White Salmon River/ Buck Creek Watershed

LANDSLIDE HAZARD ZONATION PROJECT

Klickitat and Skamania Counties, Washington

Forest Practices Division, Adaptive Management Program in coordination with the Washington State Division of Geology and Earth Resources

Priority 3

Mass Wasting Assessment
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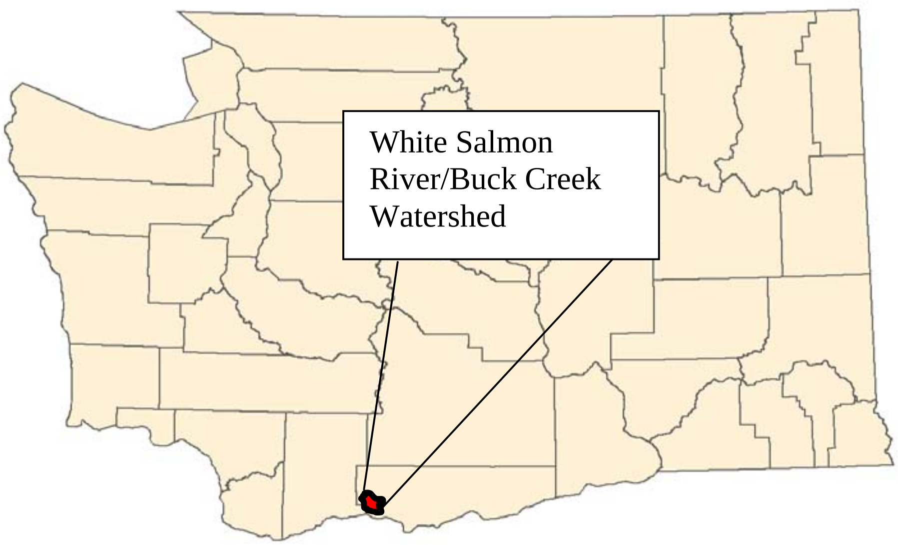

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http://www.dnr.wa.gov/geology/

CONTENTS

Project Summary

The White Salmon River/Buck Creek watershed lies approximately 8 miles east of the Cascade Crest near the Washington/Oregon border. Buck Creek drains south to the White Salmon River that in turn flows into the Columbia River just north of Hood River, Oregon. This Landslide Hazard Zonation (LHZ) analysis divided the 23,897 acre watershed into 12 landforms (plus federal lands) that were found to contain 232 features, of which 149 delivered to a resource or typed water of the state. Mapped landforms (summarized in Table 1) include some high hazard units defined in Washington State Forest Practices Rules such as: inner gorges, bedrock hollows, and toes of deep-seated landslides. Other high hazard landforms mapped within this watershed include bedrock outcrops, the Husum water line, slack water deposits and moderate to steep slopes (60 to +80%).

Landform Number	Name of Landform	Landform Slope Stability Hazard Rating	Slope of Landform (DEM)	Total Area of Landform in Acres	**No. of Delivering Landslides in Landform**	Comment
#1	Inner Gorges	Very High	>65%	434	23	FP Rule identified High Hazard
#2	Bedrock Hollows	Very High	>65%	185	12	FP Rule identified High Hazard
#6	Bedrock Outcrops	Very High	>60%	663	22	FP Rule identified High Hazard
#8	Toes Deep-Seated Landslides	Very High	>65%	254	12	FP Rule identified High Hazard
#10	Husum Water Pipeline	Very High	>10% variable	75	8	Unique landform to this watershed
#11	Slack Water Deposits	Very High	>45%	277	20	Unique landform to this watershed
#12	Steep Bedrock Above Public Resources	Very High	70%+	154	13	Unique landform to this watershed
#13	Low Angle Convergent Headwalls	High	60%+	1667	18	
#14	Valley & Stream Bottoms	Low	0-10%	1469	1	LHZ protocol Low Hazard
#15	Low Gradient Hill & Valley Side Slopes	Low	11-40%	12289	7	LHZ protocol Low Hazard
#16	Ridge & Hill Tops	Low	0-10%	2248	0	LHZ protocol Low Hazard
#17	Intermediate Slopes	Low	20-40%	3900	13	Unique landform to this watershed
	Federal Lands*	NA	NA	264	NA	Area was not evaluated
	Overall	High	NA	23,897	149	

* area not evaluated under the Landslide Hazard Zonation Project protocol.

Table 1. Summary of the 12 landforms mapped in the White Salmon River/Buck Creek watershed.

2.0 Introduction

The White Salmon River/Buck Creek watershed administrative unit (WAU), covering 23,897 acres, is located 8 miles east of the Cascade Crest and 3.5 miles north of the junction of the White Salmon and Columbia Rivers. A majority of the Buck Creek watershed is in private and state ownership. The watershed is roughly oval shaped, oriented northwest to southeast, and drains from north to south (see Fig. 1). Nearly the entire watershed is managed as forest and range. The city of Husum obtains water from a diversion dam located on the upper portion of Buck Creek. Water is piped underground from the dam to Husum along a cut bench on the west bank of Buck Creek. The watershed above the diversion dam has been leased by the City of Husum from the Department of Natural Resources to function as a supplemental water source for municipal purposes.

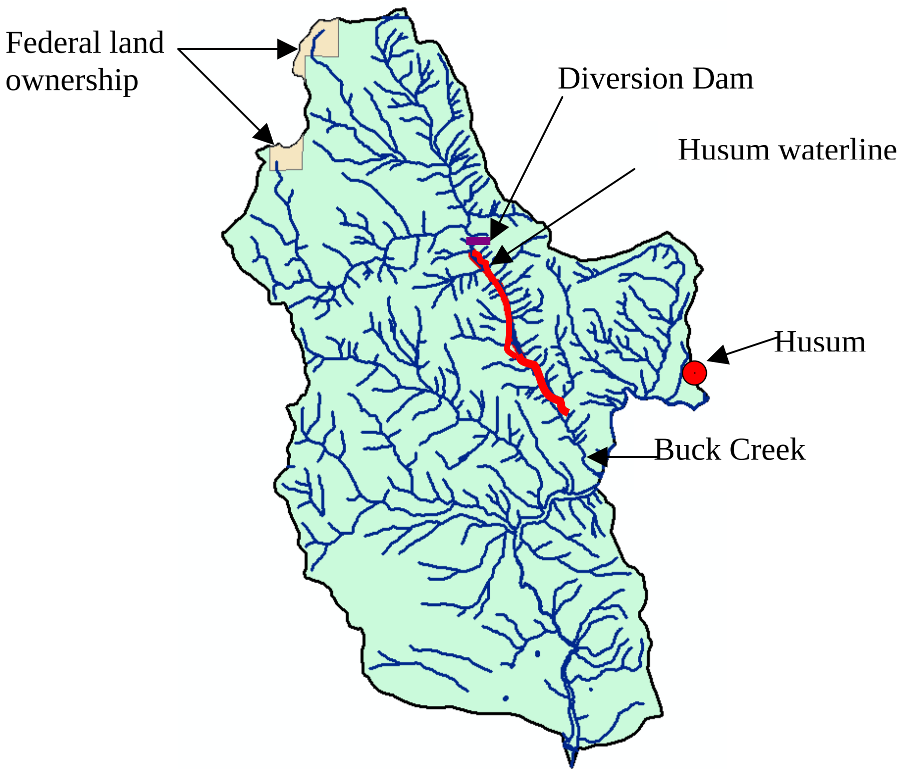

Figure 1. Location of Husum's waterline and the leased upper portion of the watershed in the upper sub-basin of the WAU.

3.0 Topography

Elevations in the Buck Creek watershed range from a low of 72 ft at the confluence of the Columbia and White Salmon Rivers at the southernmost tip of the WAU to a high of 4039 ft on the east side of Monte Carlo peak at the northern edge of the WAU. Figure 2 shows this correlation in a profile view across the watershed from northwest to southeast.

