_67_33	4	0.14		MZPZms(r)
1210	2	P	1987	3			1	1	110		P	5	1705	NW87_24_67_33	1	0.17		MZPZms(r)
1211	1	P	1987	3			7	3	92		P	5	1548	NW87_24_67_33	1	0.13		MZPZms(r)
1212	2	P	1987	3			1	1	80		Y	1	975	NW87_24_67_32	1	0.34		MZPZms(r)
1213	2	Q	1987	3			1	1	97		Y	1	1152	NW87_24_67_34	1	0.34		MZPZms(r)
1214	1	Q	1987	5			1	2	108		Y	1	1122	NW87_24_67_34	1	1.72		MZPZms(r)
1215	1	Q	1987	3			9	1	41		Y	1	680	NW87_24_67_34	7	0.25		Qgt
1216	1	Q	1987	2			9	1	45		Y	1	493	NW87_24_67_34	7	0.07		Qga
1217	1	P	1987	3			8	2	83		I	1	978	NW87_24_67_36	8	0.24	4	Qga
1218	1	D	1987	2			8	2	74		I	1	750	NW87_24_67_36	8	0.08	4	Qga
1219	1	P	1987	2			8	2	131		I	1	973	NW87_24_67_36	8	0.02	4	Qga
1220	1	Q	1987	1			8	2	82		I	1	978	NW87_24_67_36	8	0.02	4	Qga
1221	1	Q	1987	2			2	1	81		Y	1	1873	NW87_24_67_32	1	0.05		MZPZms(r)
1222	1	Q	1987	2			2	2	119		P	5	1503	NW87_24_67_32	1	0.10		MZPZms(r)
1223	1	P	1987	3			4	3	35		N	1	537	NW87_30_70_195	9	0.12		Qga
1224	1	P	1987	2			4	3	64		N	1	474	NW87_30_70_195	6	0.04	8	Qgpc
1225	1	P	1987	3			4	3	39		N	1	550	NW87_30_70_195	6	0.22	8	Qgpc
1226	1	P	1987	2			4	3	61		N	1	470	NW87_30_70_195	6	0.06	8	Qgpc
1227	1	P	1987	2			4	3	82		N	1	468	NW87_30_70_195	6	0.05	8	Qgpc
1228	1	P	1987	2			4	3	48		N	1	652	NW87_30_70_195	6	0.10	8	Qga
1229	1	P	1987	2			4	3	64		N	1	566	NW87_30_70_195	6	0.07	8	Qga
1230	1	P	1987	2			4	3	35		N	1	643	NW87_30_70_195	6	0.09	8	Qga
1231	1	P	1987	2			4	3	59		N	1	516	NW87_30_70_195	6	0.08	8	Qga
1232	1	P	1987	3			4	3	57		N	1	519	NW87_30_70_195	6	0.20	8	Qga
1233	2	P	1987	2			1	1	71		Y	1	432	NW87_30_70_193	3	0.09		MZPZms(r)
1234	1	Q	1987	2			9	2	65		Y	1	739	NW87_30_70_193	2	0.03		MZPZms(r)
1235	1	P	1987	2			9	2	84		Y	1	505	NW87_30_70_193	3	0.03	1	MZPZms(r)
1236	1	P	1987	2			9	2	82		Y	1	541	NW87_30_70_193	3	0.05		MZPZms(r)
1237	1	D	1987	5			9	2	89		Y	1	1882	NW87_30_70_193	1	1.24	1	MZPZms(r)
1238	4	Q	1998	5			5	2	155		N	4	1057	NWH_98	1	3.90	1	MZPZms(r)
1239	1	Q	1987	2			2	2	69		P	1	2294	NW87_30_70_193	1	0.10		MZPZms(r)
1240	1	P	1987	3			9	2	70		Y	1	2157	NW87_30_70_193	1	0.12		MZPZms(r)

