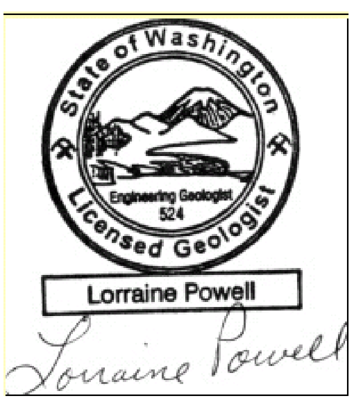
Major Creek/ Bingin Watershed
LANDSLIDE HAZARD ZONATION PROJECT

Klickitat County, Washington

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



Priority 3

Mass Wasting Assessment
January 4, 2007

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

DISCLAIMER

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1.0 **Project Summary**

The Major Creek/Bingin watershed administrative unit (WAU) lies approximately 18 miles east of the Cascade Crest and is bounded by the White Salmon River on the west, the Klickitat River to the east and the Columbia River to the south. Major Creek occupies the center of the watershed and drains south to the Columbia River just north of Mosier, Oregon. Although the LHZ Protocol is normally applied to private ownership and state-managed lands, all ownerships in this watershed were inventoried, including federal lands. Errors in Department of Natural Resources land ownership databases precluded identification and location of federal lands and their exclusion from evaluation within this WAU. This Landslide Hazard Zonation (LHZ) analysis divided the 40,568 acre watershed into 7 landforms that were found to contain 124 slope failures of which 78 delivered to a resource or typed water of the state.

Mapped landforms (summarized in Table 1) include two high hazard units defined in Washington State Forest Practices Rules, inner gorges and toes of deep-seated landslides. One other high hazard landform, Steep Bedrock Draped with Thin Soils, was mapped within this watershed. These three High Hazard Landforms contained 60% of all delivering landslides inventoried within this WAU. Many of the landslides in the Steep Bedrock Draped with Thin Soils landform (Landform 12) occurred on >65% slopes on which intense grazing has resulted in the development of extensive cattle trail networks. These trails often traverse across and down slopes at steep angles, channeling surface water to natural springs formed at outcrops of interbedded sediment layers in the basalts. During intense precipitation events the trails become incised by the channeled water and often coalesce at a spring watering areas creating point discharges that initiate debris flows. Due to the steep nature of slopes in this landform and proximity to stream channels, delivery often occurs.

Two hazard calculations were done for Landform 12, one including and one excluding non-forest related (cattle trail) slope failures. When failures attributed to cattle trail development were excluded, the Hazard Rating was halved from 422 to 274 and the Delivery Rate dropped from 182 to 145 resulting in a reduction from an overall High Hazard Rating to a Moderate Hazard Rating in Landform #12. This unique calculation was done to emphasize the sensitivity of this landform to vegetation disturbance and to channeling water to a point source discharge. Timber harvest and/or harvest related activities that disturb the vegetative cover or channel water on or to these grassy slopes may result in slope instability.

Landform Number	Name of Landform	Landform Slope Stability Hazard Rating	Slope of Landform	Total Area of Landform in Acres	No. of Delivering Landslides in Landform	Comment
#1	Inner Gorges	High	>70%	220	6	FP Rule-identified High Hazard
#8	Toes Deep-Seated Landslides	High	>65%	129	1	FP Rule-identified High Hazard
#12	Steep Bedrock Draped with Thin Soils (>60%)	High	>60%	2,560	40	Unique landform to this watershed
#12a	Steep Bedrock Draped with Thin Soils Excluding Cattle Trail Initiated Failures (>60%)	Medium	>60%	2,560	26	Unique landform excluding cattle trail initiated failures
#13	Intermediate Slopes (11 – 59%)	High	11 – 59%	17,713	27	Unique landform to this watershed
#14	Valley & Stream Bottoms	Low	0-10%	1,356	0	LHZ protocol Low Hazard
#15	Ridge & Hill Tops (0-10%)	Low	0-10%	6,907	0	LHZ protocol Low Hazard
#99	Non Forest use lands	Low	Any slope	9,147	4	Unique landform to this watershed
	Overall		NA	40,568	78	

Table 1. Summary of 7 landforms mapped in the Major Creek/Bingin watershed administrative unit.

2.0 Introduction

The Major Creek/Bingin WAU, covering 40,568 acres, is located approximately 18 miles east of the Cascade Mountains on the north side of the Columbia River (Figure 1). The watershed contains a mixture of federal, private and state ownership. It is roughly oval shaped, oriented north to south, and drains from northwest to southeast.   Major Creek forms the major WAU drainage with Catherine and Hanson creeks occupying much smaller adjacent basins. Nearly 23 percent of the watershed is managed as non-forest use (vineyards, orchards, residential, commercial, agricultural farming and grazing, utility corridors, recreational parks, etc.). A significant area within this WAU has been or is currently being developed into home sites and clustered developments interfacing with commercial private forest, federal and state owned lands. Many of the roads accessing these homes or undeveloped acreages were not built to Forest Practices standards but rather developed to service the homeowners' private access needs.

Vegetation and land use varies across the watershed. The dryer eastern and southern portions of the watershed contain extensive oak forests interspersed with scattered pine and fir. Poison oad is common in this watershed. Denser more continuous conifer forests occupy the northern and northwestern portion of the watershed. Many benches and hilltops in the eastern and southern portions of the watershed are currently cleared of trees and are utilized as home sites, dry land grazing or dry land hay production. Cattle grazing on steep slopes (>65%) draped with thin soils have establish trails across and down slopes that channel water during precipitation events. These trails appear to funnel water along and down some trails resulting in the triggering of debris flows that often deliver sediment to streams.

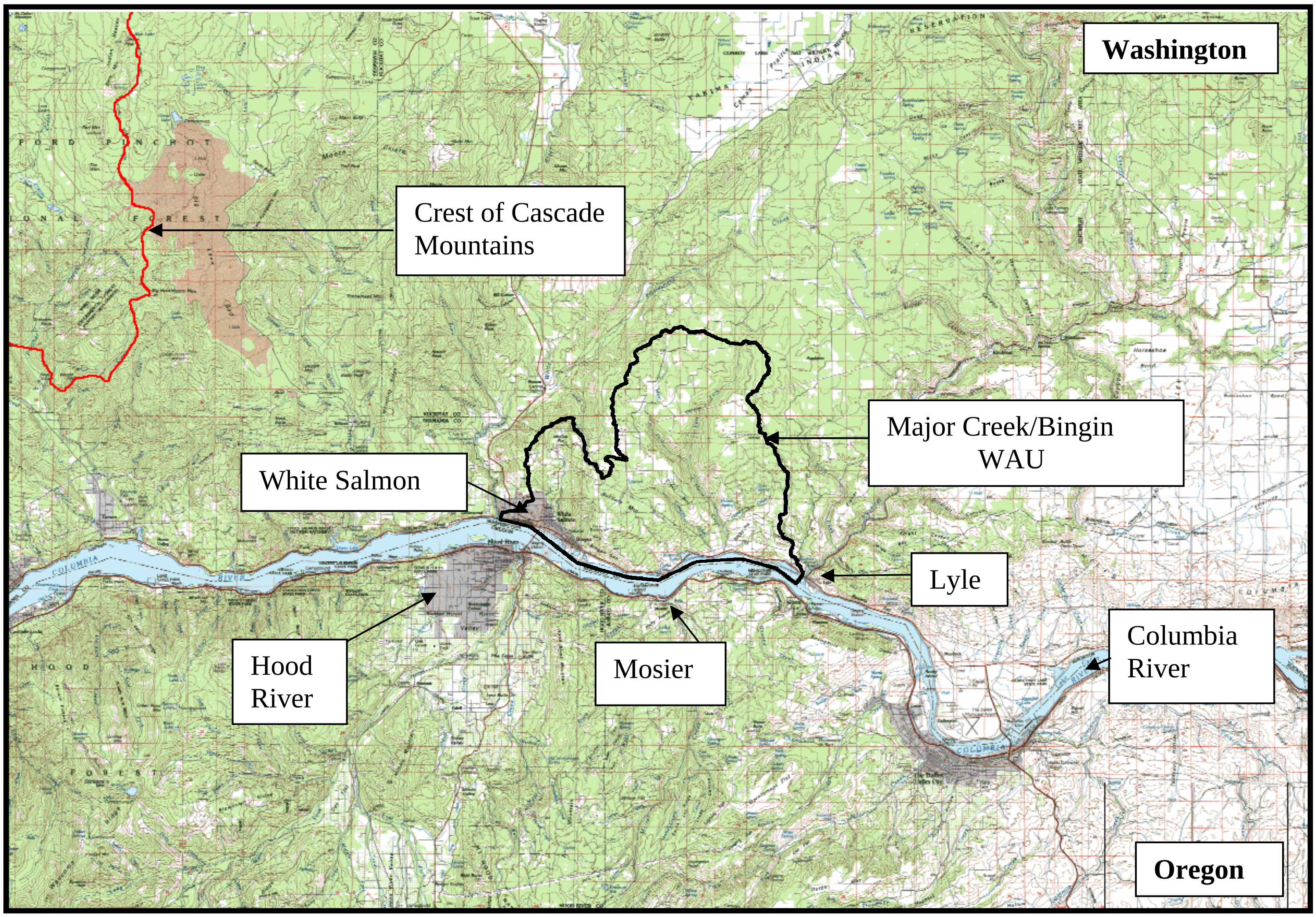

Figure 1. Location of the Major Creek/Bingin WAU east of the Cascade Mountain crest between Washington and Oregon

3.0 Topography

Topographically, the basin is a southeast dipping basalt plateau dissected by Major Creek. Dissection of the plateau has resulted in the development of tilted mesas. Large deep-seated landslides in the basalt that move from northwest to southeast toward the Columbia River along the basalt dip plane create a rolling, disturbed surface of basalt blocks (Map-A-1).

