WASHINGTON STATE DEPARTMENT OF
Natural Resources

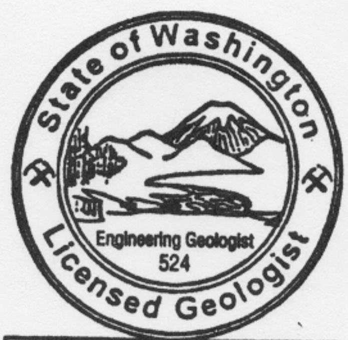
Mass Wasting Assessment: Landslide Hazard Inventory Project

Cle Elum Watershed, Kittitas County, Washington

Prepared by:

Lorraine Powell

June 21, 2005



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1.0 Introduction and Summary of Methods

1.1 Use of This Report

The purpose of this mass wasting assessment is to identify non-federal, non-tribal areas within the Cle Elum WAU that have landforms[1] with moderate or high risk of landslides due to the effects of forest management (logging, roading, thinning, yarding, etc.). Maps of these landforms (Map A2 herein) will be used by the Department of Natural Resources region staff to identify those Forest Practice Applications (see Chapter 222-20 WAC) that may require a site investigation to assign a class of forest practice relative to potential unstable slopes and landforms (Chapter 222-15-050).

This is a reconnaissance study and its level of resolution must be kept in mind when using this document and Maps A1 and A2. Moreover, the report was prepared according to the schedule necessary to produce a statewide screening tool as quickly as reasonably possible. For this reason, it is likely that some landslides or landforms have been accidentally omitted, some benign features are improperly mapped as landslides, and some data have been miscoded.

Jack Powell reviewed and edited this text, and provided extensive technical and field support. Laura Vaugeois kindly completed the final edit of the document. Tom Boyd helped develop the individual coverage layers and final map layouts.

This assessment was conducted using aerial photographs, various maps, and field observations. Information was collected and compiled from these sources in a manner designed to respond to the critical questions or to suggest areas where more detailed information is necessary. The objective of the data collection is to generate information sufficient to establish:

- A generalized characterization of mass wasting processes active in the basin.
- Portions of the landscape sharing similar physical characteristics relating to mass-movement behavior.
- The relative potential for mass wasting within each landscape unit.

1.2 Previous Investigations

Comprehensive large-scale systematic mass wasting and/or slope stability studies have not been conducted in this watershed. MountainStar Resort, a major development company, has a master development plan covering approximately 6000 acres under development in the Domerie Flats and Bullfrog area in the lower, southern portion of the watershed that has generated slope stability analysis for specific areas within the development. Several Forest Practices applications have generated site-specific slope stability analyses for proposed harvest areas.

[1] These can be more inclusive than the small-scale landforms commonly defined in rule (WAC 222-16-050). Rule-identified landforms include inner gorges, convergent headwalls, the outside of meander bends, bedrock (and other) hollows, and toes of deep-seated landslides.

1.3 Summary of Methods

This assessment follows the Landslide Hazard Inventory Protocol dated August 17, 2004 (Department of Natural Resources, 2004), with minor modification. All available 1979, 1984, 1985, and 1998 1:12,000 stereo aerial photographs were viewed through a mirrored stereoscope with 3x magnification (Table 1). LIDAR is not available for this area. 1 set of 1:60,000 aerial photos were reviewed. Only partial and limited SLPSTAB data was available.

Year	**Scale**	**Image**	**Flight Line Number**	**Reference Ownership**	**Comment**
1979	1:12,000	Black & White	KYK-79	DNR	Complete coverage
1984	1:12,000	Color	SCC-84	DNR	Partial coverage
1985	1:12,000	Color	SCC-85	DNR	Partial coverage
1998	1:12,000	Black & White	SC-98	DNR	Complete coverage
1969	1:60,000	Black & White	EC-67	DNR	Complete coverage

Table 1. Photographic surveys used in this study.

The following landslide processes were used to identify and classify features observed on the stereo photos: shallow-rapid landslides (debris slides), debris flows, debris avalanches, deep-seated landslides, shallow sporadic deep-seated landslides, large persistent deep-seated landslides, earth flows, rock topple, and snow avalanches. Table 2 provides a summary of the number and type of process features catalogued during this investigation.

Process	Number of features
Shallow undifferentiated landslides	22
Debris Flows	14
Debris slide/avalanche	2
Deep-seated	18
Earth flow	0
Rock topples/falls	0
Snow avalanche	0

Table 2. Inventoried mass wasting features in the Cle Elum Watershed.

Mass wasting features were mapped on transparent overlays from 1:12,000 stereo photo pairs. The transparent overlays were placed over a computer screen and data was transferred directly to USGS 7.5 minute quadrangles electronically enlarged using ArcMap 8.3 to closely match road and stream locations taken from the stereo photos. A slope-percent map derived from the USGS 10-meter digital elevation model (DEM) of the watershed and USGS 1:100,000 geologic map aided in evaluation of slope conditions prior to slope failures, assisted in predicting areas of potential future failures and aided in delineation of the landforms. This mapping technique results in a maximum resolution of 10 meters. Small failures identified on the photos are not represented by the 10-meter DEM"s as slope distances of less than 10 meters are not represented and are averaged into gentler slopes above and below. Failed slopes of less than 5 meters are common in inner gorges and along the toes of deep-seated landslides and are not accurately reflected by the 10m DEM contour map.

Slope gradients were determined by exploring a DEM-derived slope percent map within each feature polygon in its individual shape file. The slope angle cannot be reliably determined for small or narrow landslides where accuracy is limited by the 10-meter resolution of the DEM. Slope angle is understated where steep slopes or inner gorge faces are less than 60 feet high as the 10-meter resolution averages gentler slopes above and below the steep face into the calculation. Slopes derived from DEMs are generally lower than those measured in the field, but are less subjective. Conversely, the steepest slopes on rotational failures are on the failure plane and therefore steeper than the slope of the ground just before landslide initiation. As a result, the method of slope gradient estimation presented is an approximation.

Once the locations of mass wasting features were mapped and evaluated, areas of similar mass-wasting potential were grouped into individual landforms. These are shown on Map A-2 and described in Appendix B. Two days were spent verifying features mapped in the Cle Elum WAU. Features not visible on the photos were also mapped and added to the inventory.

1.4 Introduction to Mass Wasting Processes and Terminology

For the purposes of this study, most landslides that fail below rooting depth are categorized as deep-seated, consistent with the Forest Practices Board Manual. Those deep-seated landslides that moved rapidly and clearly deliver are included in the analyses of sediment delivery.

Five types of mass wasting process were identified in the Cle Elum WAU related to forest practices:

1. Shallow soils sliding down steep bedrock surfaces in convergent headwalls and in inner gorges. Shallow soils draped over steep (>70%) slopes were found in inner gorges and in convergent headwalls. These soils are extremely sensitive to surface disturbance and loss of root strength. Forest practices and road building activities can have a significant impact on these areas.
2. Toes of deep-seated landslides adjacent to streams. Toes of deep-seated landslides that are within asymmetrical inner gorges containing active streams are actively failing as demonstrated by sag areas, grabens, active head scarps, and leaning trees.
3. Slope ravel and shallow landslides on glacial terrace faces along the Cle Elum River. Terrace faces are actively raveling and failing into the Cle Elum River. Shallow undifferentiated failures are present scattered along the terrace faces. Impoundment of water due to mining at the top of one terrace resulted in a drainage overflow producing a debris flow choking the river with gravel during the winter of 2002/2003.
   Outside of meander bends along the Cle Elum River. The outsides of meander bends along the Cle Elum River from the Cle Elum Dam to the confluence with the Yakima River are actively under cutting their banks. Migration of the river over its flood plain is ongoing and can be delineated from one aerial photo sequence to the next.
4. Large deep-seated landslides are located throughout the watershed but are apparently not affected by forest practices activities. No road failures or forest practices initiated slope failures were noted in the bodies of any deep-seated landslides.

Mass wasting is directly related to slope shape, slope angle, bedrock, colluvial/soil material and depth, hydrology, glacial history, and forest practices. Steep (>60%) convergent (concave) slopes on dipping bedrock units that have been folded, fractured, and weathered to unstable minerals, draped by thin soils, colluvium, and/or glacially derived sediments are usually the most prone to failure. When these sediments or soils are severely disturbed (i.e., forest practices, scarification, road building, and skidding) the impact of the loss of root strength and then saturation during a major hydrologic event initiates mass wasting processes immediately. Scouring of the stream channel initiates downcutting and the creation of inner gorges. Bedrock hollows evacuate as a result of loss of root strength from harvest and an increase in groundwater flow due to loss of canopy interception of precipitation. Evacuation of hollows due to increased groundwater flow and loss of root strength contributes to eroding slopes to bedrock, scouring stream channels, and deepening inner gorges. Downcutting of the floor of inner gorges results in oversteepening the walls of the gorge, triggering slope failures (slope ravel, shallow landslides, rotational failures, small deep-seated landslides). Harvest along the edges of inner gorges reduces the root strength on slopes above the gorge accelerating wall failures. Inner gorges that undercut the toes of deep-seated landslides oversteepen the toes and may result in reactivation of the toes.