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1241	1	P	1987	3			9	2	80		Y	1	2495	NW87_30_70_193	1	0.11		MZPZms(r)
1242	1	P	1987	3			8	2	91		I	1	2544	NW87_30_70_193	1	0.20		MZPZms(r)
1243	2	Q	1987	3			1	1	61		Y	1	3030	NW87_30_70_192	1	0.14		MZPZms(r)
1244	1	Q	1987	3			5	2	67		Y	5	2539	NW87_30_70_192	1	0.20	2	MZPZms(r)
1245	1	Q	1987	2			5	2	61		I	1	2461	NW87_30_70_192	1	0.06		MZPZms(r)
1246	1	P	1987	3			9	2	54		Y	1	3112	NW87_30_70_191	1	0.11		MZPZms(r)
1247	1	Q	1987	3			1	1	76		P	1	2191	NW87_30_70_192	1	0.35		MZPZms(r)
1248	1	P	1987	3			4	3	78		N	1	879	NW87_30_72_138	8	0.15		Qga
1249	1	P	1987	2			4	3	81		N	1	888	NW87_30_72_138	8	0.06		Qga
1250	1	P	1987	2			4	3	44		N	1	902	NW87_30_72_137	7	0.02		Qga
1251	1	P	1987	2			4	3	43		N	1	602	NW87_30_72_137	9	0.05		Qga
1252	2	P	1987	3			1	1	82		Y	1	1981	NW87_30_72_133	1	0.40		MZPZms(r)
1253	1	D	1987	4			9	1	65		Y	1	2084	NW87_30_72_133	1	0.78		MZPZms(r)
1254	6	P	1987	5			8	3	66	64	Y	1	1246	NW87_30_72_133	1	2.05		MZPZms(r)
1255	6	P	1987	5			1	3	70	77	Y	1	1386	NW87_30_72_133	1	5.86		MZPZms(r)
1256	5	Q	1987	5			4	3	83		N	2	1007	NW87_31_71_32	8	1.06		Qga
1257	1	P	1987	2			2	2	24		Y	2	1568	NW87_31_71_29	9	0.07		MZPZms(r)
1258	2	P	2004	4			4	1	64		Y	3	419	field	8	0.67	1	Qga
1259	2	P	2004	3			4	1	83		Y	3	493	field	5	0.37	1	Qga
1260	2	P	2004	5			4	1	79		Y	3	557	field	8	1.91	1	Qga
1261	2	P	2004	4			4	1	66		Y	1	656	field	7	0.90	1	Qga
1262	1	P	2004	4			4	3	54		Y	1	740	field	7	1.02	1	Qga
1263	1	D	2004	3			4	1	95		Y	1	796	field	7	0.23	1	Qga
1264	1	P	2004	3			4	1	80		N	2	807	field	7	0.26	2	Qga
1265	1	P	2004	3			4	2	50		P	2	805	field	6	0.20		Qga
1266	1	P	2004	3			4	2	48		Y	2	685	field	6	0.26		Qga
1267	1	P	2004	4			4	2	71		N	2	1016	field	6	1.01		Qga
1268	1	D	2004	4			4	2	86		P	2	991	field	6	0.70		Qga
1269	4	P	2004	5			4	2	63	64	Y	4	882	field	6	6.78	4	Qga
1270	1	P	1998	3			8	3	45	45	N	1	798	field	6	0.27	4	Qga
1271	5	P	2004	5			4	2	64		Y	4	801	field	6	3.43		Qga
1272	4	P	2004	5			4	2	42	33	Y	4	641	field	8	26.34		Qga
1273	1	P	2004	3			4	2	89		Y	1	591	field	6	0.27		Qga
1274	1	P	2004	4			4	2	44		Y	1	591	field	6	0.54		Qga
1275	1	D	2004	4			4	1	103		Y	3	713	field	6	0.52		Qga
1276	7	P	2004	5			4	2	30	84	Y	4	599	field	8	21.37		Qga
1277	7	P	2004	5			4	2	59		N	4	706	field	8	1.59		Qga
1278	5	P	2004	5			4	3	42	30	N	1	719	field	6	2.68		Qga
1279	5	P	2004	4			4	2	64	57	Y	1	833	field	7	1.00		Qga
1280	7	Q	2004	5			4	2	47	36	N	4	783	field	7	2.58		Qga
1281	2	P	2004	4			4	1	155		Y	3	345	field	5	0.51	1	Qga

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient (%)	Deep-Seated Max. Gradient at Toe (%)	Delivery	Land Use	Initial Elevation (ft)	Photo_number	MWMU	Acreage	Secondary Landform	Geologic Unit (See Dragovich and others, 2002)
1282	2	P	2004	3			1	1	121		Y	3	398	field	5	0.36		Qga
1283	4	Q	1998	5			4	2	77	78	Y	4	814	NWH_98	6	11.69		Qga
1284	1	P	1998	2			8	2	51		N	1	754	NWH_98	6	0.07		Qga
1285	1	P	1998	2			8	2	59		N	1	808	NWH_98	6	0.09		Qga
1286	4	Q	1998	5			4	2	66	52	Y	4	874	NWH_98	6	5.52		Qga
1287	7	P	2004	5			4	2	73	70	Y	4	831	field	7	5.73		Qga
1288	4	Q	1998	5			4	2	110	56	Y	4	1067	NWH_98	8	44.61		Qga
1289	1	P	1998	2			8	2	61		N	1	829	NWH_98	6	0.06		Qga
1290	1	P	1998	3			8	2	48		N	1	1021	NWH_98	8	0.14		Qgt
1291	1	Q	1998	2			4	2	34		P	1	644	NWH_98	6	0.08	2	Qga
1292	1	Q	1998	3			4	2	54		I	1	752	NWH_98	6	0.25	2	Qga
1293	1	P	1998	2			8	2	61		N	1	988	NWH_98	8	0.09	4	Qga
1294	2	P	2004	3			1	1	12		Y	3	237	NWH_98	9	0.13	4	Qa
1295	7	Q	2004	5			4	2	82	88	N	4	706	field	8	9.62		Qga
1296	1	Q	1998	1			8	2	36		N	1	781	NWH_98	8	0.01		Qga
1297	1	D	2004	5			9	3	151		Y	5	348	field	3	1.14	4	MZPZms(r)
1298	2	Q	1998	3			4	1	65		Y	3	437	NWH_98	5	0.12	1	Qgpc
1299	1	Q	1998	2			4	2	52		N	1	564	NWH_98	7	0.07	2	Qgo
1300	4	Q	1998	5			4	2	52	52	Y	4	680	NWH_98	6	6.61	5	Qga
1301	1	Q	1998	3			4	2	23		N	1	752	NWH_98	9	0.15		Qga
1302	4	Q	1998	5			4	2	103	89	Y	4	951	NWH_98	8	13.48		Qga
1303	5	Q	2004	5			4	2	55		Y	3	635	field	6	1.46	5	Qga
1304	2	Q	1991	3			1	1	71		Y	1	567	NW91_32_66_220	7	0.18		Qga
1305	1	P	1991	3			1	2	70		Y	1	561	NW91_32_66_220	7	0.13		Qga
1306	1	P	1991	5			4	3	58		I	5	379	NW91_32_66_220	7	1.27		Qga
1307	1	P	1991	3			4	3	41		I	5	326	NW91_32_66_220	7	0.35		Qga
1308	1	D	1991	3			4	1	88		Y	1	589	NW91_32_66_220	7	0.21	4	Qga
1309	1	D	1991	3			4	1	58		Y	1	711	NW91_32_66_220	7	0.35	4	Qgo
1310	1	Q	1991	2			4	2	70		I	1	602	NW91_32_66_220	7	0.08		Qgo
1311	1	Q	1991	2			4	2	29		I	1	734	NW91_32_66_220	7	0.09		Qgo
1312	1	P	1991	2			4	3	62		I	5	456	NW91_32_66_220	7	0.07		Qga
1313	1	P	1991	5			4	3	50		I	5	553	NW91_32_66_220	7	1.06		Qga
1314	1	P	1991	3			4	3	77		I	5	409	NW91_32_66_220	7	0.13		Qga
1315	1	P	1991	2			4	3	72		I	5	485	NW91_32_66_220	7	0.04		Qga
1316	1	P	1991	3			4	3	58		I	5	719	NW91_32_66_220	8	0.18		Qga
1317	1	P	1991	3			4	2	91		N	1	548	NW91_32_66_220	8	0.11		Qga
1318	1	P	1991	2			4	3	45		N	1	681	NW91_32_66_220	7	0.07		Qga
1319	1	P	1991	3			4	3	75		N	1	638	NW91_32_66_220	7	0.11		Qga
1320	4	P	1991	5			4	3	67	67	Y	1	719	NW91_32_66_221	7	2.30		Qgo
1321	1	P	1991	2			4	3	59		N	1	681	NW91_32_66_221	7	0.03		Qgo
1322	1	P	1991	2			4	3	73		N	5	428	NW91_32_66_221	7	0.10		Qga

