WASHINGTON STATE DEPARTMENT OF
Natural Resources

Mass Wasting Assessment:
Landslide Hazard Inventory Project

Cabin Creek Watershed, Kittitas County, Washington

Prepared by:

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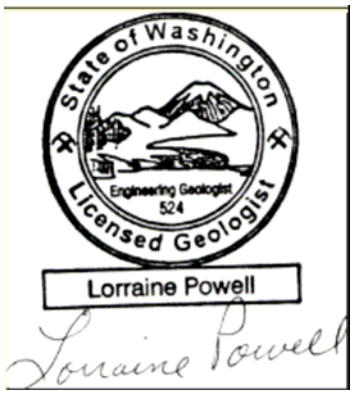

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Overview

The purpose of this mass wasting assessment is to identify areas within the Cabin Creek WAU that have a moderate or high risk of landslides due to the effects of forest management (logging, roading, thinning, yarding, etc.) on State and privately ownership. The Washington Forest Practices Board, Standard Methodology for Conducting Watershed Analysis, Version 4.0 (1997), adopted in part for use herein, requires that several critical questions are answered and that Mass Wasting Map Units (MWMUs) are defined, both of which help assess the risk that landslide debris could be delivered to public resources or affect public safety. 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. Undoubtedly, some landslides have been accidentally omitted and some benign features may be improperly mapped as landslides herein.

This assessment was conducted using aerial photographs, various maps, and field observations. Information is 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 to do so have been completed. 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.

1.1 Introduction to Mass Wasting Processes and Terminology

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 steeply 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. Side cast on steep slopes fail from capture of surface runoff saturating the fill, often initiating a debris slide or debris flow if a stream channel is present. Scouring of the stream channel initiates the beginning of 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 from clearcutting often results in the generation of debris flows that scour channels, flow down slope, eroding toward bedrock 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). Clearcutting 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.

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, shallow 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 Appendix A, Form A-1.) For the purposes of this study,

most landslides that fail below rooting depth are categorized as deep-seated, consistent with the Forest Practices rules (WAC 222-16-050). For this reason, those deep-seated landslides that moved rapidly and clearly deliver are included in the analyses of sediment delivery.

2.0 Physical Setting Pertinent to Mass-Wasting Interpretations

The Cabin Creek watershed covers 24453 acres and lies completely within Kittitas County. Approximately 6919 acres of checkerboard ownership in the western and southwestern portion of this watershed is managed by the U.S. Forest Service and is not included within this study (Map A-1). The remainder includes approximately 17534 acres of private (Plum Creek Timber Company and Boise Cascade Company) ownership and Department of Natural Resources managed lands.

The headwaters of the Cabin Creek watershed lie just east of the Cascade crest and drain to the northeast to its confluence with the Yakima River. Elevations range from a high of 5483 feet along the Cascade Crest to 2238 feet at the confluence of the Yakima River and Cabin Creek.

2.1 Topography

The Cabin Creek watershed is located directly east of the Cascade crest and south of Snoqualmie Pass. Cabin Creek drains northeast, joining the Yakima River one mile west of Lake Easton. The Cascade crest forms a portion of the western boundary of the watershed. Three streams, Cabin Creek, Log Creek, and Cole Creek, are the major drainages in this watershed. Topography is typical of the Cascades with slopes ranging from very gentle to over 40° with relief of 2000 ft common. The steepest and highest slopes in the watershed are located along the western faces of Cole Butte, Goat Peak and south of Cabin Mountain. Numerous large, deep-seated landslides are a significant geomorphic feature in this watershed. The main stems of Cabin, Cole, and Log Creeks have all been dammed by these deep-seated failures. Downcutting through the toes of these landslides has formed inner gorges that are actively headcutting upstream.

2.2 Geology

Bedrock

The major bedrocks units in the Cabin Creek WAU are the complexly deformed 40 to 44 million year old Naches Formation and the mildly deformed 30 to 37 million year old Ohanapecosh Formation. Both geologic units consist of inner-bedded volcanic and sedimentary rocks that have been deformed by extensive folding and faulting. The WAU is within the Cabin Creek “geologic” Block described by Tabor and Frizzell (1984). This “geologic” block is located at the intersection 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, twisted nature of the bedrock, combined with slippery shale units between fractured ancient lava flows, and a deeply eroded topography of this mountainous area facilitate mass wasting throughout the watershed.

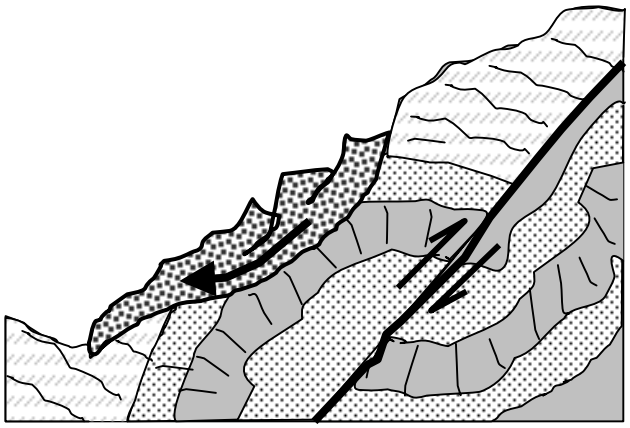


Figure 1. A sketch illustrating the faulted and folded nature of the old volcanic and sedimentary rocks that are found through out the Cabin Creek drainage. The broken inclined bedrock layers are prone to mass wasting at all scales.

Sediments

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 side drainages. Alpine glacial deposits, rock glaciers, glacial drift, small fans, bogs, and modern stream alluvium are present in the upper portions of Log and Cole Creek drainages. Alluvium in the main stem of Cabin creek extends from the confluence of Cabin Creek and the Yakima River upstream 2/3rds the length of the drainage past its confluence with Log Creek. Large deep-seated landslides are a dominant feature in the Cabin Creek watershed. Landslides deposits have dammed the main stem drainages in Cabin, Log, and Cole Creeks forming low gradient, sediment filled valleys upstream of these features. Smaller tributaries of these drainages have also been similarly dammed.

2.3 Summary of Previous Mass Wasting Investigations

Plum Creek Timber Company prepared a draft Watershed Analysis for the Cabin Creek Basin in January 1997. This document was reviewed during the initial phase of the LHZ Project (L. Powell, 2003). During this review, opportunities to improve the interpretation were noted, hence this study.

3.0 Summary of Methods

This assessment generally follows the Level II Mass Wasting methodology presented in the Standard Methods for Conducting Watershed Analysis Version 4.0 (Washington Forest Practices Board, 1997), however, the data-gathering period has been abbreviated and the synthesis and prescription phases have been omitted.

All available 1979, 1984, and 1985 stereo aerial photographs were viewed through a mirrored stereoscope with 3x magnification. 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/convergence map (SLPSTAB; Vaugeois, 2000) and a slope-percent map derived from USGS 10-meter digital elevation model (DEM) of the watershed aided in evaluation of slope conditions prior to slope failures, assisted in predicting areas of

potential future failures, and aided in delineation of the Mass Wasting Map Units (MWMUs). 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 reflectec by the 10m DEM contour map.

Two days were spent verifying features mapped in Cabin, Log, and Cole Creek. GPS readings were taken of features mapped during the photo survey using a Garmin V handheld unit. Accuracy of individual points varied from +/- 8ft to +/- 40ft depending on location. Additional features not visible on the photos were also mapped and added to the inventory. All GPS data was added to the Appendix A spreadsheet.

Table 1. Photographic surveys used in this study.

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

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 feature catalogued during this investigation.

Table 2. Inventoried mass wasting features in the Cabin Creek Watershed.