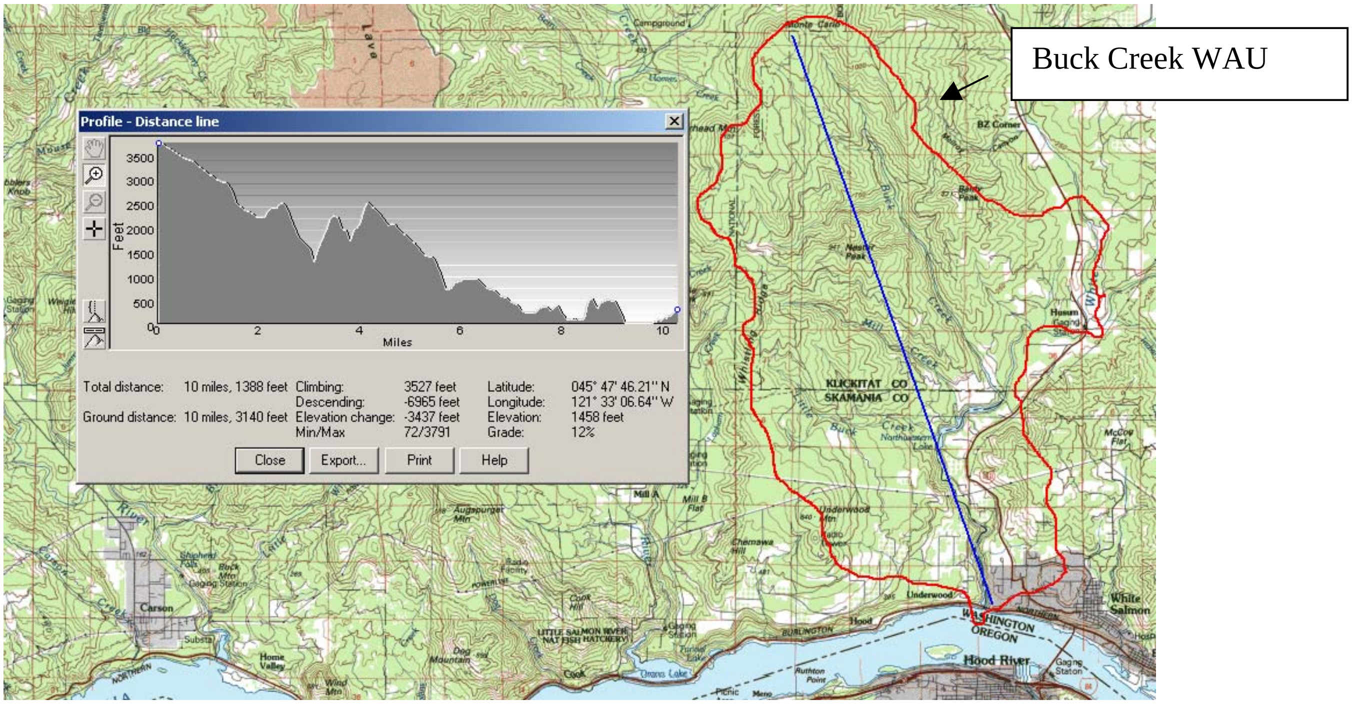

Figure 2. Profile of the White Salmon River/Buck Creek WAU from northwest to southeast. Elevation change is 3719 feet from the eastern side of Monet Carlo peak to the junction of the Columbia and White Salmon Rivers.

4.0 Hydrology

The southeastern side of this watershed receives considerably less rainfall than the northwestern area due to both the rain shadow affect on the lee (east) side of the Cascade Crest and the significantly lower elevations (see Fig. 2) present on the southeastern corner of the WAU. A USGS gauging station located on the White Salmon River below the confluence of Buck Creek has recorded stream flows beginning in 1916 (see Fig. 3). The average annual stream flow based on 85 years of record is 1115 cu. ft./sec. (USGS Washington Water Science Center). Stream flows typically peak in spring and are lowest in late fall to early winter. The highest recorded peak stream flow occurred in 1996 as measured at the USGS gauging station 14123500 located on the White Salmon River. This hydrologic event occurred during the late winter (January & February) of 1996 was significantly greater than any other on record (see Fig. 4).

Many culverts in the Buck Creek WAU failed and required replacement or repair after the 1996 event. The main road up Buck Creek was washed out, stranding a dam maintenance worker until the road could be filled and made passable for vehicular passage (personal communication, Pete Stocks, DNR). The 1996 event triggered debris flows originating from steep bedrock faces on the east side of Buck Creek drainage. These traversed down slope, blocking or washing out forest roads, plugging culverts, and delivering sediment and debris to Buck Creek.

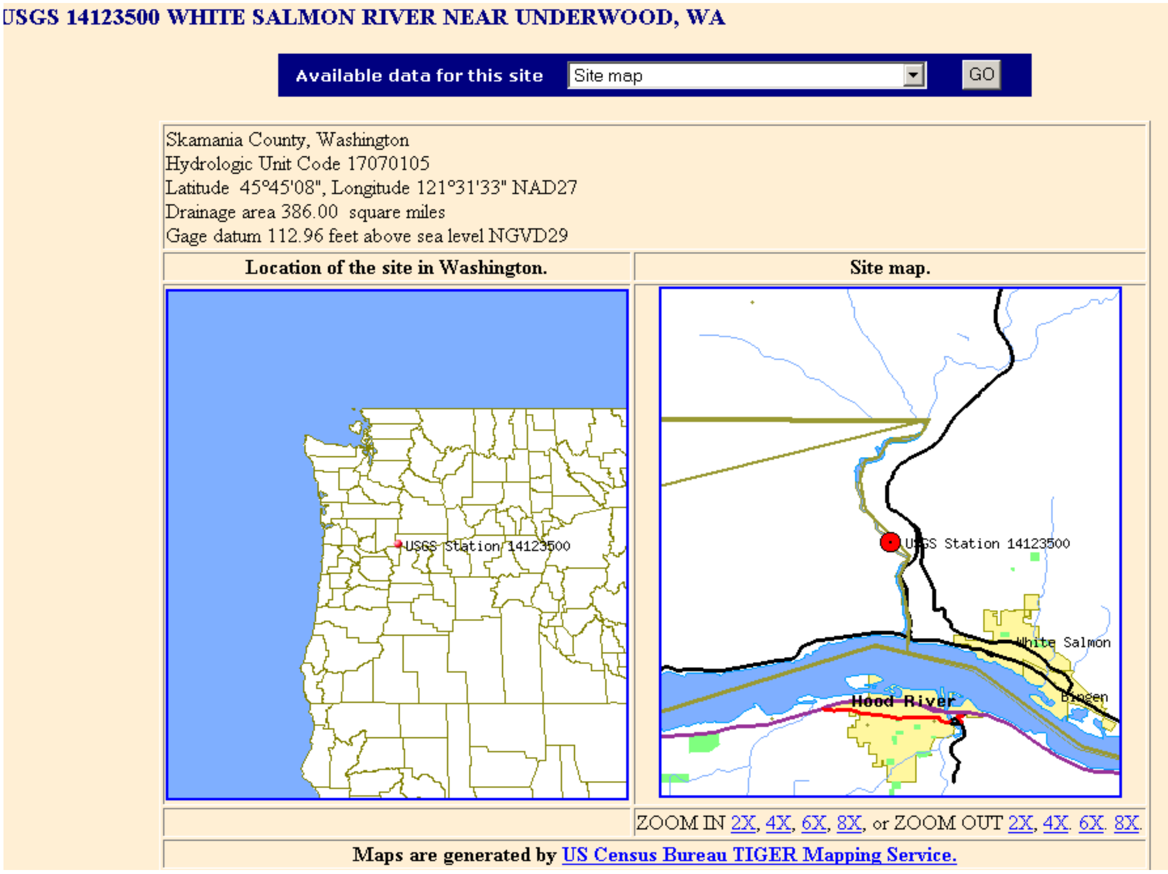

Figure 3. Location of the White Salmon River gauging station 14123500 (USGS Washington Water Science Center, US Department of the Interior).

5.0 Geology

5.1 Regional Geology

The Buck Creek WAU is located on the western margin of the Columbia River Basalt province. The predominant rock type within the watershed is basalt. Flows of the mid Miocene age (15.6-16.5 m.y.b.p.[million years before present]) Grande Ronde Basalt Formation form a majority of bedrock exposures within the WAU. Other limited basalt outcrops in the basin include flows of the Wanapum Formation and younger age monogenetic (single source) basalt flows present as depression/erosional fill features on and in Grande Ronde units (Korosec, 1987). Interbedded between basalt flows are sedimentary units of the Ellensburg Formation (5 to 15 m.y.b.p.) (Fig. 5). Landslide deposits and Missoula flood slack water silt and clay deposits drape the Grande Ronde, Wanapum, and Ellensburg units (Waitt, R. B., 1977).

5.2 Local Geology

The Buck Creek Watershed contains both large deep-seated landslides and shallow landslides in basalt and in volcaniclastic (derived from volcanic activity) sediments (cobbles, gravels, sands, silts, and clays). Numerous large deep-seated landslides in the Grande Ronde Formations occurred when large sections of basalt slid on clay and silt interbeds between some of the basalt flows (see Fig. 5). Most of these landslides occurred long ago and are now dormant or relict features. Where streams are undercutting the toes of these relict landslides, portions of these landslides reactivate, both in shallow and deep-seated fashion. The head scarps and side scarps of the large deep-seated landslides also may fail as small, shallow slides that occasionally develop into debris flows.

The Ellensburg formation is composed of volcaniclastic silts, clays, and conglomerate beds with moderate to steep dips to the southeast. Erosion often creates over-steepened slopes in this unit forming unstable slopes that fail as deep-seated landslides, shallow landslides, and debris flows.