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1323	1	P	1991	2			4	3	64		N	5	413	NW91_32_66_221	7	0.04		Qga
1324	5	Q	1991	5			4	2	58	58	Y	4	671	NW91_32_66_221	8	6.01		Qga
1325	1	P	1991	4			4	3	104		N	1	640	NW91_32_66_221	7	0.69		Qga
1326	5	Q	2004	3			5	2	56		Y	1	740	field	8	0.22	4	Qga
1327	1	P	1991	3			9	2	129		Y	1	653	NW91_27_68_69	1	0.15		MZPZms(r)
1328	7	P	1991	5			5	2	161	70	Y	4	2273	NW91_27_68_69	1	13.46		MZPZms(r)
1329	1	P	1991	4			5	2	126		Y	1	1858	NW91_27_68_69	1	0.61		MZPZms(r)
1330	1	P	1991	3			5	2	80		Y	1	1206	NW91_27_68_69	1	0.16		MZPZms(r)
1331	2	Q	1991	3			1	1	98		Y	1	2746	NW91_27_68_69	1	0.12		MZPZms(r)
1332	1	P	1991	4			2	1	118		Y	1	2802	NW91_27_68_68	1	0.83		MZPZms(r)
1333	1	P	1991	1			9	1	123		Y	1	2480	NW91_27_68_68	1	0.02		MZPZms(r)
1334	1	P	1991	3			2	1	160		Y	1	2677	NW91_27_68_68	1	0.22		MZPZms(r)
1335	1	P	1991	5			2	1	85		Y	1	2421	NW91_27_68_68	1	1.41		MZPZms(r)
1336	7	P	1991	5			5	2	132		Y	1	3298	NW91_27_68_67	1	6.52		Jph(d)
1337	1	P	1991	5			5	2	92		Y	1	2979	NW91_27_68_67	1	1.23		Jph(d)
1338	1	P	1991	4			5	2	78		Y	1	3017	NW91_27_68_67	1	0.71		Jph(d)
1339	7	P	1991	5			5	2	127	95	Y	1	3128	NW91_27_68_67	1	6.16		Jph(d)
1340	1	P	1991	4			5	2	99		Y	1	2522	NW91_27_68_67	1	0.49		Jph(d)
1341	1	P	1991	2			9	2	94		Y	1	2811	NW91_27_68_66	1	0.09		MZPZms(r)
1342	2	P	1991	3			1	1	98		Y	1	2792	NW91_27_68_66	1	0.17		MZPZms(r)
1343	4	Q	1991	5			5	2	96		N	4	3974	NW91_27_68_66	1	52.90		Jph(d)
1344	4	P	1991	5			2	2	111	60	Y	1	1165	NW91_27_68_66	8	70.71		Qga
1345	5	P	1991	5			2	2	91	93	N	1	620	NW91_27_68_66	8	7.11		Qga
1346	1	P	1991	2			4	2	66		Y	5	559	NW91_32_66_222	7	0.05	2	Qga
1347	1	P	1991	1			4	2	53		N	1	614	NW91_32_66_222	7	0.01	2	Qga
1348	1	P	1991	1			4	2	47		P	1	621	NW91_32_66_222	9	0.01	2	Qga
1349	1	P	1991	3			4	2	74		P	1	630	NW91_32_66_222	7	0.14	2	Qga
1350	4	P	1991	5			4	2	76	49	N	4	1165	NW91_32_67_251	8	46.93		Qga
1351	4	Q	1998	5			5	2	42		N	4	602	NWH_98	7	5.07		Qga
1352	1	Q	1998	3			4	2	75		P	1	870	NWH_98	7	0.28	2	Qga
1353	4	P	1998	5			4	2	74	75	Y	4	1096	NWH_98	8	40.54		Qga
1354	4	Q	1998	5			5	2	87	67	Y	4	1137	NWH_98	8	7.51		Qga
1355	4	Q	1998	5			4	2	61	48	N	4	633	NWH_98	8	3.02	5	Qga
1356	1	Q	1998	5			9	3	114		Y	3	530	NWH_98	8	1.28	4	Qga
1357	4	Q	1998	5			4	2	83	39	Y	4	1008	NWH_98	8	49.94		Qga
1358	2	Q	1998	5			1	1	82		Y	1	3390	NWH_98	2	1.09		MZPZms(r)
1359	1	Q	1998	3			1	1	74		Y	1	3408	NWH_98	2	0.10		MZPZms(r)
1360	4	Q	1998	5			4	2	61	36	N	4	822	NWH_98	8	32.87		Qgo
1361	4	Q	1998	5			5	2	92	77	Y	4	2439	NWH_98	4	80.45		Jph(d)

