LOWER WISHKAH WATERSHED

LANDSLIDE HAZARD ZONATION PROJECT

Grays Harbor County, Washington

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Forest Practices Division,
Adaptive Management Program
Priority 3
Mass Wasting Assessment
May 2009

WASHINGTON STATE DEPARTMENT OF
Natural Resources

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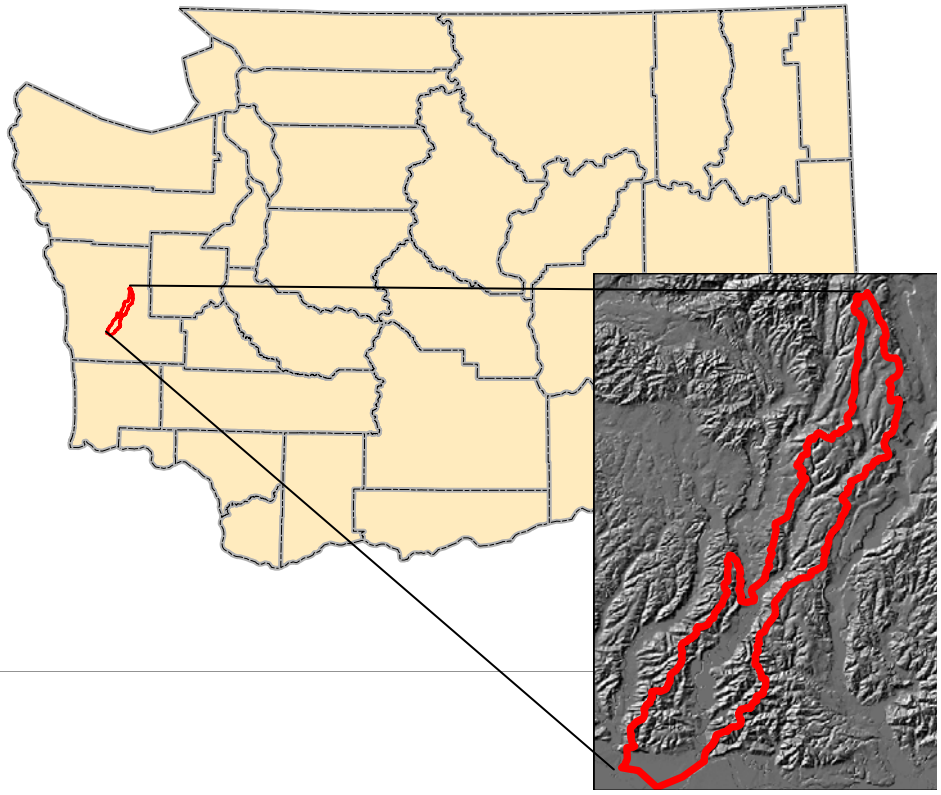

Location of Lower Wishkah WAU
in Grays Harbor County

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1.0 Project Summary

The Lower Wishkah watershed administrative unit (WAU) covers 31,103 acres located in Grays Harbor County, western Washington. The number of landslides mapped in this study amounted to 1,144 that encompassed 2,052 acres. The landslides were mapped for this study using aerial photos and limited field review. Thirteen mass wasting landforms were created and assigned slope stability hazard ratings of low and very high. Three of the landforms (Flats, Ridge Tops and Noses, and Low Gradient Hills) have a low hazard rating; ten landforms (Inner Gorges, Bedrock Hollows, Rule-Identified Deep-Seated Landslide Toes, Outer Edge of Meander Bends, Active Scarps of Deep-seated Landslides (DSLS), Non-Rule Identified Inner Gorges Steep Gradient Hillslopes, Moderate Gradient Hillslopes, Dormant Distinct Low Gradient Earthflows, and Active Deep-Seated Landslides) are identified as very high hazard. Hazard ratings are based on landslide history as delineated in the Washington State Landslide Hazard Zonation Project Protocol 2006 version 2.1 (Table 1, 2006). The lack of moderate and high hazard ratings is simply due to the substantial amount of landslides mapped during the progress of this report.

Land-form number	Name of landform	Landform slope stability hazard rating	Slope of land-form	Total area of landform in acres	No. of delivering landslides in landform	Comment
#1	Inner Gorges	Very High	>70%	116	34	Rule identified feature
#2	Bedrock Hollows	Very High	>70%	153	35	Rule identified feature
#7	Active Scarps of Deep-Seated Landslides	Very High	>20%	357	40	Unique feature
#8	Rule Identified Deep-Seated Landslide Toes	Very High	>25%	11	4	Rule identified feature
#9	Outside Edges of Meander Bends	Very High	>11%	119	74	Rule identified feature
#10	Non-Rule Identified Inner Gorges	Very High	40-70%	293	84	Unique feature
#11	Steep Gradient Hillslopes	Very High	>60%	223	29	Unique feature
#12	Moderate Gradient Hillslopes	Very High	41-60%	2,542	177	Unique feature
#14	Flats	Low	<10%	12,529	16	Protocol
#15	Ridge Tops and Noses	Low	<10%	375	0	Protocol
#16	Low Gradient Hillslopes	Low	11-40%	13,804	80	Protocol
#17	Dormant Distinct Earthflow	Very High	11-70%	497	20	Unique feature
#18	Active Landslides	Very High	20-85%	85	5	Unique feature
	Totals	High		31,103	598	

Table 1. Summary of the thirteen landforms mapped in the Lower Wishkah watershed.

2.0 Introduction

The Lower Wishkah WAU is located in central western Washington and covers 31,103 acres in the central portion of Grays Harbor County. The WAU extends from Aberdeen in the south to approximately 20 miles north and includes the town of Aberdeen Gardens (Figure 1).