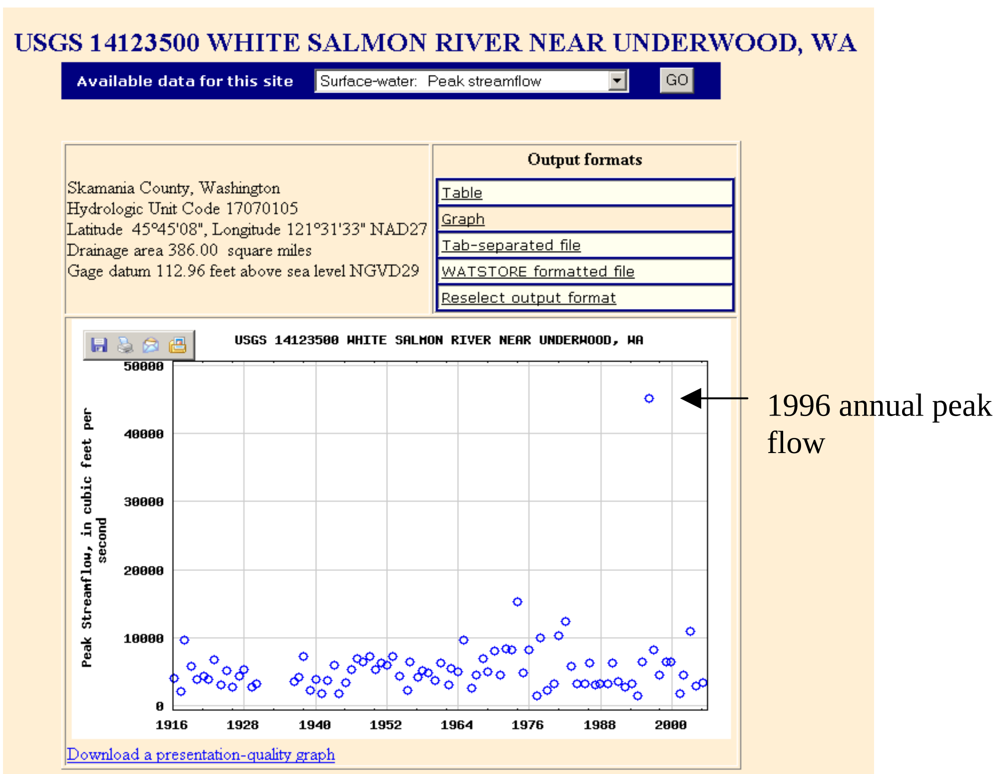

Figure 4. USGS gauging station (1471253500) annual surface water hydrograph record for the White Salmon River showing 85 years of peak flow.

As the Missoula floods swept by the mouth of the White Salmon River, clays and silts were deposited upstream in slackwater areas, along the river valley (Gf on the geologic map, Fig. 6). Both debris slides and small/shallow deep-seated landslides are common within these slackwater deposits where the White Salmon River and its tributaries have eroded this unit.

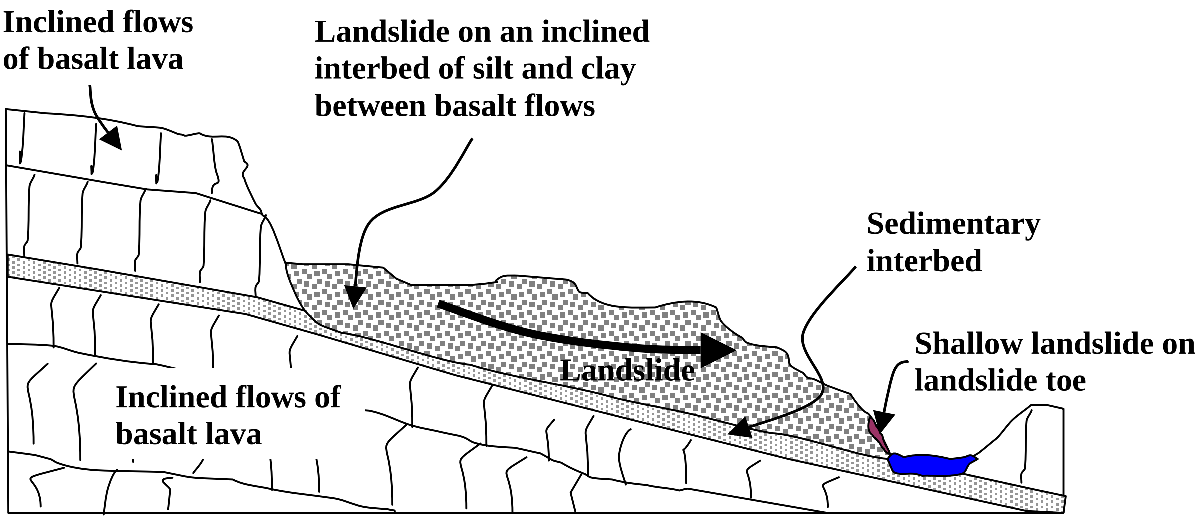

Figure 5. Sketch cross sectional diagram showing formation of large deep-seated landslides in the Buck Creek WAU. Landslides moved over silt and clay interbeds occurring between basalt flows. Secondary shallow failures are common on the toes of these large, older features.

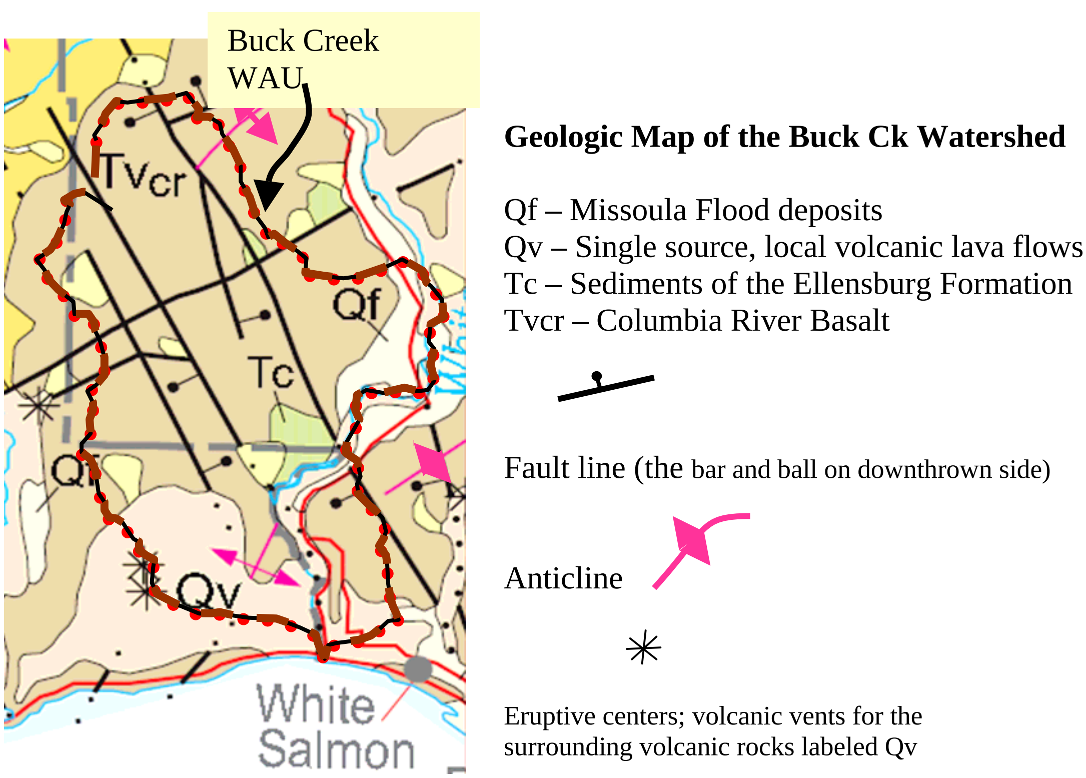

Figure 6. Simplified geologic map of the Buck Creek WAU and surrounding area modified from a portion of Washington State Geologic Map (Shuster, 2005).

6.0 Previous Investigations

Champion Pacific Timberlands, Inc., completed the Panakanic Watershed Analysis in 1996. The Panakanic WAU is adjacent and east of the Buck Creek WAU. Erosion was found to be significant and downcutting of stream channels was attributed to past logging practices, outdated road maintenance methods, grazing, and agricultural practices. Erosion of road surfaces, road fills, and stream channels was found to be associated with limited outcrops of moderate to steeply sloped ground and undersized culverts. Grazing was also found to impact stream banks, contributing substantially to their erosion.

The USFS completed a Watershed Analysis on the Little White Salmon River in 1995, on Cave-Bear Creeks in 1997, the Upper White Salmon River in 1998 (USFS, 1995; USFS, 1997; USFS, 1998). Numerous draft and final salmonid recovery studies and plans have been completed on the lower Columbia River. Impacts to salmonid habitat usually address habitat degradation but not specific mass wasting issues (Rawding, 2000).

7.0 Summary of Landslide Inventory

The photo and reconnaissance survey of the White Salmon River/Buck Creek watershed determined 145 of the 233 mapped features definitely or probably delivered to public resources. Table 2 shows the distribution of mass wasting features.

Table 2.

Mass Wasting Type	Number of Mass Wasting Features Mapped	Area (acres) of Mass Wasting Features	Percentage of Total Landslides
Shallow undifferentiated landslides	95	59.8	66
Debris flows	45	14.79	31
Debris slide/avalanche	5	1.15	3
Total	145	75.74	100

Summary of the type and number of LHZ protocol specific mass wasting features that definitely or probably delivered to typed waters or public resources in the Buck Creek WAU.

8.0 Landforms

Analysis of unstable slopes within the watershed resulted in the delineation of 12 landforms, excluding federal land ownership that was not evaluated (Table 1, Appendix A). Landforms #1, 2, & 8 are ‘rule-identified’ landforms listed in Forest Practice Rule (WAC 222-16-050 (1)(d)). All other landforms within this watershed were defined by methodology outlined in the LHZ Protocol. These landforms were assigned hazard ratings based on areas exhibiting similar mass wasting potential, potential to deliver to public resources, or potential to impact public safety. Mass wasting potential is based primarily on landslide process, failure density, lithology, geomorphology, hydrogeology, and topography. The following individual descriptions characterize each landform with additional information provided in Forms A-2 (Appendix A). Landform numbers are identical to Landforms identified in the Landslide Inventory: Form A-1 (Appendix D). Landslide hazard ratings have been summarized on Form A-4 (Appendix C).