12.0 Appendix B – Form A-2: Mass Wasting Map Unit Descriptions

Notes: In the following descriptions, most information on MWMU areas, elevations, and slope gradients were generated in GIS from digital elevation data. Total area, minimum, maximum, mean, and standard deviation (s.d.) statistics were calculated by ArcGIS tools from 10-m DEMs. Those data labeled "typical" are semi-quantitative analysts' estimates, based on examination of available maps and field experience.

Review comments regarding the initial analysis (WSL, 2004) noted that more precise slope limits could aid in the identification of potentially unstable terrain in the field. Based on reexamination (MJB, 2007) of the landslide inventory data, slope thresholds were calculated which can be used as criteria to discriminate problematic areas for special attention. Within each MWMU, the gradients of the inventoried slides (Appendix A, Form A-1) were analyzed to determine the values approximately one standard deviation below the mean, encompassing ~84% of a supposedly normal distribution; to check for abnormal samples, the ~85th percentiles were also determined separately. Analysis was done on gradients expressed as both percent and degrees: the rapid inflation of % values for steeper slopes can cause distortion of the parameters, so degrees produce better statistics. For MWMUs rated high hazard, thresholds were generally rounded down to the nearest 5% (i.e., more conservatively, including somewhat gentler slopes); these levels capture 80 to >95% of the inventoried slides. For MWMUs rated moderate and low hazard, the levels were usually rounded upward to the next 5%.

"Confidence" statements refer to the confidence in the mass-wasting unit as a whole. Generally confidence in landslide identification and the precision of mapping is generally low to moderate, as the study is designed to provide representative samples rather than exhaustive analysis.

MWMU Number: 1 **Rapidly Eroding Gorge Systems in Bedrock (≥60%) – High Overall Hazard**

Description: MWMU1 comprises the deeply-incised inner gorges of Quartz, Hatchery, and Ruxall Creeks and six similar gorge systems in the southern part of the study area. All of these inner gorges contain many rule identified unstable slopes. Steep sidewalls, knife-edged ridges, and numerous landslides characterize these gorge systems. MWMU1 covers 9% of the study area. Landslides commonly initiate in harvest units on steeper slopes. Convergent headwall and sidewall areas are of particular concern, as are slopes steeper than 60%.

Materials: Black phyllite and metamorphosed sandstone of the Slate of Rinker Ridge (Tabor and others, 2002), along with overlying veneers of glacial till and thin colluvial soils. The Slate of Rinker Ridge has prominent northwest-trending layering. The layering consists of micro-faults (rock cleavage) and interbedded black phyllite (essentially identical to the Darrington Phyllite [Tabor and others, 2002]) with stronger metamorphosed sandstone beds, typically many feet thick. Landslides commonly initiate and propagate up-slope in the weaker phyllite units.

Landform: Deeply incised gorge systems with rapidly expanding sidewalls and headwalls that form steep subsidiary gorges and knife edge ridges.

Observed Slope on Failure (from DEM):	Min: 40%	Max: 218%	Mean: 96%, s.d.= 35%
Elevation:	Min: 304’	Max: 3,629’	Typical: 1,200’ to 2,300’
Total Area:	1919 acres		
Total Area of Landslides:	266.6 acres.		
Total Number of Landslides:	138		

MW Processes: Mostly shallow-rapid debris slides, debris avalanches, and debris flows, but many small sporadic deep-seated landslides are also present.

Forest Practice Sensitivity: High, especially for harvest. Clearcuts and young stands account for 70% of all slides.

Mass Wasting Potential: High. 138 landslides have been identified.

Number of Delivering Landslides:	110
Area of Delivering Landslides:	97.8 acres
Landslide Area Rate for Delivery:	1306

Delivery Potential: High. MWMU1 has one of the highest Landslide Area Rate for Delivery of any MWMU examined during the Landslide Hazard Zonation project.

Delivery Criteria Used: Fresh shallow rapid landslides observed to have entered directly into various drainages.

Hazard Potential Rating: High.

Trigger Mechanisms: Harvest in convergent headwalls and gorges, especially near ridge crests. Road construction on lower angle ridge crests that are close to convergent headwalls and inner gorges. (In addition, it should be noted that black phyllite layers in the Slate of Rinker Ridge seems to be the locus of many if not most failures. These layers trend northwest and intersect the major gorge systems.)

