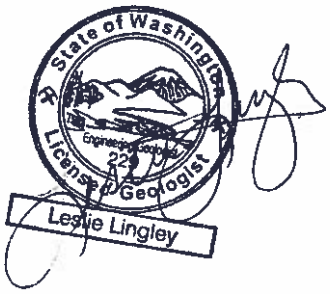
LOWER CHEHALIS - ELIZABETH CREEK WATERSHED

LANDSLIDE HAZARD ZONATION PROJECT

Grays Harbor County, Washington

By Carrie Welty
and Leslie Lingley

Forest Practices Division,
Adaptive Management Program



Priority 3
Mass Wasting Assessment
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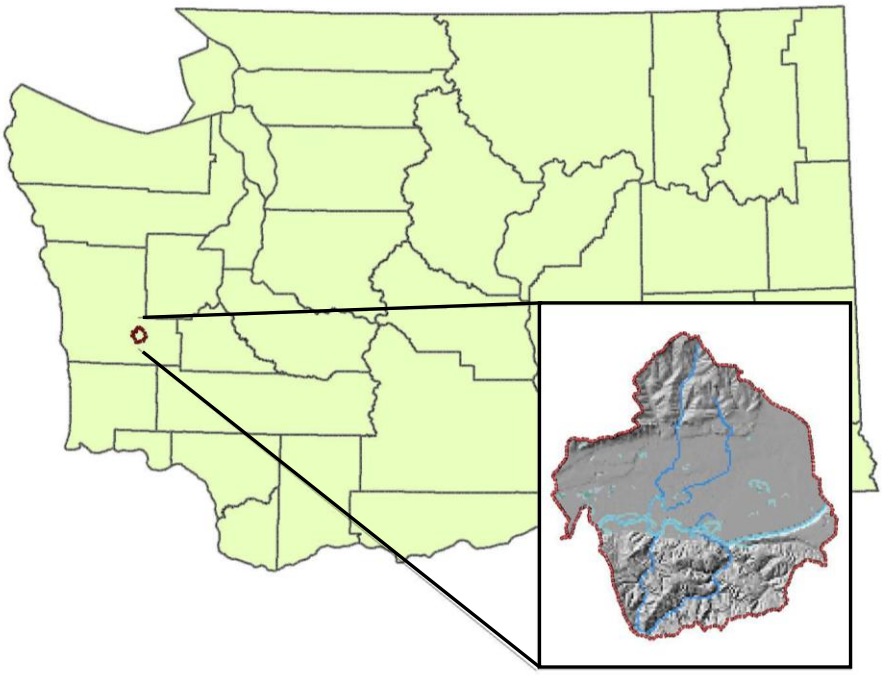

Washington State Department of Natural Resources

Forest Practices Division
PO Box 47012
Olympia, WA 98504-7012
Phone: 360-902-1400
Fax: 360-902-1785

Websites: http://www.dnr.wa.gov/forestpractices/lhzproject
http://www.dnr.wa.gov/forestpractices/adaptivemanagement

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1.0 Project Summary

The Lower Chehalis - Elizabeth Creek watershed administrative unit (WAU) covers 15,785 acres located in Grays Harbor County, western Washington. Eight hundred thirty-four landslides encompassing 521 acres were mapped for this study using aerial photos, limited field review, and some LiDAR (light detection and radar) imaging. Twelve mass wasting landforms were created and assigned slope stability hazard ratings from low to very high. Four of the landforms (Flats, Ridges and Noses, Low Gradient Hills, and Fluvial Erosion in the Chehalis River Surge Plain) were assigned a low hazard rating, and eight landforms (Inner Gorges, Bedrock Hollows, Convergent Headwalls, River Terrace Margin, Active Scarps of Deep-seated Landslides (DSLS), Non-Rule-Identified Inner Gorges, Steep Gradient Hillslopes, and Moderate Gradient Hillslopes) were calculated as having a very high hazard (Table 1). Hazard ratings are based primarily on landslide frequency and delivery rates as delineated in the Washington State Landslide Hazard Zonation Project Protocol Version 2.1.

Land-form number	Name of landform	Landform slope stability hazard rating	Slope of land-form	Total area of landform in acres	No. of delivering shallow landslides in landform	Comment
#1	Inner Gorges	Very High	>70%	477	122	Rule-identified feature
#2	Bedrock Hollows	Very High	>70%	350	165	Rule-identified feature
#4	River Terrace Margin	Very High	>25%	247	40	Forest Practice Board Manual
#5	Convergent Headwall	Very High	>70%	102	74	Rule-identified feature
#7	Active Scarps of Deep-seated Landslides	Very High	>30%	82	4	Rule-identified feature
#9	Fluvial Erosion along Channels along the Chehalis River	Low	>11%	214	54	Unique feature
#10	Non-Rule-Identified Inner Gorges	Very High	30-70%	122	53	Unique feature
#11	Steep Gradient Hillslopes	Very High	>60%	878	98	Unique feature
#12	Moderate Gradient Hillslopes	Very High	41-60%	2,028	99	Unique feature
#14	Flats	Low	<10%	7,949	0	Protocol
#15	Ridge Tops and Noses	Low	<10%	343	0	Protocol
#16	Low Gradient Hillslopes	Low	11-40%	2,994	0	Protocol
	Totals			15,785	709	

Table 1. Summary of the twelve landforms mapped in the Lower Chehalis - Elizabeth Creek WAU.