Process	Number of features
Shallow-rapid landslides	51
Debris Flows	83
Debris avalanche	0
Deep-seated	42
Shallow sporadic deep-seated	31
Large, persistent deep-seated	14
Earth flow	2
Rock topple	3
Snow avalanche	1

The resulting mass wasting coverage is displayed as Map A-1. Pertinent attributes of individual features were recorded on data sheets (Form A-1). These include: 1) the type of mass wasting process, (Lsi_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)), 2) level of certainty of the observation (D-definite, P-probably, Q-questionable), 3) photo Identification Date (ID date), 4) landslide size (1=very small, 2=small, 3=medium, 4=large, 5=very large), (5) slope shape (convergent, divergent, planar), 6) field gradient as measured in the field, 7) map gradient measured from the 10m DEM, 8) delivery (Y-yes, N-no, P-probably, I-indeterminate), 9) landuse (1=clearcut, 2=young stands, 3=submature timber, 4=mature timber, 5=road, 6=partial cut, 7=yarding, 8=alpine, 9=other), 10) initiation elevation, 11) aerial photo identification number, 12) acreage as calculated for each polygon in acres, 13) the mass wasting map unit identification number.

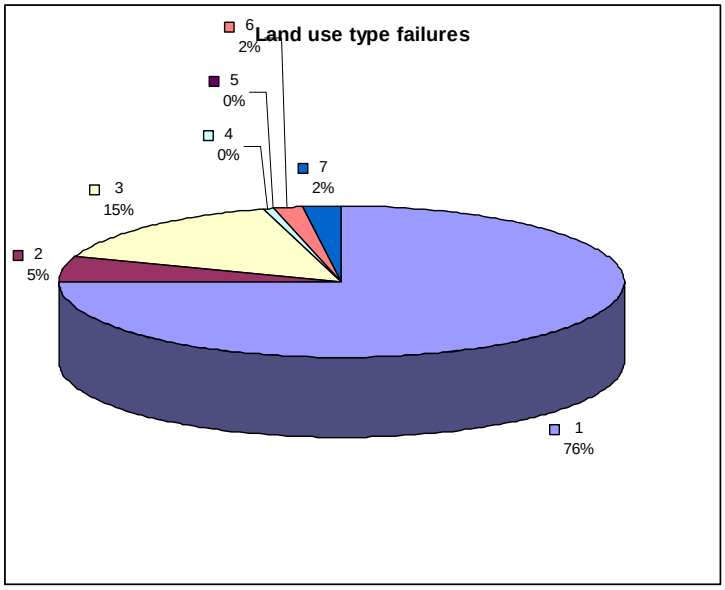
Slope gradients were determined by exploring a DEM-derived slope percent map within each feature polygon in its individual shape file. The slope angle cannot be reliably determined for small or narrow landslides where accuracy is limited by the 10-meter resolution of the DEM. Slope angle is understated 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 Mass Wasting Map Units (MWMUs). These are shown on Map A-2 and described in Appendix B.

4.0 Summary of Analysis and Results

During this review, representative samples of 227 mass wasting features were inventoried using data obtained from both black & white and color aerial photos taken in 1979, 1984, and 1985 (Form A-1). Of the landslides identified during this mass wasting assessment, 23% (52) were mapped as shallow-rapid - undifferentiated failures, 37% (83) were debris flows, 19% (42) were deep-seated landslides, 14% (31) were shallow sporadic deep-seated landslides, 6% (14) were large deep-seated landslides, 2 earth flows were identified, 3 rock topple, and 1 snow avalanche.

Land use was determined for each feature. Due to high visibility (complete removal of all vegetation) and tremendous ground disturbance in the 1979 stereo photos (intense scarification of clearcuts), 170 combined features (76%) were identified within clearcuts. Submature timber stands contained 35 (15%) of the identified features, young stands had 12 (5%) of the features, partial cuts and alpine areas contained 4 (2%) and 5 (2%) of the identified features. Only 1 mass wasting feature was identified in a mature timber stand 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 high hazard areas under forest canopy.



1 = clearcut (timber 0-5 years)

2 = young stands (timber 5 – 15 years)

3 = submature timber (15 – 50 years)

4 = mature timber (>50 years)

5 = road

6 = partial cut

7 = alpine

Figure 2. Mass Wasting features located by land use.

5.0 Mass Wasting Units

The distribution of the four Mass Wasting Map Units (MWMUs) for the Cabin Creek watershed study area are shown on Map A-1, and are described in Forms A-2. These units have been delineated to depict areas having similar mass wasting potential and potential to deliver to public resources. Mass wasting potential is based mainly on landslide process, failure density, lithology, geomorphology, and topography. Hydrogeology is considered as a critical variable for delineating MWMUs in this watershed. The following sections briefly describe the characteristics of each MWMU with additional information given in Appendix B.

5.1 MWMU#1: Toes of Deep-Seated Landslides, Stream Adjacent

Large, deep-seated landslides cover 2686 acres (4 square miles) of the Cabin Creek watershed. The oversteepened lower portion of these deep-seated landslide deposits adjacent to streams had a high number of timber harvest related mass wasting features that delivered debris to a stream. Of the 2686 acres covered by deep-seated landslides, 376 acres were identified as being high hazard areas for forest practices related landslides that could deliver to streams. This MWMU is described as consisting of the lower portion of deep-seated landslide deposits that are adjacent to or transected by streams (Figure 3).

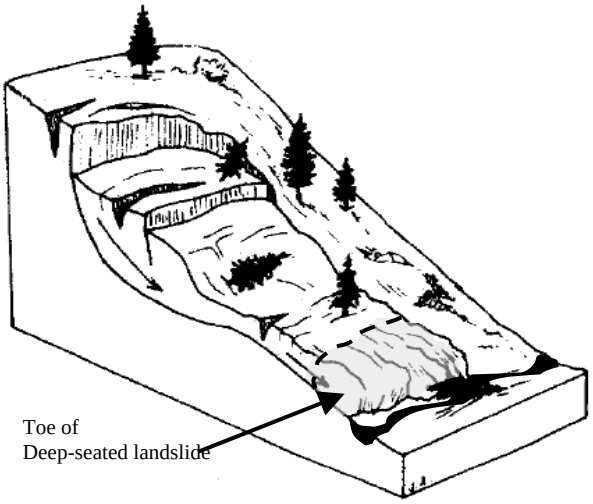


Figure 3.
Diagram showing the toe of a deep-seated landslide (after Note 50 CALIFORNIA DEPARTMENT OF CONSERVATION DIVISION OF MINES AND GEOLOGY FACTORS AFFECTING LANDSLIDES IN FORESTED TERRAIN

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, and commonly contains areas of ravel, shallow deep-seated, or shallow surficial landsliding. The toes of these deep-seated landslides are composed of the material transported and deposited by the parent deep-seated landslide. Weathering processes have covered these deposits with a blanket of colluvium and soils. The deposits can vary from large blocks of fairly intact bedrock to broken sheared bedrock mixed with colluvium. Boulders are commonly mixed with finer sediments including clay lenses. 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 older body of a landslide. The major valley stream often cuts parallel along or through the toe of the slide deposit. Side streams down cut perpendicular to and through the toe eroding inner gorges and bedrock hollows in the broken, poorly consolidated landslide deposits. Marginal streams on either side of the body of the toe can also form inner gorges and bedrock hollows that in turn can trigger shallow and small deep-seated landslides.

Where large deep-seated landslides once blocked major valley drainages, the stream commonly forms an inner gorge as it down cuts through the deposit to reestablish its channel. As the inner gorge headcuts upstream through the blockage, the walls commonly fail, nearly continuously, delivering directly to the stream. Root strength is extremely important along these unstable inner gorge walls.

Slopes >65% are most prone to failure, however, harvest related landslides have be observed on slopes of 45%. Slope was difficult to determine from DEM data, therefore, it is up to the field forester to determine which portions of the area indicated as toes of deep-seated landslides are actually in the high hazard >65% units.

The mass wasting processes active on the toes of these features are the result of streams undercutting and downcutting culminating in oversteepened deep-seated landslide deposits, 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 have formed inner gorges and bedrock hollows within the landslide toe deposit.