Landform #1: Inner Gorges - Rule-identified landform with a high mass wasting and delivery potential. These landforms are present as both asymmetrical and symmetrical inner gorges that may occur intermittently in lateral extent. Slopes are generally greater than 70% and may be much steeper in basalts than in sedimentary rocks. Shallow and deep-seated landslides are commonly located along inner gorge walls. Debris flows and floodwaters extensively scoured many inner gorges during the in 1996 rain on snow event. Inner gorges are sensitive to both roads and harvest.

Landform #2: Bedrock Hollows - Rule-identified landform with a high mass wasting and delivery potential. Hollows are long, pointed ellipse or round, inverted spoon or teardrop-shaped features. These features are often found on convergent slopes but can also form on planar slopes. They are often found up gradient from inner gorges and on steep slopes (>70%). Hollows located in steeply dipping basalt bedrock may have thin soils that form shallow depth bedrock hollows.

Landform # 6: Steep Partially Vegetated Bedrock Outcrop - LHZ Protocol identified landform. Dipping bedrock outcrops that may or may not have very thin soils draping portions of the surface. Extremely sensitive to any type of disturbance that reduces root strength or channels water.

Landform #8: Deep-Seated Landslide Toes, Stream Adjacent – Rule-identified landform on mass wasting features with a high mass wasting and delivery potential. Toes that are stream adjacent commonly experience stream undercutting and continual slide movement, which leads to over steepening that then triggers additional movement within the toe. The fractured nature of the toe material facilitates water transmissivity, reduced cohesion within the bulk of the toe material, and increased soil creep that results in continued sliding.

Landform #10: Husum Waterline Corridor – Very High hazard rating with a very high mass wasting and delivery potential. This landform is a narrow corridor on either side of the city of Husum’s buried waterline located on the west side of Buck Creek. Base grade for the waterline was cut into the toe of the slopes, over-steepening the cut bank and loading the fill placed down slope. Numerous small shallow slope failures occur along the length of the corridor. Stability of the grade is critical in maintaining the waterline for public use. This landform is limited to the waterline and adjacent slopes.

Landform #11: Moderate Slopes >45% in Missoula Slack Water Deposits Stream Adjacent – Very High hazard rating with a very high mass wasting and delivery potential. Slack water deposits are extremely unstable geologic units that are susceptible to both shallow and small deep-seated failures that deliver large quantities of sediment directly to typed waters. This landform is limited in extent within the Buck Creek WAU, occurring only where slack water deposits are adjacent to streams or rivers.

Landform #12: Steep, Bedrock Slopes > 70% Above Public Resources/Safety – Very High hazard rating with a very high mass wasting and delivery potential. This landform is confined to steep slopes above public resources and could deliver to areas creating a public safety issue. These slopes are sensitive to any type of disturbance related to forest practices. They may be barren or draped with thin soils supporting spotty vegetation on steeply dipping bedrock surfaces.

Landform #13: Lower Angle Convergent Headwalls (>60%) High hazard rating with a high mass wasting and delivery potential. This landform includes areas that are steep and convergent but do not meet the slope criteria necessary to be classified as convergent headwalls. These areas may contain unmapped bedrock hollows (landform #2), inner gorges (landform #1), and toes of deep-seated landslides (landform #8). This landform differs from Landform #12 in that slopes are not as steep and they are not located in areas that would create a public safety issue.

Landform Number: # 14- Valley & Stream Bottoms – Low hazard rating with a low mass wasting and low delivery potential. This landform contains those areas in and around rivers and streams and is more likely to be the recipient of depositional rather than erosional processes. Any type of natural slope failure is unlikely to occur.

Landform Number: # 15- Low Gradient Hill Slopes and Valley Side Slopes – Low Hazard rating with a low mass wasting potential and low delivery potential. This landform contains hillsides and slopes between 11 and 40% that have a low failure potential and are not likely to deliver to public resources or affect public safety.

Landform Number: # 16- Ridge and Hill Tops – Low hazard rating with a low mass wasting potential and low delivery potential. This landform includes all ridge tops and ridge noses with gradients between 0 and 10%.

Landform Number: # 17**-** Intermediate Slopes (41 – 59%) – Low hazard rating with a low mass wasting potential and low delivery potential. This unit contains all slope forms and lithologies present within the watershed. Lack of delivery mechanism and generally stable lithologic units prevent delivery to public resources and limit probability of delivery to public resources or impacting public safety.

9.0 Summary of Methods

Landslide inventory - The procedures described below follow the Landslide Hazard Zonation Protocol version 2.0; http://www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2_final.pdf, with minor modification. Five sets of 1:12,000 aerial photographs from 1979 to 1998, and one set of 1:60,000 photos from 1965 were analyzed with a mirror stereoscope with 3x magnification (Table 3). Other photo flight years were available from DNR's collection in Olympia. These sets were either missing many key photos or were taken too close to other photo years to be of good use and were therefore not viewed.

Year	Scale	Image	Flight Line Number	Reference Ownership	Comment
1979	1:12,000	Black & White	KYK79	DNR	Complete coverage
1984	1:12,000	Black & White	SCC84	DNR	Complete coverage
1988	1:12,000	Black & White	SW88	DNR	Partial coverage
1991	1:12,000	Black & White	SC91	DNR	Partial coverage
1998	1:12,000	Color	SC98	DNR	Complete coverage
1965	1:60,000	Black & White	EC67-RE	DNR	Complete coverage

Table 3. Aerial photographs reviewed during this investigation.

Slope failures observed on the stereo photos were classified and catalogued according to the mass wasting feature type. For the purposes of this analysis, landslides that failed below rooting depth are categorized as deep-seated landslides (Forest Practices Board Manual); all remaining landslides were classified as shallow landslides. Mass wasting types include shallow-undifferentiated landslides, debris flows, debris slides and avalanches, rock topples and falls, snow avalanches, and deep-seated landslides (including earth flows).

Mapped landslides were ranked according to their relative level of certainty as questionable, probable, or definite. Features with some combination of distinct head scarps, lateral margins, scoured run-outs, over steepened toes, obvious deposits with hummocky topography, or vegetation patterns that indicate landslide disturbance were considered to be definite landslides. Features that were more subdued or concealed by vegetation than those mentioned above could not be identified with the same level of certainty and were thus considered to be probable landslides. Features that resemble degraded landslides but could have been formed by non-mass wasting processes were considered questionable landslides (following Wieczorek, 1984). Most landslides were mapped from air photos; however several that were identified in the field were not evident on the photos, mostly in areas of heavy canopy or landslides that postdate that most recent photo set.

Following stereo air photo analysis, all observed landslides were transferred to 1:12,000 ArcGIS map layers. Transfer of photo mapped mass wasting features to a digital database was accomplished by digitally tracing landslides from clear mylar used as overlays on air photos. The landslides mapped in the Buck Creek WAU are presented on Map A-1 and itemized on Appendix D, Landslide Inventory. Lidar (light detection and radar) data was not available for this watershed.

Slope gradients for shallow landslides were determined remotely by calculating the maximum DEM-derived slope angle within each landslide initiation polygon. For deep-seated landslides, the average slope angle over the entire landslide polygon was calculated. We found that using the average slope gradient for deep-seated landslides provides the quickest and most reasonable representation of the pre-failure slope surface compared to other GIS slope measurement methods (Bilderback, 2006).

Mass wasting map units - The aerial photo survey was also used to determine land use and to map mass wasting map units that include rule-identified landforms (inner gorges, bedrock hollows, etc.) and analyst-identified landforms. The 10 m DEM and other GIS products were used to map low-hazard flat areas, low-gradient hill slopes, and ridge tops according to the LHZ Protocol. The remaining land in the WAU was divided into analyst-identified landforms. These landforms were identified from primary driving forces of mass wasting based on physical attributes of the landscape such as slope gradient, elevation, hydrology, lithology, and slope convergence. A combination of slope gradient and elevation data (derived from the 10 m DEM), slope convergence data (derived from the DNR SLPSTAB model (Shaw and Johnson, 1995), and geologic data (from USGS 1:100,000 geologic maps), aided in the designation of these landforms. The landforms are intended to predict areas within the WAU that are at a particularly high hazard of mass wasting. The landforms mapped in the Buck Creek WAU are presented on Map A-2 and described in Appendix A. Each landform was assigned a landslide frequency rate (LFR), a landslide area rate for delivery (LAR), and an overall hazard rating (low, moderate, or high) as called for by the LHZ Protocol (www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2_final.pdf).

10.0 Hazard Ratings

Pursuant to the LHZ Protocol, hazard ratings for mass-wasting landforms were determined by the following: 1) rule-identified status (WAC 222-16-050), 2) the Landslide Frequency Rate (LFR) and Landslide Area Rate for Delivery (LAR), 3) the professional judgment of the analyst, or 4) an interpretation of deep-seated landslide hazard. The Landslide Area Rate for Delivery is the area of delivering landslides normalized for the period of study and the area of each landform. These values are then multiplied by one million for easier interpretation. Limited application suggests that Landslide Area Rates for Delivery less than 76 are low hazard, rates of 76 to 150 are moderate hazard, rates of 151 to 799 are high hazard, and rates greater than 799 are very high hazard (Lingley, 2004). Note that higher Landslide Area Rates for Delivery can be achieved by reducing the area of the Landform. While this may appear to be 'data gerrymandering', it helps limit the area of high-hazard landforms to those areas that are actually demonstrated to have high hazard. The Landslide Frequency Rate is calculated similarly, however the number of delivering landslide is used instead of the area of delivering landslides. As of the writing of this report, the qualitative rating system below is used (Table 4). Form A-4 (Appendix C) summarizes all landform hazard ratings.