2.0 Introduction

The Lower Chehalis - Elizabeth Creek WAU is located in southwestern Washington along State Highway 12 and covers 15,785 acres. The WAU encompasses much of the town of Montesano in Grays Harbor County and extends east to the Satsop River and the town of Brady (Figure 1).

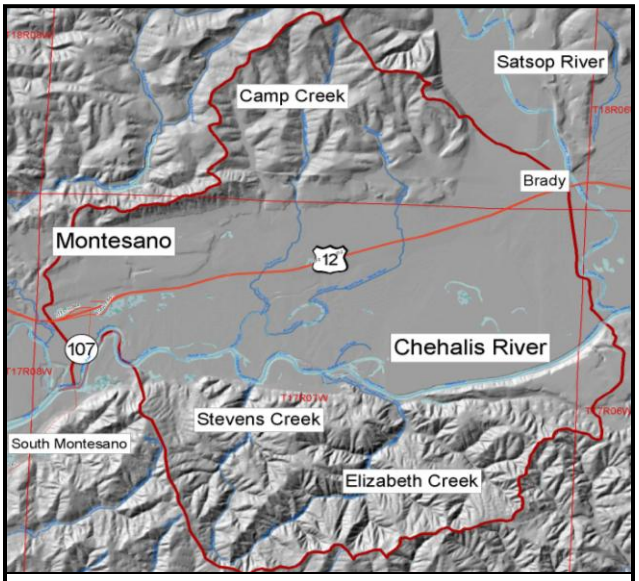

Figure 1. Lower Chehalis - Elizabeth Creek WAU and main tributaries shaded relief map.

At the confluence of the Chehalis and Wynoochee Rivers, Montesano was settled as a center for timber industry and trade in the 1850's, eventually relocating north above the floodplain. Forests within the WAU originally consisted of old growth fir, spruce, and cedar (Gannett, 1902). Past harvest patterns were driven by topography, with lower elevations harvested first. By 1889, much of the low elevation middle section of the WAU was mapped as previously cut on the Western Washington Classification of Lands Map of 1889, and "burnt areas" covered a wide section to the south of the Chehalis River along with a small patch in the northeast (Plummer, 1902). Much of the WAU contained uncut timber in the higher elevations in the north and south (Plummer, 1902). Logging railroads were constructed throughout the area to transport timber from higher elevations to rivers and streams for further transport to mills. By 1914, the Clemons Logging Railroad and a county road ran along part of the southwest boundary of the WAU (Chehalis County Engineer, 1914). Hauling timber by logging trucks became standard practice in the following decades, often placing roads over existing railroad tracks, a practice which increases the likelihood of road-related slope failures as railroad construction wood incorporated in sidecast and subsequently decomposed. The establishment of Clemons Tree Farm, the first tree farm in the WAU and the region, brought the practice of regular planting of trees for later harvest. The implementation of forest practice rules during the later part of the century aimed to reduce mass wasting as a result of harvest and road building activities.

The majority of the WAU is owned by commercial private timber companies: Weyerhaeuser Company, Green Diamond Resource Company, and Rayonier Timber Company. The remaining parcels are owned primarily by the City of Montesano, several small forest landowners, Cascade Natural Gas Corporation (pipeline), and privately owned residential housing and farmland. The Washington State Department of Fish and Wildlife owns and manages a few small parcels at and near the Chehalis River. For the LHZ project, the WAU was mapped in its entirety regardless of ownership.

3.0 Topography and Climate

The Lower Chehalis - Elizabeth Creek WAU is drained by the Chehalis River, which flows westward through the center of the WAU and eventually drains into Grays Harbor. The WAU consists of several sub-basins: the north-flowing Elizabeth and Stevens Creeks, the south-flowing Camp Creek, with Smith Canal and Metcalf and Moon Sloughs in the floodplain. The south-flowing Satsop River lies outside eastern boundary of the WAU, except for a few meander bends which cross into the WAU, and merges with the Chehalis River at the eastern edge of the WAU.

Elevations in the Lower Chehalis Elizabeth Creek WAU range from sea level at the lowest point of the Chehalis River floodplain to a maximum of 850 feet mean sea level (MSL) at the northern and southernmost ridges of the WAU. The WAU can be divided into three distinct physiographic sections (Figure 1):

- The center part of the WAU has flat and low gradient topography resulting from glacial meltwater during the last glacial maximum and the modern meandering river system.
- The southern part of the WAU contains primarily steep, rugged slopes with some gentler gradient areas.
- The northern part is overall low and moderate gradient hillslopes with a few steep planar slopes.