2.0 Physical Setting Pertinent to Mass-Wasting Interpretations

2.1 Introduction

The Cle Elum watershed covers 44,146 acres and lies completely within Kittitas County. Approximately 23,802 acres of checkerboard ownership of this watershed is managed by the U.S. Forest Service or the Bureau of Reclamation and is not included within this study (Map A-1). The remainder includes approximately 20,344 acres of private ownership and Department of Natural Resources (DNR) managed lands.

The headwaters of the Cle Elum watershed lie approximately 11 miles east of the Cascade crest and drain to the south to its confluence with the Yakima River. Elevations range from a high of approximately 5800 feet along the northern boundary to 1935 feet at its confluence with the Yakima River.

2.2 Topography

The Cle Elum watershed, located in central Washington State, approximately 11 miles east of the Cascade crest and two miles south of the Alpine Lakes Wilderness boundary, drains south, joining the Yakima River one mile southeast of the Bullfrog interchange on Interstate 90. This WAU is one of three similar adjacent northwest to southeast trending, Pleistocene glaciated drainages that were dammed in the last century to create major reservoirs for irrigation. Topography is typical of the eastern slopes of the Cascades with glacially carved valleys feeding into the Yakima River drainage system. Slopes range from flat or gently rolling lowlands south of Lake Cle Elum to steeply dipping bedrock units on the valley walls. The steepest and highest slopes in the watershed are located along Kachess Ridge that forms the western margin of the watershed. Glacial deposits are difficult to distinguish from large postglacial landslides. Numerous large, deep-seated landslides are a significant geomorphic feature in this watershed. Downcutting across dipping bedrock surfaces has formed asymmetrical inner gorges that are actively failing into their drainages (Figure 1).

2.3 Geology

Bedrock Units

This WAU is located within the Teanaway "geologic" Block described by Tabor and Frizzell (1984). The major bedrocks units in the Cle Elum WAU are sandstone, shale and coal of the Roslyn Formation, basalt and andesite flows of the Teanaway Formation, and sandstone units of the Swauk Formation. This "geologic" block is located to the northeast of two major fault systems, the northwest-southeast trending Olympic Wallowa Lineament and the north south trending Straight Creek Fault system. These major structural systems have caused bedrock units within the WAU to be broken by numerous faults and contorted by folding. This broken, tilted nature of the bedrock, combined with a thin veneer of glacially deposited material over dipping bedrock facilitates mass wasting (Figure 1).

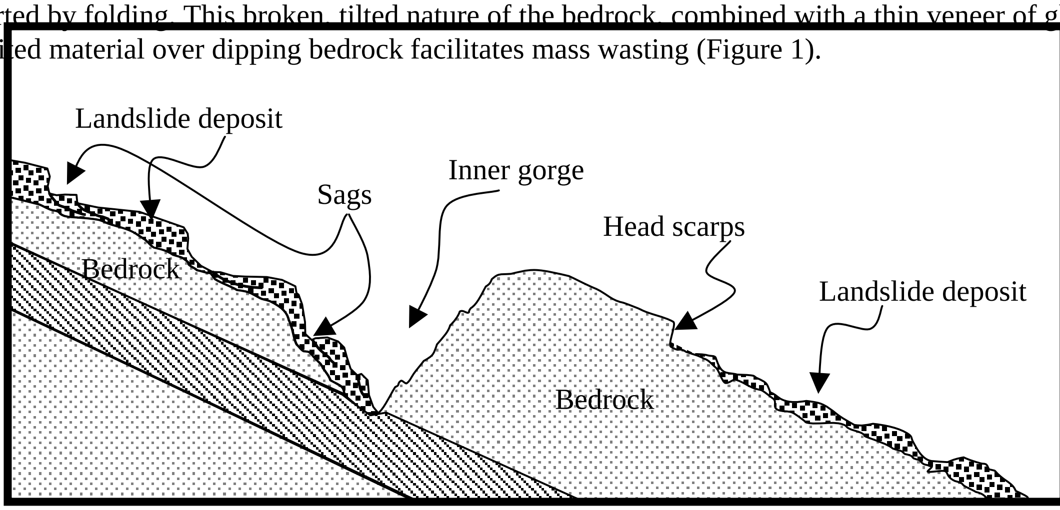


Figure 1. A profile sketch illustrating the location of landslide deposits on glacially stripped bedrock surfaces.

Poorly Consolidated Surficial Units

In more recent geologic time (1.6 million to 12,000 years ago), alpine glaciers were repeatedly active in the watershed. Glacial erosion oversteepened valley walls and deposited a blanket of unconsolidated sediments in valley floors and on stripped, southerly dipping bedrock units along both sides of the valley. Alpine glacial deposits, rock glaciers, glacial drift, small fans, bogs, and modern stream alluvium are present in the upper and lower portion of the Cle Elum River drainage. Large deep-seated and small shallow landslides in these sedimentary units are significant features in the eastern portion of the Cle Elum watershed. A broad alluvial plain (Domerie Flats) below the dam on Lake Cle Elum is composed of mixed alluvium and glacial moraine, drift, till, and outwash.

3.0 Summary of Results

During this review, a representative sample of 56 mass wasting features were inventoried using data obtained from both black & white and color aerial photos taken in 1979, 1984, 1985, and 1998 (Form A-1). Of the landslides identified during this mass wasting assessment, 39% (22) were mapped as shallow-undifferentiated failures, 25% (14) were debris flows, 4% (2) were debris slides, and 32% (18) were deep-seated landslides (Figure 2). No snow avalanche, road fill failures, rock topples/falls or earth flows were identified. The resulting mass wasting coverage is displayed as Map A-1. Pertinent attributes of individual features were recorded on data sheets (Form A-1).

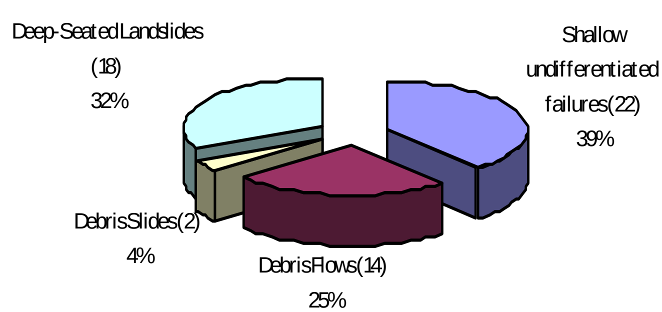


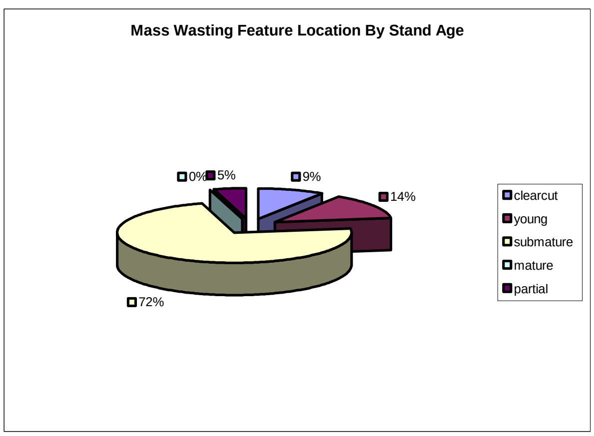
Table 2. Inventoried mass wasting features in the Cle Elum Watershed.

Figure 2. Summary of mass wasting features in the Cle Elum WAU

Process	Number of features
Shallow undiff.	22
Debris Flows	14
Debris slide/avalanche	2
Deep-seated	18
Earth flow	0
Rock topples/falls	0
Snow avalanche	0

The watershed was extensively harvested in the early 1900's in support of the coalmines in the Roslyn – Ronald-Cle Elum area. A stand replacement harvest interval of +/-80 years for this area provided second growth forests available for harvest by the late 1970's. This assessment found that over 70% of the masses wasting features identified were located in sub mature timber stands. Identification of debris flows from the photographs was difficult. Field reconnaissance demonstrated that vegetative cover found associated with sub mature timber stands commonly masked evidence of any debris flow footprint. Small shallow undifferentiated landslides present along scarp slopes in many of the inner gorges were not visible on any 1:12,000 aerial photographs. Large landslides in colluvium and mixed colluvium and glacial drift on dip slopes were difficult to identify without significant timber removal.

Land use was determined for each feature (Figure 3). A significant portion of this watershed has been extensively harvested, either by partial or clear-cut harvest methodology. Submature timber stands contained 72% of the identified features, young stands had 14% of the features, and partial cuts 5% of the identified features. No mass-wasting features were identified in a mature timber stands greater than 50 years old. The lack of recognized features in mature timber is more likely a result of canopy cover, not an absence of mass wasting features. Foresters will need to carefully evaluate all scarp slopes and high hazard areas under mature forest canopy.



clearcut (timber 0-5 years)

young stands (timber 5 – 15 years)

sub mature timber (15 – 50 years)

mature timber (>50 years)

partial cut

Figure 3. Mass wasting features charted by timber stand age at the time of inventory. Note that no features were identified in mature stands.