Confidence: Moderate. Because of large even-aged harvests and steep ground, it is easy to identify landslides and most appear to have been inventoried. However, the boundaries of MWMU1 could be refined slightly with additional work.

MWMU Number: 2 Other Gorges, Headwalls & Hollows in Bedrock (≥40%) – High Overall Hazard

Description: MWMU2 comprises other inner gorges and bedrock hollows as well as smaller convergent headwalls. Most of these features are rule identified unstable slopes. MWMU2 covers 2% of the study area. Landslides commonly initiate in harvest units on steeper slopes. Convergent headwall and sidewall areas are of particular concern. Landslides have occurred on relatively moderate slopes, dictating the field threshold of 40%.

Materials: Black phyllite and metamorphosed sandstone of the Slate of Rinker Ridge (Tabor and others, 2002) along with overlying veneers of glacial till and thin colluvial soils. The Slate of Rinker Ridge has prominent northwest-trending layering. The layering consists of micro-faults known as cleavage and of interbedded black phyllite (essentially identical to the Darrington Phyllite [Tabor and others, 2002]) with stronger metamorphosed sandstone beds, typically many feet thick. Landslides commonly initiate and propagate up-slope in the weaker phyllite units.

Landform: Inner gorges, bedrock hollows, and small convergent headwalls.

Observed Slope on Failure (from DEM):	Min: 31%	Max: 112%	Mean: 63%, s.d.= 20%
Elevation:	Min: 392’	Max: 3,632’	Typical: 1,000’ to 2,300’
Total Area:	320 acres		
Total Area of Landslides:	5.8 acres		
Total Number of Landslides:	16		

MW Processes: Mostly shallow-rapid debris slides and debris flows. Only one deep-seated slide, a small sporadic deep-seated failure, was mapped.

Forest Practice Sensitivity: High, especially for roading. Roads account for 44% of all landslides.

Mass Wasting Potential: High. 16 landslides have been identified in a relatively small area.

Number of Delivering Landslides:	13
Area of Delivering Landslides:	4.7 acres
Landslide Area Rate for Delivery:	376

Delivery Potential: High. Most of MWMU2 lies within inner gorges or other strongly convergent topography.

Delivery Criteria Used: Fresh shallow rapid landslides observed within inner gorge drainages.

Hazard Potential Rating: High.

Trigger Mechanisms: Roading and harvest in convergent headwalls and gorges, especially near ridge crests. Road construction on lower angle ridge crests that are close to convergent headwalls and inner gorges. (In addition, it should be noted that black phyllite layers in the Slate of Rinker Ridge seems to be the locus of many if not most failures. These layers trend northwest and intersect the major gorge systems.)

Confidence: High. Like MWMU1, it is easy to identify landslides in MWMU2 and most appear to have been inventoried.

MWMU Number: 3 Steep Bedrock Slopes above Finney Creek & Skagit River (≥55%) – High Overall Hazard

Description: MWMU3 comprises steep planar slopes directly above Finney Creek or the Skagit River, along with a broad mass wasting area on the northeast face of Leonards Ridge, the geology of which was mapped by Tabor and others (2002). These slopes are cut in bedrock or in thin veneers of till or other sediments over shallow bedrock; most slides have occurred on slopes steeper than 55%. Although some rule-identified features are present, most of MWMU3 is not composed of rule-identified landforms. MWMU3 covers 2% of the study area.

Materials: Mostly metamorphic rocks of the Slate of Rinker Ridge (Tabor and others, 2002), but also includes heterogeneous metamorphic rocks of the Chilliwack Group, which are very unstable in the adjacent Jackman Creek watershed (Lingley, 2004a). May include small areas having veneers of glacial terrace sediments, such as outwash sand and gravel and glacial-lacustrine clay in lower elevation areas.

Landform: Planar cliffs and steep slopes, most of which have been eroded by floodwaters from Finney Creek or the Skagit River.

Observed Slope on Failure (from DEM):	Min: 38%	Max: 151%	Mean: 81%, s.d.= 29%
Elevation:	Min: 229’	Max: 1,572	Typical: 700’
Total Area:	442 acres		
Total Area of Landslides:	12.4 acres		
Total Number of Landslides:	20		

MW Processes: Mostly shallow-rapid slides with minor debris flows and small sporadic deep-seated slides

Forest Practice Sensitivity: High. (However, most failures appear to occur only during catastrophic floods.)

Mass Wasting Potential: High. 16 landslides have been identified in a relatively small area.

Number of Delivering Landslides:	16
Area of Delivering Landslides:	8.8 acres
Landslide Area Rate for Delivery:	510

Delivery Potential: High. Most of MWMU3 lies above rivers or above public roads.

Delivery Criteria Used: Fresh shallow rapid landslides observed on roads and in Finney Creek.

Hazard Potential Rating: High.

Trigger Mechanisms: Flooding, road maintenance, and harvest.

Confidence: Moderate. Because the steep, north-facing slopes are hidden on aerial photography, some landslides may not have been inventoried. Therefore, MWMU3 is considered representative rather than exhaustive.

