WASHINGTON STATE DEPARTMENT OF
Natural Resources

Mass Wasting Assessment: Landslide Hazard Inventory Project

Lower Calawah River Watershed, Clallam County, Washington

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1.0 Overview

The purpose of this mass wasting assessment is to identify the non-federal non-tribal areas within the Calawah WAU that have moderate or high risk of landslides due to the effects of forest management (logging, roading, thinning, yarding, etc.). The Washington Forest Practices Board, Standard Methodology for Conducting Watershed Analysis, Version 4.0 (1997), adopted in part for use herein, requires that several critical questions are answered and that Mass Wasting Map Units (MWMU) are defined, both of which help assess the risk that landslide debris could be delivered to public resources (surface waters, public roads, and other infrastructure). **This is a reconnaissance study and its level of resolution must be kept in mind when using the document. For example, analysis of individual landslides or slopes is not an appropriate use of this report. Undoubtedly, some landslides have been accidentally omitted and some benign features may be improperly mapped as landslides herein.**

This assessment is conducted using aerial photographs, various maps, and field observations. Information is collected and compiled from these sources in a manner designed to respond to the critical questions or to suggest areas where more detailed information is necessary to do so have been completed. The objective of the data collection is to generate information sufficient to establish:

1. A generalized characterization of mass wasting processes active in the basin.

2. Portions of the landscape sharing similar physical characteristics relating to mass-movement behavior.

3. The relative potential for mass wasting within each landscape unit.

1.1 Introduction to Mass Wasting Processes and Terminology

Terminology used to describe mass wasting processes in this assessment follows the classification system established by the Washington Forest Practices Board (1997) as modified by Boyd and Vaugeois (2003). This system groups slope movement into nine types (shallow-rapid, debris flow, debris avalanche, shallow sporadic deep-seated, large persistent deep-seated, earth flow, rock topple/fall, and snow avalanche). Analysis is aided by designating landforms, slope shapes, land uses, and other observations associated with each group of landslides. (See form A-1.) For the purposes of this study, most landslides that fail below rooting depth are categorized as deep-seated, consistent with the Forest Practices rules (WAC 222-16-050). For this reason, those deep-seated landslides that moved rapidly and clearly deliver are included in the analyses of sediment delivery.

In this report, the term 'delivery susceptibility factor' (Lingley, 2004) is used to help quantify the ratings for potential hazard of delivery of debris and sediment to streams by non-rule-identified mass wasting units as outlined in Table A-2 of Washington Forest Practices Board (1997). Rule-identified unstable slopes (WAC 222-16-050 (d)(i) are, by definition a high hazard. The delivery susceptibility factor is simply the area of delivering landslides normalized for the period of study and the area of the Mass wasting map unit (MWMU). These values are multiplied by one million to provide whole numbers. Very limited application suggests that susceptibility factors less than 100 might be considered low, factors of 101 to 250 are moderate, and factors greater than 250 are high (Table 1). Note that higher susceptibility factors can be achieved by reducing the size of the mass wasting map unit. While this may appear to be 'data gerrymandering', it has a favorable effect; this method helps limit the area of high-hazard mass wasting map units to those areas that are actually demonstrated to have high hazard.

Table 1. Comparison of deliverability susceptibility factors for parts of MWMUs in four Washington State watersheds. Note that the MWMU categories tabulated herein include all such features regardless of the angle of the contained slope (i.e., rule-identified unstable slopes and lower angle features are both included).

Watershed	Gorges, headwalls, hollows	Gorges	Hollows	Headwalls	Superimposed on relict landslides	Cliff-dominated slopes	Lower hazard hills	Incised rivers	Glacial Outwash terraces	Valley floors	WAU or study area
Lower Calawah Valley	404						24	405		37	68
Jackman Corkindale (Lingley, 2004)	1167				1217	213	24		35		461
Jackman Corkindale (Lingley, 2004)	1142						10		19		
Nookachamps (Wegmann, 2004)		273	173	384	0		0		31	0	11
Lime and Dan Creeks (Wegmann, 2004)	119										4

2.0 Physical Setting Pertinent to Mass-Wasting Interpretations

The Lower Calawah River watershed covers 16-mi^2 in the west-central part of the Olympic Physiographic province and includes the southwestern part of the Calawah River drainage. Map A-1 shows some geographic features described in the text together with landslides identified during this study.

Much of the land in this watershed is managed by the U.S. Forest Service and not included in the study area. The remainder includes about 13-mi^2 of fee and State Trust land, the latter being managed by the Department of Natural Resources. Dense second-growth evergreen trees cover most hill slopes on U.S. Forest Service lands and some of the fee and State land although significant logging and roading occurred between 1965 and the early 1990s.