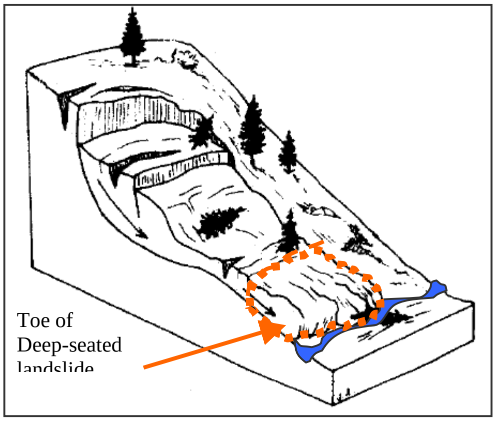
4.0 Landforms

The distribution of the seven landforms for the Cle Elum watershed study area are shown on Map A-1, and are described in Forms A-2, Appendix B. These units have been delineated to depict areas having similar mass wasting potential, potential to deliver to public resources, and potential to impact public safety. Mass wasting potential is based mainly on landslide process, failure density, lithology, geomorphology, and topography. Hydrogeology is considered as an important variable for delineating landforms in this watershed. The following sections briefly describe the characteristics of each landform with additional information given in Appendix B. Terrace faces and outside meander bends were combined into a single landform.

4.1 LANDFORM #1: Toes of Deep-Seated Landslides, Stream Adjacent

Large, deep-seated landslides cover 1551 acres (2.4 square miles) of the Cle Elum watershed. The oversteepened lower portion of these deep-seated landslide deposits adjacent to streams had a high number of mass wasting features that delivered to a stream. Of the 1551 acres covered by deep-seated landslides, 118 acres were identified as active toes. Active toes of deep-seated landslides adjacent to streams were assigned a high mass wasting potential due to features apparent on aerial photographs and field verification of failures. A high delivery potential was assigned to these units as they are stream adjacent (e.g., streams are eroding both across and parallel to the landslide toes) and deliver.

Figure 4.
Diagram showing the toe of a deep-seated landslide (after Note 50 CALIFORNIA DEPARTMENT OF CONSERVATION DIVISION OF MINES AND GEOLOGY FACTORS AFFECTING LANDSLIDES IN FORESTED TERRAIN



In the eastern half of the watershed toes of deep-seated landslides are formed from a mixture of bedrock sandstones, glacially deposited debris and colluvium. The deposits vary from large blocks of fairly intact bedrock to broken sheared bedrock intermixed with glacial deposits and colluvium. Both bedrock and glacially derived boulders are commonly mixed with finer sediments including clay lenses.

Streams often cut parallel to or through the toe of the slide deposit. Side streams down cut perpendicular to and through the toe forming asymmetrical inner gorges and bedrock hollows in the broken, poorly consolidated landslide deposits. Marginal streams on either side of the body of the toe can form inner gorges and debris slides that in turn may trigger shallow and small deep-seated landslides. Only toes adjacent to streams that provide a mechanism for sediment delivery were included within this landform unit.

Occasionally, younger, secondary large deep-seated landslides form within the footprint of an older deep-seated landslide. This may superimpose a younger, more active toe within the older body of a landslide.

Slopes >65% are most prone to failure. Slope was difficult to determine from DEM data, therefore, it is incumbent upon the field forester to determine which portions of areas mapped as stream adjacent toes of deep-seated landslides are >65% and require protection.

This unit was assigned a high mass wasting potential due to numerous debris slides and shallow undifferentiated failures associated observed in toes of deep-seated landslides in inner gorges that contained streams. A high delivery potential was assigned to this unit as toes located within inner gorges are part of the drainage network and contain streams.

4.2 LANDFORM #2*:* – Inner Gorges

Inner gorges are gullies whose walls were created by a combination of stream downcutting, mass wasting along the gully walls, and debris flow passage that cuts toe slopes. Debris flows shape inner gorges by scouring the stream channel and undercutting side slopes adjacent to the channel. Inner gorges commonly have distinctive breaks in slope along their margins. The steepness of inner gorges varies with the underlying materials. In competent bedrock, gradients of 70% or steeper can be maintained, but soil mantles are sensitive to root-strength loss at these angles. Slope gradients as gentle as about 53% can be unstable in gorges cut into incompetent bedrock, weathered materials, landslide deposits or unconsolidated deposits. The distinctive break in slope at the top edge of the inner gorge occurs where over steepened slopes related to inner gorge erosional processes join slopes formed from hill slope erosion processes. Inner gorges can be asymmetrical with one side steeper than the other. The walls can be continuous for great lengths, as seen along a highly confined stream that is actively down cutting, but there may be breaks of gentler slopes along the lower valley walls. Erosion along the gorge walls can intercept shallow groundwater forming seeps along the gully walls that promote continued mass wasting (Figure 5).

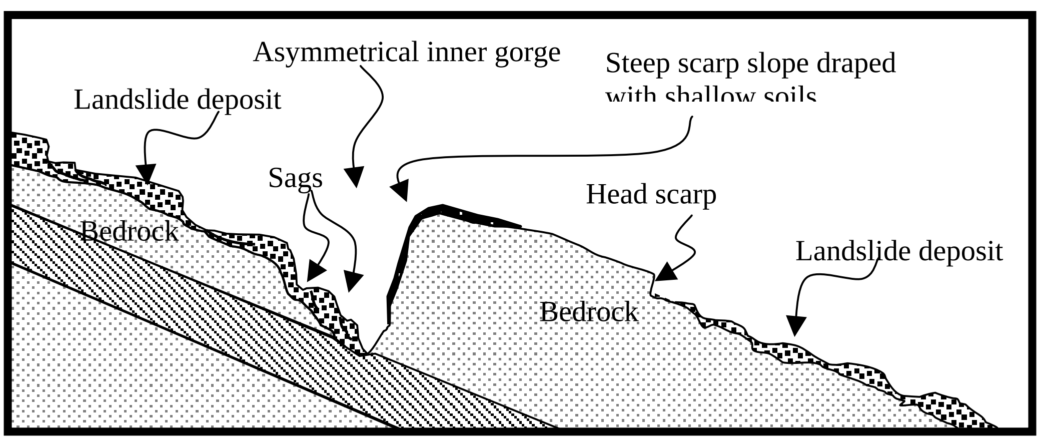


Figure 5. Profile sketch of typical asymmetrical inner gorge found on the east side of Lake Cle Elum. Shallow soils draping the steep scarp slope of the inner gorge fail in debris slides directly into the streams. Toes of deep-seated landslides often occupy the opposite, gentler slope that is commonly less than 70%.

311 acres of the Cle Elum watershed were identified as having a high hazard of mass wasting related to inner gorges. This represents 28.6% of all areas mapped as high hazard for delivery. Two common inner

gorge shape symmetries were observed, the normal symmetrical, rule identified form present in the western half of the watershed, formed in glacial outwash and colluvium, and an asymmetrical form (Figure 5) found in the eastern half of the watershed. Nearly all inner gorges formed in bedrock units located along the eastern half of the watershed were asymmetrical in form with only one gorge wall meeting the 70% slope criteria. These east side inner gorges usually trend northeast to southwest and are often intermittent, with steeper southeast walls. Many cut through the toes of deep-seated landslides as depicted in Figure 5. These large landslides are on lower angle dip slopes ranging from 30 to 45 degrees.

Steep scarp slopes in asymmetrical inner gorges do not exhibit classic bedrock hollow formation often associated with this feature. Debris slides originating in shallow soils developed on the steep scarp slopes fail along nearly plainer surfaces. Failed surfaces are smooth with usually less than two feet of relief within the bedrock hollow feature noted in the bedrock scarp face. Opposite the scarp slopes, toes of deep-seated landslides were often present. These toes often exhibited hummocky ground with numerous sags, grabens and old growth trees with sweeps of various degrees and orientations

Shallow landslides and debris slides were observed within inner gorges and on steep slopes. Careful field review will be necessary for those areas of moderate to old growth timber as the vegetation masks nearly all of these features on aerial photography. The over steepened walls of inner gorges fail as slope ravel, shallow landslides, or debris slides often initiating debris flows.

Root strength within bedrock hollows and along the walls and margins of inner gorges has been found to be a factor in limiting the rate of mass wasting. Trees adjacent to the inner gorge can have roots extending into the slopes of the gully providing slope stability. This is particularly applicable in the asymmetrical inner gorges present in the eastern portion of the watershed. Timber harvest, road construction and/or landing construction on steep slopes in poorly consolidated colluvium draping bedrock can increase slope instability due to loss of root strength. Roads and landings can destabilize slopes in bedrock hollows and inner gorges by undercutting and oversteepening slopes. Sidecast and road (or landing) fill can oversteepened and add weight to slopes; roads and landings can also capture runoff or shallow groundwater, channeling it to point locations that saturating road or landing fill and/or thin soils draping bedrock triggering landslides.

This unit was assigned a high mass wasting potential due to numerous debris slides and shallow undifferentiated failures associated with timber harvest in inner gorges. A high delivery potential was assigned to this unit as inner gorges are part of the drainage network and are adjacent to or contain streams.