MWMU Number: 4 Deep-Seated Slides on Bedrock Slopes (≥65%) – High Overall Hazard

Description: MWMU4 includes large, mostly relict, deep-seated landslides on bedrock and adjacent lands. These large landslides are the locus of numerous smaller landslides. Because of the steep angles of the headscarps, bodies, and toes of the deep-seated landslides, a large proportion of the small failures deliver sediment to superimposed or marginal drainages. The toes of these features are rule-identified unstable slopes, but other parts would normally not be considered unstable under the Forest Practices Rules; the 65% slope threshold should be applied on scarps and bodies as well. MWMU4 covers 1% of the study area. Landslides commonly initiate in harvest units on steeper slopes.

Materials: Black phyllite and metamorphosed sandstone of the Slate of Rinker Ridge (Tabor and others, 2002) along with overlying veneers of glacial till and thin colluvial soils.

Landform: Deep-seated relict landslides.

Observed Slope on Failure (from DEM):	Min: 33%	Max: 179%	Mean: 108%, s.d.= 42%
Elevation:	Min: 907'	Max: 3,446	Typical: 2,000'
Total Area:	216 acres		
Total Area of Landslides:	105.3 acres		
Total Number of Landslides:	15		

MW Processes: All shallow-rapid failures, except one debris flow.

Forest Practice Sensitivity: High, especially for harvest with 92% of delivering landslides related to recent clear-cut harvest.

Mass Wasting Potential: High. 15 landslides have been identified in a relatively small area.

Number of Delivering Landslides:	12
Area of Delivering Landslides:	3.0 acres
Landslide Area Rate for Delivery:	356

Delivery Potential: High. Most of MWMU4 lies on very steep slopes such that small landslides from deep-seated headscarps move into drainages.

Delivery Criteria Used: Fresh shallow rapid landslides observed in drainages.

Hazard Potential Rating: High.

Trigger Mechanisms: Harvest on relict landslides.

Confidence: Moderate. The difficulty in mapping MWMU4 lies in accurately locating and mapping subtle deep-seated landslides.

MWMU Number: 5 **Steep Slopes in Glacial Terrace Deposits above Roads & Rivers (≥50%) – High Overall Hazard**

Description: MWMU5 is similar to MWMU3 except that the steep slopes above the Skagit River and Finney Creek are cut in glacial terrace sediments. MWMU5 is rated as high hazard owing to fairly continuous raveling where vegetation has been removed by earlier landslides; although the number of slides is small, a significant proportion of them occurred on moderate slopes, dictating the 50% threshold. MWMU5 occupies 1% of the study area.

Materials: Where observed during this study, the glacial terrace sediments are composed of a basal unit of sand and gravel overlain by poorly-graded sand, which is in turn overlain by blue-gray glacial lake clay and more poorly-graded sand. These units correspond to advance outwash (geologic units Qga and Qgal) of the Vashon continental glaciation and (possibly) older units. These are overlain by olive gray till (mixed sand, clay, gravel, and cobbles), a thinner poorly-graded sand unit, and, at the highest elevations, sand and gravel. Although these glacial terrace sediments are generally stacked layer-cake fashion, they show considerable lateral variation owing to changes in the original environment of sediment deposition and subsequent landsliding.

Landform: Over-steepened slopes with minor inner gorges. These are well exposed along the South Skagit Road.

Observed Slope on Failure (from DEM): Min: 41% Max: 192% Mean: 103%, s.d.= 51%

Elevation: Min: 185' Max: 751' Typical: 350'

Total Area: 241.4 acres

Total Area of Landslides: 4.5 acres

Total Number of Landslides: 10

MW Processes: Mostly debris flows, but includes shallow rapid and small sporadic deep-seated landslides.

Forest Practice Sensitivity: Probably high, but many of the slopes are so steep that harvesting has not occurred.

Mass Wasting Potential: High. MWMU5 is rated high on the basis of 10 landslides in a 241-acre MWMU.

Number of Delivering Landslides: 10

Area of Delivering Landslides: 3.9 acres

Landslide Area Rate for Delivery: 414

Delivery Potential: High. All landslides appear to deliver to Finney Creek, the Skagit River, or adjacent roads.

Delivery Criteria Used: Landslides observed entering rivers or impinging on roads.

Hazard Potential Rating: High.

Trigger Mechanisms: It appears most of these slopes are so steep that any activity or major precipitation event will trigger failures. Note that several of these failures are currently raveling.

Confidence: Moderate. Landslides on steep north faces cannot be seen on aerial photography, so some MWMU5 areas may not have been mapped.

MWMU Number: 6 Rapidly Eroding Basins in Glacial Terrace Deposits (≥45%) – High Overall Hazard

Description: MWMU6 includes several large (~300 acre) convergent basins consisting of actively eroding headwalls in glacial terrace sediments. These generally have poorly developed first-order streams and zero-order hollows that coalesce to form a single outlet. The headwalls and hollows are sites of frequent landslides including varied shallow rapid processes on gentle to moderate slopes and earthflows and slumps on low-angle slopes. The underlying cause of these landslides is the interlayering of poorly permeable layers including till and glacial-lacustrine clay, with highly permeable and very poorly consolidated glacial outwash sand. More specifically, failures occur in response to deep groundwater recharge. MWMU6 occupies 5% of the study area.

Materials: Where observed during this study, the glacial terrace sediments are composed of a basal sand and gravel unit overlain by poorly-graded sand, which in turn is overlain by blue-gray glacial lake clays and more poorly-graded sand. These units correspond to advance outwash (geologic units Qga and Qgal) of the Vashon continental glaciation and (possibly) older units. These are overlain by olive gray till (mixed sand, clay, gravel, and cobbles), a thinner poorly-graded sand unit, and, at the highest elevations, sand and gravel. Although these glacial terrace sediments are generally stacked layer-cake fashion, they show considerable lateral variation owing to changes in the original environment of sediment deposition and subsequent landsliding.