The marine influenced climate of southwest Washington generates wet temperate conditions in the WAU. Average annual precipitation at the nearby Elma gauging station # 452531 is approximately 67 inches and temperature data are as follows: 62ºF average maximum and 41ºF average minimum (Western Regional Climate Center). The WAU occasionally experiences snow, but rain-on-snow events are unlikely to occur. Historical data from surface water gauging stations on the lower Chehalis River does not pre-date 2002, but historical precipitation data since 1940 at the Elma gauging station indicate that stream flow peaks usually occur in late fall to late winter. Total precipitation for the calendar year (Figure 2) has not exceeded 100 inches since record keeping began in 1940 (data available through August 2007), but has exceeded 80 inches 7 times (1959, 1968, 1990, 1996, 1997, 1999,and 2006..

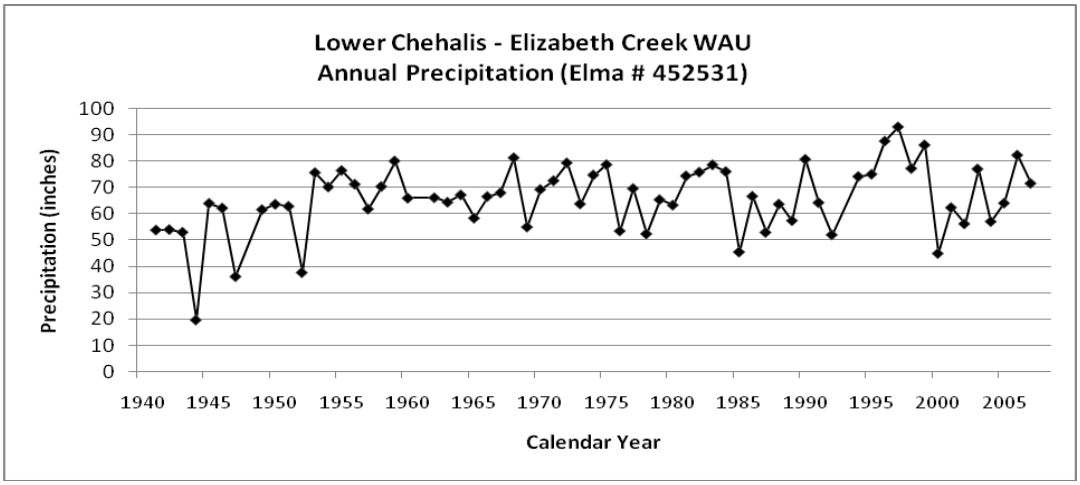

Figure 2. Annual precipitation data 1940-2008 (based on calendar year January to December) at the Elma gauging station (Western Regional Climate Center) presents an average annual precipitation of 68 inches. No data points are plotted for months in which there are more than 26 days of missing data.

It is well established that rates of slope failure tend to be higher during and after prolonged periods of above average precipitation (Gerstel and others, 1997; Badger, 1997; Shipman, 2001). Annual precipitation records (Figure 2) provide limited insight into the role of precipitation in slope failure as they do not convey how rainfall was distributed over the year. A more meaningful analysis of rainfall intensity is provided by looking at monthly rainfall totals, expressed in inches above the monthly average. To aid in recognition of exceptionally large precipitation events and/or time intervals when there were multiple consecutive months with above average precipitation, the data are presented in three month running averages (Figure 3). Examination of Figure 3 shows the late 1990's had several years with annual precipitation totals well above the annual average. The highest peak shown is February 1999, recorded at 19.51inches, with January 1999 and March 1999 also showing exceptional above average precipitation. Highest peaks in descending order: February 1999, January 1999, January 2007, March 1999, December 1975, and May 1997.