The area which is now Aberdeen first was settled in 1850's because of its heavily wooded forests and abundant fisheries. The town was not established until 1873 when a cannery was built (Alley, 2007). Finally, in 1884 the town was platted and named Aberdeen (Alley, 2007). Past harvest patterns were driven by topography, with lower elevations and those areas closest to the City of Aberdeen being harvested first. The Classification of Lands Map of Washington (1902) has the WAU mapped as almost entirely forested with the exception of those areas closest to the main stem of the river (Plummer, 1902). The eastern fork of the Wishkah had not yet been harvested and a piece was classified as a burn area in northern-most portion of the WAU (Plummer, 1902).

Once the town was established, a sawmill was constructed. During this time, logging began within the Lower Wishkah WAU but operations mainly occurred along the mouth of the river

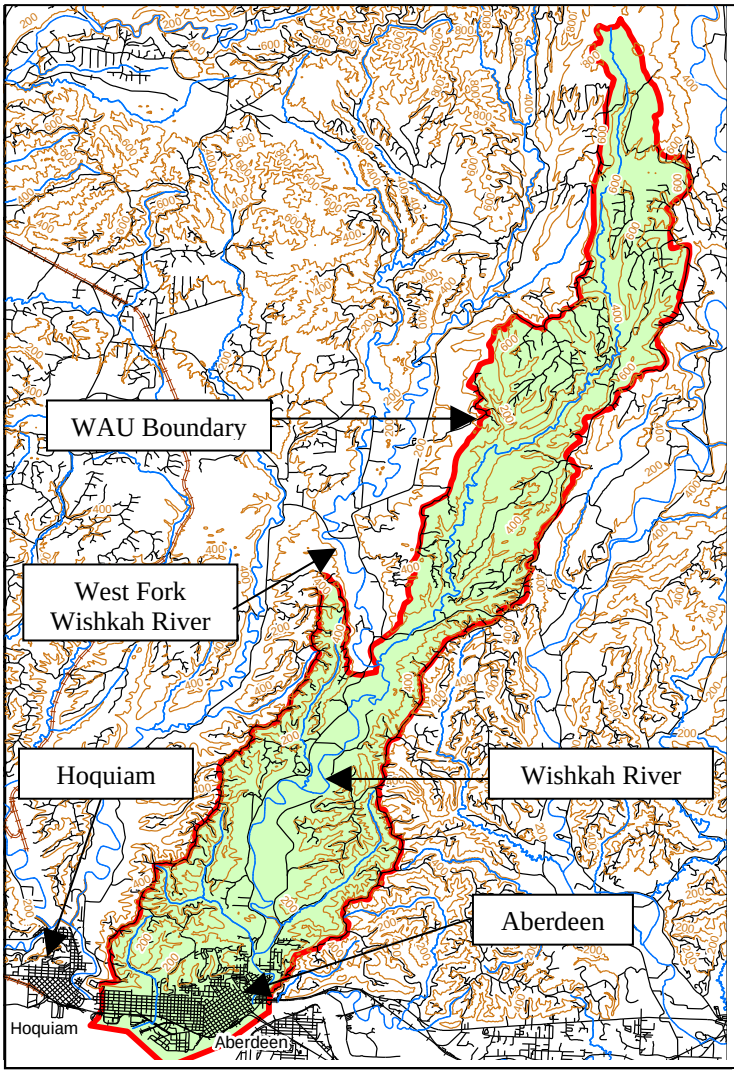

Figure 1. Lower Wishkah WAU, includes the majority of the City of Aberdeen and the southwestern portion is located directly east of the City of Hoquiam.

near its confluence with the Chehalis River. As a result of the burgeoning timber industry, harvest of the WAU migrated upstream but was relegated to the wetter seasons. Increased precipitation allowed for the logs placed in the river to be washed downstream by flows referred to as freshets. Because of the seasonal nature of freshets a number of splash dams were created to transport timber downstream to Aberdeen year round (Alley, 2007). Logs sent down the Wishkah River in the late 1800's eventually made their way to the river's confluence with the Chehalis River. The Chehalis River served as a transportation route connecting Aberdeen to cities farther east, such as Montesano.

Logging railroads were used to transport logs as well. The Lake Aberdeen B-line to the east and the Melbourne (Weyerhaeuser A-line) to the west were primary rail lines. Most lines have been abandoned and, in some places, all that remains of the lines are the pilings of the former tracks. In the past, it was common practice to use former railroad grades as road locations (Serdar, 2008). In the past, it was common practice to use former railroad grades as road locations. In the Lower Wishkah WAU, this practice can be seen on the ridges bounding the watershed to the east and the west in relation to the A- and B-line, respectively. The creation of some roads was done without first removing all of the wood debris (e.g., railroad ties). This practice typically increases the likelihood of slope failures because of the decomposition process, which leaves void spaces in road fills.

The majority of the Lower Wishkah watershed is currently privately owned and managed as forest land by the following commercial private timber owners: Weyerhaeuser Company, Rayonier Timber Company, Sierra Pacific Industries, City of Aberdeen, and numerous small forest landowners. The Washington Department of Natural Resources (WDNR) manages lands in the central and northern portions of the watershed. All areas in the watershed were included in this study regardless of ownership.

3.0 Topography and Climate

Elevations in the Lower Wishkah WAU range from sea level along the southern edge where the Wishkah River drains into the Chehalis River to 803 ft above sea level along the northern boundary of the WAU.

The Lower Wishkah WAU lies north of Aberdeen. There are two forks of the Wishkah River, the East Fork and the West Fork, though this study focuses solely on the East Fork. The WAU also includes several tributary streams, including Fry, Wilson, Stewart, Berry, Bear, and Wyman creeks. The southern part of the WAU is the steepest and the gradient becomes progressively more gentle in a northeastern direction. This transition is located approximately 2 miles northeast of the fork in the Wishkah River.