Qualitative Ratings	Landslide Frequency Rate	Landslide Area Rate for Delivery
Low	< 100	<76
Moderate	100 to 199	76 to 150
High	200 to 999	151 to 799
Very High	>999	>799

Table 4: Qualitative rating system for the Landslide Frequency Rating (LAR) and Landslide Area Rate for Delivery (LDR).

11.0 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 administrative unit 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.

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 (Brardinoni and others, 2003). The scarcity of mass wasting features identified under mature canopy, steep, and north-slope aspect shadow conditions is not necessarily an indication of the relative stability of these slopes.

Because many deep-seated landslide features are quite large, remain heavily vegetated during movement, and may not have obvious scars visible through the vegetation canopy, misinterpretation is more likely. A recent detailed study in Cowlitz County, Washington, suggests that up to 25 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 WAU 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.

12.0 Use of this report

The purpose of this mass wasting assessment is to identify non-federal, non-tribal areas within the Buck Creek watershed administrative unit (WAU) that have a risk of landsliding due to both natural phenomena and to the effects of forest practice activities (logging, roading, thinning, yarding, etc.). All lands within the WAU have been divided into designated mass wasting hazard landforms[1]. Maps of these landforms are designed for use by landowners in determining the areas likely to create landslide hazard and by the Department of Natural Resources (DNR) staff to identify sites where future forest practice applications (Chapter 222-20 WAC) may require detailed investigation prior to forest practice classification (Chapter 222-16-050 WAC).

This is a reconnaissance survey, and its relatively broad resolution must be considered when using this document and its accompanying maps. Moreover, the survey was conducted within a timeline that was budgeted to produce a statewide unstable slopes screening tool as quickly as possible. For this reason, it is likely that some landslides or unstable landforms have been overlooked, some benign features have been mistakenly mapped as landslides, and some landslides have been classified improperly. Thus, the landslide inventory presented in this report (Map A1 and Form A1) is intended to be a representative but not complete inventory.

This assessment was largely conducted remotely using the best map and image-based resources available, with support from limited field visits to verify mapping results. However, we note that landslide inventories that are conducted primarily using air photos have been demonstrated to omit up to 85% of the landslides that actually exist on the ground in heavily forested areas (Brardinoni and others, 2003). Furthermore, they tend to skew the location of the majority of landslide occurrences toward recently harvested areas because they are easier to spot in these areas than under canopy on air photos (Brardinoni and others, 2003).

Information was collected and compiled in a manner that was designed to respond to the Critical Questions that are outlined in Section II of the Landslide Hazard Zonation (LHZ) protocol, and to direct attention to areas where more detailed analysis is necessary. The objective of the data collection was to generate information sufficient to establish:

- A generalized characterization of mass wasting processes that are active in the WAU;
- Areas of landscape that share similar physical characteristics related to mass-wasting behavior;
- The relative potential for mass wasting to occur among the various landform units.

13.0 Acknowledgments

Funding for this project was provided by a Federal Salmon Recovery grant, administered through the Washington Interagency Commission on Outdoor Recreation. The Upslope Processes Science Advisory Group (UPSAG), a subcommittee of the Cooperative Monitoring, Evaluation and Research (CMER) group, provided technical oversight of this project. The following people have greatly contributed to this project (and special thanks given to): Jack Powell and Laura Vaugeois in DNR Forest Practices tromped through the woods, shared many insights about landslides, protocol definition and the LHZ project as well as providing extensive knowledge on GIS, landslides, and forest practices rules. Venice Goetz for her many hours spent over multiple sessions editing this text and Isabelle Sarikhan of the DNR Geology for invaluable GIS support unwinding corrupt shape files and much appreciated moral support throughout the GIS experience. Finally and most importantly, I wish to thank the landowners, who have graciously provided access to their lands during the field verification of landslides and landforms.

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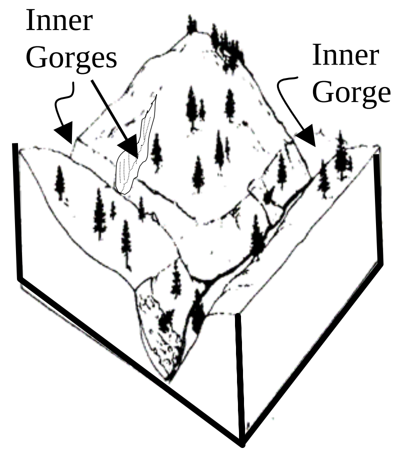
Appendix A

Landform Descriptions

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

11.0 Landform #1 - Inner Gorges – High Hazard



Description: Rule-identified inner gorges are steep-sided (>70%), typically flat-bottomed canyons or gullies formed by a combination of fluvial and mass wasting processes. The upper boundary of an inner gorge is the first break in slope of at least 10° at the crest of the inner walls. Inner gorges may be symmetrical or asymmetrical in cross section and are commonly intermittent in lateral extent. Debris slides, debris flows, slope ravel, and small rotational failures in toes of deep-seated landslides were observed in inner gorges. Colluvial evacuations from bedrock hollows or other convergent slopes upstream from inner gorges may evolve into scouring debris flows during major hydrologic events. Gorge scarp slopes revegetate rapidly often masking recent slope failures on aerial photos. Gorges located in the toes of deep-seated landslides often contain seeps and springs that feed streams.

Slopes: >70% by rule or >65% DEM-measured; field measured slopes often exceeded 70%
Material: Basalt, colluvium, alluvium, landslide deposits, soils, Missoula slack water flood silt deposits
Elevation: Variable, between 3200 ft and 90 ft.
Total Area: 434 acres

Mass Wasting Process and Triggers: Inner gorges form by a combination of stream incision, scouring by debris flows, and sidewall failures. Over-steepened walls of inner gorges commonly fail as debris slides, slope ravel, or small rotational failures that can produce debris flows. These debris flows scour the walls of inner gorges and further destabilize these unstable slopes. This process has occurred on the main stem of Buck Creek as well as the upper reaches of the North Fork and South Fork of Buck Creek.

Forest Practice Sensitivity: Root strength within inner gorges has been found to limit rates of mass wasting (Krogstad, 1995). Trees adjacent to and within the inner gorge can have roots extending into and along the slopes of the gully providing slope stability. Timber harvest, road construction, and/or landing construction on steep slopes in poorly consolidated colluvium that drapes bedrock or on the toes of deep-seated landslides can cause slope instability due to loss of root strength by removal of trees, loading of slopes and channeling water to point discharge areas. Roads and landings can destabilize slopes in inner gorges by undercutting and over steepening slopes and channeling water to a point discharge that saturates road or landing fill, landslide deposits, and/or thin soils that drape bedrock, triggering landslides. Side-cast and road (or landing) fill can over steepen and add weight to slopes.

Mass Wasting Potential: **Very High for road construction and timber harvest** in inner gorges having 23 landslides in an area of 434 acres over a 19 year time period (see LHZ protocol).

Delivery Potential/Criteria: **Very High**. Inner gorges are part of the drainage network and are stream-adjacent slopes. They either contain streams or evidence of channel incision (23 mapped landslides delivered to a public resource). Delivery criteria are also based on historical occurrences observed on aerial photographs and confirmed during field investigations. This unit has a calculated landslide rate for delivery of 2789.2 (see LHZ protocol).

Hazard Potential Rating: **Very High for roads and harvest based** on LHZ Protocol and Standard Forest Practices Rules.

Overall Hazard Potential Rating: **Very High** based on the LHZ Protocol, Table 4.

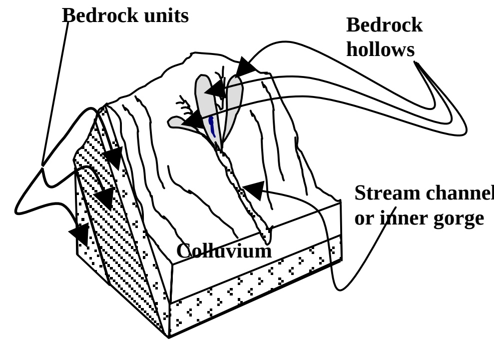
Trigger Mechanisms: Soil saturation, loss of root strength, changes in hydrology, over steepening and loading slopes in colluvium or on the toes of deep-seated landslides due to harvest, road building and landings can trigger debris slides or other landslides. These slopes are especially sensitive during 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: Debris flows and shallow undifferentiated landslides commonly occur within inner gorge features during major hydrologic events. Inner gorges in slack water silts and clays were found to be extremely sensitive to changes in root strength and were unstable at slopes of 45%. Careful field review is necessary for those areas of steep inner gorge walls in or adjacent to the toes of deep-seated landslides and any activity that disturbs slack water sediments.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform # 2- Bedrock Hollows



Description of Mass Wasting Unit: Rule-identified bedrock hollows are steep (>70% at the steepest point), shallow spoon- or elongate inverted teardrop-shaped areas of convergent topography with concave profiles. Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows. These features can exist on any steep hill slope and within other landforms. They seldom contain channels but commonly drain directly into inner gorges or other channels downslope. Colluvial debris that accumulates in these steep convergent areas is prone to saturation by shallow ground water making bedrock hollows highly susceptible to slope failures. Bedrock hollows revegetate and refill with soil, which can mask their presence on air photos and on the ground.