Elevations in the Major Creek/Bingin watershed range from a low of 72 ft at the confluence of the Columbia and White Salmon Rivers at the southwestern most tip of the WAU to a high of 2785 ft on the northeast side of the WAU (Figure 2). Figure 2 is a map with a profile view across the watershed from northwest to southeast dow n the lower reach of Major Creek. Note the deep inner gorge along Major Creek. The plateau on either side of the two branches of the creek are gently rolling with a subdued topography where there are few landslides and limited areas of unstable slopes.

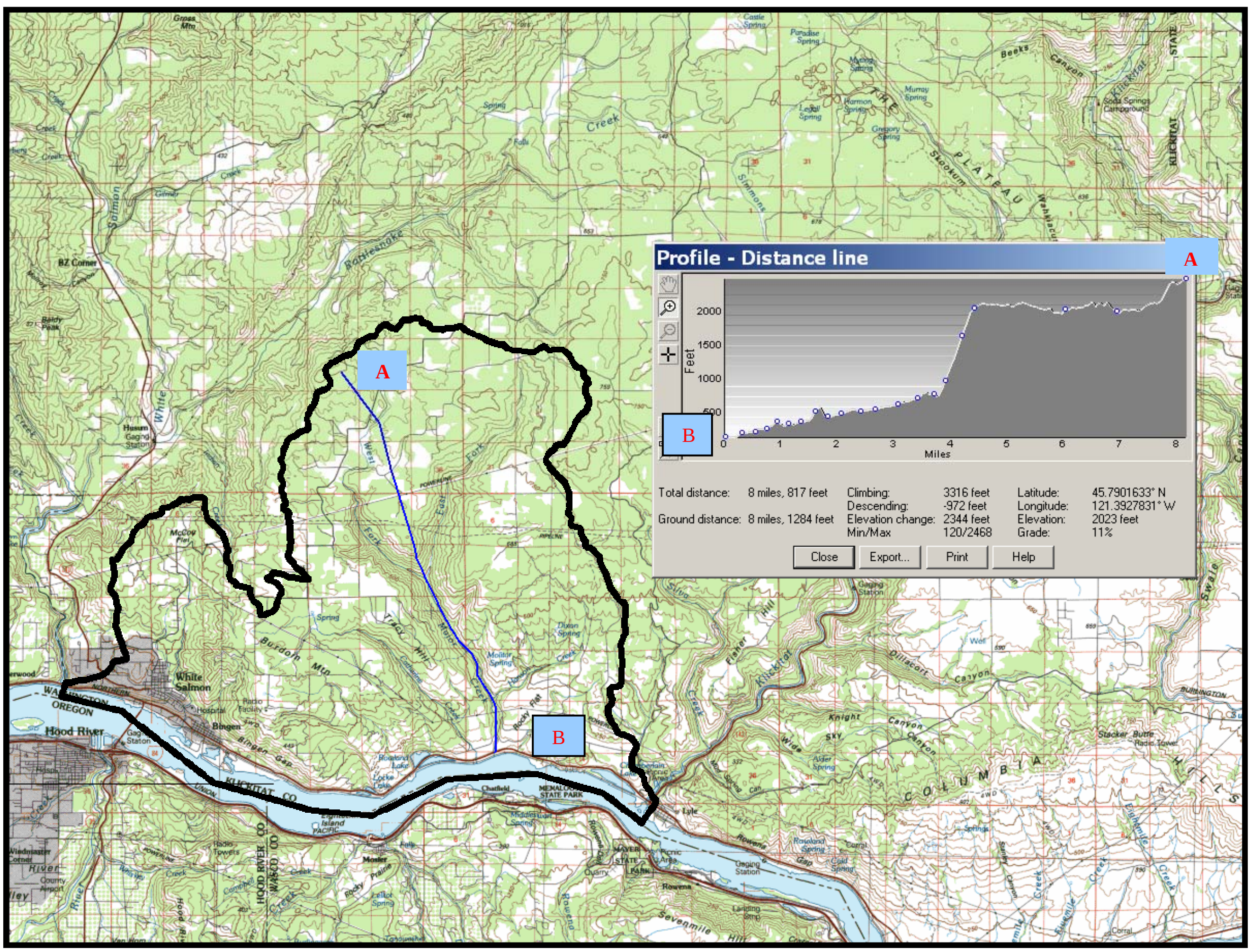

Figure 2. Profile of the Major Creek/Bingin WAU from northwest to southeast. Elevation change is 2344 feet from the northwestern margin of the WAU to the junction of the Columbia River and Major Creek drainages.

4.0 Hydrology

The southeastern side of this watershed receives considerably less rainfall than the western and northwestern areas due to both the rain shadow affect on the lee (east) side of the Cascade Crest and the significantly lower elevations present on the southeastern corner of the WAU (Figure 2). There are no USGS gauging stations located in the Major Creek/Bingin WAU, however, active stations are present to the west on the White Salmon River below the confluence of Buck Creek (station 14123500) and to the east on the Klickitat River (station 14113000) (Figure 3). The highest recorded peak stream flow for both gauging stations occurred in February 1996 (Figures 4 & 5). The average annual stream flow at station 14123500 (White Salmon River) is 1115 cu. ft./sec based on 89 years of data and the flow at station 14113000 (Klickitat River) is 1572 cu. ft./sec (USGS Washington Water Science Center). This hydrologic event occurring during the winter (February) of 1996 was significantly greater than any other on record resulting in slope failures, debris flows, road fill failures and debris slides throughout the watershed.

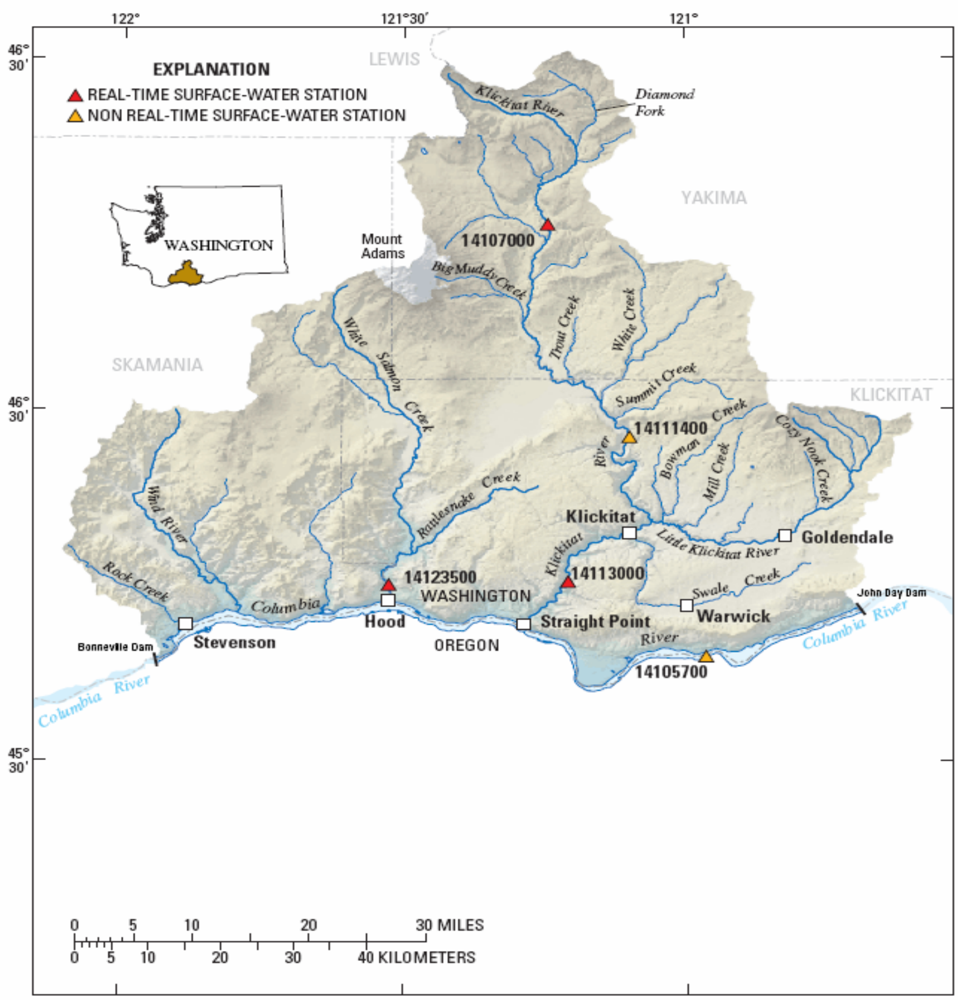

Figure 3. Location of USGS gauging stations adjacent to the Major Creek/Bingin WAU.
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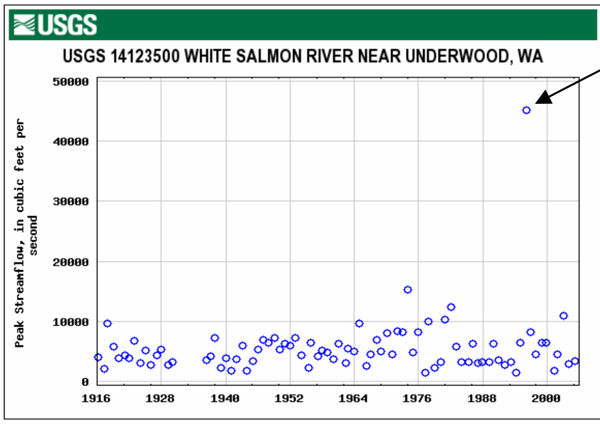