Forest Practices can destabilize oversteepened, poorly consolidated slopes by reducing the root strength after timber harvest, road construction, and/or landing construction. Roads and landings also destabilize the toes by undercutting, oversteepening, and loading slopes. Both harvest and roads effect slope stability

by changing slope hydrology, evapotranspiration, loss of canopy intercept, interception of shallow groundwater, decreasing infiltration, increasing surface runoff, as well as diverting and concentrating runoff waters.

The toes of deep-seated landslides adjacent to streams were assigned a high mass wasting potential due to numerous examples apparent on aerial photographs and in the field of failures related to timber harvest and road construction. 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).

5.2 MWMU#2*:* – Inner Gorges, Bedrock Hollows, And Slopes With Shallow Landslides and Small Rotational Failures

868 acres of the Cabin Creek watershed were mapped as having a high hazard of mass wasting related to inner gorges, bedrock hollows, and slopes prone to small, deep-seated landslides. Debris flows related to these features covered 156 acres of the study area. This represents 1/8th of the area mapped as high hazard for delivery having failed since 1979 (the earliest photo year used in this study).

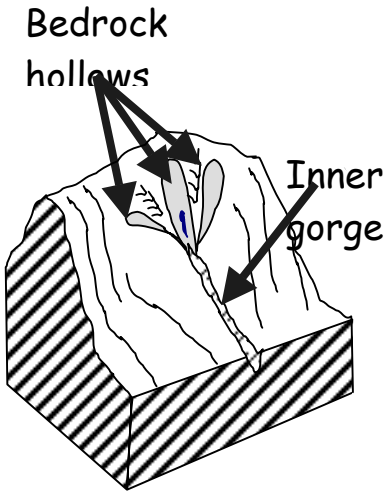


Figure 1. This sketch illustrates the relationship of bedrock hollows and inner gorges. Landslides initiating in bedrock hollows flow down the drainage carving out inner gorges. The transition between the hollow and inner gorge and bedrock is usually the point in the drainage where a channel develops.

Bedrock hollows and inner gorges are transitional into each other (Figure 1). Bedrock hollows *(*colluvial hollows, zero-order basins, swales, bedrock depressions, or simply hollows) are landforms that are commonly spoon-shaped areas of convergent topography with a concave profile. Their slopes are usually steeper than 70% (~35°) 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. Most hollows are 75 to 200 ft wide at the top and narrow to 30 to 60 ft downhill. 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. Recently failed hollows will have channels along their axis until they fill with sufficient colluvium to allow runoff water to flow subsurface. Steep bedrock hollows typically experience episodic evacuation of debris by shallow-rapid mass movement followed by slow refilling with colluvium. Unless they have recently experienced evacuation by a landslide, hollows are usually partially or completely filled with colluvial soils and typically exhibit deeper soils than those present on adjacent spurs and planar slopes. (Hollows that are completely filled with colluvium may show no surface concavity.) Many hollows have no visible surface water. Those that have been evacuated by landslides may contain seeps and springs. Hollows that have recently failed in the Cabin Creek Watershed usually have a debris flow transporting the failed material downstream or down slope if a distinct stream channel is not present. Many bedrock hollows were observed to have recently failed in newly harvested clear cuts. Distinct debris flow scars from many recently failed hollows were visible on the 1979, 1984, and 1985 aerial photographs.

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. Bedrock hollows can transition down slope into inner gorges as a defined stream channel develops. 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 35° (70%) or steeper can be maintained, but soil mantles are sensitive to root-strength loss at these angles. Slope gradients as gentle as about 28° (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.

Shallow landslides and small rotational failures were observed within inner gorges, on steep slopes, and below roads and landings, occasionally displacing whole sections of haul road. Some large, irregular shaped bedrock hollows may have been identified as shallow landslides. All shallow landslides outside inner gorges were located in clear cuts. Old growth canopies effectively hide shallow landslides and small rotational failures from detection on aerial photos. Careful field review will be necessary for those areas of moderate to old growth timber as the vegetation masks most of these features on aerial photography.

This MWMU also includes isolated areas prone to small deep-seated landslides or large debris slides. These features are usually located on slopes with diverse topographic characters with a common similarity in that they occur on slopes that failed after the last major harvest activity. Most appear related to harvest roads and skid trails concentrating runoff waters.

Harvest related landslides within these features usually occur on slopes between 50 - 100%. Slopes > 65% have the highest rate of failure, however, harvest related debris flows and road failures were mapped on slopes as low as 45% (measured from topographic maps in Sec. 4 & 5 of T19N, R13E). Note: bedrock

hollow slopes are measured on the steepest part of the slopes (i.e., the fall line), not along the axis of the feature. The slope of the inner gorge is measured on the steepest portion of the gully walls.

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. The over steepened walls of inner gorges fail as slope ravel, shallow landslides, or small rotational failures 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. 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 landslides associated with road construction and timber harvest in bedrock hollows and inner gorges. A high delivery potential was assigned to this unit as inner gorges and bedrock hollows are part of the drainage network and are adjacent to or contain streams.

5.3 MWMU#3: Moderate Hazard Slopes

MWMU#3 consists of moderate hazard slopes adjacent to high hazard bedrock hollows and inner gorges mapped as MWMU#2. These slopes are steep (>50%) and usually convergent and concave although they can be planar immediately adjacent to High Hazard MWMU#2. Inclusions of unmapped areas ofMWMU#2 (i.e., bedrock hollows and inner gorges) may be located within MWMU #3. This unit consists of steep convergent slopes, rock glaciers, avalanche chutes, convergent headwalls, and minor cliff bands. This map unit covers 1592 acres (2 ½ square miles) within the watershed and contains mass wasting features such as shallow landslides, debris flows, snow avalanches, rock fall/topple, and rock glaciers. This map unit contains landslides related to timber harvest, road construction and/or landing construction, however, the map unit has been assigned a moderate delivery potential because it is not adjacent to streams. Its mass wasting hazard potential is moderate for timber harvest and road construction because landslides are rare in this map unit.

5.4 MWMU#4: 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. MWMU#4 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, and valley floors. A majority of the unit contains slopes < 70%, however, steeper areas that do not deliver or that have a low landslide potential are included.

Shallow 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 road and landing fill failures in scarified, clear cut slopes and deep-seated landslides or portions of deep-seated landslides away from public resources. Roads, landings, and skidding trails appear to be the most significant triggering mechanism for landsliding within this MWMU. Undersized and plugged culverts were observed in field review to have contributed to several road fill failures. Large-scale clear cutting with intense scarification of slopes appeared to trigger landslides on planar slopes, however, they rarely delivered to a stream. The low mass wasting potential is due to lack of channel access. Road and landing failures on planar or low angle slopes do not travel great distances. Steeper areas such as avalanche chutes, headwall scarps and cliffs lack sediment delivery mechanisms.

6.0 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 Cabin Creek WAU, a total 87 landslides (deep-seated, shallow sporadic deep-seated, and large persistent deep-seated), 51 shallow-rapid failures, 83 debris flows, 2 earth flows, 3 rock topple, and 1 avalanche chute were identified over a 6-year photo history.

What mass wasting processes are active?

Debris flows, rock topple/fall, rock glaciers, earth flow, debris slides, snow avalanche, ravel, failures on the outside of meanders, inner gorges, bedrock hollows, toes of deep-seated landslides, shallow-rapid landsliding, small sporadic deep-seated and deep-seated landslides are active mass wasting processes in the Cabin Creek Watershed (Form A-1).

How are mass wasting features distributed throughout the landscape?

A majority of the features identified (76%) were located within active forest management areas. Clearcuts were distributed fairly evenly throughout the watershed.

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

Landslides do deliver to streams. Past forest practices have resulted in road and fill failures that deliver as debris flows or shallow landslides to waters of the state. Landslides do not threaten public works or safety in this watershed.