Slope: >70%
Material: Basalt, colluvium, soils, sedimentary interbeds
Elevation: Variable, nearly all elevations possible 3800 ft to 150 ft
Total Area: 185 acres

Mass Wasting Process and Triggers: Debris slides or other shallow landslides occur due to soil saturation, loss of root strength and oversteepening slopes in bedrock hollows due to road building have lead to landslides within this landform. When located on steep inner gorge slopes, hollow evacuations often feed directly into streams, evolving into debris flows that scour channels.

Forest Practice Sensitivity: Root strength within bedrock hollows has been found to limit the rates of mass wasting. Timber harvest, on steep slopes in weathered bedrock or poorly consolidated colluvium draping bedrock can increase slope instability due to loss of root strength. Roads and landings can destabilize slopes in bedrock hollows by undercutting and over steepening slopes. Side-cast and road (or landing) fill can over steepen and add weight to slopes; roads and landings can also capture runoff or shallow groundwater and channel it to point locations that saturate road or landing fill and/or thin soils that drape bedrock, triggering landslides.

Mass Wasting Potential: **<u>Very High for road construction and timber harvest</u>** based on 12 mass wasting features identified in a landform covering 185 acres over a 19-year photo record.

Delivery Potential/Criteria: <u>High</u>. Bedrock hollows are part of the drainage network or are the area on a hillslope that is characteristically topographically above where live streams begin. After a landslide evacuates a bedrock hollow it may contain a spring and a channel on the surface but when a hollow is filled with colluvium it does not appear contain water or evidence of a channel. Delivery criteria are also based on historical occurrence observed on aerial photographs and confirmed during field investigations. This unit has a calculated landslide rate for delivery of 674.3 (see LHZ protocol).

Hazard Potential Rating: <u>High for roads and harvest</u> based on LHZ Protocol and Standard Forest Practices Rules.

Overall Hazard Potential Rating: <u>Very High</u> based on the LHZ Protocol, Table 4.

Trigger Mechanisms: Mass wasting is triggered by loss of root strength, changes in hydrology, oversteepening of slopes and loading slopes due to harvest techniques, road building, and landing construction. These activities have destabilized slopes that failed directly into the river.

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

Comments: Heavy timber canopy cover often masks hollows in steep headwall basins and inner gorges.
Ground verification is necessary on steep (>70%) slopes. Thin soils over steeply dipping bedrock are prone to failure when disturbed throughout this watershed. Bedrock hollows are fully described in the Forest Board Manual, Section 16.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 6 – Steep (>60%) Partially Vegetated Bedrock Slopes

Description of Mass Wasting Unit: Slopes >60% on bedrock surfaces containing less than 40% vegetative cover. Thin to nonexistent soil on actively raveling slopes. Commonly south-facing with dip slopes that deliver directly to waters.

Slopes: >60% on DEM >65% in the field
Material: Basalt, sedimentary units of the Ellensburg Formation
Elevation:
Total Area: 663 acres

Mass Wasting Process and Triggers: Ravel on steep bedrock slopes with thin soils, shallow slope failures, evacuated bedrock hollows, shallow and deep-seated landslides in inner gorges, and debris flows were observed in this landform.

Forest Practice Sensitivity: Roads, harvest that reduces root strength, and skid trails appear to be the most significant triggering mechanisms for slope failures within this landform. Any activity that diminishes root strength may result in slope failure.

Mass Wasting Potential: **<u>Very High for road construction and timber harvest</u>** on bedrock slopes based on 22 mass wasting features identified in this 663 acre landform over a 19 year photo record.

Delivery Potential/Criteria: **<u>Very High</u>.** Streams and rivers are often located directly below steep bedrock slopes. Landslides on these slopes often deliver directly to typed waters.

Hazard Potential Rating: **<u>High for roads and harvest</u>** based on LHZ Protocol and standard Forest Practices Rules.

Overall Hazard Potential Rating: **<u>Very High</u>** based on the LHZ Protocol, Table 4.

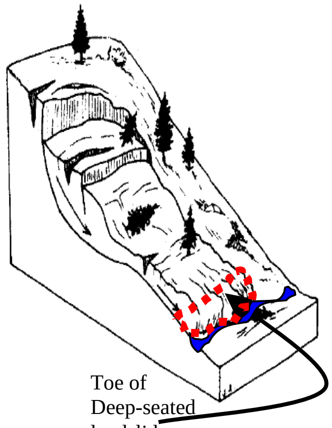
Trigger Mechanisms: Loss of root strength resulting from harvest and ground disturbance caused by yarding are the major triggering mechanisms. Very few roads were constructed on this landform due to the extreme natural instability of the ground.

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

Comments: Road failures due to sloughing side-cast, fill failures, and culvert blockages in stream drainages can generate debris flows and debris avalanches that deliver sediment to streams.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: #8 - **Deep-Seated Landslide Toes, Stream Adjacent**



Description of Mass Wasting Unit: The toe area is usually hummocky, steep (>65%), planar or irregular, and may contain areas of ravel, shallow deep-seated, or shallow surficial landsliding. The downslope edge of the toe can become oversteepend from stream erosion or from rotation of the slide mass. Occasionally, younger, secondary deep-seated landslides form within the footprint of an older deep-seated landslide. This may superimpose a younger toe on the body of an older toe.

Slopes: > 65%
Material: Fractured basalt, sedimentary interbeds, flood sands, silts, and landslide deposits
Elevation: Variable between 2500 ft and 300 ft
Total Area: 254 acres

Mass Wasting Process and Triggers: Downcutting and undercutting by marginal streams and streams that flow across the base of these deep-seated landslide toes have over-steepened and destabilized the toes of deep-seated landslides and triggered slope ravel, debris slides, and small deep-seated landslides. Inner gorges and bedrock hollows can form within the landslide toe.

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 and harvest based on 12 features identified over a 19 year photo record in a landform covering 254 acres.

Delivery Potential/Criteria: <u>**Very High**</u>**.** The delivery rate for this unit is 1021.5. Delivery is related to the proximity of the streams.

Hazard Potential Rating: <u>**Very High**</u> for road construction and timber harvest based on 12 landslides with a total area of 4.93 acres in this landform that totals 254 acres. This landform has a Landslide Frequency Rating of 2486.5 (see LHZ Protocol).

Overall Hazard Potential Rating: <u>**Very High**</u> based on the LHZ Protocol, Table 4.

Trigger Mechanisms: Loss of root strength, changes in hydrology, over-steepening of slopes, and loading slopes due to harvest, road building, and landing construction have resulted in the destabilization of this landform.

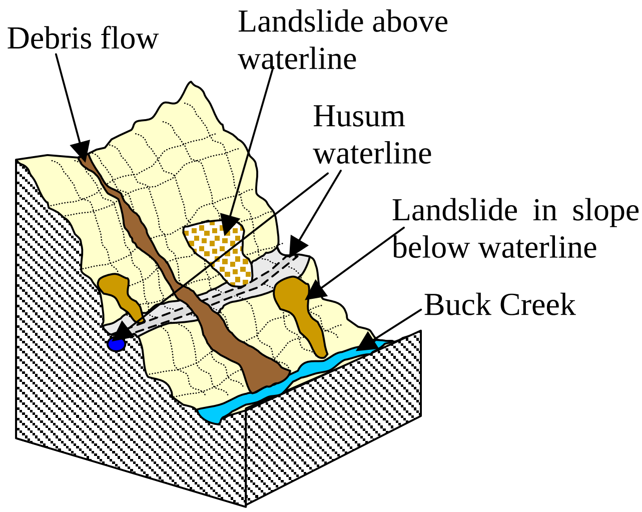
Confidence: High - The excellent exposure of a large percentage of the watershed, complete aerial photo coverage, and two days field checking the photo interpretation have provided a high level of confidence in this watershed.

Comments: All toes of deep-seated landslides in or near a stream or inner gorge will require a field review.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: 10 –Husum Waterline Corridor

Description of Mass Wasting Unit: This map unit consists of a narrow corridor directly adjacent to (above and below) the Husum waterline. This area lies above and immediately west of Buck Creek and consists of locally over-steepened and unstable slopes that include a number of slope forms and a wide range of slope gradients.



Slopes: Variable
Material: Basalt colluvium, alluvium, soils
Elevation: 565ft south to 1061ft north
Total Area: 75 acres

Mass Wasting Process and Triggers: Shallow landslides, shallow deep-seated landslides, debris avalanches and debris flows are present along the length of this narrow unit. Debris flows in inner gorges cut this feature delivering directly to Buck creek. This landform contains both steep, naturally unstable slopes and stable slopes that have been destabilized by excavation and fill related to the pipeline construction that has undercut and over-steepened them.

Forest Practice Sensitivity: Roads, landings, harvest reducing root strength and skid trails appear to be the most significant triggering mechanism for landsliding within this landform.

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

Delivery Potential/Criteria: Very High Landslides within this unit could damage the Husum waterline and/or deliver debris to Buck Creek.

Hazard Potential Rating: High for the entire unit based on 8 landslides with an area of 1.61 acres in this landform that covers 75 acres. It has a Landslide Frequency Rating of 5614 (see LHZ Protocol).

Trigger Mechanisms: Mass wasting triggering mechanisms vary; however, any disturbance that decreases root strength or undercuts or loads the slopes above or below the corridor in this landform has a high potential to impact public resources (city of Husum's water line) and typed waters.