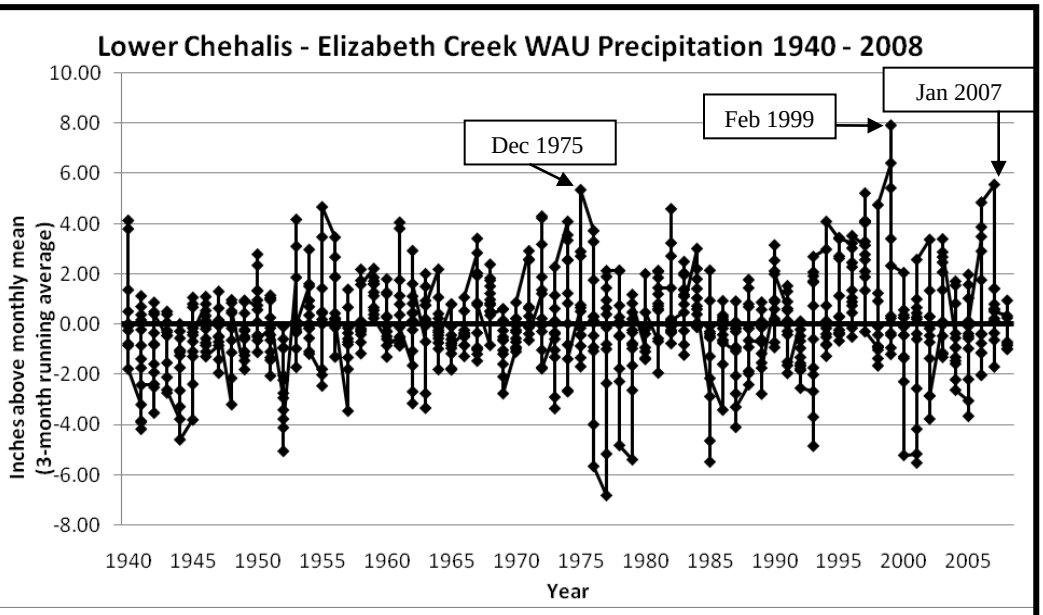

Figure 3. Three month running average of precipitation recorded above the monthly mean from the Elma gauging station from 1940 to 2008.

The region periodically experiences hurricane-force winds such as the Columbus Day Storm of October 1962 and the December 2007 storm. These storms caused significant damage by creating huge areas of blown down timber. Although this basin did not experience the intensity of the of December 2007 winds that destroyed timber in nearby WAU's, there were isolated pockets of conifer and hardwood blowdown. Mapping by Washington State Department of Natural Resources Forest Health Program (2008) identified 3 pockets of the WAU totaling 88 acres in size within which a significant amount of trees were lost per stand. The 2008 survey following recent storms shows that some blowdown of conifers and hardwoods occurred in the northern part of the WAU, including: one 50 acre pocket and another 12 acre pocket of 1-25% blowdown, and 26 acres of 26-50% blowdown.

4.0 Geology

The majority of the Lower Chehalis - Elizabeth Creek WAU is underlain by Tertiary marine sediments (Figure 4). The sedimentary rocks are sandstone and siltstone of the Montesano and Astoria Formations (represented as Tm in Figure 4a), found primarily at intermediate to high elevations in the northern and southern parts of the WAU, respectively. The Montesano Formation lies unconformably above the Astoria Formation (Rau, 1966; Bigelow, 1987; Logan, 1987, 2003). Folding and faulting of rock units caused by plate convergence along the continental margin formed broad synclines and anticlines within the WAU (Figure 4a) (Walsh, 1987; Walsh and others, 1987; Snavely and Wells, 1991; Schuster, 2005). This folding, combined with the presence of the easily weathered bedrock units (Astoria and Montesano Formations) on dip slopes result in a greater possibility of slope failure. Both formations are prone to rapid weathering, a situation that is exacerbated by the high annual precipitation (Gerstel and Badger, 2002; 2003).

Although the WAU remained largely unglaciated during the last Ice Age, there are several units of glacial deposits within the WAU at low to intermediate elevations above the Chehalis River floodplain. There is a small unit of Quaternary alpine glacial outwash (Wedekind Formation) exposed north of Montesano and several larger units of continental glacial drift exposed in sections to the north and south of the floodplain (partially represented, Qgd in Figure 4a). A large (~2500 acre) section of younger continental glacial outwash (Vashon Stade Formation) is exposed north of the floodplain (Logan, 1987; 2003). Quaternary alluvium is found in the lowest elevations in the WAU, covering the Chehalis River floodplain (represented as Qa in Figure 4a).

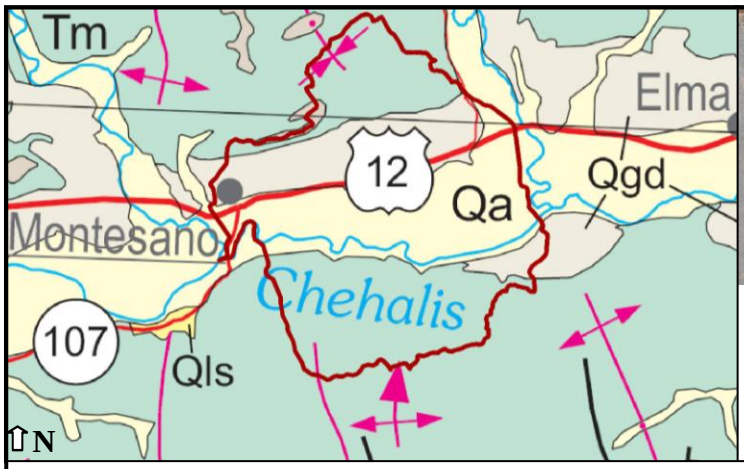

Figure 4b (above). Blue-gray sandstones and clay-shales in the Astoria Formation are soft and cause landslides when exposed on steep slopes (Etherington, 1930).