4.3 LANDFORM #3 Terrace Faces and Outside of Meander Bends

Terrace faces in contact with meander bends and outside of meander bends landforms were combined into a single landform map unit as the mechanism of delivery is identical. Glacial terraces formed from glacial outwash deposited by the Cle Elum Valley alpine glacier. These glacial terrace faces, located on both sides of the Cle Elum River from the south end of Lake Cle Elum to the Yakima River, can be undercut at the toe of the terrace by the river actively migrating across its floodplain. The outside of meander bends contacts the toes of the terrace faces, removing material at the toe, and oversteepening the slopes. The resulting slope failures can be seen as shallow landslides and occasional small deep-seated landslides failing into the river and its floodplain. These features are constantly raveling with rapid failures occurring during high water regimes. As the river migrates back and forth across the floodplain through time, the meanders travel downstream impacting the terrace faces on both sides of the river. Simultaneously, the outsides of meander bends are reworking alluvium and glacial outwash debris delivered to the floodplain by the terrace face failures (Figure 7).

Terrace faces that could deliver debris directly into streams or threaten public safety cover 322 acres of the 428 acres within this landform. All are located adjacent to the Cle Elum River from the Bureau of Reclamation dam, located at the south end of Lake Cle Elum, to Interstate 90 at the southern edge of the watershed. 106 acres associated with the outside of meander bends have been identified as having a high mass wasting potential with a high delivery potential in landform #3. Only those meander bends currently containing flowing water or those that carry water during the freshet were classed in this map unit.

The Cle Elum River is downcutting through alluvium and glacial outwash deposits that fill the broad valley leading from the southern terminus of Lake Cle Elum to the Yakima River. A few small rotational slides and shallow undifferentiated failures also are present along these terrace faces. Any disturbance that destabilized the vegetation appears to lead to accelerated ravel and occasionally slumps. Scars down the terrace faces from dirt bikes and ATV tracks appear to accelerate the mass wasting activity. Any harvest that reduces root strength or disturbs the ground surface will result in destabilization of the terrace face.

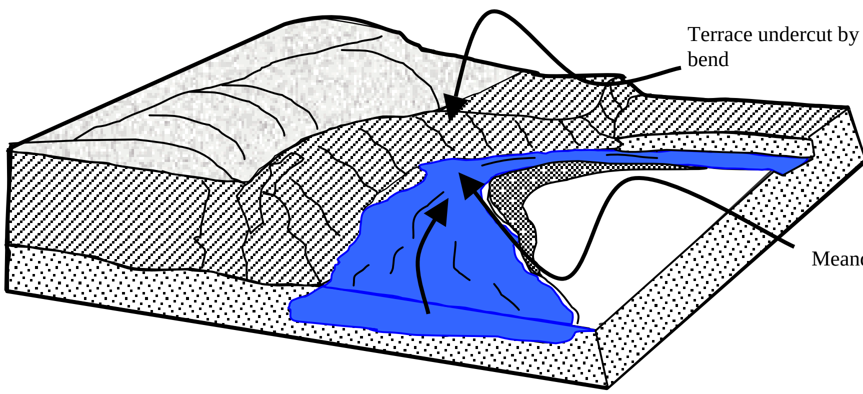


Figure 7. Terrace faces along the Cle Elum River are being undercut, failing into the river. A very unstable landform with direct delivery to water (adapted from Varness, 1978).

Based on current failures, impacts from recreational vehicle activity on the terrace faces, and the immediate delivery to public waters or potential threat to public safety impacting roads, bridges and power lines, this unit was assigned a high mass wasting potential and a high delivery potential.

4.4 LANDFORM #4 Convergent Headwalls

Convergent headwalls are funnel shaped, convergent landform that terminates in a single stream channel draining the entire area (Figure 8). Channel gradients are extremely steep within convergent headwalls, and generally remain so for long distances downstream. Landslides that evolve into debris flows in convergent headwalls typically deliver debris to larger channels below. Channels that exit the bottoms of headwalls have been formed by repeated debris flows and are efficient at conducting them. Convergent headwalls may commonly have debris fans at the base of their slopes as well. It is the arrangement of bedrock hollows and first-order channels on the landscape that causes a convergent headwall to be a unique mass-wasting feature. An incised stream channel located in a major inner gorge drains each of the mapped convergent headwall features identified within this watershed.

Convergent headwalls generally range in size from about 30 to 300 acres; slope gradients are typically steeper than 70% and may exceed 100%. Soils are thin due to frequent slides in this landform. The highly convergent shape of the slopes, coupled with thin soils (due to frequent slides), allows rapid onset of subsurface storm water flow. The mass-wasting response of these areas to storms, to disturbances such as fire, and to forest practices is much greater than is observed on other steep hill slopes in the same geologic settings. Convergent headwalls are also prone to surface erosion.

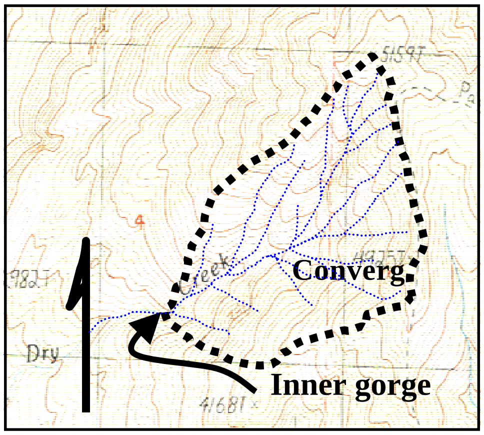


Figure 8. Map view of convergent headwall located in Dry Creek, Cle Elum Watershed demonstrating steep slopes, and interfingering ridges. Note the incised inner gorge below the headwall.

Convergent headwalls in the Cle Elum WAU are confined to the northern half of the watershed. Most of these features are located on federally owned and managed lands. Of the area covered by this investigation, 756 acres, located in the eastern middle portion of the watershed, were identified as containing convergent headwalls. The steepness of the headwalls decreases from north to south transitioning from true convergent headwalls to steep headwall basins containing disconnected areas of steep convergent ground. The gradation from convergent headwall to steep headwall basin resulted in a demarcation call by this investigator. When more than 40% of a drainage did not meet the definition of “convergent headwall” as defined in the board manual and stated above, it was classified as a steep headwall basin.

Based on the active slope ravel, bedrock hollows, past debris flow evidence and immediate delivery potential in these convergent headwalls, this landform has been assigned a high delivery potential for harvest and roads.

4.5 LANDFORM #5 Bedrock Hollows

Bedrock hollows are landforms that are commonly spoon-shaped areas of convergent topography with a concave profile. Their slopes are usually steeper than 70% (~35°) and they generally occur on the upper portion of ridges but can be found mid-slope or on steep, deep-seated landslide head scarps or toes. They usually terminate where distinct channels begin, either at the point of channel initiation (where water is discharged from a slope and has carved an actual incision) or along a streamside. Bedrock hollows often transitional into inner gorges (Figure 9). Many hollows have no surface water, but those that have been evacuated by landslides may contain seeps and springs. Hollows that have recently failed in the Cle Elum Watershed usually have a debris flow transporting the failed material downstream.

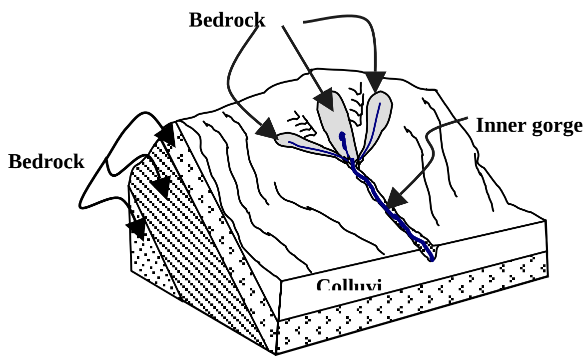


Figure 9. Steep bedrock hollows in bedrock mantled with colluvium and glacial debris transitioning into an inner gorge.

Mass wasting in bedrock hollows often results from soil saturation, loss of root strength, and/or over steepening slopes that can trigger debris slides or other shallow landslides. If these landslides become channelized they may form debris flows that erode stream channels and inner gorges.

4.6 LANDFORM #6: Steep Headwall Basins and Other Moderate Hazard Slopes

Landform#6 consists of moderate hazard slopes adjacent to inner gorges mapped as landform #2 and steep headwall basins. These areas are a composite of steep (>70%) and gentler slopes (25% to 60%) and are usually convergent and concave although they can be planar immediately adjacent to High Hazard landform #2. This map unit covers 979 acres (1.5 square miles) within the watershed and contains mass wasting features such as shallow landslides, debris flows, rock fall/topple and debris avalanches. Inclusions of unmapped areas of landform #2 and landform #6 (i.e., bedrock hollows and inner gorges) may be located within landform#6. It also may contain steep convergent slopes, headwall basins, and minor cliff bands. Landslides related to timber harvest, road construction and/or landing construction may be present, however, the map unit has been assigned a moderate delivery potential because it is not a threat to public safety, is not adjacent to streams, and has no delivery mechanism. The mass wasting hazard potential is moderate for timber harvest and road construction because landslides are rare in this map unit and delivery is rare.