Confidence: High for the entire unit based on extensive field review.

Comments: Poor aerial photo resolution, north and shadowed aspects in photo coverage and dense canopy masked nearly all of the landslides identified during field reconnaissance. Very little landslide activity was noted during photo review, however, numerous slope failures were observed along the west bank of Buck Creek and identified along a complete traverse of the corridor during 2 days of field review. Any activity adjacent to this landform should be carefully evaluated as the Husum waterline is a major local public resource and is vulnerable to damage by mass wasting processes.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 11 – Moderate Slopes (> 45%) in Stream-Adjacent Missoula Slack Water Deposits
Description of Mass Wasting Unit: Slopes > 45 degrees in Missoula flood slack water deposit sediments that are stream-adjacent and can deliver to waters of the state.

Slopes: >45%
Material: Silts, sands and clays (Qfs)
Elevation: 718 ft to 300 ft
Total Area: 277 acres

Mass Wasting Process and Triggers: Shallow, small slumps and shallow deep-seated landslides occur along the entire stream corridor where slopes are greater than 45%. These shallow slides are typically 40 feet wide, 60 feet long, and 5 to 15 feet deep. They can be quite small when only one landslide is present or may form a series of adjacent slope failures grouped together to create a complex several hundred feet wide.

Forest Practice Sensitivity: Sensitive to any type of forest harvest activity that removes/impairs root strength, under cuts or oversteepens slopes or channels water onto these slopes.

Mass Wasting Potential: **Very High for road construction and timber harvest** based on 20 features identified over a 19-year photo record in a landform covering 277 acres.

Delivery Potential/Criteria: **Very High.** The delivery rate for this unit is 1558.0. Delivery is related to the proximity of these sediments to streams within and adjacent to the geologic unit.

Hazard Potential Rating: **Very High** for entire unit based on 20 landslides with an area of 8.2 acres in a 277 acre landform. This landform has a Landslide Frequency Rating of 1558.0 (see LHZ Protocol).

Trigger Mechanisms: Mass wasting occurs during periods of soil saturation during winter rain-on-snow or heavy rain events. Loss of root strength, undercutting or over-steepening slopes, redirecting water onto stream adjacent slopes may trigger landslides.

Confidence: Moderate. Slope failures on this landform were not visible on any air photos and landslides in this unit were discovered in the field.

Comments: Trees on these slopes can be tilted or deformed with pistol butts or sweeps. Field verification of all areas of this landform and geologic unit (Qfs) that are adjacent to streams is recommended as this landform is almost always completely tree covered and ground visibility in aerial photos is limited.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 12 – Steep Bedrock Slopes ≥ 70% Above Public Resources/Safety

Description of Mass Wasting Unit: Slopes ≥70% located above and with a high potential to impact public resources. Barren bedrock or thin, intermittent soils drape steeply dipping bedrock surfaces. This landform is located above the Husum waterline, steep gorge areas along the White Salmon River, and above public highways on both sides of the White Salmon River Gorge. Landslides initiating within this landform have a high probability of delivering directly to public resources or impacting public safety.

Slopes: ≥70%
Material: Basalt, colluvium, landslide deposits
Elevation: 1700 ft to 140 ft
Total Area: 154 acres

Mass Wasting Process and Triggers: Impermeable, barren bedrock slopes with sporadic thin, soils that drape steeply dipping bedrock surfaces produce rapid runoff that saturates the soils on and below the landform generating debris avalanches, shallow undifferentiated landslides, deep-seated landslides, ravel, debris flows, rock fall, and road fill failures.

Forest Practice Sensitivity: These are naturally unstable slopes that can be further destabilized by any type of ground or vegetation disturbance. Roads that channel water to a point source, loading on slopes, side-cast or fill failures, and loss of root strength due to harvest can trigger failures.

Mass Wasting Potential: **Very High for road construction and timber harvest** based on 13 landslides identified over a 19-year period in a landform covering 154 acres.

Delivery Potential/Criteria: **Very High.** The delivery rate for this unit is 3407.4. Delivery is related to the proximity of this landform to streams, roads, and public waterlines located at the base of the slopes.

Hazard Potential Rating: **Very High** for entire unit based on 13 landslides identified over a 19-year period in a landform covering 154 acres. This landform has a Landslide Frequency Rating of 4442.9 (see LHZ Protocol).

Trigger Mechanisms: Roads channeling water to a point source, saturation of side-cast or fill, and loss of root strength due to harvest have triggered slope failures within this landform.

Confidence: High. Good photo coverage and field verification.

Comments: Several county roads have been abandoned within this unit as severe instability resulted in ongoing public safety and resource damage issues. Slope failures within this unit have impacted the Husum waterline.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 13 Lower Angle Convergent Headwalls (>60%)

Description of Mass Wasting Unit: These slopes are both steep and convergent but most are not as steep as rule-identified convergent headwalls. This unit contains isolated areas of cliffs and some slopes steeper than 70%, however the majority of the slopes fall below the 70% cutoff for the Forest Practices Rules. This landform commonly contains deep-seated landslides and may include areas of unmapped bedrock hollows (landform #2), inner gorges (landform #1), and steep bedrock outcrops (landform #6).

Slopes: variable between 60 to 80%
Material: Basalt, Ellensburg Formation sedimentary units, landslide deposits, colluvium, soil
Elevation: Variable throughout the watershed
Total Area: 1667 acres

Mass Wasting Process and Triggers: 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 a loss of root strength. Roads and landings can cause instability by undercutting and over steepening slopes. Side-cast and road (or landing) fill can over steepen and add weight to slopes; roads and landings can also capture water runoff or shallow groundwater and channel it to point locations that saturate road or landing fill and/or thin soils that drape bedrock and thus trigger slope failures and debris flows.

Mass Wasting Potential: **High** for timber harvest and road construction based on 18 features identified over a 19-year photo record in a landform covering 10.19 acres.

Delivery Potential/Criteria: **High**. This landform has a high delivery potential due to its proximity to streams and rivers. The delivery rate for this unit is 321.7.

Hazard Potential Rating: High for timber harvest and road construction. This landform has a Landslide Frequency Rating of 568.3 (see LHZ Protocol).

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

Confidence: Moderate confidence due to canopy masking exposures. Much of this landform has not been harvested in the last 70 years.

Comments: Several of the landslides observed on photos may be rule-identified features masked by vegetation canopy and could not be identified. Remote location without road access precluded intensive field review

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 14- Valley & Stream Bottoms **-** Low Hazard Slopes

Description of Mass Wasting Unit: This map unit includes all slope forms and gradients 10% or less located in the valley and stream bottoms, flat terraces, prairies and major stream flood plains 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. (Note: Other map units could be included in landform #14 due to error, omission, and map scale issues.)

Slopes: Variable 0 to 10%
Material: Basalt, colluvium, alluvium, and landslide deposits
Elevation: 2150 ft to 515 ft
Total Area: 1469 acres

Mass Wasting Process and Triggers: Shallow landslides and debris flows may occur but are rare and generally do not have the potential to deliver to waters of the state or impact public safety or resources.

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

Mass Wasting Potential: Low for road construction and timber harvest based on one landslide identified over a 19-year photo record in a landform covering 1469 acres.

Delivery Potential/Criteria: Low. The delivery rate for this unit is 0.4. One landslide was noted within this landform. Delivery is unlikely as very low hill slope gradients preclude transportation of mass wasting events to public resources.

Overall Hazard Potential Rating: Low for entire unit. This landform has a Landslide Frequency Rating of 35.8 (see LHZ Protocol).

Trigger Mechanisms: Landslides are unlikely to begin on this landform or deliver sediment/debris to public resources unless there has been failure of roads, drainage structures, etc. (plugged culvert, side-cast fill failure, overused skidding trail, etc.). Poor management practices can cause mass wasting to occur on almost any type of landform with any slope gradient even if the landform is not inherently 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: Only 1 slope failure observed within this landform due to a culvert failure.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 15- Low Gradient Hill Slopes and Valley Side Slopes – Low Hazard

Description of Mass Wasting Unit: This map unit includes all hill slope forms and gradients between 11% and 40% 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. (Note: Other map units could be included in landform #15 due to error, omission, and map scale issues.)

Slopes: Variable between 11% and 40%
Material: Basalt, colluvium, alluvium, and landslide deposits.
Elevation: Variable throughout the watershed
Total Area: 12,289 acres

Mass Wasting Process and Triggers: Shallow landslides, deep-seated 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. The most common mass wasting processes observed on aerial photographs were slope failures on head scarps and toes of older deep-seated landslides that did not deliver and were located away from public resources.

Forest Practice Sensitivity: This landform is not very sensitive to Forest Practices activities. The low slope gradients preclude initiation of most mass wasting features.

Mass Wasting Potential: No potential for roads construction and low for timber harvest based on 7 features identified over a 19-year photo record in a landform covering 12289 acres. Several of the shallow landslides identified within this feature may have initiated in unmapped landforms with steeper slopes.

Delivery Potential/Criteria: Low. The delivery rate for this unit is 14.4. Lack of channel access to landslides is the limiting criteria. Road and landing failures do not travel great distances without access to stream channels. Steeper areas, terrace faces, and toes of deep-seated landslides lack sediment delivery mechanisms. Distances from stream channels and topography inhibit transport of landslide debris to public resources and does not appear to impact public safety.