Figure 4a (above left). Geologic Map of the Lower Chehalis - Elizabeth Creek WAU. The area has experienced tectonic activity that resulted in extensive folding of marine sedimentary and underlying volcanic rocks (Schuster, 2005). WAU boundary shown as a red line, black lines represent faults, pink lines with inward pointing arrows are synclines (folded rock units with the apex pointing down) and with outward pointing arrows are anticlines (fold apex pointing up).
Geologic Formations: Qgd-Pleistocene continental glacial drift, Qls-Quaternary mass wasting deposits, and Qa-Quaternary alluvium.

5.0 Previous Investigations

No historical landslide activity in the WAU has been identified as having the potential to directly and critically affect major roadways or public resources (Kliem and others, 2005), likely explaining why no comprehensive landslide studies had been conducted within the Lower Chehalis - Elizabeth Creek WAU prior to this LHZ analysis.

6.0 Summary of Landslide Inventory

The Lower Chehalis - Elizabeth Creek WAU assessment consists of a representative sample of 834 mass wasting features inventoried from aerial photography, minimal coverage of LiDAR imagery, and limited field investigations (Appendix A - Landslide Inventory - Form A-1). Mapped landslides with probable certainty on the earliest set of aerial photographs (1962) and with questionable certainty from all aerial photographs were not used in hazard calculations or hazard ratings. This conservative strategy is based on LHZ protocol and allows for a greater degree of confidence in the final product.

Landslide types identified during this mass wasting assessment include 92% mapped as shallow undifferentiated failures, 3% debris flows, 1% debris slides/avalanches and topples, 3% deep-seated landslides, and 1% earthflows (Table 2). Of the 771 shallow undifferentiated landslides, 54 (7%) were mapped in the floodplain in areas characterized as fluvial erosion locations or parts of channel migration zone erosional surfaces. The resulting mass wasting coverage is displayed as Landslide Inventory - Map A-1. Pertinent landslide attributes of individual features were recorded on data sheets and are included in this report as Appendix A, Form A-1.

Landuse was determined for each type of landslide (Appendix B – Mass Wasting Summary Tables - Form A-3). Approximately 30% of the inventoried mass wasting features was related to roads, 20% in submature timber (15-50 yrs old), 18% in clearcut areas, 15% in young stands of timber (5-15 yrs old), 11% in mature timber (greater than 50 years old), and the remaining 6% was associated with non-forestry related landuse, including agriculture and housing.

Mass Wasting Type	Number of Mass Wasting Features Mapped	Area (acres) of Mass Wasting Features	Percentage of Total Landslides
Shallow undifferentiated landslides	771	120	92%
Debris flows	28	18	3%
Debris slides/avalanches	8	5	1%
Deep-seated landslides	22	211	3%
Earthflows	5	168	1%
Total	834	521	100%

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

7.0 Landforms

The distribution of twelve landforms identified in the Lower Chehalis - Elizabeth Creek WAU is shown on Map A-2 – Landform Hazard Map and described in Appendix C – Landform Descriptions - Form A-2. These landforms represent areas having similar mass wasting potential, potential to deliver to public resources, and/or potential to impact public safety. Mass wasting potential is based primarily on landslide process, failure density, lithology, geomorphology, hydrogeology, and topography. The following narratives briefly describe the characteristics of each landform with additional information provided in Appendix C. Landform numbers here match those listed in the Appendix A - Landslide Inventory - Form A-1 under the column heading of WAU LSI Landform. 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 in Appendix D – Landform Hazard Rating Table – Form A-4.

LANDFORM #1: Inner Gorges – Slopes of 70% or greater gradient. Rule-identified feature with a high mass wasting potential and high delivery potential. Very high hazard rating. Inner gorges are present as both asymmetrical and symmetrical forms and may be intermittent in lateral extent. Shallow and deep-seated landslides are commonly located along the gorge walls. Buried wood in debris-filled channel bottoms indicates past landsliding and even-aged alder dates these events. Inner gorges are sensitive to both roads and harvest. Shallow undifferentiated landslides account for 96% of the mass wasting events in this landform.

LANDFORM #2: Bedrock Hollows – Slopes of 70% or greater gradient. Rule-identified feature with a high mass wasting and high delivery potential. Very high hazard rating. Hollows can be long or short, elliptical or round, or can have an inverted spoon shape. They occur primarily on convergent slopes but can also be found on planar slopes and on deep-seated landslide scarps. Hollows are commonly found upslope from inner gorges. Digital Elevation Models (DEM) and SLPSTAB, a GIS layer that identifies convergence and steepness, showed many areas to have planar slopes, which were mapped as bedrock hollows after field observations revealed some of these areas to have broadly concave-planar slopes. Bedrock hollows that had not recently failed were observed filled with debris and those that had evacuated more recently showed thin soils draping weakly cemented bedrock. Shallow undifferentiated landslides account for 93% of the landslides in this landform.