The climate of the Lower Wishkah WAU is temperate and wet. Average annual precipitation at the Aberdeen gauging station #45008 is approximately 83 inches and temperature data has a 58ºF average maximum and a 43ºF average minimum (Western Regional Climate Center). The WAU occasionally experiences snow, such as in December and January 2009. No surface water gauging stations are located on the Wishkah River or near the river itself, but precipitation data from the Aberdeen gauging station #45008 indicates that stream flow peaks usually occur in late winter to early spring. Because annual precipitation has exceeded the average for 24 of the 48 years documented on the graph, 100 inches of precipitation was used to show years with

markedly high precipitation; in other words, years where annual precipitation was approximately 20 inches above the annual average. Total precipitation for the calendar year has exceeded 100 inches five times since 1960 (1983,1990, 1997, 1999, and 2006) (Figure 2). Figure 2 shows that the late 1995 to 1999 had the heaviest precipitation for when compared to the period of record.

It is well established that rates of slope failure tend to be high during and after prolonged periods of above average precipitation (Gerstel et al., 1997; Badger, 1997; Shipman, 2001). Annual precipitation records, shown in Figure 2, provide limited insight into the role of precipitation in slope failure because these records do not convey how rainfall is distributed over the year. An analysis of rainfall intensity is provided by looking at three-month rainfall totals, in inches (Figure 3). Figure 3 shows that precipitation is heaviest in late fall and through winter, and also correlates with Figure 2 and the heaviest precipitation in the late 1990s.

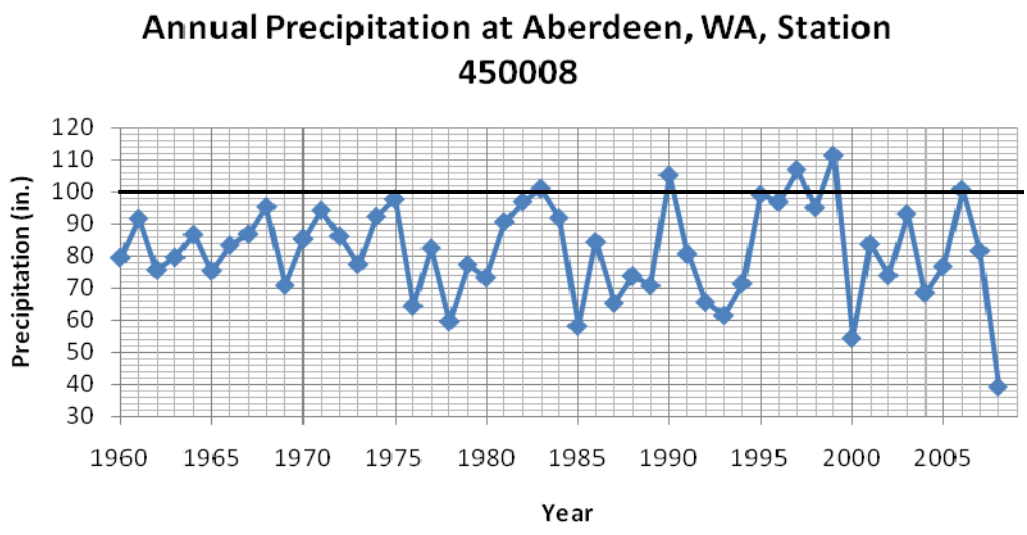

Figure 2. Annual precipitation data ranging from 1960 to 2008 from the Aberdeen gauging station (45008) recorded by the Western Regional Climate Center shows annual precipitation highs in the years 1990, 1997, and 1999.

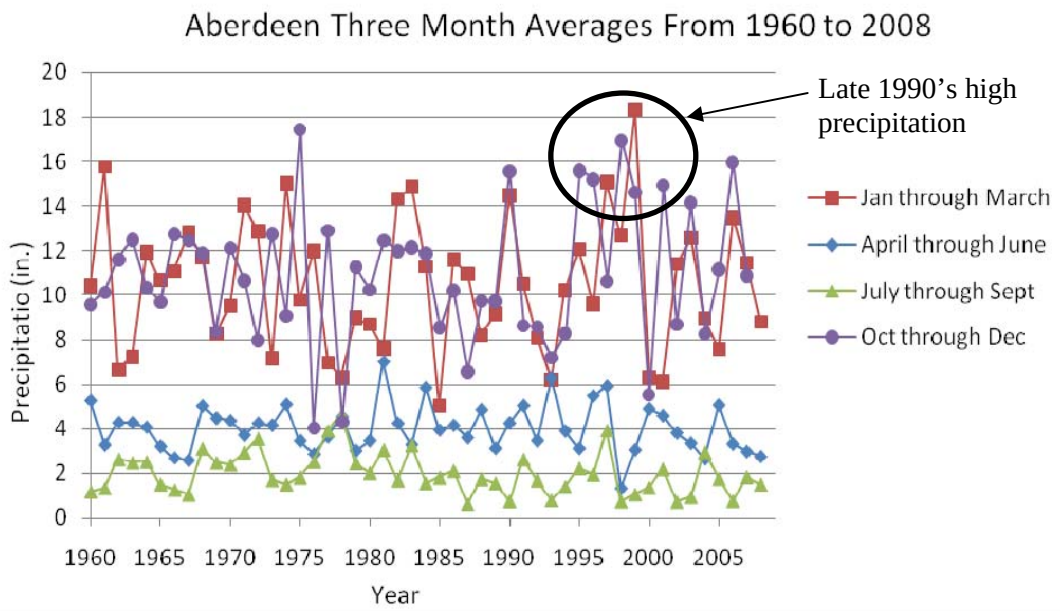

Figure 3. Three-month averages of precipitation recorded from 1960 to 2008. Three month averages are shown to better demonstrate seasonal precipitation variances and specifically shows high winter precipitation events.