Hazard Potential Rating: Low for entire unit. This landform has a Landslide Frequency Rating of 30.0 based on 7 failures delivering from a combined area of 3.36 acres (see LHZ Protocol).

Trigger Mechanisms: Landslides are unlikely to begin on this landform or deliver sediment/debris to public resources unless there has been failure of roads, drainage structures, etc. (plugged culvert, side-cast fill failure, overused skidding trail, etc.). Poor management practices can cause mass wasting to occur on almost any type of landform with any slope gradient even if the landform is not inherently unstable.

Confidence: High for the entire unit based on field review and excellent photo quality and coverage. There may be some 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 landslide activity noted.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 16- Ridge and Hill Tops – Low Hazard

Description of Mass Wasting Unit: This map unit includes all ridge tops and ridge noses with gradients between 0 % and 11 %. This landform contains all slope forms and exhibits a low landslide potential. It is unlikely to, deliver sediment to a stream, impact public safety or impact a public resource. (Note: Other map units could be included in landform #16 due to error, omission, and map scale issues.)

Slopes: Variable 0 to 11%
Material: Basalt, colluvium, soils,
Elevation: Variable: 3800 ft to 360 ft
Total Area: 2248 acres

Mass Wasting Process and Triggers: No failures were observed in this landform. Shallow landslides, deep-seated landslides, and debris flows were not found and would not have the potential to deliver to waters of the state or impact public safety or resources.

Forest Practice Sensitivity: No Forest Practice related failures were observed on photos or in the field.

Mass Wasting Potential: Low for road construction and timber harvest based on no landslides identified in a landform covering 2248 acres over a 19-year photo record.

Delivery Potential/Criteria: **Low due to** lack of channel access. The distances from a stream channel and the topography inhibits the transport of debris to public resources. Remote ridge tops do not impact public infrastructure or safety.

Hazard Potential Rating: Low for entire unit. This landform has a Landslide Frequency Rating of 0 (see LHZ Protocol).

Trigger Mechanisms: No failures were observed in this landform.

Confidence: High for the entire unit based on field review and excellent photo quality and coverage.

Comments: No failure activity was noted.

Form A-2 Descriptions of Landforms for the Buck Creek Watershed

Landform Number: # 17- Intermediate Slopes (20 – 40%)

Description of Mass Wasting Unit: This map unit includes all slope forms and gradients between 20 % and 40% (Note: Other map units could be included in landform #17 due to error, omission, and map scale issues.)

Slopes: Variable in slope and form (20 to 40%)
Material: Basalt, colluvium, soils,
Elevation: Variable across watershed
Total Area: 3900 acres

Mass Wasting Process and Triggers: Shallow landslides, deep-seated 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. The most common mass wasting process observed on aerial photographs were shallow landslides superimposed on portions of deep-seated landslides away from public resources.

Forest Practice Sensitivity: Of the 7 landslides mapped in this landform, most or all of them could have initiated in other higher hazard unmapped landforms or on over steepened road cuts or fill.

Mass Wasting Potential: Moderate for road construction and timber harvest based on 13 features identified over a 19-year photo record in a landform covering 3900 acres.

Delivery Potential/Criteria: Low. Lack of channel access. Road and landing failures do not travel great distances unless they enter waterways. Steeper areas and the toes of deep-seated landslides lack sediment delivery mechanisms. Distance from a landslide sediment source to a stream channel and topography that captures failure debris precludes transport of landslide debris to public resources and does not impact public safety. Delivery rate for this landform is 28.2.

Hazard Potential Rating: Low for entire unit. This landform has a Landslide Frequency Rating of 175.4 (see LHZ Protocol).

Trigger Mechanisms: Landslides are unlikely to begin on this landform or deliver sediment/debris to public resources unless there has been failure of roads, drainage structures, etc. (plugged culvert, side-cast fill failure, overused skidding trail, etc.). Poor management practices can cause mass wasting to occur on almost any type of landform with any slope gradient even if the landform is not inherently 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: The slope failure activity noted might actually be other rule-identified landforms that were masked by canopy cover. Remote location and lack of access to many features precluded field verification.

Appendix B

Mass Wasting Summary Tables

Total					
Activity	Shallow Landslides	Debris Flows	Debris Avalanches/Slides	Deep-Seated Landslides	Total
1 = clearcut (timber 0-5 yrs)	9	6	0	9	24
2 = young stands (timber 5-15 yrs)	28	9	0	17	54
3 = submature timber (15-50 years)	44	30	1	32	107
4 = mature timber (>50 years)	25	1		3	29
5 = road	2	2	4	0	8
6 = partial cut	2	0	0	4	6
7 = yarding	0	0	0	0	0
8 = alpine	0	0	0	0	0
9 = other- e.g., housing, agriculture	1	0	0	4	5

White Salmon River/Buck Creek Landform Summary

Mass Wasting Summary Table: Landform #1 - Inner Gorges

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)		1			1
Young Stands (timber 5-15 yrs)	4	1			5
Submature (timber 15-50 yrs)	5	5			10
Mature (timber > 50 yrs)	1	1			2
Road	1				1
Partial Cut	2				2
Yarding					
Alpine					
Other (e.g. housing, agriculture)					

Mass Wasting Summary Table: Landform #2 - Bedrock Hollows

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)					
Young Stands (timber 5-15 yrs)	1	5			6
Submature (timber 15-50 yrs)		6			6
Mature (timber > 50 yrs)					
Road					
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)					

Mass Wasting Summary Table: Landform #6 - Rock Outcrop

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)		1			1
Young Stands (timber 5-15 yrs)	4				4
Submature (timber 15-50 yrs)	9	11			20
Mature (timber > 50 yrs)					
Road		1			1
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)					

Mass Wasting Summary Table: Landform #8 - Deep-Seated Landslide Toes Stream Adjacent

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)	3			10	13
Young Stands (timber 5-15 yrs)	5			17	22
Submature (timber 15-50 yrs)	2	1		32	35
Mature (timber > 50 yrs)				4	4
Road				6	6
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)				9	9

Mass Wasting Summary Table: Landform #10 - Husum Water Pipeline

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

Mass Wasting Summary Table: Landform #11 - Missoula Slack Water Deposits Stream Adjacent

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)					
Young Stands (timber 5-15 yrs)	10				10
Submature (timber 15-50 yrs)	8				8
Mature (timber > 50 yrs)					
Road	1				1
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)	1				1

Mass Wasting Summary Table: Landform #12 - Steep Bedrock Faces Above Public Resources

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)					
Young Stands (timber 5-15 yrs)					
Submature (timber 15-50 yrs)	3				3
Mature (timber > 50 yrs)	10				10
Road	1				1
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)					

Mass Wasting Summary Table: Landform #13 - Moderate to Steep Hill Slopes (>60%)

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)	5	1			6
Young Stands (timber 5-15 yrs)	5	3			8
Submature (timber 15-50 yrs)	3	3			6
Mature (timber > 50 yrs)	1				1
Road			1		1
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)					

Mass Wasting Summary Table: Landform #14 - Valley & Stream Bottoms (0-10%)

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

Mass Wasting Summary Table: Landform #15 - Low Gradient Hill and Valley Side Slopes (11-40%)

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

Mass Wasting Summary Table: Landform #16 - Ridge & Hill Tops (0-10%)

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

Mass Wasting Summary Table: Landform #17 - Intermediate Slopes (20-40%)

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanche	Deep-Seated Landslides	Totals
Clear Cut (timber 0-5 yrs)		2			2
Young Stands (timber 5-15 yrs)	6				6
Submature (timber 15-50 yrs)	5	3			8
Mature (timber > 50 yrs)					
Road			3		3
Partial Cut					
Yarding					
Alpine					
Other (e.g. housing, agriculture)					

Appendix C

Landform Hazard Rating Table

LANDFORMS	LANDFORM 1 Inner Gorge	LANDFORM 2 Bedrock Hollows	LANDFORM 6 Rock Outcrops	LANDFORM 8 Deep-Seated LS	LANDFORM 10 Husum Pipeline	LANDFORM 11 Slack Water Dep	LANDFORM 12 Steep Bedrock Public Resources	LANDFORM 13 Moderate to Steep Slopes 60-+80%	LANDFORM 14 Valley & Stream Bottoms	LANDFORM 15 Low Gradient hill & valley sides 11-40%	LANDFORM 16 Ridge & Hill tops 0-10%	Landform 17 Intermediate Slopes	Private & State Land Area	Federal * Land Area	WAU ** area
Landform Area (acres)	434	185	663	254	75	277	154	1667	1469	12289	2248	3900	23633	264	23897
Number of Landslides	23	12	22	12	8	20	13	18	1	7	0	13	149	NA	NA
Area of "Delivering" Landslides (acres)	15.23	2.37	19.68	4.93	1.61	8.2	9.97	10.19	.01	3.36	0	2.09	77.64	NA	NA
Landslide Frequency Rate (Number of slides/Landform Area/Years) x 10^6	2789.2	3413.9	1746.4	2486.5	5614	3800.1	4442.9	568.3	35.8	30.0	0	175.4	331.8	NA	NA
Landslide Area Rate for Delivery (Delivering Landslide Area/Landform Area/Years) x 10^6	1847	674.3	1562.3	1012.5	1129.8	1558.0	3407.4	321.7	0.4	14.4	0	28.2	172.9	NA	NA

- Federal lands were not inventoried. Totals for the watershed area are not applicable.

Appendix C

Landslide Inventory