LANDFORM #4: River Terrace Margin – High mass wasting and delivery potential. Very high hazard rating. Glacial meltwaters carved the wide floodplain, which is now oversized for the present day river. After the meltwaters receded, it is likely the terrace margins in this WAU had typical planar-type faces, which have since experienced extensive landsliding. The weak nature of the marine sedimentary bedrock, heavy precipitation, stream action, and road and railroad undercutting all contribute to instability and erosion of the terrace margin (Figure 5).

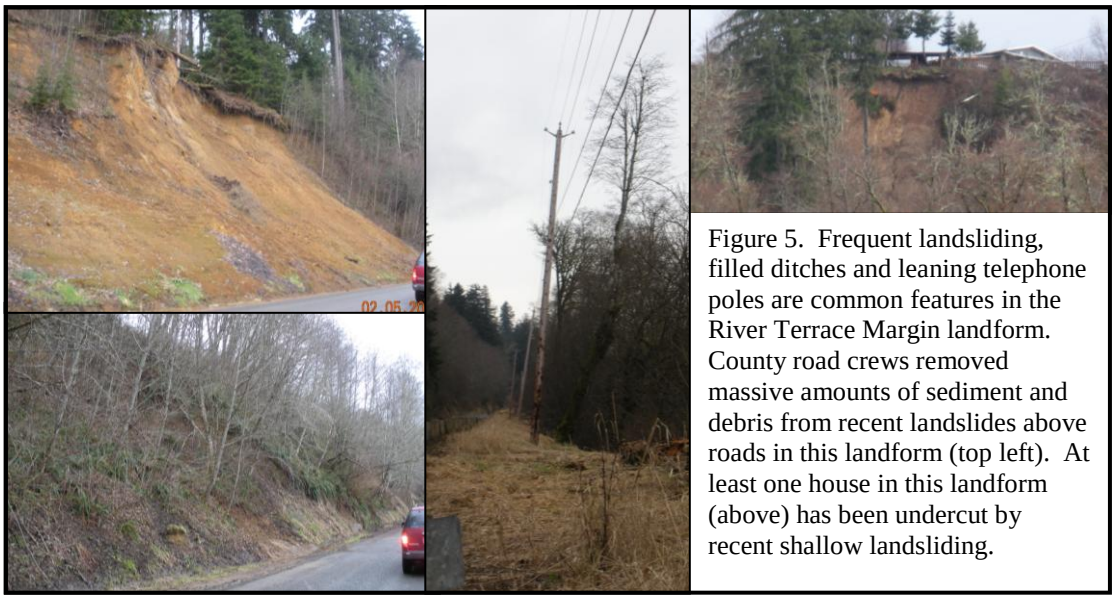

Figure 5. Frequent landsliding, filled ditches and leaning telephone poles are common features in the River Terrace Margin landform. County road crews removed massive amounts of sediment and debris from recent landslides above roads in this landform (top left). At least one house in this landform (above) has been undercut by recent shallow landsliding.

LANDFORM #5: Convergent Headwalls – Slopes of 70% or greater gradient. Rule-identified feature with a high mass wasting potential and high delivery potential. Very high hazard rating. One convergent headwall was mapped in this WAU. The convergent headwall contained numerous landslides, sharp ridges in convergent topography, and very steep slopes. Of the 75 landslides in this landform, 97% were classified as shallow undifferentiated landslides.

LANDFORM #7: Active Scarps of Deep-seated Landslides – Very high mass wasting potential and a high susceptibility to road-related landsliding. Very high hazard rating with the inclusion of road-related failures, but a moderate hazard rating when road-related landslides are not included in calculations. This landform consists of head and interior scarps of previously failed deep-seated landslides that contain secondary landslides. Slopes of this landform are mostly steep (>65%), but can be as gentle as ~30% (DEM derived, may be underestimated). Shallow undifferentiated landslides account for 95% of the mass wasting features in this landform.

LANDFORM #9: Fluvial Erosion along Channels of the Chehalis River. (Figure 6) – The LHZ protocol for a level one analysis prescribes that floodplains are delineated as low hazard areas along with prairies and flats. These bank failures would have been calculated as having a very high hazard rating, but assigned a low hazard rating by judgment of the analyst based the occurrence of the landform within the floodplain. Alluvium found along the Chehalis River Surge Plain is highly susceptible to bank failure. Bank failures occur primarily along the outer edges of the meander bends, but a few are found along straight banks due to the daily rise and fall of the tides, which affects pore water pressure of the slopes adjacent to the river. Debris delivers directly to the Chehalis River. This landform is unlikely to be impacted by forest practices, as it occurs entirely within the Chehalis River floodplain.

Figure 6. The tidally influenced river edge in the Chehalis River Surge Plain at mid- to high tide. Sediment deposits at the base of the steep river edge (left), and removed vegetation (right) are signs of recent bank failure.