4.0 Geology

The southern portion of the Lower Wishkah WAU is composed mainly of Tertiary marine sediments and near shore sedimentary rocks of the Lincoln Creek, Astoria, and Montesano Formations, which include sandstones, shales, and conglomerates (Schuster, 2005). Unconformities are found between each of these formations as well as folding and faulting (Rau, 1966; Bigelow, 1987; Logan, 1987, 2003; Schuster, 2005). In the Lower Wishkah WAU, specifically where formations are folded, the Montesano and Astoria formations are found at lower elevations beneath the Lincoln Creek Formation, which is a reversal of the time sequence in which the formations were deposited (Bigelow, 1987; Logan, 1987; Walsh et al., 1987). These formations are mainly found in the southern portions of the WAU, although some outcrops exist in the northern portion. Based on the composition of the Lincoln Creek and Astoria Formations, both are prone to rapid weathering and increased erosion (Gerstel and Badger, 2002; 2003; Schuster, 2005). Weathering and erosion are intensified by high annual precipitation and increased infiltration of rainfall into the subsurface.

The most prevalent lithologic exposure is the Pleistocene alpine glacial outwash. This formation overlies the marine sediments and is found mainly in the northern portion of the WAU and along the eastern and western boundaries (Logan, 1987; 2003). The portions of the WAU that express glacial outwash at the surface contain fewer deep-seated landslides in comparison to areas of exposed marine sediments. This spatial distribution of deep-seated landslides does not suggest, however, that areas overlain by outwash are not susceptible to large, deep-seated landslides.

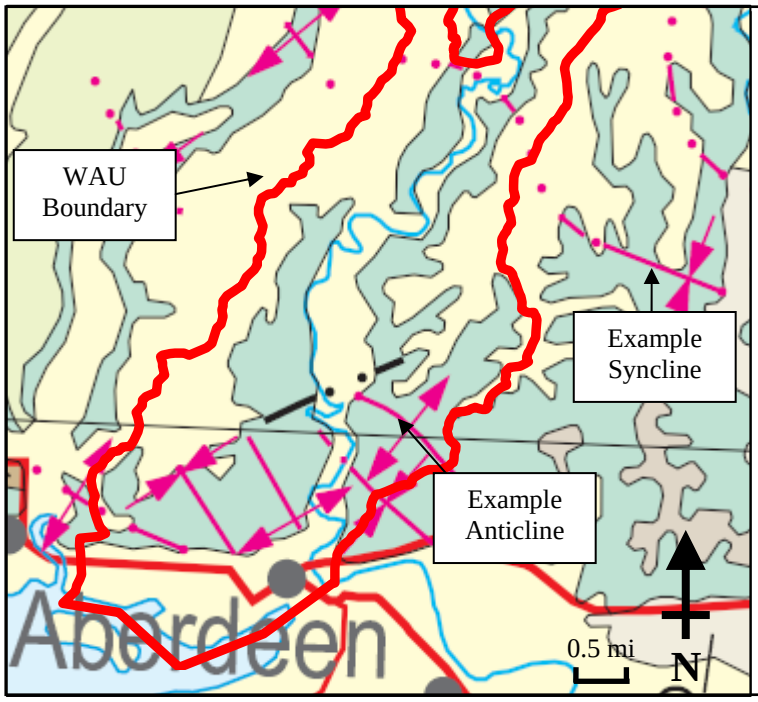

Figure 4. The Lower Wishkah WAU has experienced tectonic folding of the area's marine sediments resulting in several anticlines and synclines. The presence of these geologic structures has allowed for the exposure of soft sediments that are easily eroded and prone to large mass wasting events. Synclines are identified by symbols showing two arrows pointing towards one another and anticlines are identified by symbols showing two arrows pointing away from one another (after Schuster, 2005).

Folding and faulting of rock units within the WAU is a result of plate convergence and subduction along the continental margin. Among the more prominent folds are double syncline-anticlines pairs located in the southern portion of the WAU, near Aberdeen (Figure 4, Logan, 1987, 2003; Walsh et al., 1987; Snavely and Wells, 1991; Schuster, 2005). There are also a few other folds found in the WAU when traveling northward along Wishkah Road. The folding in the southern half of the WAU, combined with the presence of easily weathered bedrock units, results in a greater possibility of slope failure in the form of large, deep-seated landslides (Figure 4 and Map A1). Finally, there is a complicated package of faults found in the very northern portion of the WAU; however, these faults seem to have little control on the presence of deep-seated and smaller, shallow landslides.

5.0 Previous Investigations

No comprehensive landslide studies have been conducted within the Lower Wishkah WAU prior to LHZ analysis. Furthermore, no deep-seated landslides have been mapped in the WAU prior to this investigation unlike several WAUs in the vicinity, such as the Chehalis Sloughs.

6.0 Summary of Landslide Inventory

The Lower Wishkah WAU evaluation consists of a representative sample of 1,175 mass-wasting features inventoried from aerial photography from 1962, 1981, and 1997 as well as limited field investigations (Landslide Inventory, Form A-1). Landslides identified during this mass wasting assessment include 75% mapped as shallow undifferentiated failures, 6% as debris flows, 7% as debris slides/avalanches and topples, 11% as deep-seated landslides and 1% as large earthflows (Table 2). The resulting mass wasting coverage is displayed as Map A-1. Pertinent attributes of

Mass Wasting Type	Number of Mass Wasting Features Mapped	Area (acres) of Mass Wasting Features	Percentage of Total Landslides
Shallow undifferentiated landslides	896	146	75%
Debris flows	60	35	6%
Debris slide/avalanche	55	44	7%
Deep-seated landslides	124	1,670	11%
Earthflows	9	159	1%
Total	1,175	2,054	100%

Table 2. Summary of the type and number of LHZ Protocol-specified mass-wasting features mapped in the Lower Wishkah WAU.

the individual features were recorded on data sheets and have been included in this report as the Landslide Inventory Appendix A, Form A-1. Mapped landslides with probable certainty on the earliest set of aerial photographs (1962) and all questionable certainty landslides were excluded from hazard calculations or hazard ratings. This conservative strategy is based on LHZ protocol and allows a greater degree of confidence in the final product. Also, no deep-seated landslides were included in hazard calculations, but their statistics, including certainty of feature and activity level, and location have been provided in this report in Appendix A, Form A-1 and Appendix B, Form A-3, Mass Wasting Summary Table.