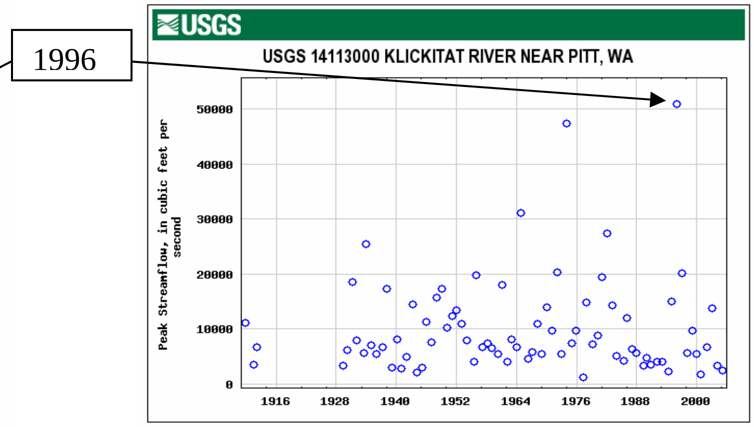

Figure 4. Peak stream flow White Salmon

Figure 5. Peak stream flow Klickitat River.

In 1996, several debris flows occurred in Landform #12 below a county road (Old Highway 8/Lyle White Salmon Road) east of Rocky Flat. At this location water channeled from and by the county road onto grassy slopes below the road triggered shallow debris slides that became debris flows and ultimately delivered sediment and debris to Hewett Lake (Figure 6). Multiple debris fans formed in Hewett Lake along the bank of the Columbia River just east of the mouth of Major Creek (Figure 7). Many culverts in the WAU failed during the 1996 event and required maintenance, replacement or repair (personal communication, DNR foresters)

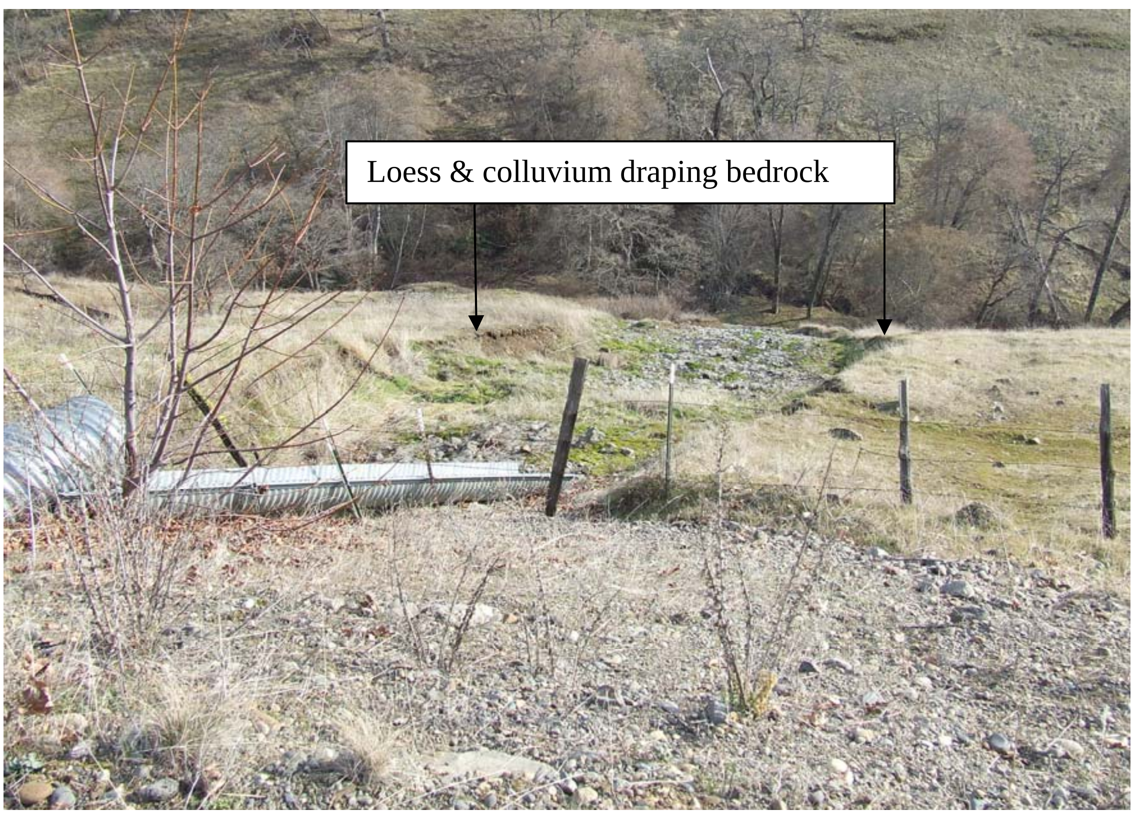

Figure 6. Large culvert channeled road concentrated water onto grassy slope below. The extension was added after the 1996 precipitation event. 2007 photo.

Figure 7. One of several debris fans deposited in Hewett Lake during the 1996 event. 2007 photo.

5.0 Geology

5.1 Regional Geology

The Major Creek/Bingin WAU is located on the western margin of the Columbia River Basalt (CRB) 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 The Ellensburg Formation (5 to 15 m.y.b.p.) is composed of volcaniclastic (derived from volcanic activity) sedimentary rocks (cobbles, gravels, sands, silts, and clay 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 8). Landslide deposits drape all three (Grande Ronde, Wanapum, and Ellensburg) formations (Waitt, R. B., 1977). The area adjacent to the Columbia River and below an elevation of approximately 600 feet experienced repeated scouring during the Missoula flood events. Sand, gravel and minor slack water clay deposits delivered by these catastrophic floods are present on the north bank of the Columbia River.

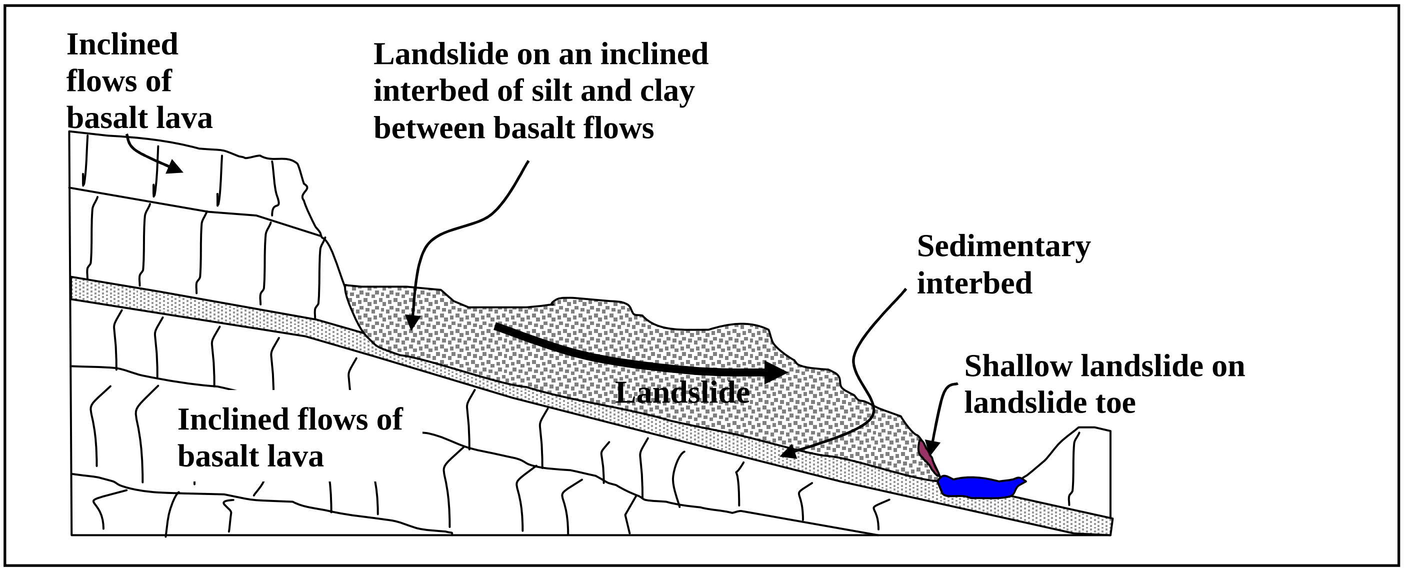

Figure 8. Sketch cross sectional diagram showing formation of large deep-seated landslides in the Major Creek/Bingin WAU. Landslides moved over silt and clay interbeds that occur between basalt flows. Secondary shallow failures are common on the toes of these large, older features.