How do forest management activities create or contribute to instability?

Roads, landings, and skidding trails appear to be the most significant triggering mechanism for landsliding within this MWMU. 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. 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. Clearcutting removes root strength necessary to stabilize slopes near failure thresholds.

What areas of the landscape are susceptible to slope instability?

Slopes above inner gorge walls, the toes of deep-seated landslides that are stream adjacent, steep, convergent, clearcut and scarified slopes, slopes in and adjacent to bedrock hollows.

7.0 Confidence in Work Products

The confidence in this mass wasting assessment is moderate/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 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 slopes with mature vegetation regimes.

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). Therefore confidence in work products related to classification of deep-seated landslide processes in this watershed is 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 hill slope angle. Given these sources of error, the

confidence in the precise location and accuracy of measurements of individual landslides is considered moderate.

8.0 Acknowledgement

This report was written using a format developed by Dave Parks (2000). Jack Powell reviewed and edited this text, and provided extensive technical support. Laura Vaugeois kindly completed the final edit of the document. Tom Boyd helped develop the mass wasting layers and final map layouts, creating order from a variety of polygons. Bill Lingley contributed greatly through his patience in GIS map format updates to the LHZ program.

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Appendix A

10.0 Appendix A -- A-1 Form: Cabin Creek Landslide Inventory

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size_acres	Comments
501		P	5	D	1979	5			8	3		84.4	P	4	KYK_79_22E_20	5	
502			2	D	1979	4			1	2		56.6	N	2	KYK_79_21C_18	0.9	
503		P	5	D	1979	5			8	2		77.1	Y	6	KYK_79_21C_16	2	
504		P	5	D	1979	3			8	2		78	Y	3	KYK_79_21C_18	0.3	
505			1	D	1979	3			8	3		82	Y	3	KYK_79_21C_18	0.3	
506			2	P	1979	4			1	1		72.2	P	2	KYK_79_21C_18	0.9	older probable debris flow
507			2	P	1979	5			1	1		74.4	P	3	KYK_79_21C_18	1	probable older debris flow
508			2	P	1979	5			1	2		75.7	I	3	KYK_79_21C_18	1.2	probable older debris flow
509		P	1	D	1979	3			8	1		32	Y	3	KYK_79_21C_18	0.3	reactivated toe deep seated 515
510			2	Q	1979	5			1	2		95.9	N	3	KYK_79_21C_18	1.5	probable older debris flow
511		P	4	D	1979	5			8	5		79.4	Y	6	KYK_79_21C_18	32.9	
512		P	5	D	1979	5			8	1		79.6	Y	2	KYK_79_21C_18	3.3	
513		P	5	D	1979	5			8	1		99.3	Y	3	KYK_79_21C_18	2.9	
514			9	D	1979	5			3	1		156	N	8	KYK_79_21C_18	7.6	
515		P	6	D	1000	5			8	2		101.6	Y	3	KYK_79_21C_18	250	dormant -indistinct, some reactivation
516			2	D	1979	5			1	2		57.7	N	6	KYK_79_21C_18	1.4	
517		P	5	D	1000	5			8	1		75.8	Y	3	KYK_79_21C_16	6.8	dormant -indistinct, some reactivation
518		P	4	P	1000	5			8	1		38.3	N	2	KYK_79_21C_16	2.9	dormant - indistinct
519			2	D	1979	5			1	2		53.6	Y	1	KYK_79_21C_14	2.8	
520		S	4	D	1979	5			8	1		63.9	N	2	KYK_79_21C_16	16.9	smaller, more recent landslide within older larger slide
521		S	5	D	1979	5			8	2		55.2	N	1	KYK_79_21C_16	1.6	secondary landslide
522		S	6	D	1979	5			8	1		91.4	Y	3	KYK_79_21C_16	6.4	reactivation of large toe road related?
523		P	6	P	1979	5			8	1		53.8	I	1	KYK_79_21C_16	80.1	dormant -indistinct, some reactivation
524		P	4	D	1979	4			8	3		79.3	N	3	KYK_79_21C_16	0.5	
525		P	5	D	1979	4			8	3		112.4	N	3	KYK_79_21C_16	0.8	
526		P	4	D	1979	5			8	4		99.7	N	2	KYK_79_21C_16	8.5	
527		P	5	D	1979	3			8	2		92.8	N	3	KYK_79_21C_16	0.2	road cut bank failure
528		S	5	D	1979	4			8	3		87.5	Y	1	KYK_79_21C_16	0.5	reactivation of toe deep seated landslide
529		P	7	D	1979	5			8	1		56.5	P	1	KYK_79_21C_14	81.4	earth flow

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
530			7	D	1979	5			8	3		49.8	Y	1	KYK_79_21C_14	42.3	earth flow over rode older landslide damming drainage
531			2	D	1979	3			8	5		27.4	Y	1	KYK_79_21C_14	0.32	road failure/debris flow
532			2	D	1979	5			1	3		85.4	Y	1	KYK_79_21C_14	1.7	
533			2	D	1979	5			1	2		31.6	Y	1	KYK_79_21C_14	8.4	clearly visible
534			2	P	1979	5			1	2		51.5	N	1	KYK_79_21C_16	4.1	stream channel, no inner gorge
535			2	D	1979	5			1	2		31.3	Y	1	KYK_79_21C_16	16.8	stream channel, no inner gorge
536		P	4	D	1979	5			8	1		94.8	Y	6	KYK_79_21C_16	10.2	
537		P	5	D	1979	5			8	2		82	Y	3	KYK_79_21C_14	1.4	outside meander undercut toe of slope
538		P	6	P	1979	5			8	2		73.9	I	3	SCC_85_55_020_156	45.9	
539		P	5	P	1979	5			8	3		48.8	N	1	KYK_79_21C_14	4.1	relict feature
540		P	6	D	1979	5			8	5		174.4	P	1	KYK_79_21C_14	107.3	feature dammed drainage
541		P	4	D	1979	5			8	5		53.8	N	1	KYK_79_21C_14	6.7	
542		S	4	D	1979	5			8	4		135.7	N	1	KYK_79_21C_14	2.7	secondary failure inside larger, older landslide
543		P	5	Q	1979	5			8	3		40.9	P	1	KYK_79_21C_14	29.8	
544			8	D	1979	5			6	5		109.5	N	8	KYK_79_21C_14	10.6	
545			2	D	1979	5			1	2		109.5	Y	1	KYK_79_21C_14	2.9	
546			2	D	1979	5			1	2		37.5	Y	3	KYK_79_21C_14	3.3	
547			1	D	1979	1			1	2		53.5	Y	1	KYK_79_21C_16	0.02	
548			1	D	1979	1			1	2		56.3	Y	1	KYK_79_21C_16	0.01	
549			1	D	1979	1			1	2		46.1	Y	1	KYK_79_21C_16	0.01	
550			1	D	1979	1			1	2		34.8	Y	1	KYK_79_21C_16	0.01	
551			1	D	1979	3			1	3		35.8	Y	1	KYK_79_21C_16	0.1	
552			2	P	1979	5			1	2		52.8	P	1	KYK_79_21C_14	1.3	
553			5	D	1979	3			8	3		58.9	Y	1	KYK_79_21C_14	0.23	
554			2	D	1979	5			1	2		80.6	Y	1	KYK_79_21C_12	1.9	
555			2	D	1979	4			1	2		45.8	Y	1	KYK_79_21C_12	0.7	
556			2	D	1979	4			1	2		26.2	Y	1	KYK_79_21C_12	0.4	debris flow cut road
557			2	D	1979	5			1	2		31.7	Y	1	KYK_79_21C_12	1.1	debris flow cut road
558			8	D	1979	4			6	3		108	N	8	KYK_79_21C_12	0.8	talus
559			8	D	1979	3			6	4		45.3	N	8	KYK_79_21C_12	0.2	talus