Land use was recorded for each landslide feature based on air photos and field observations (Appendix B, Form A-3). Based on landslide mapping and land use associated with the mapped landslides, it was found that approximately 54% of the inventoried mass wasting features were located in sub-mature timber (15-50 years old), 22% of landslides were mapped in young stands (5-15 years old), 9% of landslides were mapped in mature timber (>50 years old) and 10% in clearcut timber (0-5 years old), 3% of landslides were road-related failures, and 3% of landslides were initiated from an “other” category, which includes streams, housing and agriculture.

7.0 Landforms

Distribution of the thirteen landform units identified in the Lower Wishkah WAU study area are presented in Map A-2 and described in Appendix C, Form A-2. These units represent areas having similar mass wasting potential and/or process, potential for delivery to public resources, and/or potential to impact public safety. Mass wasting potential is based primarily on landslide process, density, lithology, geomorphology, hydrogeology, and topography. The following subsections briefly describe the characteristics of each landform with additional information provided in Appendix C. Also provided are the percentages of the most common types of mass wasting for each landform based on the complete number of landslides counted in the landform and reported in Form A3, the Mass Wasting Summery table. Landform numbers here match those listed in the Landslide Inventory, Appendix A, Form A-1. Not all rule-identified landforms occur in a given watershed and therefore the identifying numbers of landforms in any given watershed may not be listed consecutively. Landslide hazard ratings have been summarized on the Landform Hazard Rating Table, Form A-4, Appendix D.

LANDFORM #1: Inner Gorges (>70%)– Rule-identified features 70% or greater, with very high mass wasting and delivery potential and a very high hazard rating. Inner gorges are present as both asymmetrical and symmetrical forms and may be intermittent in lateral extent. Failing gorge walls have been observed on slopes of 65%. Shallow and deep-seated landslides as well as debris flows are commonly located along the gorge walls. Debris-filled channel bottoms yield useful evidence for frequency and approximate age determination. For instance, alder trees can be cut or bored to determine minimum age of mass wasting activity. Buried wood in stream channels is also evidence of past movement. Landslides occurring in inner gorges are sensitive to both road construction and timber harvest. Shallow undifferentiated landslides account for 72% of the mass wasting activity in this landform and debris flows and deep-seated landslides account for 13% of activity.

LANDFORM #2: Bedrock Hollows (>70%)– Rule-identified features with slopes 70% or greater with very high mass wasting and delivery potential and a very high hazard rating. Hollows can be round, elliptical, spoon-shaped, or irregular-shaped features. These features occur primarily on convergent slopes but can also be found on planar slopes. They are often found upslope from inner gorges, non-rule identified inner gorges, and along steep gradient hillslopes. Many of these landforms were mapped using Digital Elevation Models (DEM) and SLPSTAB, a GIS layer that identifies convergence and steepness. Due to the inaccuracy of the DEM-derived slope percent layer used in this mapping project, many of the bedrock hollows mapped in the southern portion of the Lower Wishkah WAU were field identified or verified. Shallow undifferentiated landslides account for 61% of the mass wasting activity of the bedrock hollow landform. Hollows were also found to be present within 24 deep-seated landslides and large earthflows.

LANDFORM #7: Active Scarps of Deep-Seated Landslide Scarps (>20%)– This feature has very high mass wasting potential, high delivery potential, and a very high hazard rating. The landform is composed of previously failed deep-seated landslide headscarps in which slopes are slightly steepened (>40%), but slopes can be as gentle as 11% (DEM derived, and underestimated). Secondary mass wasting on the scarps of older deep-seated landslides occurs due to over steepening of the deep-seated landslide scarp and exposure of bedrock after the initial movement of the landslide mass. When comparing the unique landform's area to number of smaller, shallow landslides, it can be noted that mass wasting on scarps of deep-seated landslides has the largest mass wasting frequency to landform area ratio. Lastly, shallow undifferentiated secondary landslides on deep-seated landslide scarps account for 91% of the mass wasting activity related to this landform.

LANDFORM #8: Rule-Identified Deep-Seated Landslide Toes (>65%) – Rule-identified feature with a very high mass wasting and delivery potential and a very high hazard rating. This landform is usually stream adjacent with a high potential for delivery. Deep-seated landslide toes are especially prone to reactivation of movement and/or are affected by smaller, shallower mass wasting where they are adjacent to streams and roads.

LANDFORM #9: Outside Edges of Meander Bends – Rule-identified features with very high mass wasting and delivery potential and a very high hazard rating. In the northern half of the Lower Wishkah WAU, the narrowing of the river valley causes outer edges of meander bends to have increasingly direct effect on valley walls leading to undercutting of slopes and the initiation of shallow undifferentiated landslides, debris slides, and, in many cases, deep-seated landslides. Shallow landslides account for 59% of the mass wasting activity within this feature and debris slides account for another 28%.

LANDFORM #10: Non-Rule Identified Inner Gorges (35-65%) – Features have very high mass wasting and delivery potential and a very high hazard rating. These features contain DEM-derived slopes between 35% and 65% with convergent asymmetrical and symmetrical inner gorge characteristics and are often intermittent in lateral extent. Computer-generated DEM slopes (35-65%) used to map this feature are typically underrepresented. Many of these features were field-verified due to the presence of landslides mapped within the feature. The field-verified features generally had steeper slopes than identified by the DEM-derived slopes, but still had slope gradients between 35-65%. The remaining features of landform #10 that were not identified or verified in the field could be rule-identified and should be field reviewed. Shallow landslides account for 73% of the landslides associated with this landform.