Landform: Convergent basins consisting of actively eroding headwalls. Superimposed on these features are moderate gradient inner gorges and sediment hollows.

Observed Slope on Failure (from DEM):	Min: 34%	Max: 103%	Mean: 63%, s.d.= 18%
Elevation:	Min: 183’	Max: 1,144’	Typical: 500’
Total Area:	1094 acres		
Total Area of Landslides:	54.7 acres		
Total Number of Landslides:	37		

MW Processes: Shallow rapid landslides account for 68% of all failures but deep-seated slumps and small sporadic deep-seated landslides are a surprisingly high 24% of observed failures.

Forest Practice Sensitivity: High. 73% of observed landslides are associated with clear cuts or young stands.

Mass Wasting Potential:	High.
Number of Delivering Landslides:	15
Area of Delivering Landslides:	17.4 acres
Landslide Area Rate for Delivery:	408

Delivery Potential: High. Although the number of delivering landslides is a low percentage, the Landslide Area Rate for Delivery is high.

Delivery Criteria Used: Landslides observed failing into inner gorges and creeks.

Hazard Potential Rating: High.

Trigger Mechanisms: Harvest and roading on terrace margins and convergent slopes.

Confidence: Moderate. Fieldwork suggests that air-photo interpretation is insufficient for identifying the small shallow rapid landslides common in MWMU6, so some basins may not be mapped with a high level of precision.

MWMU Number: 7 **Other Gorges, Headwalls & Hollows in Glacial Terrace Deposits (≥45%) – High Overall Hazard**

Description: MWMU7 consists of inner gorges, convergent headwalls, and sediment hollows typical of unstable forested areas throughout Washington. But in this study area, landslides form along terrace margins and the unstable landforms commonly fail at lower slope angles (mean slope on failure = 63%) than most rule-identified equivalents (see WAC 222-16-050), dictating a lower slope threshold of 45%. MWMU7 occupies 3% of the study area.

Materials: Where observed during this study, the glacial terrace sediments are composed of a basal sand and gravel unit overlain by poorly-graded sand, which in turn is overlain by blue-gray glacial lake clays and more poorly-graded sand. These units correspond to advance outwash (geologic units Qga and Qgal) of the Vashon continental glaciation and (possibly) older units. These are overlain by olive gray till (mixed sand, clay, gravel, and cobbles), a thinner poorly-graded sand unit, and, at the highest elevations, sand and gravel. Although these glacial terrace sediments are generally stacked layer-cake fashion, they show considerable lateral variation owing to changes in the original environment of sediment deposition and subsequent landsliding.

Landform: Low to high angle terrace margins, inner gorges, hollows, and headwalls superimposed on a two-step glacial terrace complex.

Observed Slope on Failure (from DEM):	Min: 29%	Max: 104%	Mean: 63%, s.d.= 18%
Elevation:	Min: 273’	Max: 1,012’	Typical: 500’
Total Area:	669.7 acres		
Total Area of Landslides:	29.6 acres		
Total Number of Landslides:	50		

MW Processes: Mostly shallow-rapid undifferentiated, but includes many other types.

Forest Practice Sensitivity:	High.
Mass Wasting Potential:	High.
Number of Delivering Landslides:	22
Area of Delivering Landslides:	14.8 acres
Landslide Area Rate for Delivery:	567

Delivery Potential: High. However, a surprisingly high percentage of all landslides do not appear to deliver (22 out of 50).

Delivery Criteria Used: Landslides observed entering small streams.

Hazard Potential Rating: High.

Trigger Mechanisms: Harvest and roading on convergent slopes and terrace margins.

Confidence: Moderate. It is possible that some of the small gorges and hollows that make up this study were not observed on the DNR topographic maps, DEMs, and hydrologic layers used in this study.

MWMU Number: 8 Deep-Seated Slides in Glacial Terrace Deposits & Adjacent Lands (≥55%) – High Overall Hazard

Description: MWMU8 includes large deep-seated landslides within the glacial terraces and adjacent lands. Loss of cohesion and/or disrupted hydrology within the deep-seated failures has resulted in 18 superimposed shallow rapid slides. MWMU8 occupies 5% of the study area.

Materials: MWMU8 includes disrupted sediments including randomly oriented angular blocks of till, clay, sand, gravel, and boulders that compose the deep-seated landslide deposits. It also includes the suite of sediment types associated with the other glacial terrace MWMUs.

Landform: Large deep-seated landslides superimposed on a two-step glacial terrace together with adjacent lands.

Observed Slope on Failure (from DEM):	Min: 30%	Max: 131%	Mean: 78%, s.d.= 22%
Elevation:	Min: 317’	Max: 1,174’	Typical: 800’
Total Area:	1,057.0 acres		
Total Area of Landslides:	591.6 acres		
Total Number of Landslides:	62		

MW Processes: Of the superimposed landslides, most are shallow rapid failures but debris flows are also common. Also includes many large deep-seated failures.

Forest Practice Sensitivity:	High.
Mass Wasting Potential:	High.
Number of Delivering Landslides:	26
Area of Delivering Landslides:	15.8 acres
Landslide Area Rate for Delivery:	383 (for shallow-rapid failure)

Delivery Potential: High. However, many landslides do not deliver.