4.7 LANDFORM #7 Low Hazard, Low Delivery All Other Areas

This map unit includes all slope forms and gradients that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety or impact a public resource. The unit was mapped by remote sensing methods and may contain mapping errors where high hazard features were erroneously included. Landform #7 includes slopes that are divergent and convergent in map view and convex, planar, and concave in profile. It includes cliffs, ridge tops, cirques, scarps and bodies of deep-seated landslides, moderate and low gradient slopes, low gradient stream drainages, terraces and valley floors. A majority of the unit contains slopes < 60%, however, steeper areas that do not deliver or that have a low landslide potential are included.

Shallow landslides, deep-seated landslides and debris flows may occur in the unit but they are not common and generally do not have the potential to deliver to waters of the state or impact public safety or resources. The most common mass wasting processes observed on aerial photographs were shallow undifferentiated slope failures or portions of deep-seated landslides away from public resources. The low mass wasting potential is due to lack of channel access or delivery potential to a public resource. Steeper areas such as headwall scarps and cliffs lack sediment delivery mechanisms.

5.0 Confidence in Work Products

The confidence in this mass wasting assessment is high. This rating is based on the Landslide Hazard Zonation Project design to provide a watershed overview of slope stability in a timely manner with minimal field verification. As a consequence, fieldwork and the number of aerial photograph sets examined are held to reasonable minimums. Omissions will be present due to the limited field verification of individual features, particularly in heavy canopy forested areas.

It is critical for the reader to understand that while these decisions are sufficient to characterize aspects of the slope failure as functions of forest management, this assessment would be entirely insufficient and misleading if it is used as a stand alone document for protecting private and public resources or for land use planning. Keep in mind that this is only a reconnaissance study, and undoubtedly, some landslides have been accidentally omitted and some benign features may be improperly mapped as landslides herein.

In addition, there are several sources of systematic error that reduce the confidence in the work products of this analysis, those being omission, misinterpretation, accuracy, and precision. Omission occurs when mass wasting features are not identified on aerial photographs or in the field due to canopy cover, gaps in the aerial photo record, quality of aerial photos, or interpreter errors. Misinterpretation occurs when a mass-wasting feature is identified but incorrectly classified or data are transposed, and where unrecognized software/file instability occurs. Accuracy involves the degree to which the physical parameters of a mass-wasting feature are correctly measured, and precision describes how variability within an assessment can be controlled when making multiple measurements over varying time and spatial scales (Parks, 2000).

This mass wasting assessment was primarily conducted with aerial photographs, and as a result, there is a high likelihood that errors of omission occurred primarily in areas covered by mature forest canopies, steep north facing slopes always in shadow at any given time, and those areas covered with extensive glacial deposits. The scarcity of mass wasting features identified under mature canopy and steep north slope aspect shadow conditions is not necessarily an indication of the relative stability of slopes with mature vegetation regimes or steep north face aspects.

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 percent of inferred deep-seated landslides identified from aerial photograph analysis are misinterpreted (Wegmann, 2003). Confidence in work products related to classification of deep-seated landslide processes in this watershed is high due to visibility and completeness of photo coverage.

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 hill slope angle. Given these sources of error, the confidence in the precise location and accuracy of measurements of individual landslides is considered moderate.

6.0 References

Boyd, T. G. and Vaugeois, L. M., 2003, On the development of a statewide landslide inventory [abstract]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 18.

Department of Natural Resources, Geographic Information Systems, 2003, PRECIP: ARC / INFO spatial coverage, accessed on 3/20/04.

Department of Natural Resources, Forest Practices Division, 1991, Rain-On-Snow: ARC / INFO spatial Coverage, accessed on 7/20/04.

Frizzell, V.A. Jr., Tabor R.W., Booth D.B., Ort K.M., and Waitt R.B. Jr. 1984. Preliminary geologic map of the Snoqualmie Pass 1:100,000 quadrangle, Washington. U.S.G.S. Open-File Map OF-84-693.

Landslide Hazard Zonation Manual website: http://www.wadnr.gov:81/cgi-bin/lhzreview.cgi

Tabor, R.W., Frizzell, V.A. Jr., Vance, J.A., and Naeser, C.W., 1984, Ages and stratigraphy of lower and middle Tertiary sedimentary and volcanic rocks of the Central Cascades, Washington: Applications to the tectonic history of the Straight Creek Fault: Geological Society of America, v. 95, no. 1, p. 26-44.

Vaugeois, Laura, 2000, Creation of a slope stability screening tool from landslide prediction models, Forest Practice Board Presentation: Washington Department of Natural Resources, Olympia, Washington.

Washington Forest Practices Board 1997 Standard methodology for conducting watershed analysis Version 4.0: Washington Department of Natural Resources, Olympia, Washington 1 v.

Appendix A

Appendix A. Form A-1 Cle Elum Landslide Inventory

slide_id	lsi_process	certainty	id_date	ls_size	id2_date	id2_size	init_elev	photo_num	landform	slp_shp	gradient	delivery	land_use	geologic un	acreage	comments	ls_activity_level	ls_type
100	2	D	1979				4160	KYK79_27C_22	1	1	83	Y	2	Evb(t)	10.6			
101	2	D	1979				3350	KYK79_27C_22	1	1	67	Y	2	Evb(t)	4.8			
102	2	D	1979				3830	KYK79_27C_22	1	1	95	Y	2	Evb(t)	5.9			
103	4	D	1979	5			3560	KYK79_28E-5	8	1	44	Y	3	Qls(m)	151	active sag, grabens, shallow debris slides into creek. Field verified	AR	C
104	1	D	1979	4			2880	KYK79_28E-5	1	2	77	P	3	Ec(2rl)	0.5			
105	4	D	1979	5	1998	5	3331	SC_98_21_29_196	8	2	80	P	3	Ec(2rl)	26.3		AR	C
106	4	P	1998	5			2734	SC_98_21_29_196	8	2	59	N	3	Ec(2rm)	4.9		D	I
107	4	Q	1998	4			2480	SC_98_21_29_196	8	3	35	N	3	Ec(2rl)	0.9		D	I
108	4	P	1998	5			3312	SC_98_21_29_196	8	1	52	P	2	Ec(2rm)	50.8		D	I
109	4	Q	1998	5			2860	SC_98_21_29_196	8	2	73	I	2	Ec(2ru)	17.7		D	I
110	4	P	1998	5			3220	SC_98_21_29_196	8	4	58	I	2	Ec(2rl)	22.9		D	I
111	1	D	1979	5			2801	KYK79_28E-3	9	2	94	Y	3	Ec(2rm)	4.1	cluster of many active bedrock hollows failing into stream drainage		
112	1	D	1979	4			3180	KYK_79_27D_7	9	2	60	Y	3	Evb(t)	0.7			
113	1	D	1979	5			3377	KYK_79_27D_7	9	2	66	Y	3	Evb(t)	1.1			
114	1	D	1979	4			3265	KYK_79_27D_7	9	1	78	Y	3	Evb(t)	0.7			
115	1	D	1979	3			3398	KYK_79_27D_7	9	3	78	Y	3	Evb(t)	0.3			
116	4	D	1979	5			3270	KYK_79_27D_9	8	1	82	P	3	Ec(1s)	4.4		D	I
117	1	D	1979	4			2070	KYK_79_30D_9	4	3	60	Y	3	Qa	0.7			
118	1	D	1979	4			2065	KYK_79_30D_9	4	3	67	Y	3	Qa	1.8			
119	1	D	1979	5			2280	KYK_79_30D_9	4	2	52	Y	9	Qad(e)	12.7	gravel pit mining south portion of terrace face. Blowout nearly dammed river '02.		
120	1	D	1979	4			2236	KYK_79_30D_9	4	3	61	N	2	Qad(e)	0.7	water channeled by logging directly onto terrace face		
121	1	D	1979	3			2031	KYK_79_30D_9	4	3	54	Y	3	Qa	0.7	skid trail channeled water		
122	1	D	1979	5			2120	KYK_79_30D_11	4	2	40	Y	3	Qad(e)	5.6	partial cut above terrace		
123	1	D	1979	3			2120	KYK_79_30D_11	4	3	23	Y	3	Qad(e)	0.4	partial cut above terrace		
124	2	P	1979				2200	KYK_79_30D_11	4	2	37	N	3	Qad(e)	0.2	clearcut above terrace		
125	2	P	1979				2170	KYK_79_30D_11	4	2	38	N	3	Qad(e)	0.3	clearcut above terrace		
126	2	P	1979				2193	KYK_79_30D_11	4	2	33	N	3	Qad(e)	0.8	clearcut above terrace		
127	4	P	1979	5			3600	KYK_79_27C_22	8	1	44	P	3	Ec(2m)	221	replaces #17613 lsi_uniqid inventory	D	C
128	1	D	1979	5			2216	KYK_79_29D_22	4	2	56	Y	3	Qad(e)	5.8			