LANDFORM #11: Steep Gradient Hillslopes (>65%) – Features have very high mass wasting potential, high delivery potential, and a very high hazard rating. These features are mainly found in the southern half of the Lower Wishkah WAU. However, some can be found in the northwestern portion of the WAU. This landform is associated with convergent to planar-divergent slopes. Several deep-seated landslides are also present on steep gradient hillslopes associated with the landslide's scarp. Steep gradient hillslopes were also commonly seen located between bedrock hollows and inner gorges. Shallow landslides account for 66% of the mass wasting activity within in this landform.

LANDFORM #12: Moderate Gradient Hillslopes (41-64%) – Features have very high mass wasting potential, high delivery potential, and a very high hazard rating. Computer-generated DEM slopes were used to draw this landform and slope gradient was typically underrepresented. The weak nature of the marine sedimentary bedrock, folding and faulting within the WAU, and high precipitation have resulted in landslides occurring on the gentler slopes of this landform. Shallow undifferentiated landslides account for 80% of the mass wasting activity in this landform and 51% of all mass wasting activity associated with this landform occurred within submature timber (15-50 years old). Also, 41 deep-seated landslides were mapped in this unit suggesting that a steep gradient hillslope (>70%) is unnecessary for the propagation of deep-seated landslide movement and, perhaps, structural geology, lithology characteristics, and climate exert greater control on deep-seated mass wasting processes.

LANDFORM #14: Floodplain and Flats (0-10%)– Features have low mass wasting and delivery potential and a low hazard rating. Low gradient (0-10%) valley and stream bottoms are generally composed of alluvium, colluvium, soil, glacial, and landslide deposits. Wetlands have also been included in this landform. This landform contains areas in and around rivers and streams that are more likely to receive debris and alluvial deposits from mass wasting events rather than experience mass wasting processes. Mass wasting on these naturally stable slopes is unlikely but possible due to improper routing of surface waters and the unstable nature of several formations, like glacial till and the marine sediments.

LANDFORM #15: Ridge Tops and Noses (0-10%) – Features have low mass wasting and delivery potential and a low hazard rating. Low gradient (0-10%) areas along the tops of the ridges and along the noses of ridges are included. Landslides have occurred below and outside of some of these low gradient ridge tops but these failures are excluded from this landform.

LANDFORM #16: Low Gradient Hillslopes (11-40%) – Features have high mass wasting potential and low delivery potential. Due to the size of the landform, overall hazard rating is low Failures within this landform possibly occur on slopes steeper than 40% but inaccuracies in the DEM data preclude identification of steeper slopes. Shallow landslides account for 79% of mass wasting activity in this landform.

LANDFORM #17: Dormant Distinct Low Gradient Earthflows (11-85%) – Very high mass wasting potential, high delivery potential, and a very high hazard rating. The landform of dormant distinct low gradient earthflows was used in areas where large deep-seated landslides and earthflows contained one or more smaller delivering landslides, debris slides, and debris flows Figure 5 shows several large low-angle earthflows (55-65%) that were verified in the field. These earthflows possessed deranged drainages, hydrophilic plants covering the earthflow mass, and exposed bedrock in some places. Mass wasting in this landform is most likely the result of dip-slope movement of the overlying soil and disaggregated rock along an internal bedding plane. Shallow landslides accounted for 67% of the mass wasting occurring in this landform. Also, approximately 36% of secondary mass wasting occurred 0 to 15 years after harvesting activities based on air photo analysis.

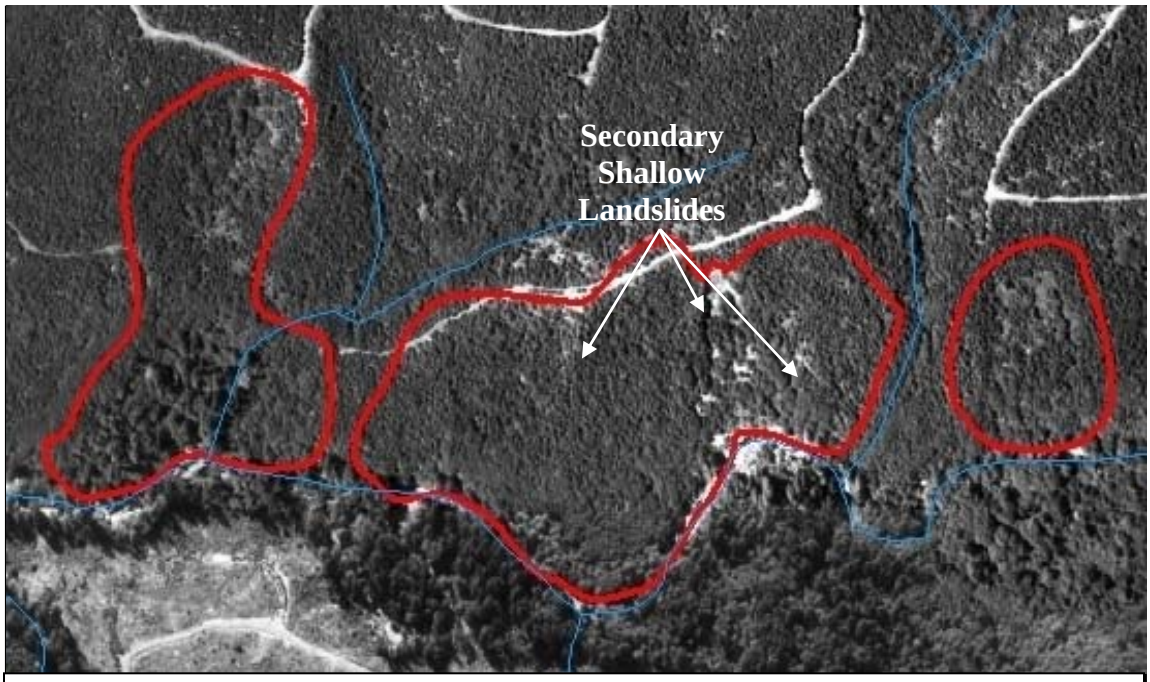

Figure 5. Several low gradient, dormant distinct earthflows are shown in this aerial photo outlined in red. These earthflows are found in the northern portion of the WAU. Slopes measured in the field for these specific earthflows showed angles of 55-65%. Secondary mass wasting can be seen within many of the features, many of which deliver to public resources. (DNR Black & White 3-foot (1-meter) Orthophotos, Years 1990 - 2000)