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
560		P	4	D	1979	5			8	1		68.7	N	3	KYK_79_20C_17	59	
561			2	D	1979	5			1	1		68	Y	3	KYK_79_20C_23	0.05	delivered to railroad
562			2	D	1979	4			1	1		49	Y	1	KYK_79_20C_14	0.5	debris flow cut road
563			2	D	1979	3			1	1		30	Y	1	KYK_79_20C_14	0.2	debris flow cut road
564			2	D	1979	4			1	1		43	Y	1	KYK_79_20C_14	0.5	debris flow cut road
565			2	D	1979	4			1	1		34	Y	1	KYK_79_20C_14	0.4	debris flow cut road
566		P	4	P	1979	5			8	1		81	Y	1	KYK_79_20C_14	97	cirque failure with reactivation in areas, most older features relict
567		P	5	Q	1979	5			8	1		87	N	1	KYK_79_19C_25	10	
568																	USFS ownership
569			2	D	1979	5			1	2		61	P	1	KYK_79_19C_15	2	
570		P	4	P	1979	5			8	3		65	N	3	KYK_79_19C_25	6.8	
571		P	4	P	1979	5			8	3		80	P	3	KYK_79_19C_25	8.6	
572		P	5	P	1979	5			8	3		115	N	3	KYK_79_19C_25	2.4	
573			2	D	1979	4			1	3		44	Y	3	KYK_79_19C_25	0.9	
574			2	D	1979	5			1	2		65	Y	3	KYK_79_19C_25	3.8	road failure in clearcut triggering debris flow
575			2	D	1979	5			1	1		71	I	1	KYK_79_19C_25	1.4	debris flow initiating in clearcut traveling down stream
576			2	Q	1979	4			1	2		61	I	3	KYK_79_19C_25	0.8	initiating at toe of shallow rapid landslide
577			5	D	1979	4			6	2		85	P	3	KYK_79_19C_25	0.9	landslide between clearcut above and timber below
578			2	P	1979	5			1	2		33	P	3	KYK_79_19C_25	3.9	initiated in clearcut, traveled into timber
579			2	D	1979	5			1	3		48	I	1	KYK_79_19C_25	2.5	debris appears to stop above RR filled drainage
580			1	D	1979	4			7	5		67	N	1	KYK_79_19C_25	0.4	
581			2	D	1979	5			1	2		47	P	1	KYK_79_19C_23	1.7	road failure in clearcut triggered debris flow
582			2	D	1979	3			1	1		38	P	1	KYK_79_19C_23	0.3	road failure in clearcut triggered debris flow
583	CC-20		2	D	1979	5			1	1		32	P	1	KYK_79_19C_23	2	road failure in clearcut triggered debris flow
584			2	D	1979	4			1	1		55	P	1	KYK_79_19C_23	0.9	road failure in clearcut triggered debris flow
585			2	D	1979	4			7	1		75	P	1	KYK_79_19C_23	0.5	multiple road failures close proximity debris flows
586			2	D	1979	4			1	2		71	P	1	KYK_79_19C_23	0.6	coalescing debris flow
587			2	D	1979	3			7	2		54	N	1	KYK_79_19C_23	0.3	road failure in clearcut triggered debris flow
588			2	D	1979	4			7	2		48	P	1	KYK_79_19C_23	0.4	road failure in clearcut triggered debris flow
589		P	6	D	1979	5			8	1		48	Y	1	KYK_79_19C_23	12.6	dormant distinct
590		P	4	D	1979	5			8	3		53	Y	1	KYK_79_19C_23	2.8	ridge nose failure

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
591		P	4	Q	1979	5			8	3		82	I	1	KYK_79_19C_23	6.7	dammed stream, downcutting in toe triggered multiple large and small failures.
592			1	D	1979	4			9	1		79	Y	1	KYK_79_19C_23	0.7	outside meander
593			2	D	1979	5			7	2		46	Y	1	KYK_79_19C_23	5.2	multiple road failures, close proximity triggered debris flows
594			2	D	1979	5			7	2		49	Y	1	KYK_79_19C_21	1.9	
595			2	P	1979	5			7	2		80	I	1	KYK_79_19C_21	1.8	
596			2	P	1979	4			7	2		47	P	8	KYK_79_19C_21	0.6	
597			1	D	1979	2			7	5		34	Y	1	KYK_79_15D_19	0.1	series of small shallow rapids below landing
598			1	D	1979	1			7	5		29	Y	1	KYK_79_15D_19	0.1	series of small shallow rapids below landing
599			5	D	1979	4			7	3		41	P	3	KYK_79_19C_21	0.6	
600			5	D	1979	5			8	2		50	P	1	KYK_79_15D_19	13	small shallow slump
601		P	5	P	1979	5			7	3		38	I	1	KYK_79_19C_21	4.3	relict indistinct
602		P	4	D	1979	5			8	5		59	Y	1	KYK_79_19C_21	13.3	dormant indistinct, dammed creek
603		P	4	Q	1979	5			8	3		43	P	1	KYK_79_19C_21	24.8	dormant indistinct
604		P	4	D	1979	5			8	1		82	Y	1	KYK_79_19C_21	16	dormant indistinct
605		P	4	P	1979	5			9	3		47	Y	1	KYK_79_19C_19	3	dormant distinct
606			2	D	1979	4			1	1		45	Y	1	KYK_79_19C_19	0.8	
607			2	P	1979	4			7	3		46	I	1	KYK_79_19C_19	0.6	road failure initiated debris flow
608			2	D	1979	4			7	1		59	Y	1	KYK_79_19C_19	1	road failure initiated debris flow
609			2	D	1979	5			1	1		65	P	1	KYK_79_19C_19	2	road failure initiated debris flow
610			2	D	1979	3			1	1		68	P	1	KYK_79_19C_19	0.2	
611			2	D	1979	5			1	1		58	P	1	KYK_79_19C_19	2	road failure initiated debris flow
612			2	D	1979	5			1	2		70	Y	1	KYK_79_19C_19	3	road failure initiated debris flow
613			2	P	1979	4			1	2		30	Y	1	KYK_79_19C_19	0.8	
614			6	D	1979	4			9	2		36	Y	1	KYK_79_19C_19	1	
615		P	5	D	1979	5			8	2		64	Y	1	KYK_79_19C_17	6	
616		P	5	D	1979	5			8	2		68	Y	1	KYK_79_19C_17	5	major road failure
617		P	6	D	1979	5			8	2		94	P	1	KYK_79_19C_17	95	reactivation at toe
618			2	D	1979	4			1	1		60	Y	1	KYK_79_19C_17	1	
619			5	P	1979	4			9	1		35	Y	1	KYK_79_19C_17	0.8	indistinct failure surface
620			5	P	1979	4			9	1		39	Y	1	KYK_79_19C_17	0.7	indistinct failure surface
621			1	D	1979	4			9	7		50	Y	1	KYK_79_19C_17	0.1	reactivation at toe of deep seated landslide