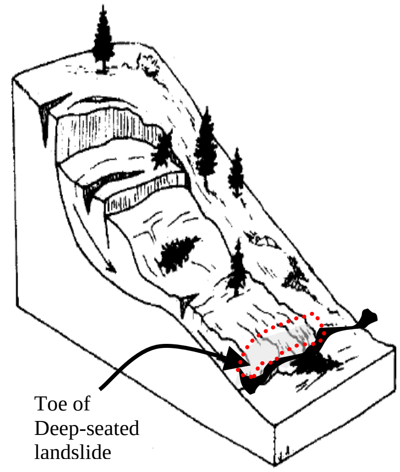
slide_id	lsi_process	certainty	id_date	ls_size	id2_date	id2_size	init_elev	photo_num	landform	slp_shp	gradient	delivery	land_use	geologic unit	acreage	comments	ls_activity_level	ls_type
129	4	P	1979	5			2208	KYK_79_31E_34	8	2	53	Y	3	Qad(e)	9.7		AR	C
130	2	D	1985	4			2733	SC_85_52_027-212	1	3	94	Y	3	Evb(t)	0.7	USFS ownership		
131	4	D	1979	4			2120	KYK_79_31E_34	4	3	54	N	3	Qad(e)	1.1		AR	T
132	1	D	1979	5			2100	KYK_79_31E_34	4	2	42	N	3	Qad(e)	1.5			
133	1	D	1979	3	1985	4	2171	SC_85_39_028_279	9	3	6	Y	2	Qa	0.5	high energy stream outflow eroding adjacent terrace/meander		
134	1	D	1979	2	1985	3	2171	SC_85_39_028_279	9	3	5	Y	2	Qf	0.4	high energy stream outflow eroding adjacent terrace/meander		
135	1	D	1985	5			3696	SC_85_55_028_008	5	1	71	Y	3	Evb(t)	2.1			
136	1	D	1985	5			3640	SC_85_55_028_008	5	1	87	Y	3	Evb(t)	2.2			
137	1	D	1985	5			4780	SC_85_55_028_008	5	1	82	Y	3	Evb(t)	6			
138	2	D	1985				3739	SC_85_55_028_008	5	1	65	Y	3	Evb(t)	0.5			
139	2	D	1998				2521	SC_98_21_27_266	7	3	34	Y	1	Ec(2rm)	0.8			
140	2	D	1998				2798	SC_98_21_27_266	7	3	36	Y	1	Ec(2rm)	2.5			
141	2	d	1998				3010	SC_98_21_28_233	1	2	38	y	1	Ec(2rl)	0.2	very small trace		
142	1	D	1998	2			3042	SC_98_21_28_233	1	2	62	Y	1	Ec(2rl)	0.1	similar to bedrock shallow failures in the Teanaway		
143	1	D	1998	1			2930	SC_98_21_28_233	1	2	45	Y	1	Ec(2rl)	0.01			
144	4	D	1998	5			3093	SC_98_21_28_235	8	1	46	Y	1	Qls(m)	2.9		AR	R
145	4	P	1998	5			3598	SC_98_21_28_235	8	2	31	P	6	Ec(2rl)	21.9	field checked & verified	DD	C
146	4	P	1998	5			3490	SC_98_21_28_235	8	2	55	P	1	Qls(m)	496		R	I
147	4	P	1998	5			3440	SC_98_21_28_235	8	3	37	P	6	Evb(t)	345		R	I
148	4	P	2004	5			2759	field	8	2	20	P	6	Evb(t)	156	field identification	R	I
149	2	D	1998				2917	SC_98_21_29_196	1	2	46	Y	3	Ec(2rl)	2			
150	2	D	2004				2890	field	1	2	33	Y	3	Ec(2rl)	2.2	field identified. Unable to detect from photos as canopy cover masks151		
151	4	D	1998	5			2635	SC_98_21_27_271	8		45	N	6	Qls(m)	17.3	dormant distinct feature superimposed on older relict indistinct landslide	DD	C
152	4	D	1998	4			2581	SC_98_21_27_271	8		37	N	6	Qls(m)	0.8	active distinct small landslide superimposed on older less distinct feature	AR	T
153	2	P	1998				3114	SC_98_21_27_271	1	2	25	Y	6	Evb(t)	.1.0			
154	1	D	2004	2			2735	field	1	3	90	Y	3	Ec(2rl)	1.1	inclusive area of several small recent failures adjacent to healing failures		
155	1	D	2004	2			2876	field	1	3	90	Y	3	Ec(2rl)	0.9	inclusive area of several small recent failures adjacent to healing failures		

LSI_UNIQID	*Slide_id*	*Source_idno*	*Lsi_process*	*Certainty*	*Id_date*
CALCULATED IN THE ENTRY PROCESS	**up to 5 integers** Put the same number on both the map and spreadsheet	CALCULATED IN THE ENTRY PROCESS	1 = shallow-rapid 2 = debris flow 3 = debris avalanche 4 = deep-seated 5 = shallow, sporadic deep-seated 6 = large, persistent deep-seated 7 = earth flow 8 = rock topple 9 = snow avalanche	D = definite: originator of landslide information is certain that this is a landslide P = probable: originator of landslide information is almost certain that this is a landslide Q = questionable: originator of landslide information is not certain that this is a landslide, but is including it for completeness of the inventory.	First year of landslide identification use photo year or best estimate of landslide age. **4 digit year, e.g. 1996**

Delivery	*Landuse*	*Init_elev*	*Photo_num*
Y = yes, delivery occurred N = no, delivery did not occur P = probably sediment delivered I = indeterminate	1 = clearcut (timber 0-5 yrs) 2 = young stands (timber 5-15 yrs) 3 = submature timber (15-50 years) 4 = mature timber (>50 years) 5 = road 6 = partial cut 7 = yarding 8 = alpine 9 = other-e.g., housing, agriculture	elevation (in feet) of the landslide initiation site **integer**	the full photo numb **15 characters**

Ls_size	***Id2_date***	***Id2_size***	***Landform***	***Slp_shp***	***Gradient***
Approximate size at ID_Date	Next year of landslide identification,	Approximate size at ID2_Date	1 = inner gorge	1 = concave, convergent	percent slope at the failure location
1 = very small	if slide has changed size or shape	(see LS_Size for values)	2 = bedrock hollow	2 = concave-planar	
2 = small	**4 digit year, e.g. 1996**		3 = avalanche chute	3 = planar	**integer**
3 = medium			4 = terrace face	4 = planar-convex	
4 = large			5 = headwall	5 = convex, divergent	
5 = very large			6 = rock outcrop		
			7 = other		
very small: (1-100 square yards) (1-900 SQ FT)			8 = deep seated		
small: (101-500 square yards) (901 - 4500 sq ft)			9 = stream influenced		
medium: (501-2000 square yards) (4501 - 18000 sq ft)					
large: (2001-5000 square yards) 18001 - 45000 sq ft)					
very large: (greater than 5000 square yards) (>45,000 sq ft)					

11.0 Landform Number: #1 - Toes of Deep-Seated Landslides, Stream Adj



Description of Mass Wasting Unit: The toes of deep-seated landslides are hummocky deposits, commonly oversteepened by stream erosion removing material from the toe. This slope, undercut by stream action, is usually steep (>65%), planar or irregular, and commonly contains areas of ravel, shallow deep-seated, or shallow surficial landsliding. Occasionally, younger, secondary large deep-seated landslides form within the footprint of an older deep-seated landslide. This may superimpose a younger toe within the body of an older landslide.

Slopes: 65 to 100 +%
Material: colluvium, sandstone bedrock, glacial deposits and soils
Elevation: Variable
Total Area: 118 acres

Mass Wasting Process: Streams undercutting and downcutting have oversteepened the toes of deep-seated landslides triggering slope ravel, debris slides, and small deep-seated landslides. Downcutting by side streams across the toe or marginal streams and debris flows associated with these streams can form inner gorges and bedrock hollows within the landslide toe deposit. Occasionally, slopes of 45% or less fail within these stream channels. Debris flows and debris slides are often located within the inner gorges in the toes.

Forest Practice Sensitivity: This landform is sensitive to any forest Practice activity that reduces root strength, undercuts or over steepens or loads these slopes, and/or redirects water onto these slopes.

Mass Wasting Potential: High for roads, High for harvest

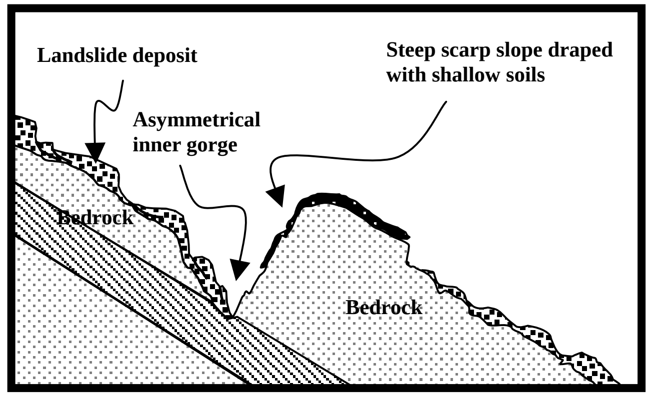
Delivery Potential/Criteria: **High.** Delivery criteria related to the proximity of the toes of these deep-seated landslides to streams within and adjacent to the landslide toe deposit. The delivery rate for this unit is 269.

Hazard Potential Rating: High for roads and for harvest. This landform has a Landslide Frequency Rating of 537 (see LHZ Protocol).

Trigger Mechanisms: Loss of root strength, changes in hydrology, oversteepening of slopes and loading slopes due to harvest, road building, and landing construction have destabilized slopes that failed during major rain-on-snow storms or intense precipitation events.