LANDFORM #10: Non-Rule-Identified Inner Gorges – Very high mass wasting and delivery potential. These features contain DEM slopes between 30% and 70% with convergent symmetrical and asymmetrical inner gorge characteristics. Slopes were mapped with computer generated DEM slopes which are typically underrepresented. Many of these features were field identified as having steeper slopes and were re-mapped as rule-identified inner gorges (landform #1). The remaining landform features may also be rule-identified and should be field reviewed. Within this landform, 97% of the landslides occurred as shallow landslides, often located along the gorge walls.

LANDFORM #11: Steep Gradient Hillslopes (>60%) – Very high mass wasting and delivery potential. Very high hazard rating. These steep slopes are found throughout the WAU as convergent or planar slopes and often adjoin inner gorges and bedrock hollows. Deep-seated landslides commonly occur within this landform. Shallow undifferentiated landslides account for 91% of the landslides in this landform.

LANDFORM #12: Moderate Gradient Hillslopes (41-60%) – High mass wasting and delivery potential with a high susceptibility of road-related landsliding. Very high hazard rating with the inclusion of road-related failures, but moderate hazard rating when road-related landslides are not included in calculations. Computer-generated DEM slopes were used to draw the majority of this landform. DEM slope angles are typically underrepresented and this landform may contain isolated areas of Steep Gradient Hillslopes landform. The weak nature of the marine sedimentary bedrock, folding and faulting within the WAU, and high precipitation have contributed to shallow and deep-seated landsliding found in this landform. Shallow undifferentiated landslides account for 89% of the landslides within this landform.

LANDFORM #14: Flats – Low mass wasting and delivery potential. Low hazard rating. Low gradient (0-10%) valleys and stream bottoms are generally composed of alluvium, colluvium, soil, and landslide deposits. Wetlands are included in this landform as well as some portions of DSLS bodies. This landform contains areas in and around rivers and streams and is more likely to be a site of debris and alluvial deposition than a site of erosion. No shallow landslides were mapped within this landform.

LANDFORM #15: Ridge Tops and Noses (0-10%) – Low mass wasting and delivery potential. Low hazard rating. Low gradient (0-10%) areas along the tops of the ridges and along the noses of ridges are included. No shallow landslides were mapped within this landform.

LANDFORM #16: Low Gradient Hillslopes (11-40%) – Low mass wasting and delivery potential. Low hazard rating. Failures within this landform probably occur on slopes steeper than 40% but inaccuracies in the DEM data preclude identification of steeper slopes. Landslides mapped in this landform had questionable certainty.

8.0 Summary of Methods

Landslide inventory data sources - The procedures below follow, with minor modification, the Landslide Hazard Zonation Protocol version 2.1 dated September 2006 and is available at:

[www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2.1_final.pdf].

As original aerial photographs could not be used for this project, color photo copies of (stereo) originals were made onto cardstock paper. Image quality varied from good to poor. Four sets of the 1:12,000 aerial photograph copies dated from 1962 to 1997, one set of 1:63,000 photos from 1974, and one set of 1:40,000 photos from 1981 were analyzed with a mirror stereoscope at 3x magnification (Table 3). Color ortho-photograph images from 2006 were used as a layer for GIS analysis and mapping.

Cadastral and archival maps were used to determine pre-aerial photography logging activities, transportation routes, and areas affected by forest fires. Most information about logging activity, transportation routes, and areas affected by forest fires came from the 1898 USGS map of Washington showing Classification of Lands, which was scanned and entered into ArcGIS and geo-referenced using a methodology adapted from Collins and others (2003).

Year	Scale	Image	Flight Line Number	Reference Ownership	Comment
1962	1:12,000	Black & White	GH-62 38B-7 to 42A-22	DNR	Complete coverage
1974	1:63,000	Black & White	NW-H-74 7W-33 to 6W-36	DNR	Complete coverage
1981	1:40,000	Black & White	OSI 81 5-19-126 to 2-21-149	DNR	Partial coverage
1981	1:12,000	Black & White	OL-81 2-56-8 to 2-62-278	DNR	Complete coverage
1990	1:12,000	Black & White	OL-90 9-56-126 to 30-62-30	DNR	Partial coverage
1997	1:12,000	Black & White	OL-97 9-55-63 to 41-61-170	DNR	Complete coverage
2006	18 inch pixel*	Color Digital Orthophotos		DNR	Complete coverage in corporate geodatabase

Table 3. Aerial photograph years and flight lines used for this study.
* Source photography was flown at a scale of 1:40,000.

Landslide inventory mapping - Slope failures observed on the aerial photographs were classified and catalogued according to the following mass wasting feature types: shallow-undifferentiated landslides, debris flows, debris slides, debris avalanches, rock topples and deep-seated landslides. For the purposes of this analysis, slopes that failed below rooting depth were categorized as deep-seated landslides (Washington Forest Practices Board, 2004).