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
622			2	D	1979	5			1	2		73	Y	1	KYK_79_19C_17	3	road failure debris flow
623			2	D	1979	3			1	2		60	Y	1	KYK_79_19C_17	0.2	road failure debris flow
624			2	D	1979	3			7	2		65	P	1	KYK_79_19C_17	0.2	road failure debris flow
625			2	Q	1979	4			9	2		59	P	1	KYK_79_19C_17	0.5	stream gully, no inner gorge
626			2	D	1979	5			1	2		46	Y	1	KYK_79_19C_17	2.6	road failure debris flow
627			2	D	1979	3			1	2		47	Y	1	KYK_79_19C_17	0.2	road failure debris flow
628			2	D	1979	5			1	2		61	Y	3	KYK_79_19C_17	2	road failure near bottom of draw above stream junction
629			1	D	1979	3			7	4		50	N	1	KYK_79_15D_13	0.2	road prism failure
630			2	P	1979	5			1	2		34	P	1	KYK_79_15D_13	1.7	initiated in clearcut area
631		P	4	D	1979	5			1	2		69	P	1	KYK_79_15D_13	44	
632		P	4	P	1979	5			1	2		52	Y	1	KYK_79_15D_13	85	
633			1	D	1979	4			1	2		72	Y	1	KYK_79_15D_21	0.4	
634			1	D	1979	4			1	2		67	Y	1	KYK_79_15D_21	1	
635			2	D	1979	5			1	2		26	Y	1	KYK_79_15D_19	1.6	
636																	USFS deleted feature
637			2	D	1979	3			1	2		40	I	1	KYK_79_15D_19	0.3	
638																	duplicate feature this one deleted
639		P	6	P	1979	5			8	1		109	I	1	KYK_79_15D_19	72	
640		P	4	D	1979	5			8	2		72	N	1	KYK_79_15D_19	2	
641			2	P	1979	4			1	3		27	Y	1	KYK_79_15D_19	1	intermittent clearcut and submature timber stands
642	CC-3		2	P	1979	5			1	3	70	48	N	1	KYK_79_15D_17	1.4	shallow rapid feeding a debris flow
643																	part of 652 deleted number
644			4	P	1979	5			8	2		62	P	1	KYK_79_15D_17	13	
645			4	D	1979	5			8	2		53	I	1	KYK_79_15D_17	10	
646	CC-13	P	4	D	1979	5			8	2	91	89	P	1	KYK_79_15D_17	57	
647		P	4	D	1979	4			8	2		39	N	1	KYK_79_15D_17	1	
648			1	D	1979	5			7	3		48	I	1	KYK_79_19C_19	2	SR triggered debris flow
649			1	D	1979	3			9	4		31	Y	1	KYK_79_15D_15	0.2	
650			1	D	1979	2			1	3		45	I	1	KYK_79_15D_15	0.1	
651			1	D	1979	3			1	3		60	I	1	KYK_79_15D_15	0.2	
652			5	D	1979	5			1	2		54	Y	1	KYK_79_14C_22	2	small deep seated landslide becoming debris flow

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
653			1	D	1979	2			9	2		44	Y	3	KYK_79_15D_15	0.1	
654			2	D	1979	5			1	2		40	P	1	KYK_79_15D_15	5.8	
655			1	D	1979	2			7	2		25	Y	1	KYK_79_15D_15	0.1	
656			2	D	1979	5			9	3		19	Y	3	KYK_79_14C_22	1.2	road related failure/debris flow
657		S	4	D	1979	4			5	3		51	N	1	KYK_79_14C_22	0.4	secondary failure on margin of older landslide
658		P	4	D	1979	5			8	2		63	Y	1	KYK_79_14C_22	15	landslide dammed stream creating lake filling valley
659		S	4	D	1979	5			8	1		52	P	1	KYK_79_14C_22	22	secondary landslide inside larger distinct landslide
660		P	6	D	1979	5			8	1		61	P	1	KYK_79_14C_22	56	sharp failure plane top of landslide, along bedding plane?
661		P	4	Q	1979	5			8	1		75	I	1	KYK_79_14C_20	71	questionable boundary, poor exposures
662			1	D	1979	2			9	2		32	Y	1	KYK_79_14C_20	0.1	outside meander failures
663			1	D	1979	4			9	2		62	Y	1	KYK_79_14C_20	0.7	
664			1	D	1979	3			7	3		43	N	1	KYK_79_15D_15	0.2	cut slope failure onto road
665			1	D	1979	3			7	2		60	P	1	KYK_79_14C_18	0.2	
666			1	D	1979	4			7	2		66	P	1	KYK_79_14C_18	0.4	
667			1	D	1979	2			1	2		43	Y	3	KYK_79_14C_18	0.1	
668			1	P	1979	5			2	1		24	N	1	KYK_79_13D_9	1.2	possible large bedrock hollow evacuation, low angle slope, intensely disturbed ground
669			2	P	1979	5			1	3		18	Y	1	KYK_79_13D_6	3.8	
670			2	P	1979	5			1	3		34	Y	1	KYK_79_13D_6	1.7	
671		P	6	P	1985	5			8	1		89	Y	1,3	SC_C_85_55_020_156	234	
672			2	D	1985	5			7	4		51	N	1	SC_C_85_55_022_164	1.1	stream channel but no inner gorge
673			2	D	1985	4			1	2		56	P	1	SC_C_85_55_022_162	1	inner gorge without debris flow
674			2	D	1985	5			1	2		70	Y	1	SC_C_85_55_022_162	1.7	
675			1	D	1985	3			1	2		70	Y	1	SC_C_85_55_022_162	0.2	
676			1	D	1985	2			1	2		64	Y	1	SC_C_85_55_022_162	0.1	many shallow rapid failures within the inner gorge
677			2	D	1985	4			7	3		54	N	1	SC_C_85_55_022_164	0.9	stream channel but no inner gorge
678			1	D	1985	2			7	3		52	N	1	SC_C_85_55_022_164	0.1	stream channel but no inner gorge
679			1	D	1985	2			7	3		67	Y	1	SC_C_85_55_022_164	0.1	stream channel but no inner gorge
680			1	D	1985	2			7	3		87	Y	1	SC_C_85_55_022_164	0.1	stream channel but no inner gorge
681			1	D	1985	3			1	3		90	Y	1	SC_C_85_55_022_164	0.3	
682			1	D	1985	2			1	2		52	Y	3	SC_C_85_55_022_164	0.1	
683			1	D	1985	2			1	2		76	Y	1	SC_C_85_55_022_164	0.1	

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
684			1	D	1985	2			1	3		62	Y	1	SC_C_85_55_022_164	0.1	
685			1	D	1985	2			1	3		73	Y	1	SC_C_85_55_022_160	0.1	
686			2	D	1985	4			7	2		62	P	1	SC_C_85_55_022_164	0.7	
687		P	4	P	1984	5			8	3		127	I	3	SC_C_84_7_19_66	42	
688			1	D	1984	5			5	1		91	P	1	SC_C_84_7_19_66	1.1	
689			1	D	1984	2			1	2		50	P	2	SC_C_84_7_19_66	0.1	
690			1	D	1984	2			7	3		61	P	1	SC_C_84_7_19_66	0.1	
691		P	4	P	1984	5			8	1		64	N	1	SC_C_84_7_19_62	7	
692			1	D	1984	4			1	2		89	Y	1	SC_C_84_7_19_64	0.6	
693			1	D	1984	4			1	2		67	Y	1	SC_C_84_7_19_64	0.6	
694			1	D	1984	2			1	4		71	Y	1	SC_C_84_7_19_64	0.1	
695		S	6	P	1984	5			8	4		75	Y	1	SC_C_84_7_19_64	34	dammed valley, moved stream
696		P	5	D	1984	4			8	3		55	N	1	SC_C_84_7_19_64	1	
697			1	D	1984	3			7	3		29	N	1	SC_C_84_7_19_64	0.3	road failure triggered shallow-rapid
698			1	D	1984	3			7	2		75	N	1	SC_C_84_7_19_64	0.3	
699			1	D	1984	3			1	3		75	Y	1	SC_C_84_7_19_62	0.2	
700			2	D	1984	3			7	2		81	P	1	SC_C_84_7_19_62	0.3	road failure triggered shallow-rapid
701			2	P	1984	4			7	1		71	P	1	SC_C_84_7_19_62	0.7	
702			2	P	1984	5			7	1		80	P	1	SC_C_84_7_19_62	1.2	probably road failure
703			1	D	1984	3			9	2		25	Y	1	SC_C_84_7_19_60	0.3	meander undercut toe of slope
704			2	D	1984	4			7	1		77	P	1	SC_C_84_7_19_60	0.8	road failure triggered debris flow
705			5	P	1984	5			8	2		23	I	1	SC_C_84_7_19_58	1.2	
706			4	D	1984	4			8	1		72	N	2	SC_C_84_7_19_56	0.8	
707			1	D	1984	5			9	3		79	Y	3	SC_C_84_6_16_163	1.1	
708			2	P	1984	5			7	2		26	Y	1	SC_C_84_6_16_163	4.3	stream channel no inner gorge
709		S	4	D	1984	5			8	5		29	N	1	SC_C_84_7_19_58	3	deep-seated landslide inside older deep seated landslide
710			4	D	1984				8	1			N	1	SC_C_84_7_19_56		USFS ownership
711			2	D	1984	3			2	3		28	P	1	SC_C_84_6_16_163	0.2	No inner gorge
712			2	D	1984	5			2	2		26	P	1	SC_C_84_6_16_163	1.2	No inner gorge
713		P	5	D	1984	5			8	2		59	P	1	SC_C_84_6_16_163	5	