5.2 Local Geology

The Major Creek/Bingin Watershed contains both large deep-seated landslides and shallow landslides in the Grande Ronde, Wanapum, and Ellensburg Formations. Numerous large deep-seated landslides in the basalts occurred when large sections of basalt slid on clay and silt interbeds (Figure 9). Most of these landslides occurred long ago and are now dormant or relict features. Where streams or highways undercut the toes of these relict landslides, portions of both shallow and deep-seated landslides may be reactivated. 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 as well as rock topple and rock fall. Extensive talus deposits have formed along several of the side scarps. This is of particular concern where these scarps are present above county and state highways along the Columbia River.

6.0 Previous Investigations

The White Salmon River/Buck Creek WAU Landslide Hazard Zonation Project evaluation completed by Powell in 2006 is located adjacent to and northwest of the Major Creek/Bingin WAU. Slope failure statistics in the White Salmon River/Buck Creek WAU vary significantly from this WAU in that the number and percentage of shallow landslides versus debris flows is reversed. The total number of slope failures is 60 percent less in the Bingin inventory than in the Buck Creek inventory.

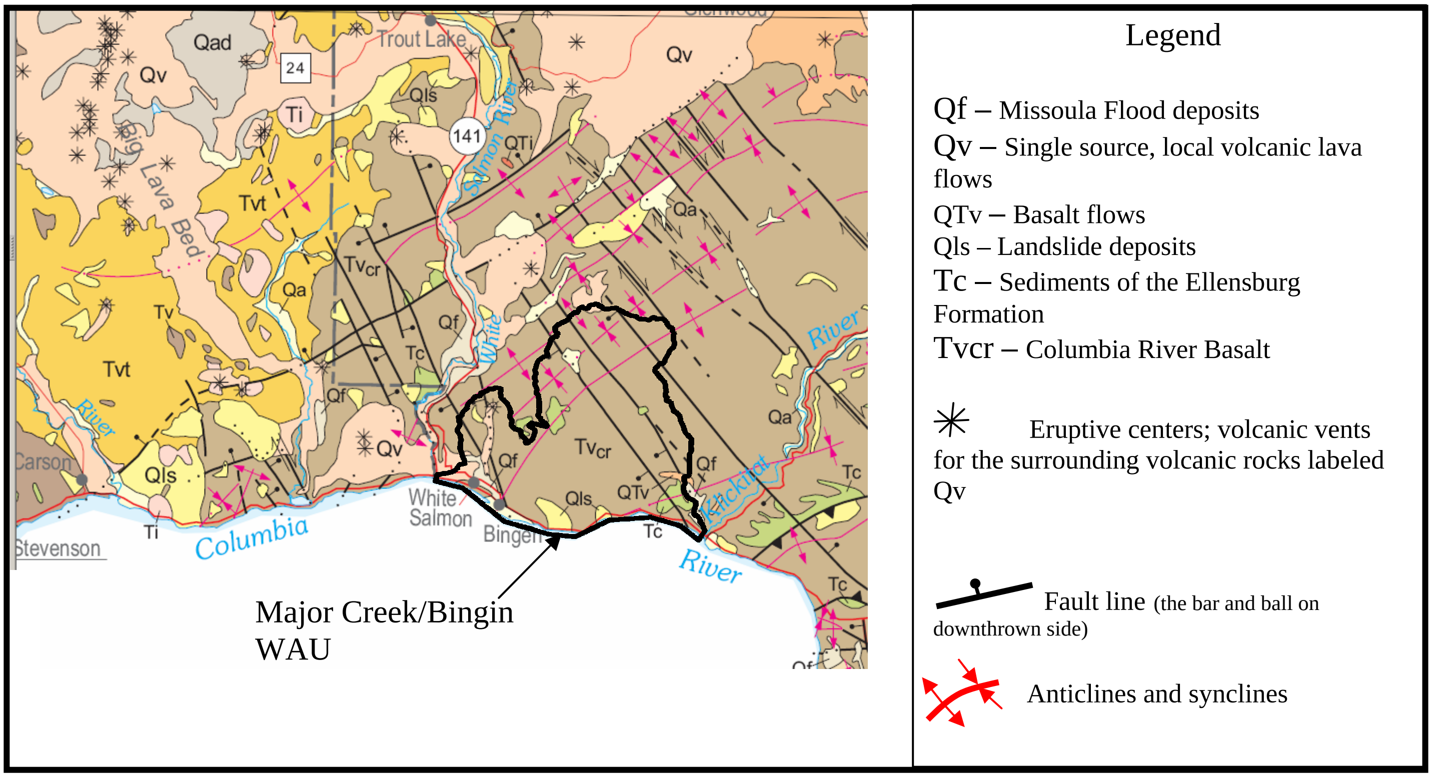

Figure 9. Simplified geologic map of the Major Creek/Bingin WAU and surrounding area modified from a portion of the Washington State Geologic Map (Shuster, 2005).

Champion Pacific Timberlands, Inc., completed the Panakanic Watershed Analysis in 1996. The Panakanic WAU is adjacent and north of the Major Creel/Bingin 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.

Other works include the USFS watershed Analyses on the Little White Salmon River in 1995, on Cave-Bear Creeks in 1997, and 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 Major Creek/Bingin watershed determined 87 of the 124 mapped features definitely or probably delivered to public resources. Table 2 shows the distribution of mass wasting features.

Mass Wasting Type	Number of Mass Wasting Features Mapped	Area (acres) of Mass Wasting Features	Percentage of Total Landslides
Shallow undifferentiated landslides	11	8	13
Debris flows	65	33	75
Debris slide/avalanche	5	1	6
Rock Topple, Rock Fall	6	100	6
Total	87	330	100

Table 2. Summary of the type and number of LHZ protocol specific mass wasting features excluding deep-seated landslides or toes of deep-seated landslides that definitely or probably delivered to typed waters or public resources in the Major Creek/Bingin WAU.

8.0 Landforms

Analysis of unstable slopes within the watershed resulted in the delineation of 7 landforms (Table 1, Appendix C). Landforms #1, & #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 the 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 C). The landform numbers here are the same as those identified in the Landslide Inventory: Form A-1 (Appendix A). Landslide hazard ratings have been summarized on Form A-4 (Appendix D).

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 generated by the February, 1996 rain-on-snow event extensively scoured many inner gorges, especially along Major Creek, Catherine Creek, and a small unnamed drainage located on the east side of Rocky Flat and Major Creek.

Landform #8: Deep-Seated Landslide Toes >65% and Stream-adjacent – Rule-identified landform 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 material facilitates water transmissivity, reduced cohesion, and increased soil creep that results in continued sliding. Toes of deep-seated landslides that have been undercut by roads that over-steepen the slopes have also been reactivated.

Landform #12: Steep Slopes Draped with Thin Soils - All slope shapes and angles >65% draped with thin soils have a High hazard rating (422) with a High mass wasting and delivery potential (182). These slopes may or may not contain continuous tree cover and are often contain large areas of grassland. Grazing cattle on these grasslands have produced a network of trails that appear to control many of the slope failures that were observed on this landform. A major concentration of this landform is found upslope of inner gorges in Major Creek, Catherine Creek, Hanson Creek, and Jewel Creek as well as the west and southwest face of Burdoin Mountain, and along the Columbia River. Water channeled by roads onto this landform were observed to result in numerous slope failures. The Landslide Frequency Rate recalculated to exclude cattle trail initiated failures is 274, approximately one-half the composite calculation. The Landslide Delivery Rate recalculated to exclude cattle trail initiated failures is 145 and is considered a Moderate hazard. This is a reduction from the High hazard rate calculated with inclusion of the cattle trail slope failures (Appendix D).

Landform #13: Intermediate Slopes (11 – 59%) This map unit includes all slope forms and gradients between 11 % and 59% and has a Low hazard rating with a Low mass wasting and delivery potential.

Landform # 14: Valley & Stream Bottoms –This landform contains those areas in and around rivers and streams and is more likely to be the recipient of debris and alluvial deposits rather than erosional processes. This landform has a Low hazard and Low delivery potential. No landslides were identified in this landform.

Landform # 15: Ridge and Hill Tops – This landform includes all ridge tops and ridge noses with gradients between 0 and 10%. A Low hazard rating, a Low mass wasting potential and low delivery potential were calculated for this landform as no landslides were identified in it. No landslides were identified in this landform.

Landform # 99: – Non-forest Use Lands (any slope angle or form) - This landform includes all lands currently accessed for non-forest uses. These uses include but are not limited to; power and gas line corridors, agricultural lands, orchards, vineyards, private residences and yards, commercial businesses, highways, railroads, hay fields, pastures, corrals and feed yards, and cleared dry land hay fields/grazing lands. Commercial timber is not present or is actively suppressed in maintaining timber cleared agricultural managed farms or homes. Cultivation (deep plowing, fallowed fields) has generated debris flows that delivered to public resources in this WAU. This landform has a Low hazard rating with a Low mass wasting potential and Low delivery potential.