LANDFORM #18: Active Deep-seated Landslides (20-85%) – Features have very high mass wasting potential, high delivery potential, and a very high hazard rating. All active deep-seated landslides were field verified and are located in the southern portion of the WAU, near the city of Aberdeen. The landform consists of three deep-seated landslides and one earthflow. The three deep-seated landslides are located near Fern Hill Cemetery, in the southeastern corner of the WAU. All three deep-seated landslides have grown in size since first identification. It was also reported by workers of the cemetery that the deep-seated landslides on the northern side of the cemetery have increased in size over the past ten years (Figure 6). An active, extremely low slope gradient (>20%) earthflow was identified in the western portion of the watershed, adjacent to

Wishkah Road (Figure 7). The earthflow initiated within a clearcut harvest in 1997 and delivers to residential property. The overall landform is prone to shallow landslides with potential to deliver since the three deep-seated landslides are stream adjacent and the smaller earthflow delivers directly to residential property.

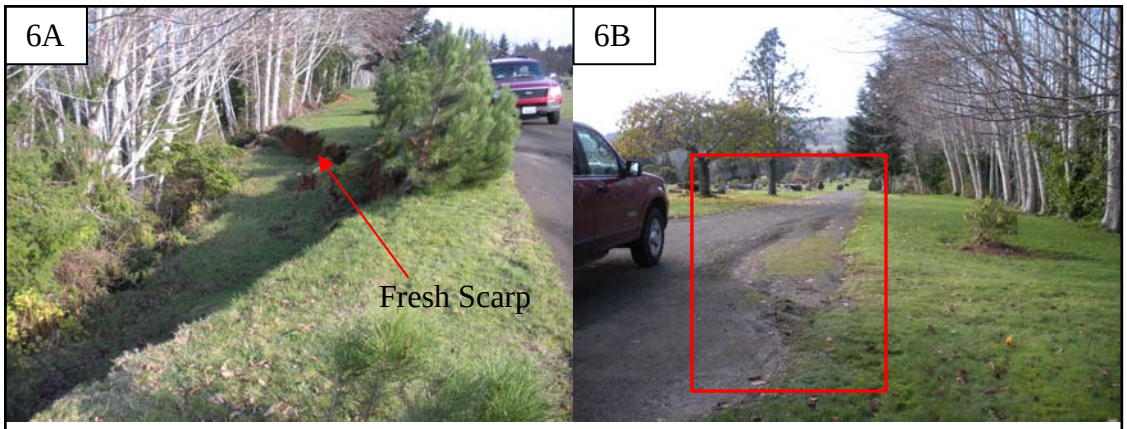

Figure 6. 6A shows the active scarp of the western landslide found on the northern side of Fern Hill Cemetery. The vehicle in the background can be used for scale. 6B shows a slight drop of the road and the beginning of tension cracks as a result of movement of the eastern active deep-seated landslide located on the northern side of Fern Hill cemetery. Both landslides were first identified in 1981 and have been reported as having continued movement for the past 10 years.

Figure7. 7A shows the toe of the earthflow, portions of which have been removed by backhoe to the side of the house. 7B shows the upper portions of the earthflow. Note the jack-strawed alder trees and tension cracks on the bare ground.

8.0 Summary of Methods

Landslide inventory - The procedures described below follow (with minor modification) the Landslide Hazard Zonation Protocol version 2.1 dated September 2006 found at: http://www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2.1_final.pdf
Color photo copies of three sets of 1:12,000 aerial photographs from 1962, 1981, and 1997 were analyzed with a mirror stereoscope at 3 x magnifications (Table 3). Original air photos were photocopied to card stock and image quality varied from good to poor. Color ortho-photographs from 2005 were used as a layer during GIS analysis and mapping. No high elevation photos were used for this project due to incomplete flight lines.

Slope failures observed on the stereo photocopies were classified and catalogued according to the mass wasting process type. For the purposes of this analysis, slopes that failed below rooting depth are categorized as deep-seated landslides (Washington Forest Practices Board, 2004); all remaining landslides are classified as shallow. The mass wasting process types include shallow-undifferentiated landslides, debris flows, debris slides, and deep-seated landslides.

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

Following aerial photo analysis, all observed landslides were mapped directly into GIS by "heads-up" digitization of landslides into a GIS map in conjunction with the use of the following data layers: streams, roads, townships, and geology. The landslides on Map A-1 are also itemized in the Landslide Inventory Appendix A, Form A-1.

Year	Scale	Image	Flight Line Number	Reference Ownership	Comment
1962	1:12,000	Black & White	GH-62 22B-8 to 34B-33	DNR	Complete coverage
1981	1:12,000	Black & White	OL81 1-42-8 to 5-54-182	DNR	Complete coverage
1997	1:12,000	Black & White	OL-97 6-42-184 to 8-53-249	DNR	Complete coverage
2006	3 ft pixel*	Color Digital Orthophotos	OLC-QT05 150-010 to 013 160-010 to 015 170-010 to 015 180-010 to 013 190-010 to 012	DNR	Complete coverage in corporate geo-database

Table 3. Photocopies of aerial photographs used in this study.
* Source photography was flown at a scale of 1:32,000.