slide_IDN	GPS_ID	Ls_Order	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Field Gradient	Map Gradient	Delivery	Landuse	Photo_num	Ls_size	Comments
714		P	5	D	1984	5			8	2		42	N	1	SC_C_84_6_16_163	3	
715		P	6	P	1984	5			8	1		124	P	1	SC_C_84_6_16_161	69	older headwall deep seated landslide
716		P	4	D	1984	5			8	3		31	N	1	SC_C_84_6_16_161	2	more recent failure adjacent to older deep seated
717		P	4	D	1984	5			8	3		40	P	1	SC_C_84_6_16_161	11	
718		P	4	D	1984	5			8	3		40	P	1	SC_C_84_6_16_161	9	distinct scarp
719		P	4	P	1991	5			8	3		53	N	1	SC-91-44-19-107	5	
720		P	4	P	1991	5			8	2		63	N	1	SC-91-44-20-16	5	
721		P	4	P	1979	5			8	2		65	Y	1	KYK_79_15D_13	40	active toe, may have glacial component
722		P	4	Q	1979	5			8	2		60	P	1	KYK_79_15D_13	19	indistinct body
723			2	P	1979	5			1	2		59	P	1	KYK_79_15D_15	3.9	
724		P	4	D	1979	5			8	2		68	Y	1	KYK_79_15D_21	3	
725		P	5	P	1979	3			8	3		29	Y	1	KYK_79_19C_17	0.2	
726		P	5	D	1979	3			8	2		43	Y	1	KYK_79_15D_21	0.3	
727		P	6	P	1979	5			8	2		44	P	1	KYK_79_15D_15	47	complex feature
728		P	5	D	2004	4			8	5		49	N	2	Field Identified	0.7	active landslide impacting haul road, GPS CC-35
729	CC-39		2	D	2004	5			1	2		70	Y	2	Field Identified	1.3	Field identified, GPS CC-39
730	CC-38		2	D	2004	3			1	2		56	Y	2	Field Identified	0.3	Field identified, GPS CC-38
731	CC-2	P	1	D	2003	3			7	2	71	66	P	2	Field Identified	0.3	shallow debris flow initiated at edge of clearcut
732	CC-1		1	D	2003	2			7	2	70	58	P		Field Identified	0.01	road fill failure

Appendix B

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

CABIN CREEK FORM A-2

Mass Wasting Map Unit #1 (MWMU#1) - Toes of Deep-Seated Landslides, Stream Adjacent

Description: Unit consists of the lower portion of deep-seated landslide deposits that are adjacent to or transected by streams.

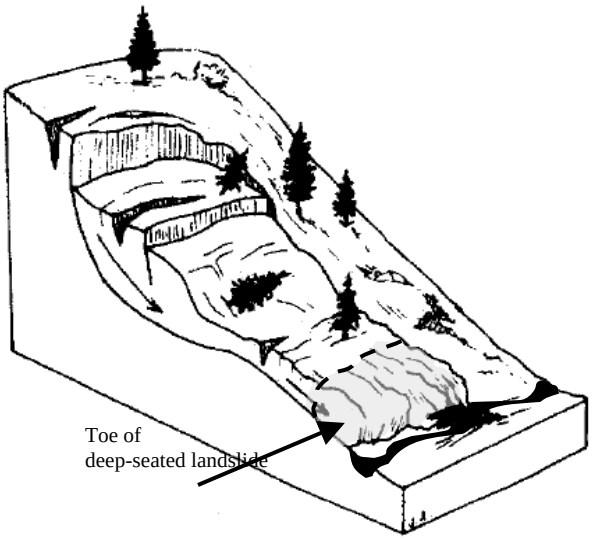

Diagram showing the toe of a deep-seated landslide (after Note 50 CALIFORNIA DEPARTMENT OF CONSERVATION DIVISION OF MINES AND GEOLOGY FACTORS AFFECTING LANDSLIDES IN FORESTED TERRAIN

Materials: Landslide deposits covered with colluvium and soils. The deposits can vary from large blocks of fairly intact bedrock to broken sheared bedrock mixed with colluvium. Boulders are commonly mixed with finer sediments including clay lenses.

Landform: 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, 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 older body of an older landslide. The major valley stream normally cuts parallel along or through the toe of the slide deposit. Side streams down cut perpendicular to and through the toe eroding inner gorges and bedrock hollows in the broken, poorly consolidated landslide deposits. Marginal streams on either side of the body of the toe can also form inner gorges and bedrock hollows that in turn can trigger shallow and small deep-seated landslides. Where large deep-seated landslides once blocked the main major valley drainages, the streams commonly form inner gorges as they down cut through the landslide deposit reestablishing their channels.

Slope: (45% - 100%) Slopes >65% are most prone to failure, however, harvest related landslides have be observed on slopes of 45%. Slope was difficult to determine from aerial photos, therefore, it is up to the field forester to determine which portions of the area indicated as toes of deep-seated landslides are actually in the high hazard >55% units.

Elevation: Variable

Total Area: 376 acres

Mass Wasting Processes: Stream 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 have formed inner gorges and bedrock hollows within the landslide toe deposit.
Occasionally, slopes of 45% or less fail within these stream channels. Debris flows are often located within the inner gorges in the toes.

Forest Practice Sensitivity: These oversteepened poorly consolidated slopes are can be further destabilized by loss of root strength due to timber harvest, road construction, and landing construction. Roads and landings also destabilize the toes by undercutting, oversteepening, and loading slopes. Both harvest and roads effect slope stability by change the slope hydrology, changes in evapotranspiration, loss of canopy interception, interception of shallow groundwater, decreasing infiltration, increasing surface runoff, as well as diverting and concentrating runoff waters.

Mass Wasting Potential: High for roads, High for harvest

Delivery Potential: High

Delivery Criteria Used: The high delivery criteria is related to the proximity of the toes of these deep-seated landslide to streams both within and adjacent to the landslide toe deposit

Hazard Potential Rating: High for roads, High for harvest

Trigger Mechanisms: 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 confidence due to the excellent exposure as a result of the extensive clearcutting since the mid 1970's of a large percentage of the watershed. Complete aerial photo coverage (3 missing photos) and two days field checking the photo interpretation have provided a high level of confidence in this watershed.