9.0 Summary of Methods

Landslide inventory - The procedures described below follow the 2005 Landslide Hazard Zonation Protocol version 2.0; with minor modification. Five sets of 1:12,000 aerial photographs from 1961 to 1998, one set of color orthophotos, 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 but 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
1961	1:12,000	Black & White	WWK-61	DNR	Complete coverage
1969	1:12,000	Black & White	KLB-69	DNR	Complete coverage
1979	1:12,000	Black & White	KYK-79	DNR	Partial coverage
1991	1:12,000	Black & White	SC91	DNR	Partial coverage
1998	1:12,000	Color	SC98	DNR	Complete coverage
2002	Orthophotos	Color	Orthophotos	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 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 the 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 A, 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 C. 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

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 landslides 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 D) 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 moderate. 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 of the project design, fieldwork and the number of aerial photograph sets examined are held to reasonable minimums. Omissions are due to the limited field verification of individual features, particularly in remote, limited access and 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.

In addition, there are several sources of systematic error that could 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 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). .

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 (minimal tree density) 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 all lands within the Major Creek/Bingin 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.). A lack of accurate data as to land ownership in the Department of Natural Resources land ownership geodatabase precluded separation of federal lands from private and state managed lands. All lands within the WAU have been divided into designated mass wasting hazard landforms. 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, DNR Forest Practices, tromped through the woods, shared many insights about landslides, Forest Practices Rules and the LHZ project. A special thanks to Isabelle Sarikhan, DNR Geology, for invaluable GIS support de-slivering geodatabases and much appreciated moral support throughout the GIS experience. Jack Powell and Venice Goetz, DNR Forest Practices, spent many hours consulting, reviewing, and editing this report. Finally and most importantly, I wish to thank the landowners in the WAU who graciously provided access to their lands during the field verification of landslides and landforms, for without their assistance and support verification would not be possible.

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	SLIDE_ID	LSI_PROCES	CERTAINTY	ID_DATE	LS_SIZE	ID2_DATE	ID2_SIZE	INIT_ELEV	PHOTO_NUM	LANDFORM	LANDFORM_	SLP_SHP	GRADIENT	DELIVERY	LANDUSE	WAU_LANDF	ACTIVITY_L	TYPE
2	100	8	D	1961		0	0	620	WWK-61-1-24	9	0	1	85	I	4	12		
3	105	4	D	1961	5	0	0	326	WWK-61-1-28	1	0	1	50	Y	4	13	DD	CO
4	106	4	D	1961	5	0	0	1541	WWK-61-1-28	8	0	1	31	Y	4	13	DI	TR
5	107	8	D	1961		0	0	1079	WWK-61-1-28	6	0	1	50	N	4	13		
6	110	8	D	1961		0	0	1743	WWK-61-1-29	6	0	3	87	N	4	12		
7	112	2	D	1961		0	0	455	WWK-61-1-31	2	8	3	33	P	4	13		
8	113	2	D	1961		0	0	788	WWK-61-1-31	2	0	3	50	Y	4	8		
9	114	2	D	1961		0	0	418	WWK-61-1-31	2	0	3	50	P	4	12		
10	115	2	D	1961		0	0	391	WWK-61-1-31	2	0	3	65	Y	4	12		
11	116	2	D	1961		0	0	684	WWK-61-1-33	6	0	3	50	P	4	12		
12	117	2	D	1961		0	0	1060	WWK-61-1-33	6	0	1	73	P	4	12		
13	118	2	D	1961		0	0	1028	WWk-61-1-33	6	0	1	49	P	4	12		
14	119	2	D	1961		0	0	921	WWK61-1-33	6	0	1	47	P	4	12		
15	120	2	D	1961		0	0	719	WWK61-1-33	6	0	1	53	P	4	12		
16	121	2	D	1961		0	0	377	WWK61_1_33	6	0	1	68	P	9	12		
17	122	4	P	1961	5	0	0	388	WWK61-2-23	8	0	1	41	P	4	13	RE	TR
18	123	4	P	1961	5	0	0	979	WWK61-3-23	8	0	1	15	N	4	13	RE	TR
19	124	1	D	1961		0	0	913	WWK61-3-23	1	0	1	47	P	4	13		
20	125	2	D	1961		0	0	838	WWK61-3-27	9	0	1	51	P	4	12		
21	126	2	D	1961		0	0	1723	WWK61-3-29	7	0	3	52	Y	4	12		
22	127	2	D	1961		0	0	1622	WWK61-3-29	7	0	3	55	Y	4	12		
23	128	2	D	1961		0	0	1531	WWK61-3-29	7	0	3	54	Y	4	13		
24	129	2	D	1961		0	0	1160	WWK61-3-29	7	0	3	70	Y	4	12		
25	130	4	P	1961	5	0	0	1395	WWK61_3_35	8	0	1	58	P	4	13	RE	TR
26	131	3	D	1961		0	0	1648	WWK61_4_28	2	0	3	55	Y	9	12		
27	132	2	D	1961		0	0	1530	WWK61_4_28	7	0	3	59	Y	9	12		
28	133	1	D	1961		0	0	1402	WWK61_4_28	1	0	3	58	Y	9	12		
29	134	4	P	1961	5	0	0	1161	WWK61_4_28	8	0	3	54	Y	4	12	DI	TR
30	135	4	P	1961	5	0	0	1909	WWK61_4_28	8	0	3	43	N	3	13	DI	TR
31	136	1	D	1961		0	0	932	WWK61_4_28	6	0	2	69	P	4	12		
32	137	4	P	1961	5	0	0	1320	WWK61_4_28	8	0	1	49	N	9	13	DI	CO

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
33	138	4	P	1961	5	0	0	1061	WWK61_4_30	8	0	3	44	P	4	12	DI	TR
34	139	4	Q	1961	5	0	0	1890	WWK61_4_30	8	0	4	35	P	2	13	RE	CO
35	140	2	D	1961		0	0	1794	WWK61_4_30	7	0	3	57	Y	3	12		
36	141	2	D	1961		0	0	1734	WWK61_4_30	7	0	3	63	Y	3	12		
37	142	2	D	1961		0	0	1631	WWK61_4_30	7	0	3	64	Y	3	12		
38	143	2	D	1961		0	0	1544	WWK61_4_30	2	0	1	53	Y	4	13		
39	144	2	P	1961		0	0	1612	WWK61_4_30	7	0	3	51	Y	1	13		
40	145	4	P	1969	5	0	0	82	KLB69_27_7b_61	8	0	1	53	P	9	13	DD	CO
41	146	2	D	1969		0	0	400	KLB69_28_8B_55	7	0	1	45	Y	5	99		
42	147	4	P	1969	5	0	0	2250	KLB69_28_8B_64	8	0	1	65	P	6	13	RE	CO
43	148	4	D	1969	5	0	0	2045	KLB69_28_8B_64	8	0	1	45	P	6	13	DD	TR
44	149	2	D	1969		0	0	1312	KLB69_28_8B_64	7	0	1	77	P	3	12		
45	150	2	D	1969		0	0	623	KLB69_28_8B_64	8	0	3	98	P	9	12		
46	151	2	D	1969		0	0	879	KLB69_28_9D_11	7	0	3	68	Y	9	12		
47	152	2	D	1969		0	0	1071	KLB69_28_9D_11	7	0	3	52	P	9	13		
48	153	2	D	1969		0	0	669	KLB69_28_9D_13	7	0	3	40	P	9	13		
49	154	2	D	1969		0	0	776	KLB69_28_9D_13	7	0	3	47	P	9	13		
50	155	2	D	1969		0	0	1014	KLB69_28_9D_13	7	0	3	64	P	9	12		
51	156	2	D	1969		0	0	1026	KLB69_28_9D_13	7	0	3	36	P	9	13		
52	157	2	D	1969		0	0	1239	KLB69_28_9D_13	7	0	3	69	P	9	12		
53	158	8	D	2002		0	0	514	color ortho	6	0	3	85	N	9	13		
54	159	8	D	2002		0	0	356	color ortho	6	0	2	77	N	9	12		
55	160	8	D	2002		0	0	345	color ortho	6	0	3	100	N	9	12		
56	161	8	D	2002		0	0	479	color ortho	6	0	3	78	N	9	13		
57	162	8	D	2002		0	0	445	color ortho	6	0	3	57	I	9	13		
58	163	8	D	2002		0	0	491	color ortho	6	0	3	75	I	9	13		
59	164	8	D	2002		0	0	225	color ortho	6	0	3	66	I	9	13		
60	165	8	D	2002		0	0	402	color ortho	6	0	3	78	N	9	13		
61	166	8	D	2002		0	0	219	color ortho	6	0	3	71	N	9	13		
62	167	8	D	2002		0	0	267	color ortho	6	0	3	71	N	9	13		
63	168	8	D	2002		0	0	861	color ortho	6	0	3	71	N	9	13		
64	169	8	D	2002		0	0	961	SC98_6_9_50	6	0	3	72	I	9	12		
65	170	8	D	2002		0	0	901	SC98_6_9_50	6	0	3	62	I	9	12		
66	171	8	D	2002		0	0	1379	SC98_6_9_50	6	0	3	64	N	9	12		
67	172	8	D	1998		0	0	914	SC98_6_9_50	6	0	3	92	I	9	12		
68	173	4	P	1998	5	0	0	1415	SC98_5_6_188	8	0	3	30	N	4	13	RE	CO