Confidence: High confidence due to the excellent exposure as a result of the extensive clearcutting since the mid 1900's of a large percentage of the watershed. Complete aerial photo coverage and two days field checking the photo interpretation have provided a high level of confidence in this watershed.

Comments: All toes of deep-seated landslides in or near inner gorges need field review.



Landform Number: #2 - Inner Gorges

Description of Mass Wasting Unit: Unit consists of inner gorges, often asymmetrical in form. Debris slides, shallow landslides and small rotational failures were observed within the inner gorges. Gorge scarp slopes covered with minor vegetation contain numerous small debris slides that were masked on all aerial photos.

Slopes: 60% to 100+%
Material: Colluvium, landslide deposits, glacial deposits and soil
Elevation: Variable between 4000 ft and 2300 ft.
Total Area: 311 acres

Mass Wasting Process: Soil saturation, loss of root strength, and/or over steepening slopes in colluvium and glacial deposits can trigger debris slides or other shallow landslides. If these landslides become channelized they may form debris flows that erode gullies to form inner gorges. The over steepened walls of inner gorges fail as debris slides, slope ravel, shallow landslides, or small rotational failures sometimes initiating debris flows.

Forest Practice Sensitivity: Root strength within bedrock hollows and along walls and margins of inner gorges has been found to be a factor in limiting the rates of mass wasting. Trees adjacent to the inner gorge can have roots extending into the slopes of the gully providing slope stability. Timber harvest, road construction and/or landing construction on steep slopes in poorly consolidated colluvium draping bedrock can cause slope instability due to loss of root strength. Roads and landing can destabilize slopes in bedrock hollows and inner gorges by undercutting and oversteepening slopes. Sidecast and road (or landing) fill can oversteepen and add weight to slopes; roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate road or landing fill and/or thin soils draping bedrock, triggering landslides.

Mass Wasting Potential: High for road construction and timber harvest in inner gorges.

Delivery Potential/Criteria: **Very High.** Inner gorges are part of the drainage network and are adjacent to or contain streams. Delivery criteria are also based on historical occurrence observed on aerial photographs and confirmed during field investigations. The delivery rate for this unit is 3413.

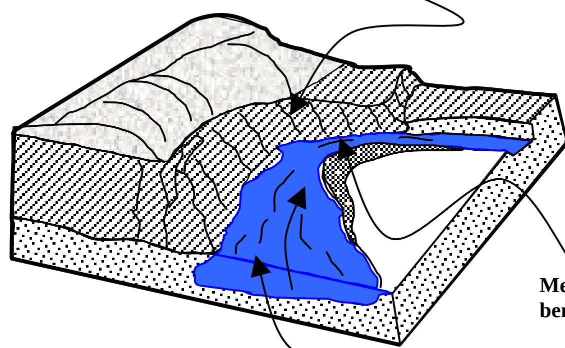
Hazard Potential Rating: **Very High** for roads and for harvest. This landform has a Landslide Frequency Rating of 2207 (see LHZ Protocol).

Trigger Mechanisms: Mass wasting is triggered by loss of root strength, changes in hydrology, oversteepening of slopes and loading slopes due to harvest, ground scarification, road building, and landing construction have destabilized slopes that failed during major rain-on-snow storms or intense precipitation events.

Confidence: High based on the number of landslides located in this landform, excellent photo quality and coverage, and field observations.

Comments: Careful field review will be necessary for those areas of steep inner gorge walls to delineate all unstable slopes.

Landform Number: #3 - Outside of Meander Bends and Terrace Faces



Description of Mass Wasting Unit: Glacial terrace faces located on both sides of the Cle Elum River directly adjacent to meander bends and the outside of meander bends from the spillway at the south end of Lake Cle Elum to the confluence with the Yakima River

Slopes: all slope gradients
Material: Flood plain, glacial outwash, soil, colluvium, alluvium,
Elevation: 2280 to 1960 feet
Total Area: 428 acres

Mass Wasting Process: Avulsion, shallow undifferentiated landslides, small deep-seated slides and slumping, and ravel of the terrace face along the Cle Elum River, especially on the outside of meander bends.

Forest Practice Sensitivity: Any disturbance of root strength, road building channeling waters, disturbing sedimentary deposits, importation of fines for road building. Timber harvest, road construction and/or landing construction on these steep terrace faces results in the loss of root strength. Roads and landing can cause instability by undercutting and oversteepening slopes. Sidecast and road (or landing) fill can oversteepened and add weight to terrace faces; roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate road or landing fill.

Mass Wasting Potential: **High** for roads and for harvest

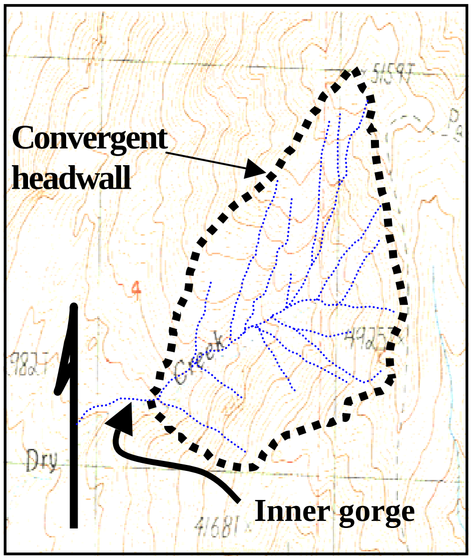
Delivery Potential/Criteria: **Very High.** Proximity to streams adjacent to and cross cutting these features. The delivery rate for this unit is 10,874.

Hazard Potential Rating: **Very High** for harvest and roads. This landform has a Landslide Frequency Rating of 16,832 (see LHZ Protocol).

Trigger Mechanisms: Erosion of bank due to stream action along the outside of meanders. Delivery directly to the mainstem Cle Elum River, with potential impact to bridges (road and railroad) and roads located down stream. Loss of root strength, changes in slope gradient, and changes in hydrology due to ground disturbance on terrace top, timber harvest and road or landing construction have destabilized similar slopes that failed during major rain-on-snow storm or intense precipitation events.

Confidence: High for the entire unit based on observed direct delivery to typed waters, excellent photo coverage, and field verification.

Comments: Minor surface disturbances, bike trails, hiking trails, off road vehicle travel creates gullies, ravel, slope instability visible on aerial photos. A major slope failure of the terrace face at the Bullfrog gravel mine due to water impoundment and discharge channelization at the top of the terrace nearly blocked the Cle Elum River.
Only those outside of meander bends that lie outside the areas of riparian management zones (RMZ) and the channel migration zones (CMZ) are delineated and protected under WAC222-16-050-1(d)(i)(E).



Landform Number: #4 - Convergent Headwalls

Description of Mass Wasting Unit: Steep, headwall basins located at the upper end of drainage systems. Channels draining the convergent headwalls have experienced repeated debris flows forming incised streams within inner gorges.

Slopes: >69%
Material: bedrock units of sandstone and basalt
Elevation: 3250 to 5100 feet
Total Area: 756 acres

Mass Wasting Process: Soil saturation, loss of root strength, ravel, debris slides, shallow landslides. If these failures become channelized they may form debris flows that erode stream channels and inner gorges. These headwall basins are prone to surface erosion from fire, forest practices, and off road recreational vehicle impacts as well. Thin soils drape bedrock units of sandstone and basalt fail frequently in response to storm events as debris flows, debris slides, ravel, and small shallow landslides.

Forest Practice Sensitivity: Root strength within bedrock hollows and on steep convergent slopes has been found to be a factor in limiting the rates of mass wasting. Trees on steep slopes with thin soils can have roots extending into the slopes providing slope stability. Timber harvest, road construction and/or landing construction on steep slopes in poorly consolidated colluvium and thin soils draping bedrock can increase slope instability due to loss of root strength. Roads and landing can destabilize slopes in bedrock hollows and on steep convergent headwalls by undercutting and oversteepening slopes. Sidecast and road (or landing) fill can oversteepen and add weight to slopes; roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate road or landing fill and/or thin soils draping bedrock, triggering landslides.

Mass Wasting Potential: High for roads, High for harvest

Delivery Potential/Criteria: <u>High</u>. This unit has a calculated landslide rate for delivery of 760 (see LHZ protocol). The high delivery criterion is based on the convergent headwalls forming the headwater drainage network and water collection system for typed waters, on historical occurrence observed on aerial photographs, and confirmed during field investigations. The delivery rate for this unit is 760.

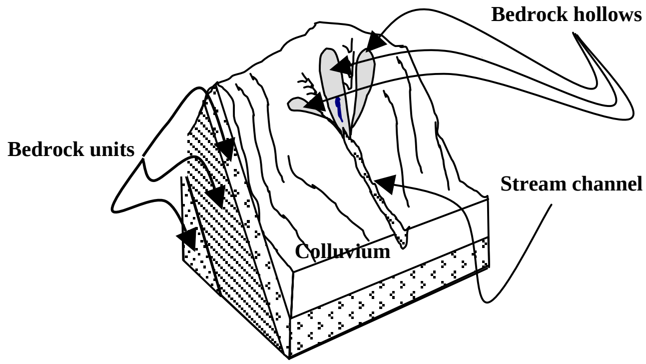
Hazard Potential Rating: <u>High</u> for harvest and roads for roads. This landform has a Landslide Frequency Rating of 278 (see LHZ Protocol).