CABIN CREEK FORM A-2

MWMU#2: – Inner Gorges, Bedrock Hollows, Shallow Landslides, Small Rotational Failures, not Associated With Toes of Deep-seated Landslides

Description: Unit consists of inner gorges, bedrock hollows, and slopes prone to small deep-seated landslides

Materials: Colluvium, alluvium (minor), landslide deposits, and soil

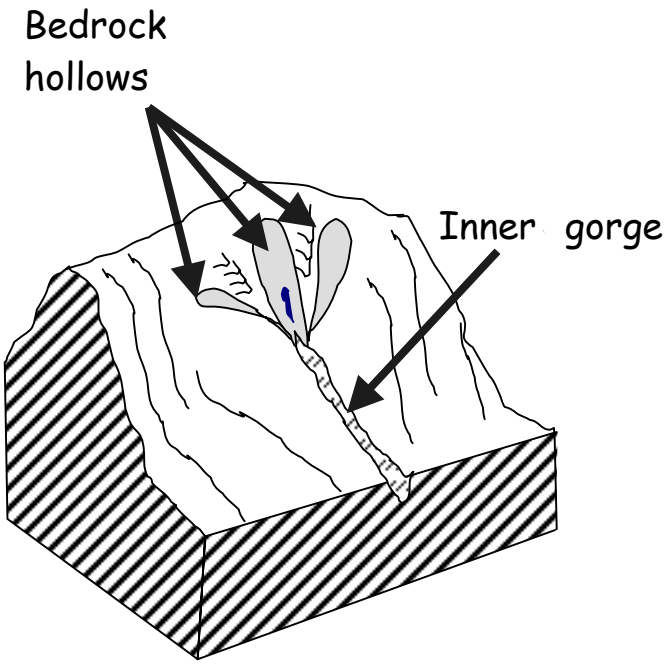

Figure shows the relationship of bedrock hollows and inner gorges. Landslides initiating in bedrock hollows flows down the drainage carving out the inner gorges. The transition between the hollow and inner gorge and bedrock is usually the point in the drainage where a channel develops.

Landform: Bedrock hollows and inner gorges are transitional into each other (as shown in Figure 1) Bedrock hollows (colluvial hollows, zero-order basins, swales, bedrock depressions, or simply hollows) are landforms that are commonly spoon-shaped areas of convergent topography with a concave profile. Their slopes are usually steeper than 70% (~35°) 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. Most hollows are 75 to 200 ft wide at the top and narrow to 30 to 60 ft downhill. 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. Recently failed hollows will have channels along their axis until they fill with sufficient colluvium to allow runoff water to flow subsurface. Steep bedrock hollows typically experience episodic evacuation of debris by shallow-rapid mass movement followed by slow refilling with colluvium. Unless they have recently experienced emptying by a landslide, hollows are partially or completely filled with colluvial soils that are typically deeper than soils on adjacent spurs and planar slopes. (Hollows that are completely filled with colluvium may show no surface concavity.) 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 Cabin Creek Watershed usually have a debris flow transporting the failed material downstream or down slope if a distinct stream channel is not present. Many bedrock hollows were observed to have recently failed in newly harvested clear cuts. Distinct debris flow scars from many recently failed hollows were visible on the 1979, 1984, and 1985 aerial photographs.

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. Bedrock hollows can transition down slope into inner gorges as a defined stream channel develops. 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 35° (70%) or steeper can be maintained, but soil mantles are sensitive to root-strength loss at these angles. Slope gradients as gentle as about 28° (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 erosion processes join slopes formed from hill slope erosion processes. Inner gorges can be asymmetrical with one side being 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 promotes continued mass wasting.

Shallow landslides and small rotational failures were observed within the inner gorges, on steep slopes, and below roads and landings, occasionally displacing whole sections of haul road. Some large, irregular shaped bedrock hollows may have been identified as shallow landslides. All shallow landslides outside inner gorges were located in clear cuts. Old growth canopies effectively hide shallow landslides and small rotational failures from detection on aerial photos. Careful field review will be necessary for those areas of moderate to old growth timber as the vegetation masks most of these features on aerial photography.

This MWMU also includes isolated areas prone to small deep-seated landslides or large debris slides. These features are usually located on slopes with diverse topographic characters with a common similarity in that they occur on slopes that failed after the last major harvest activity. Most appear related to harvest roads and skid trails concentrating runoff waters

Slope: Harvest related landslides with in these features usually occur on slopes between 50 - 100%. Slopes > 65% have the highest rate of failure, however, harvest related debris flows and road failures were mapped on slopes as low as 45% (measured from topographic maps in Sec. 4 & 5 of T19N, R13E). Note: bedrock hollow slopes are measured on the steepest part of the slopes (i.e., the fall line), not along the axis of the feature. The slope of the inner gorge is measured on the steepest portion of the gully walls.

Elevation: Variable between 4800 ft and 3400 ft.

Total Area: 860 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 inner gorges. The over steepened walls of inner gorges fail as slope ravel, shallow landslides, or small rotational failures sometimes initiating debris flows.

Forest Practices 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 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 bedrock hollows and inner gorges.

Delivery Potential: High

Delivery Criteria Used: High as inner gorges and 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.

Hazard Potential Rating: High for roads, High for harvest.

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 recent landslides located in this MWMU, excellent photo quality and coverage, and field observations.

CABIN CREEK FORM A-2

MWMU#3 – Steep (>55%) Convergent Slopes Adjacent to MWMU#2

Description: This Mass Wasting Map Unit (MWMU) consist of slopes >55% adjacent to the high hazard MWMU#2 (bedrock hollows and inner gorges).

Materials: Colluvium, soils, and deep-seated landslide deposits.

Landform: These slopes are steep (>50%) and usually convergent and concave although they can be planar immediately adjacent to High Hazard MWMU#2. Inclusions of unmapped areas MWMU#2 (i.e., bedrock hollows and inner gorges) may be located within this MWMU #3 This unit consists of steep convergent slopes, rock glaciers, avalanche chutes, convergent headwalls, and minor cliff bands.

Slope: >50%

Elevation: Variable

Total Area: 1592 acres

Mass Wasting Process: Shallow landslides, debris flows, snow avalanches, rock fall/topple, and rock glaciers occur within this map unit.

Forest Practices Sensitivity: Timber harvest, road construction and/or landing construction on these steep 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

Mass Wasting Potential: Moderate for timber harvest and road construction

Delivery Potential: Moderate

Delivery Criteria Used: This map unit has been assigned a moderate delivery potential because it is often spatially separated from streams by the high hazard MWMU 2.

Hazard Potential Rating: Moderate for timber harvest and road construction because landslides are rare in this map unit.

Trigger Mechanisms: Loss of root strength, changes in slope gradient, and changes in hydrology due to ground scarification, 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 confidence due to the excellent exposure as a result of the extensive clearcutting since the mid 1970's of a large percentage of the watershed. Complete aerial photo coverage (3 missing photos) and two days field checking the photo interpretation have provided a high level of confidence in this watershed.

CABIN CREEK FORM A-2

Mass Wasting Map Unit #4 (MWMU#4) – Low Hazard, Low Delivery All Other Areas

Description: 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 MWMU#4 through mapping errors.)

Materials: Soil, colluvium, alluvium, talus, deep-seated landslide deposits, glacial deposits, and outcropping of various bedrock types.

Landform: All slope forms and gradients including slopes that are divergent and convergent in map view and convex, planar, and concave in profile. Landforms include cliffs, ridge tops, scarps and bodies of deep-seated landslides, moderate and low gradient slopes, low gradient stream drainages, and valley floors

Slope: A majority of the unit contains slopes < 70%, however, steeper areas that do not deliver or that have a low landslide potential are included.

Elevation: Variable from 5400 ft to 2400 ft.

Total Area: 14,706 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 road and landing fill failures in scarified, clearcut slopes and deep-seated landslides or portions of deep-seated landslides away from public resources.

Forest Practices Sensitivity: Roads, landings, and skidding trails appear to be the most significant triggering mechanism for landsliding within this MWMU. Undersized and plugged culverts were observed in field review to have contributed to several road fill failures. Large-scale clear cutting with intense scarification of slopes appeared to trigger bedrock hollow evacuations onto planar slopes.

Mass Wasting Potential: Low for roads construction and timber harvest

Delivery Potential: Low due to lack of channel access. Road and landing failures do not travel great distances. Steeper areas, headwall scarps, cliffs, lack sediment delivery mechanisms.

Delivery Criteria Used: Distance from stream a channel, topography inhibits transport of landslide debris to public resources and does not impact public resources.

Hazard Potential Rating: Low for entire unit.

Trigger Mechanisms: Mass wasting triggering mechanism varies with landform type, 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 event if the landform is not commonly unstable.

Confidence: High for the entire unit based on 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.