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
69	174	4	P	1998	5	0	0	1182	SC98_5_6_188	8	0	1	39	N	4	12	DI	CO
70	175	4	D	1998	5	0	0	1950	SC98_5_6_190	8	0	1	25	P	4	13	DI	CO
71	176	1	D	1998		0	0	1183	SC98_5_7_232	7	0	3	48	P	4	13		
72	177	4	P	1998	5	0	0	2126	SC98_6_9_50	8	0	3	24	P	4	13	RE	TR
73	178	4	P	1998	5	0	0	2036	SC98_6_11_147	1	0	1	37	P	4	13	RE	CO
74	179	2	D	1998		0	0	244	SC98_6_13_238	9	0	1	39	Y	9	13		
75	180	2	D	1998		0	0	268	SC98_6_13_238	6	0	5	26	Y	9	13		
76	181	2	D	1998		0	0	96	SC98_6_13_238	6	0	1	62	Y	9	13		
77	182	2	D	1998		0	0	291	SC98_6_13_238	6	0	1	23	Y	9	13		
78	183	2	D	1998		0	0	278	SC98_6_13_238	6	0	5	19	Y	9	13		
79	184	2	D	1998		0	0	252	SC98_6_13_238	6	0	3	25	Y	9	13		
80	185	2	D	1998		0	0	335	SC98_6_13_238	6	0	1	36	Y	9	13		
81	186	2	D	1998		0	0	272	SC98_6_13_238	6	0	3	41	Y	9	13		
82	187	2	D	1998		0	0	256	SC98_6_13_238	6	0	3	41	Y	9	13		
83	188	2	D	1998		0	0	331	SC98_6_13_238	6	0	3	22	Y	9	13		
84	189	2	D	1998		0	0	328	SC98_6_13_238	6	0	3	28	Y	9	13		
85	190	2	D	1998		0	0	260	SC98_6_13_238	6	0	3	49	Y	9	13		
86	191	4	P	1998	5	0	0	2617	KYK79_14A_14	8	0	1	39	P	4	13	DI	CO
87	192	2	D	1979		0	0	1596	KYK79_8A_6	7	0	1	53	Y	1	12		
88	194	3	D	1979		0	0	1683	KYK79_8A-6	7	0	4	76	Y	1	12		
89	195	3	D	1979		0	0	1589	KYK79_8A_6	6	0	1	68	Y	1	12		
90	196	3	D	1979		0	0	1540	KYK79_8A_6	6	0	2	78	Y	1	12		
91	197	3	D	1979		0	0	1478	KYK79_8A_6	6	0	4	78	Y	1	12		
92	198	2	D	1979		0	0	1435	KYK79_8A_6	2	0	4	51	Y	9	13		
93	199	2	D	1979		0	0	1389	KYK79_8A_6	7	0	1	48	Y	1	12		
94	200	2	D	1979		0	0	647	KYK79_8A_6	7	0	1	53	N	9	13		
95	201	2	D	1979		0	0	1887	KYK79_8A_6	7	0	1	32	P	6	13		
96	202	2	D	1979		0	0	1820	KYK79_8A_6	7	0	4	57	P	4	12		
97	203	2	D	1979		0	0	1199	KYK79_8A_6	7	0	1	59	P	9	12		
98	204	2	D	1979		0	0	1154	KYK79_8A_6	7	0	4	57	P	9	13		
99	205	3	D	1979		0	0	2055	KYK79_8A_6	7	0	1	38	N	1	13		
100	206	4	P	1979	5	0	0	1729	KYK79_8A_8	8	0	1	37	N	4	13	DI	CO
101	208	1	D	1979		0	0	1579	KYK79_8A_8	8	0	3	29	P	4	13		
102	209	4	D	1979	5	0	0	2120	KYK79_9A_7	8	0	7	41	I	1	13	DI	CO
103	210	2	D	1979		0	0	999	KYK79_10A_4	2	0	1	50	P	9	12		
104	211	2	D	1979		0	0	950	KYK79_10A_4	6	0	4	78	N	9	12		

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
105	212	2	D	1979		0	0	880	KYK79_10A_4	8	0	4	21	P	9	13		
106	213	2	D	1979		0	0	1078	KYK79_10A_4	7	0	2	53	N	9	12		
107	214	2	D	1979		0	0	924	KYK79_10A_4	7	0	2	73	P	9	12		
108	215	1	D	1979		0	0	1180	KYK79_10A_11	1	0	3	74	Y	4	1		
109	216	1	D	1979		0	0	1540	KYK70_10A_11	1	0	2	101	Y	4	1		
110	217	1	D	1979		0	0	1346	KYK79_10A_11	1	0	3	99	Y	4	1		
111	218	1	D	1979		0	0	1489	KYK79_10A_11	1	0	1	90	Y	4	1		
112	219	1	D	1979		0	0	1619	KYK79_10A_11	1	0	5	85	Y	4	1		
113	220	1	D	1979		0	0	1637	KYK79_10A_11	1	0	3	95	Y	4	1		
114	221	4	D	1979	5	0	0	2100	KYK79_12A_12	8	0	2	46	P	1	13	DI	CO
115	222	2	D	1979		0	0	1321	KYK79_14A_8	7	0	1	18	Y	9	99		
116	223	2	D	1979		0	0	1334	KYK79_14A_8	7	0	1	20	Y	9	99		
117	224	2	D	1991		0	0	1374	KYK79_14A_8	7	0	1	22	Y	9	99		
118	225	2	D	1991		0	0	1846	SC91_18_12_70	7	0	1	54	P	9	12		
119	226	2	D	1991		0	0	1364	SC91_18_12_70	7	0	2	59	P	9	12		
120	227	2	D	1991		0	0	1342	SC91_18_12_70	7	0	2	56	P	9	12		
121	228	2	D	1991		0	0	1653	SC91_18_12_70	7	0	1	58	P	9	12		
122	229	2	D	1991		0	0	1283	SC91_18_12_70	7	0	1	56	P	9	12		
123	230	4	P	1969	5	0	0	1756	KLB69_30_12_109	8	1	1	41	P	2	13	DI	CO
124	231	4	P	1969	5	0	0	1423	KLB69_30_12_109	8	1	1	50	P	4	13	RE	CO
125	232	2	D	1969		0	0	1423	KLB69_30_12_109	1	0	1	51	Y	3	13		

	S	T
1	COMMENTS	ACRES
2	cliff ravel directly into Columbia River	83.1
3	DSL in innergorge, oe undercut by stream	1.4
4	probable Missoula flood triggered dsl. replaces landslide 37817 in state inventory	114.2
5	talus ravel into Columbia River. replaces landslide 37817 in state inventory	103.1
6	talus slope with debris slides below cliffs	76.1
7	debris flow dipping bedrock surface with thin soil mantle	0.4
8	debris flow dipping bedrock surface with thin soil mantle at toe dsl	0.8
9	steep rock face	0.4
10	steep rock face	0.1
11	steep rock face above public highway and railroad	0.5
12	steep rock face above public highway & railroad	3.0
13	steep rock face above public highway	1.9
14	steep rock face above public highway	1.8
15	steep rock face above public highway and railroad	0.7
16		0.1
17		9.7
18		21.5
19		0.6
20	road or landing trigger	0.4
21	road trelated	0.3
22	road related	0.1
23	road related	0.8
24	cattle trail on steep ground resulting in slope failure, debris flow that delivered. No harvest related impacts.	0.0
25	probably relict	20.0
26	open grassy slope no timber	0.3
27	open grass slope. flow originated at toe of shallow landslide	0.2
28		0.1
29	may be relict	25.2
30	may be relict	53.4
31		0.3
32	grassland with scattered trees	16.6

	S	T
33	possibly relic dsl mix of grass and scattered timber	19.5
34	toe blocked stream, offset stream channel	12.1
35	road or landing initiation	0.3
36	road or landing initiatied	0.2
37	road or landing initiated	0.1
38	new debris flow originating in small bedrock hollow probably an innerbed between basalt flows	0.2
39	road and landing failure source	0.0
40	talus and basalt bedrock outcrop	12.1
41	road related, concentrating runoff into inner gorge	0.1
42	large old landslide clearly delineated.	276.4
43		134.4
44		0.6
45		0.1
46	grasslands no timber cowtrails?	0.6
47	grasslands no timber cowtrails?	0.2
48	grassland	0.2
49	grassland	0.3
50	grassland	0.1
51	grassland	0.2
52	grassland	0.1
53	grasslands	1.0
54	grasslands	0.7
55	grasslands	0.1
56	grasslands	0.8
57	grasslands	0.4
58	grasslands	1.8
59	grasslands	1.0
60	grasslands	4.3
61	grasslands	2.5
62	grasslands	1.7
63	grasslands	9.1
64	grasslands	30.5
65	grasslands	47.0
66	grasslands	2.8
67	talus and cliff above state highway. grasslands	20.7
68	on margin of WAU	42.8

	S	T
69		9.7
70	probably relict. replaces landslide 37771 in state inventory	264.9
71		3.4
72	large deepseated ls with sag ponds at head. old dip slope failure that is probably of missoula flood age. replaces landslide 37813 in state inventory	888.3
73		32.3
74	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.9
75	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	1.0
76	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.1
77	grassy thin soil hill slope in canyon. Debris flow partiallly filled lake. County road related	0.3
78	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.3
79	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.2
80	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.3
81	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.1
82	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.1
83	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.2
84	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.2
85	grassy thin soil hill slope in canyon. Debris flow partially filled lake. County road related	0.0
86		101.1
87	logging road fill failure in clearcut <3 years old. Multiple side slope failures feeding into debris flow	3.2
88	road bed failure developed into debris avalanche	0.2
89		0.1
90		0.1
91		0.1
92	grassy steep hillside, cattle	1.2
93	debris flow starting from road fill failure	0.4
94	debris flow originating from grassy hill slope	0.1
95	debris flow originating from road fill failure	0.1
96	3 seperate debris slides forming a debris flow downstream. May be road related trigger	0.6
97	road failure related debris flow	0.0
98	failure below road on steep grassy hill slope, water channeled?	0.0
99	road fill failure	0.0
100		6.2
101	shallow ls under powerline on edge of dsl	0.2
102	homes built on top of body below headwall	97.8
103	steep grassy hill side with multiple cattle trails	1.1
104	steep grassy hill side with multuiple cattle trails	0.2