Trigger Mechanisms: Loss of root strength, changes in hydrology, oversteepening of slopes and loading slopes due to harvest, road building, and landing construction destabilizing slopes that fail during major rain-on-snow storms or intense precipitation events.

Confidence: High confidence due to excellent exposures as a result of the extensive clearcutting since the mid 1900's of a large percentage of the watershed. Complete aerial photo coverage and two days field checking the photo interpretation have provided a high level of confidence in this watershed.

Comments: Most of these features are located on federally owned and managed lands.

Landform Number: #5 - Bedrock Hollows



Description of Mass Wasting Unit: Shallow, cuplike depressions when present on steep scarp slopes often feed directly into streams. Bedrock hollows in convergent headwalls tend to be shallow and elongated and are difficult to delineate on photographs.

Slope: > or = 70%
Material: Sandstone, basalt, colluvium, alluvium , landslide deposits, glacial deposits, and soil.
Elevation: varies
Total Area: 33 acres

Mass Wasting Process: Soil saturation, loss of root strength, and/or over steepening slopes in bedrock hollows can trigger debris slides or other shallow landslides. If these landslides become channelized they may form debris flows that erode stream channels and form inner gorges.

Forest Practice Sensitivity: Root strength within bedrock hollows has been found to be a factor in limiting the rates of mass wasting. Timber harvest, road construction and/or landing construction on steep slopes in poorly consolidated colluvium draping bedrock can increase slope instability due to loss of root strength. Roads and landing can destabilize slopes in bedrock hollows by undercutting and oversteepening slopes. Sidecast and road (or landing) fill can oversteepen and add weight to slopes; roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate road or landing fill and/or thin soils draping bedrock, triggering landslides.

Mass Wasting Potential: High for road construction and timber harvest in bedrock hollows and inner gorges.

Delivery Potential/Criteria: High. Bedrock hollows are part of the drainage network and are adjacent to or contain streams. Delivery criteria are also based on historical occurrence observed on aerial photographs and confirmed during field investigations. The delivery rate for this unit is 797.

Hazard Potential Rating: Very High for roads and for harvest. This landform has a Landslide Frequency Rating of 1595 (see LHZ Protocol).

Trigger Mechanisms: Mass wasting is triggered by loss of root strength, changes in hydrology, oversteepening of slopes and loading slopes due to harvest, ground scarification, road building, and landing construction have destabilized slopes that failed during major rain-on-snow storms or intense precipitation events.

Confidence: High based on the excellent photo quality and coverage, and field observations.

Comments: Identification of bedrock hollows located in the steeply dipping sandstone units is difficult from aerial photo interpretation. Ground verification is necessary on steep (>70%) slopes.

Landform Number: #6 - Steep Headwall Basins and Other Moderate Hazard Slopes

Description of Mass Wasting Unit: These slopes are convergent but not as steep as convergent headwalls. They contain isolated areas of cliffs, and steeper (>70%) slopes, however the majority of all areas falling below the threshold of convergent headwalls excludes their classification as true convergent headwalls. Inclusions of unmapped landforms #1, #2, #4, & #5 may be located within landform #6.

Slopes: variable with more than 50% of the area falling below 70% slopes
Material: Sandstones, volcanics, colluvium, glacial deposits
Elevation: Variable
Total Area: 1124 acres

Mass Wasting Process: Debris flows, rock fall/topple, large deep-seated landslides, and shallow undifferentiated landslides may occur within this map unit.

Forest Practice Sensitivity: Timber harvest, road construction and/or landing construction on steep slopes results in the loss of root strength. Roads and landing can cause instability by undercutting and oversteepening slopes. Sidecast and road (or landing) fill can oversteepened and add weight to slopes; roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate road or landing fill and/or thin soils draping bedrock triggering slope failures and debris flows.

Mass Wasting Potential: Moderate for timber harvest and road construction

Delivery Potential/Criteria: Moderate. This map unit has been assigned a moderate delivery potential because it is often spatially separated from streams by the high hazard landforms. The delivery rate for this unit is 941.

Hazard Potential Rating: High for timber harvest and road construction. This landform has a Landslide Frequency Rating of 406 (see LHZ Protocol).

Trigger Mechanisms: Loss of root strength, changes in slope gradient, and changes in hydrology, timber harvest and road or landing construction has destabilized similar slopes that failed during major rain-on-snow storm or intense precipitation events.

Confidence: High confidence due to the excellent exposure as a result of the extensive clearcutting since the mid 1900's of a large percentage of the watershed. Complete aerial photo coverage and two days field checking the photo interpretation have provided a high level of confidence in this watershed.

Landform Number: #7 - Low Hazard Slopes

Description of Mass Wasting Unit: This map unit includes all slope forms and gradients that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety or impact a public resource. (Caution: Other map units could have been erroneously been included in landform #7 through mapping errors.)

Slopes: Variable
Material: Sandstone, volcanics, colluvium, alluvium, glacial deposits
Elevation: 5000 feet to 1940 feet
Total Area: 13,863 acres

Mass Wasting Process: Shallow landslides and debris flows may occur but are not common and generally do not have the potential to deliver to waters of the state or impact public safety or resources. Most common mass wasting process observed on aerial photographs were portions of deep-seated landslides away from public resources.

Forest Practice Sensitivity: Roads, landings, and skidding trails appear to be the most significant triggering mechanism for landsliding within this landform. Undersized culverts may lead to road fill failures and debris flows.

Mass Wasting Potential: Low for roads construction and timber harvest

Delivery Potential/Criteria: Low. Lack of channel access. Road and landing failures do not travel great distances. Steeper areas, headwall scarps, cliffs, terrace faces, toes of deep-seated landslides lack sediment delivery mechanisms. Distance from a stream channel, topography inhibits transport of landslide debris to public resources and does not impact public safety.

Hazard Potential Rating: Low for entire unit.

Trigger Mechanisms: Mass wasting triggering mechanism varies with landform, however, landslides occurring in this map unit are unlikely to deliver to a public resource unless something like an undersized culvert causes a road failure. This type of mass wasting event can be engineered on any type of landform with any type of slope gradient even if the landform is not commonly unstable.

Confidence: High for the entire unit based on field review and excellent photo quality and coverage. There are areas not identifiable on aerial photos that may have a higher potential for delivery. These areas will need to be delineated by the forester on the ground.

Comments: Very little failure activity noted. Large tracts of Low Hazard areas are currently being sold for development into housing. Harvest on steep slopes (>70%) above these housing units will require careful review by the foresters.

Landform (LF)	LF 1	LF 2	LF 3	LF 4	LF 5	LF 6	LF 7	WAU (excluding fed. land)
Landform area (acres)	103	310	106	756	33	1297	13,863	16,468
Numbering of “Delivering” Landslides	1	13	7	4	1	10		36
Area of “Delivering” Landslides (acres)	.5	20.1	21.9	10.92	.5	3.2		77.12
Landslide Frequency Rate (number of slides/Landform area/Years) x 10^6	537	2207	16,823	278	1595	406		
Landslide Area Rate for Delivery (delivering landslide area/landform area/years) x 10^6	268.5	3412.6	10,874	760	797	130		

Table 3. Landslide Area Rates

Mass Wasting Summary Table: Landform #1 – Toes of Deep-seated Landslides Stream Adjacent

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

Mass Wasting Summary Table: Landform #2 – Inner Gorges

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

Mass Wasting Summary Table: Landform #3 – Outside Meander Bends and Terrace Faces

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Snow Avalanche	Totals
Clear Cut (timber 0-5 yrs)								
Young Stands (timber 5-15 yrs)								
Submature (timber 15-50 yrs)	5							**5**
Mature (timber > 50 yrs)								
Road								
Partial Cut								
Yarding								
Alpine								
Other (e.g. housing, agriculture)	1							**1**

Mass Wasting Summary Table: Landform #4 – Convergent Headwalls

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Snow Avalanche	Totals
Clear Cut (timber 0-5 yrs)								
Young Stands (timber 5-15 yrs)								
Submature (timber 15-50 yrs)	3	1						**4**
Mature (timber > 50 yrs)								
Road								
Partial Cut								
Yarding								
Alpine								
Other (e.g. housing, agriculture)								

Mass Wasting Summary Table: Landform #5 – Bedrock Hollows

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Snow Avalanche	Totals
Clear Cut (timber 0-5 yrs)								
Young Stands (timber 5-15 yrs)								
Submature (timber 15-50 yrs)	1							**1**
Mature (timber > 50 yrs)								
Road								
Partial Cut								
Yarding								
Alpine								
Other (e.g. housing, agriculture)								

Mass Wasting Summary Table: Landform #6 – Steep Headwall Basins and other Moderate Slopes

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

Mass Wasting Summary Table: Landform #7 – Low Hazard Slopes

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Snow Avalanche	Totals
Clear Cut (timber 0-5 yrs)								
Young Stands (timber 5-15 yrs)								
Submature (timber 15-50 yrs)				14				**14**
Mature (timber > 50 yrs)								
Road								
Partial Cut								
Yarding								
Alpine								
Other (e.g. housing, agriculture)								