Delivery Criteria Used: Landslides observed entering small streams.

Hazard Potential Rating: High.

Trigger Mechanisms: Harvest or roading on convergent slopes superimposed on the landslides or on the headwalls or toes of the landslides.

Confidence: Moderate. The difficulty in mapping MWMU8 lies in accurately locating and mapping subtle deep-seated landslides.

MWMU Number: 9 Other Hills and Floodplains – Low Overall Hazard

Description: MWMU9 includes both bedrock- and sediment-covered slopes in the parts of the study area not designated in one of the other units. The landslides are randomly dispersed across the landscape, thus precluding classification within other mass wasting map units.

Materials: All geologic units found in the basins.

Landform: Generally gentler hillslopes, lacking the potentially unstable landforms designated in other MWMUs; also broad terrace surfaces, and floodplains of Finney Creek and the Skagit River.

Observed Slope on Failure (from DEM): Min: 12% Max: 134% Mean: 47%, s.d.= 36%

Elevation: Min: 185’ Max: 3,880’

Total Area: 14,939.1 acres

Total Area of Landslides: 4.4 acres

Total Number of Landslides: 13

MW Processes: No patterns observable.

Forest Practice Sensitivity: Probably low, but too few failures to characterize.

Mass Wasting Potential: Low.

Number of Delivering Landslides: 4

Area of Delivering Landslides: 0.5 acres

Landslide Area Rate for Delivery: 1

Delivery Potential: Low.

Delivery Criteria Used: Landslides observed entering creeks.

Hazard Potential Rating: Low.

Trigger Mechanisms: Too few failures to characterize.

Confidence: Moderate.

13.0 Appendix C – Form A-3: Mass Wasting Summary Tables

Mass Wasting Summary Table: MWMU#1

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche s	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	66	13	3	0	0	2	0	84
Young Stands (timber 5-15 yrs.)	8	1	0	0	3	0	0	12
Submature Stands (Timber 15-50 yrs.)	5	6	4	0	2	1	3	21
Mature (timber >50 yrs.)	0	0	0	8	0	0	1	9
Road Related	9	2	0	0	1	0	0	12
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#2

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche s	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	2	2	0	0	0	0	0	4
Young Stands (timber 5-15 yrs.)	2	0	0	0	0	0	0	2
Submature Stands (Timber 15-50 yrs.)	2	0	0	0	1	0	0	3
Mature (timber >50 yrs.)	0	0	0	0	0	0	0	0
Road Related	5	2	0	0		0	0	7
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#3

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	4	3	0	0	2	0	0	9
Young Stands (timber 5-15 yrs.)	3	0	0	0	0	0	0	3
Submature Stands (Timber 15-50 yrs.)	0	0	0	0	0	0	0	0
Mature (timber >50 yrs.)	0	0	0	0	0	0	0	0
Road Related	6	1	0	0	1	0	0	8
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#4

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	10	1	0	0	0	0	0	11
Young Stands (timber 5-15 yrs.)	0	0	0	0	0	0	0	0
Submature Stands (Timber 15-50 yrs.)	0	0	0	0	0	0	0	0
Mature (timber >50 yrs.)	0	0	0	2	0	0	0	2
Road Related	2	0	0	0	0	0	0	2
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#5

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	0	0	0	0	1	0	0	1
Young Stands (timber 5-15 yrs.)	1	0	0	0	0	0	0	1
Submature Stands (Timber 15-50 yrs.)	0	0	0	0	0	0	0	0
Mature (timber >50 yrs.)	0	0	0	0	0	0	0	0
Road Related	1	7	0	0	0	0	0	8
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#6

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	19	1	0	0	2	0	0	22
Young Stands (timber 5-15 yrs.)	5	0	0	0	0	0	0	5
Submature Stands (Timber 15-50 yrs.)	1	0	0	0	2	0	0	3
Mature (timber >50 yrs.)	0	0	0	5	1	0	0	6
Road Related	0	1	0	0	0	0	0	1
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#7

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	28	2	0	1	1	0	0	32
Young Stands (timber 5-15 yrs.)	2	0	0	0	0	0	0	2
Submature Stands (Timber 15-50 yrs.)	1	1	1	0	0	0	0	3
Mature (timber >50 yrs.)	0	0	0	1	1	0	2	4
Road Related	9	0	0	0	0	0	0	9
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#8

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	19	0	0	1	2	0	0	22
Young Stands (timber 5-15 yrs.)	3	1	0	0	2	1	0	7
Submature Stands (Timber 15-50 yrs.)	2	2	0	0	1	0	0	5
Mature (timber >50 yrs.)	1	0	0	12	1	2	4	20
Road Related	2	5	0	0	1	0	0	8
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

Mass Wasting Summary Table: MWMU#9

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides Undiffer'd	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs.)	6	0	0	0	0	0	0	6
Young Stands (timber 5-15 yrs.)	3	0	0	0	0	0	0	3
Submature Stands (Timber 15-50 yrs.)	0	1	0	0	1	0	0	2
Mature (timber >50 yrs.)	0	0	0	1	1	0	0	2
Road Related	0	0	0	0	0	0	0	0
Partial Cut	0	0	0	0	0	0	0	0
Yarding	0	0	0	0	0	0	0	0
Alpine	0	0	0	0	0	0	0	0
Other (e.g., housing, agriculture)	0	0	0	0	0	0	0	0

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