	S	T
105	road related due to excess drainage discharged onto grassy slope that failed and cut channel down steep grassy hill slope	1.1
106	steep grassy hill side with multiple cattle trails	0.7
107	steep grassy hill side with multiple cattle trails	0.6
108	stream influenced in inner gorge	0.3
109	stream influenced in inner gorge	0.5
110	stream influenced in inner gorge	0.5
111	stream influenced in inner gorge	1.1
112	stream influenced in inner gorge	0.7
113		0.2
114	partial clear cut definite dsl that moved stream at toe	61.4
115	agricultural field bleeding sediment into stream	0.6
116	agricultural field source of debris flow into adjacent stream	0.2
117	agricultural field source of debris flow into adjacent stream	0.2
118	grassland	2.0
119	grassland	0.7
120	initiation in grassy slopes	0.4
121	grassland	1.1
122	grasslands	0.7
123	toe and body of more recent dsl that formed as a reactivation on older relict dsl	33.9
124	headscarp of large relict dsl	270.3
125	gas line road failure created debris flow down slope	0.4

Appendix B

Mass Wasting Summary Tables: Form A-3

Major Creek/Bingin WAU Summary Landslide Inventory

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)	0	3	5	2	0	10
2 = young stands (timber 5-15 yrs)	0	0	0	2	0	2
3 = submature timber (15-50 years)	0	5	0	1	0	6
4 = mature timber (>50 years)	10	16	0	15	3	44
5 = road	0	1	0	0	0	1
6 = partial cut	0	1	0	2	0	3
7 = yarding	0	0	0	0	0	0
8 = alpine	0	0	0	0	0	0
9 = other- e.g., housing, agriculture	1	39	1	2	15	58
TOTAL	11	65	6	24	18	124

Mass Wasting Summary Table: Landform #1 - Inner Gorges

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)						
2 = young stands (timber 5-15 yrs)						
3 = submature timber (15-50 years)						
4 = mature timber (>50 years)	6					6
5 = road						
6 = partial cut						
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture						

Mass Wasting Summary Table: Landform #8 – Toes Deep-Seated Landslides Stream-adjacent

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)						
2 = young stands (timber 5-15 yrs)						
3 = submature timber (15-50 years)						
4 = mature timber (>50 years)		1				1
5 = road						
6 = partial cut						
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture						

Mass Wasting Summary Table: Landform #12 – Steep Bedrock with Thin Soils

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)		2	4			6
2 = young stands (timber 5-15 yrs)						
3 = submature timber (15-50 years)		4				4
4 = mature timber (>50 years)	1	12		3	2	18
5 = road						
6 = partial cut						
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture	1	16	1		6	24

Mass Wasting Summary Table: Landform #13 – Intermediate Slopes

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)		1		2		3
2 = young stands (timber 5-15 yrs)				2		2
3 = submature timber (15-50 years)		1		1		2
4 = mature timber (>50 years)	3	3		12		18
5 = road			1			1
6 = partial cut		1		2		3
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture		20		2	10	32

Mass Wasting Summary Table: Landform #14 – Valley and Stream Bottoms

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)						
2 = young stands (timber 5-15 yrs)						
3 = submature timber (15-50 years)						
4 = mature timber (>50 years)						
5 = road						
6 = partial cut						
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture						0

Mass Wasting Summary Table: Landform #15 – Ridge and Hill Tops

Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)						
2 = young stands (timber 5-15 yrs)						
3 = submature timber (15-50 years)						
4 = mature timber (>50 years)						
5 = road						
6 = partial cut						
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture						0

Mass Wasting Summary Table: Landform #99 – Non-forest Lands

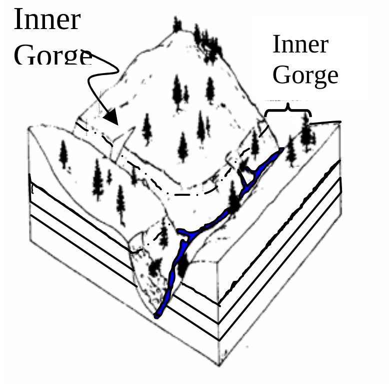
Activity	Shallow Landslides	Debris Flows	Debris Slides/ Avalanches	Deep-Seated Landslides	Rock Topples/ Falls	Total
1 = clearcut (timber 0-5 yrs)						
2 = young stands (timber 5-15 yrs)						
3 = submature timber (15-50 years)						
4 = mature timber (>50 years)		1				1
5 = road						
6 = partial cut						
7 = yarding						
8 = alpine						
9 = other- e.g., housing, agriculture		3				3

Appendix C

Form A-2

Descriptions of Landforms for the Major Creek/Bingin Watershed

11.0 **Landform #1 -** Inner Gorges – High Hazard by Rule



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, however, due to the physical characteristic of flood basalt flow sequences, small breaks in slope angle located at the base of basalt flows often develop a bench-step character that is not addressed in rule. Inner gorges in basalt terrain may be symmetrical or asymmetrical in cross section and are commonly interbedded with sedimentary units. Debris slides, debris flows, slope ravel, and deep-seated landslides were observed in inner gorges in the Bingin WAU.

Slopes: >70% by rule or >65% DEM-measured; field-measured slopes often exceeded 70%
Material: Basalt, colluvium, alluvium, landslide deposits, loess soils
Elevation: Variable, between 3200 ft and 90 ft.
Total Area: 220 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 landslides that can produce debris flows. Debris flows scour the walls of inner gorges, over-steepen them, which leads to further destabilization.

Forest Practice Sensitivity: Root strength within inner gorges has been found to limit rates of mass wasting (Krogstad, 1995). The roots of trees adjacent to and within inner gorges extend into and along gully slopes providing slope stability. Water channeled onto grassy slopes where all trees had been removed in inner gorges were observed to result in slope failures. Streams were observed to undercut slope toes, and old skid trails and roads that channel water on steep slopes were observed within this watershed.

Mass Wasting Potential: <u>High for road construction and timber harvest</u> in inner gorges having 6 landslides in an area of 220 acres over a 37 year time period (see LHZ protocol).

Delivery Potential/Criteria: <u>High</u>. Inner gorges are part of the drainage network as stream-adjacent slopes. They either contain streams or evidence of channel incision (6 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 delivery rate of 376 (see LHZ protocol).

Hazard Potential Rating: <u>High for roads and harvest based</u> on LHZ Protocol and Standard Forest Practices Rules. This landform has a landslide frequency rate of 684.

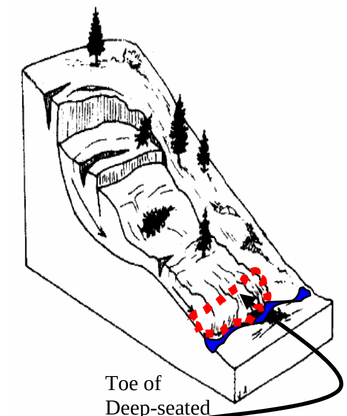
Overall Hazard Potential Rating: <u>High</u> based on the LHZ Protocol, Table 4.

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 can trigger debris slides or other landslides. These slopes are especially sensitive during major rain-on-snow storms or intense precipitation events. Channeling water to point discharges on these slopes has resulted in debris slides and debris flows.

Confidence: Moderate based on the number of landslides located in this landform, excellent photo quality and coverage, and field observations. Many toes were remote and were not field verified.

Comments: Debris flows and shallow undifferentiated landslides commonly occur within inner gorge features during major hydrologic events. Channeling water on inner gorge walls has created unstable slopes. Careful field review is necessary for those areas of steep inner gorge walls in or adjacent to the toes of deep-seated landslides and for any activity that disturbs or re-channels surface waters.

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 over-steepened 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
Elevation: Variable between 2500 ft and 300 ft
Total Area: 129 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 redirects water onto these toes, reduces root strength, undercuts or over-steepens the toes.

Mass Wasting Potential: High for roads and harvest based on 6 features identified over a 37 year photo record in a landform covering 129 acres.

Delivery Potential/Criteria: **<u>High</u>.** The landslide delivery rate for this unit is 167. Delivery is related to the proximity of the streams.

Hazard Potential Rating: **<u>High</u>** based on 1 landslide with a total area of .8 acres in this landform that totals 129 acres. This landform has a landslide frequency rate of 209 (see LHZ Protocol).

Overall Hazard Potential Rating: **<u>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, respectively, have resulted in the destabilization of this landform.

Confidence: Moderate **-** The exposure of a large percentage of the watershed, complete aerial photo coverage, and two days field checking the photo interpretation provided a moderate level of confidence in this analysis.

Comments: All toes of deep-seated landslides in or near a stream or inner gorge should be field reviewed.