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; they could not be identified with the same level of certainty than those mentioned above. 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 aerial photos; however some that were identified in the field were not evident on the photos because they were mostly in areas of heavy canopy. Many of these field-identified landslides postdated the most recent photo set.

Following stereo aerial photograph analysis, all observed landslides were mapped directly into GIS by "heads-up" digitization of landslides onto a GIS map. The final landslide inventory map (Map A-1) displays the following data layers: landslides, streams, roads, sections, townships, ranges, and 100 ft contours. The landslides mapped on Map A-1 are also itemized in Appendix A - Landslide Inventory.

Typically, DEM-derived slope gradients are underestimated by at least 10% relative to field-measured gradients (Dragovich et al., 1993), particularly 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 those shown on Landform Map A-2. It should be emphasized that all slope gradient estimates presented in this report are likely minimum values.

LiDAR from 2005 was available for a small portion of the WAU that covers the Chehalis River Floodplain and a short distance into low gradient areas through the center of the WAU. Maximum resolution of the LiDAR derived map base is approximately 3 meters (~10 feet).

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 most time-efficient and most reasonable representation of the pre-failure slope surface compared to other GIS slope measurement methods.

Landform map units – As part of the LHZ protocol, landforms were mapped based on the physical attributes of the landscape including slope gradient and form, lithology and delivery potential. These landforms are intended to be used as screening tools for recognizing potentially unstable slopes in proposed harvest units within the WAU.

Landform mapping followed a three step process. First, low hazard landforms (flats, floodplains, ridge tops, and noses, and low gradient hills) were delineated according to the LHZ Protocol, using a slope map with standardized slope angles. Second, rule-identified landforms (inner gorges, bedrock hollows, convergent headwalls, etc.) were delineated. And thirdly, the remainder of the WAU was divided into analyst-described landforms (active scarps of deep-seated landslides, steep gradient hillslopes, moderate gradient hillslopes, and fluvial erosion in the Chehalis River Surge Plain, etc). These landforms were developed using a combination of remotely-sensed observations of the physical attributes of the landscape where the landslides occurred together with some field-checking. A combination of slope gradient and elevation data (derived from the DEM), slope convergence data (derived from the DNR SLPSTAB model based on a slope morphology model (Shaw and Johnson, 1995)), geologic data (from DNR geology layers on GIS), and delivery potential were used in the delineation of all landforms.

9.0 Hazard Ratings

An Overall Hazard Rating (low, moderate, high, or very high) is assigned to each landform according to LHZ Protocol. In most cases these ratings are either determined by rule-identified status (WAC 222-16-050) or calculated from the Landslide Frequency Rate (LFR) and Landslide Area Delivery Rate (LAR). On rare occasions the professional judgment of an analyst is used in lieu of the LFR and LAR calculations or, for some active deep-seated landslides, the hazard rating is based on apparent activity level.

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 calculated similarly, but using the *area* in addition to the number of delivering landslides. Lingley (2004) has determined qualitative hazard ratings that are associated with specific LFR and LAR values (Table 4). Deep-seated landslides are not included in the calculations for hazard ratings. Note that higher LAR values 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. As described in Table 5 of the LHZ Protocol, the LFR and LAR are combined to determine an Overall Hazard Rating for each landform. The qualitative rating system for each landform in the WAU is calculated and shown on Form A-4. Form A-2 summarizes these ratings along with the detailed landform descriptions; Map A-2 shows the distribution and hazard rating of the landforms within the WAU.

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.

For this study of the Lower Chehalis - Elizabeth Creek WAU, the qualitative rating system detailed above was used, as summarized in Form A-4 (Appendix D). The hazard ratings determined in Form A-4 were used for describing the overall hazard rating of all landforms, except the Fluvial Erosion Along the Chehalis River landform was classified as low hazard by the analyst because of its occurrence in the floodplain and lack of impact from forest practice activities. Form A-2 (Appendix C) contains the detailed landform descriptions and their overall hazard ratings; Map A-2 depicts the distribution of the landforms.

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 limited field observation. 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 will be present due to the limited field verification of individual features; particularly in heavy forest canopy areas.

It is critical to understand that while these decisions are sufficient to characterize aspects of slope failure as functions of forest management, <u>this assessment would be entirely insufficient and misleading if it is used as a standalone document for protecting private and public resources or for landuse planning.</u> As this is only a reconnaissance study, some landslides may have been accidentally omitted and some benign features may be improperly mapped as landslides.

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 the landscape that share similar physical characteristics related to mass wasting behavior;
- 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 Chehalis - Elizabeth Creek WAU that have a risk of landsliding due to natural phenomena and the effects of forest practice activities (logging, roading, thinning, yarding, etc.). All areas and ownerships in the WAU have been included in this study and 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 (WAC 222-20) may require detailed investigation prior to forest practice classification (WAC 222-16-050).

This is a comprehensive survey, 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 inventory.

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