Typically, DEM-derived slope gradients are underestimated by at least 10% relative to field-measured gradients (Dragovich et al., 1993), and more so on smaller features that are smoothed over by the DEM's coarse resolution. Based on limited comparisons between the DEM and field measurements, gradients in the field may be steeper than the gradients reported for each landform on Landform Hazard Map A-2 and the Landform Descriptions, Form A-2. It should be emphasized that all slope gradient estimates presented in this report are likely minimum values.

Slope gradients for shallow landslides were determined by calculating the maximum 10 meter DEM-derived slope angle within each landslide initiation polygon. For deep-seated landslides, the average slope angle over the entire landslide polygon was calculated. Bilderback (2006) 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.

Landform map units – As part of an LHZ project, landforms derived from the landslide inventory and the physical attributes of the landscape where the landslides occurred are mapped and shown on Landform Hazard Map A-2. The delineations of the potentially unstable landforms are intended to help in screening potential forest practice activities within the WAU to identify those that pose hazards for mass wasting.

The aerial photograph survey was also used to determine land use and some landforms. Low hazard landforms (Flats, Ridge Tops and Noses, Prairies and Floodplains, and Low Gradient Hills) were delineated first according to the LHZ Protocol by using a slope map with standardized slope angles. Following this rule-identified landforms were delineated. The remainder of the WAU was divided into analyst-described landforms. These landforms were developed from the physical attributes of the landscape where the landslides occurred. A combination of slope gradient and elevation data, slope convergence data (derived from the DNR SLPSTAB model based on a slope morphology model (Shaw and Johnson, 1995; Shaw and Vaugeois, 1999), and geologic data (from USGS 1:100,000 geologic maps) aided in the delineation of these landforms.

9.0 Hazard Ratings

Each landform identified on Map A-2 and described in Appendix C (Landform Descriptions, Form A-2) was assigned an overall Hazard Rating based on landslide frequency rate (LFR) and a landslide area rate for delivery (LAR) (Table 4). The hazard rating (low, moderate, or high) is then assigned as called for by the LHZ Protocol [www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2.1_final.pdf]. Hazard ratings for mass-wasting landforms were determined by the following: 1) rule-identified status (WAC 222-16-050), 2) the Landslide Frequency Rating (LFR)and the Landslide area rating (LAR), 3) in rare occasions, the professional judgment of the analyst may be used in lieu of the LFR and LAR matrices, or for deep-seated landslides, or 4) an interpretation of deep-seated landslide hazard. For each landform the LFR is obtained by taking the *number* of delivering landslides, dividing by the total area of that landform, and normalizing to the period of study. The resulting values are multiplied by one million for easier interpretation. The LAR is the area of delivering landslides normalized to the period of study and the area of each landform. The resulting values are multiplied by one million for easier interpretation. Limited application suggests that LAR 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

Qualitative Ratings	Landslide Frequency Rate (LFR)	Landslide Area Rate for Delivery (LAR)
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 LFR and LAR.

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. Landform hazard ratings in the Lower Wishkah WAU are summarized in Appendix D, Form A-4 (Landform Hazard Rating Table). Deep-seated landslides are not included in the calculations for Form A-4. As of the writing of this report, the qualitative rating system above is used (Table 4). Landform hazard ratings in the Lower Wishkah WAU are summarized in Appendix D, Form A-4 (Landform Hazard Rating Table).

10.0 Confidence in Work Products

The confidence in this mass wasting assessment is moderate based on a range of photocopy quality and coverage, and field observation. This rating is based on the Landslide Hazard Zonation Project design to provide a WAU 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 will be present due to the limited field verification of individual features; particularly in heavy canopy forested areas (Brardinoni, 2003).

It is critical for the reader to understand that while these decisions may be sufficient to characterize triggering mechanisms of slope failure as functions of forest management, <u>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.</u> This is a reconnaissance study and some landslides may have been accidentally omitted and some benign features may be improperly mapped as landslides.

In addition, there are some typical sources of systematic error that reduce the confidence in the work products of this analysis:

1. **Omission**: This mass wasting assessment was primarily conducted with color copies of 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 et al., 2003).

2. **Misinterpretation:** Misinterpretation may occur when a mass-wasting feature is identified but incorrectly classified or data are transposed, and where unrecognized software/file

instability occurs. 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 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). In spite of this, confidence in work products related to classification of deep-seated landslide processes in this WAU is high-moderate due to visibility, field verification, and completeness of photo coverage.

3. **Accuracy and Precision**; 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.

4. DEM data available for a majority of this watershed was observed to be of a lower resolution and thus, lower utility. However, the author has a moderate level of confidence in the assessment based on good photo coverage, and limited field observations.

11.0 Use of Report

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 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; and
- The relative potential for mass wasting to occur among the various landform units.

The purpose of this mass wasting assessment is to identify all areas on private and state land within the Lower Wishkah 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 areas and ownerships in the watershed have been included in this study and it is therefore a comprehensive landslide assessment. All lands within the WAU have been divided into mass wasting hazard landforms. Maps of landforms are designed for use by landowners in determining the areas likely to create landslide hazard and by 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 comprehensive landslide assessment, and its relatively broad resolution must be considered when using this document and its accompanying maps. Moreover, the survey was conducted within a constrained timeline that was budgeted to produce a statewide unstable slopes screening tool as quickly as possible. Thus, the landslide inventory presented in this report (Map A1 and Form A1) is intended to be a representative but not an exhaustive assessment.

12.0 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): Carol Serdar of DNR Forest Practices for her patience and guidance. Carrie Welty, Venice Goetz, and Rich Young of DNR Forest Practices for field work and insight.

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