Landform Number: #12 – **Steep Slopes (>65%) Draped with Thin Soils**

Description of Mass Wasting Unit: All slope shapes and angles >65% draped with thin loess or colluvial soils which consist of intermixed loess and angular fragments of basalt. These slopes may or may not contain continuous tree cover and are often broken by large expanses of grasslands. Much of this unit is located upslope of inner gorges in Major Creek, Catherine Creek, Hanson Creek, and Jewel Creek as well as the west and southwest face of Burdoin Mountain and along the Columbia River. Public roads along the Columbia may be affected by landslides from this unit.

Slopes: > 65%
Material: Fractured basalt, sedimentary interbeds draped by loess and colluvium
Elevation: Variable between 2500 ft and 300 ft
Total Area: 129 acres

Mass Wasting Process and Triggers: Any disturbance of vegetative cover or activity that cuts the thin soils, channels water, or loads the slope has triggered landslides in this landform. The thin soils are unstable when saturated and easily eroded during intense precipitation events.

Forest Practice Sensitivity: This landform is likely to be sensitive to any forest practice activity that redirects water onto slopes, disturbs the thin soils or creates breaks in vegetative cover. A majority of the slope failures on grass covered treeless slopes appears to have been a direct result of the development of cattle trails channeling water.

Mass Wasting Potential: High for roads and harvest based on 40 features identified over a 37-year photo record in a landform covering 2560 acres.

Delivery Potential/Criteria: **High.** The landslide delivery rate for this unit is 182. Delivery is related to the proximity of the streams.

Hazard Potential Rating: **High** for road construction and timber harvest based on 40 landslides with a total area of 17.2 acres in this landform that totals 2560 acres. This landform has a landslide frequency rate of 684 (see LHZ Protocol).

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

Trigger Mechanisms: Loss of root strength, changes in hydrology, disturbance of the soil ground cover due to intense cattle grazing and trails have resulted in the destabilization of this landform.

Confidence: Moderate - The exposure of a large percentage of the watershed and complete aerial photo coverage permitted moderate confidence in delineating slope failures in this landform. Field verification was limited due to lack of access to slope failures.

Comments: Over 60% of the slope failures (debris flows) in this landform occurred on grass slopes with no forest or forest practices in proximity. Channeling of precipitation due to a high density of cattle trails across and down slopes, often converging at natural spring areas, appears to have concentrated runoff to point discharges that saturated the thin soils and triggered debris slides that developed into debris flows.

Landform Number: # 13- Intermediate Slopes (11 – 59%)

Description of Mass Wasting Unit: This map unit includes all slope forms and gradients between
11 % and 59% (Caution: Other map units could have been erroneously been included in landform #13 through mapping errors.).

Slopes: Variable 11 to 59%
Material: Basalt, colluvium, soils,
Elevation: Variable across watershed
Total Area: 17,713 acres

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

Forest Practice Sensitivity: Roads, landings, culverts and skid trails appear to be the most significant triggering mechanism for slope failure within this landform. Undersized culverts may lead to road fill failures and debris flows. Road related failures comprise 47.5% of failures within this landform (excluding deep-seated landslides).

Mass Wasting Potential: Moderate for road construction and timber harvest based on 27 features identified in a landform covering 17,713 acres over a 37-year photo record.

Delivery Potential/Criteria: Low. Landslide deposits generally lack channel access in this WAU. Road and landing failures do not travel great distances. Steeper areas and the toes of deep-seated landslides lack sediment delivery mechanisms. Distance from a stream channel and topography inhibits transport of landslide debris to public resources and does not impact public safety. The landslide delivery rate for this landform is 28.

Hazard Potential Rating: Low for entire unit. This landform has a landslide frequency rate of 41 (see LHZ Protocol).

Overall Hazard Potential Rating: Low based on the LHZ Protocol, Appendix D, A-4.

Trigger Mechanisms: Mass wasting triggering mechanism varies with landform; however, 47.5% of all landslides within this landform were road-related. Road placement and water management are critical on steeper slopes in this landform.

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 failure activity noted in mature forest canopy may actually be other hidden rule-identified landforms. Remote locations and lack of access to many features precluded field verification. Failures on grassy slopes with significant cattle trail development comprised 37.5% of all failures within this landform (excluding deep-seated landslides).

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 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.

Slopes: Variable 0 to 10%
Material: Basalt, colluvium, alluvium, and landslide deposits
Elevation: 118 ft to 2729 ft
Total Area: 1358 acres

Mass Wasting Process: Shallow landslides and debris flow deposits may transport debris to this landform but were not observed to occur within it and generally do not 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 or may channel water down the road tread delivering fine sediment to streams.

Mass Wasting Potential: Low for road construction and timber harvest based on no features identified in a landform covering 1358 acres over a 37-year photo record.

Delivery Potential/Criteria: Low. The landslide delivery rate for this unit is 0. No mass wasting features were noted within this landform. Delivery is unlikely as lack of delivery to a stream channel precludes transport. Road and landing failures do not travel great distances. Distance from stream channels and topography inhibits transport of landslide debris deposited onto this landform from upper elevation sources and does not impact public safety.

Hazard Potential Rating: Low for timber harvest and road construction. This landform has a landslide frequency rate of 0 (see LHZ Protocol).

Overall Hazard Potential Rating: Low for entire unit. Appendix D, A-4.

Trigger Mechanisms: Mass wasting triggering mechanisms vary; however, landslides originating in this landform are unlikely to deliver to a public resource unless poorly designed road related (plugged culvert, side cast fill failure, landing fill failure) features. This type of mass wasting event can be present on any type of landform with any type of slope gradient even if the landform is not considered 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: No slope failures were observed within this landform.

Landform Number: # 15- Ridge and Hill Tops – Low Hazard

Description of Mass Wasting Unit: This map unit includes all ridge top and noses of ridges slope forms and gradients between 0 % and 10% 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.

Slopes: Variable 0 to 10%
Material: Basalt, colluvium, soils,
Elevation: Variable: 81ft to 2342ft
Total Area: 6907 acres

Mass Wasting Process: Deep-seated landslide head scarps 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 frost heaving and soil creep.

Forest Practice Sensitivity: No forest related failures were observed within this landform. Undersized culverts may lead to road fill failures and/or debris flows.

Mass Wasting Potential: Low for road construction and timber harvest based on no features identified in a landform covering 6907 acres over a 37 year photo record.

Delivery Potential/Criteria: **Low**. Lack of channel access. Distance from a stream channel and topography inhibits transport of debris to public resources. Remote ridge tops do not impact public infrastructure or safety. This landform has a landslide delivery rate of 0.

Hazard Potential Rating: **Low** for entire unit. This landform has a landslide frequency rate of 0 (see LHZ Protocol).

Overall Hazard Potential Rating: **Low** based on the LHZ Protocol, Appendix D, A-4.

Trigger Mechanisms: Potential mass wasting triggering mechanism varies within this landform; however, any landslide that may occur in this map unit are unlikely to deliver to a public resource unless engineered (plugged culvert, side cast fill failure, landing fill failure). This type of mass wasting event can be designed on any type of landform with any type of slope gradient even if the landform is not commonly unstable.

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

Comments: No slope failure activity was noted.

Landform Number: # 99- Non-forest Use and Agricultural Lands **-** Low Hazard Slopes

Description of Mass Wasting Unit: This map unit includes all slope forms and gradients located on all slope forms and gradients that are no longer/or will not return to forest production. This includes power line right-of-ways, vineyards, orchards, residential developments, commercial development, surface mines, railroads, county and state roads, cultivated lands, dry land agriculture (hay), cleared grazing lands.

Slopes: Variable 0 to 130%
Material: Basalt, colluvium, alluvium, and landslide deposits
Elevation: 74 ft to 2341 ft
Total Area: 9147 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 four debris flows identified over a 37-year photo record in a landform covering 9147 acres.

Delivery Potential/Criteria: **Low**. The landslide delivery rate for this unit is 2.7. 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 10.7 (see LHZ Protocol).

Trigger Mechanisms: Rainfall on freshly cultivated fields appears to have been the trigger for erosion leading to debris flows as runoff traversed cultivated fields then traveled to steeper slopes in adjacent canyons.

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

Comments: Only 4 slope failures observed within this landform, all related to recently cultivated (plowed and disked) fields. This landform is not generally regulated under the Forest Practices Rules.

Appendix D

Landform Hazard Rating Table: Form A-4

Major Creek/Bingin WAU

LANDFORMS	LANDFORM 1 Inner Gorge	LANDFORM 8 Toes Deep-Seated Landslides	LANDFORM 12 Steep Bedrock Draped with Thin Soils	LANDFORM 12A Steep Bedrock Draped with Thin Soils –minus cattle trail failures	LANDFORM 13 Intermediate Slopes	LANDFORM 14 Valley & Stream Bottoms (0 – 10%)	LANDFORM 15 Ridge & Hill Tops 0-10%	Landform 99 Non-Forest lands use	WAU TOTALS
Landform Area (acres)	220	129	2560	2560	17713	1358	6907	9147	40568
Number of Landslides	6	1	40	26	27	0	0	4	78
Area of "Delivering" Landslides (acres)	3.3	.8	17.2	13.7	18.1	0	0	1	169.3
Landslide Frequency Rate (Number of slides/Landform Area/Years) x 10^6	684	209	422	274	41	0	0	10.7	51.1
Landslide Area Rate for Delivery (Delivering Landslide Area/Landform Area/Years) x 10^6	376	167	182	145	28	0	0	2.7	102