2.1 Topography

The study area, occupying 8,032 acres of the 10,000 acre Lower Calawah River watershed, ranges in elevation from about 75 feet above mean sea level along the banks of the Bogachiel River to 1,475-feet on Calawah Ridge and 1,720-feet on Elk Ridge. Major drainages include the Calawah River from Mile 0 to about Mile 10 (U.S. Geological Survey 1981a, 1981b, 1981c) and its major tributary, Elk Creek. The Calawah River joins the Bogachiel River at the western edge of the watershed.

The study area can be divided into three main physiographic elements: 1) Forks Prairie, a flat glacial-outwash plain bounded by the Sol Duc and Bogachiel River watersheds, 2) the incised channel of the Calawah River which cuts the prairie, and 3) gentle rolling hills characterized mainly by low to moderate slopes and planar convex to planar concave topography. Streams located in the Lower Calawah Valley watershed display well-developed dendritic (branching) drainage pattern with minor 'hooking' at the headwaters. Hook-patterned headwater drainages are common in the western Olympic Mountains and probably result from rapid uplift. (See Lingley and others, 1996).

Analysis of the Calawah River floodplain (U.S. Army, 1938; U.S. Geological Survey, 1957, 1952, 1981a-c and DNR aerial photography set OL-97) indicates that the river has been remarkably stable over a 70-year period. In fact, meanders mapped in 1981 are in the same position they occupied in 1934. The probable reason for this phenomenon is rapid regional uplift of the western edge of the North American plate that is forcing the river to cut vertically down into Forks Prairie. This uplift essentially locks the river into its existing meanders, giving it a configuration known as an antecedent drainage.

2.2 Geology

Bedrock

Thorough discussions of the general bedrock geology in the vicinity of the study area are presented in Gerstel and Lingley (2000), Lingley (1995), Lingley and others (1996), and Rau (1979). Bedrock in the study area is chiefly thinly-layered sedimentary rocks (15 to 45 million years) of the Olympic Core complex (Tabor and Cady, 1978; Gerstel and Lingley, 2000). These are 15 to 45 million year old sandstone and siltstone with minor claystone, all of which weather readily to thick gummy soils (Figure 1). A few thicker sandstones bodies are present and form subsidiary summits on ridge crests in the eastern parts of the study area. No rocks in the Lower Calawah WAU have been deeply buried. As a result, the sandstones have retained much of the original pore space between individual grains of sand. These pore spaces create a small amount of permeability and permit vegetation and soil overlying the sandstone to bond to the bedrock, thus reducing the propensity for slope failure. (See Lingley, 2002.) Bonding probably occurs where rootlets or cohesive clay minerals penetrate pore spaces.

Sediments

The oldest mapped sediments in the study area are heterogeneous, sandstone-rich, glacial deposits from alpine glaciers that flowed out of the Olympic Mountains more than 100,000 years ago. These sediments are preserved as a low ridge, which trends southwest, mainly in section 5, T28N, R13W (Thackray, 1996). Failure style (deep-seated) on both ends of the ridge suggests that it may contain ancient till and glacial lacustrine clay. On the Forks Prairie, a blanket of sand and gravel deposited in front of the Juan de Fuca lobe of the Vashon glacier about 15,000 years ago overlies the older alpine glacial sediment. This sand and gravel is rich in metamorphic and granitic rock pebbles and seldom prone to failure because of their mechanical strength and permeability. However, the sand and gravel do fail along the Calawah River as a result of local over steepening that is occurring during rapid uplift. The youngest sediments in the study area are Calawah River alluvium, mostly composed of reworked sediment from continental glaciation.

Structures

Most of the bedrock is uniformly and sharply layered at 0.05 to 0.6 inches. Most of the bedrock is being rapidly uplifted along faults that slant northeastward into the earth at an angle of about 30 to 50 percent. These faults carry well-layered bedrock units on their hanging walls, somewhat like dragging a magazine (the layered rock) across a table by pulling on the tablecloth (the fault zone). As a result, the bedrock tends to slant into the earth at the same 30 to 50 percent angle. The combination of the faulting and this layering tends to make the beds slip on each other like a deck of cards and to develop thick blocky soils. A component of some landslide slip results from failure along the layering. (See PBS, 2000.)

2.3 Hydrology

Precipitation within the basin is high, ranging from 60 inches per year in the low elevations along the southern portions of the study area to 120 inches per year in the headwaters of Elk Creek (DNR, 2003). Most of the annual rainfall occurs between October and May, but Forks always seems to be among the wettest areas in North America. More than 150 inches of precipitation occurred in 1953, 1961, 1968, 1974, 1975, 1997, and 1999 (Oregon Climate Service, 2004). Most of the study area lies below the rain-on-snow threshold.

Precipitation intensity and duration in the Lower Calawah River WAU are important factors that likely contribute to initiation of mass wasting events (Montgomery and Dietrich, 1994). Typical large peak flows on the lower Calawah River, near Forks, exceeded 31,000 cfs during 1991, 1997, and 1999 (U.S. geological Survey, 2004.

Groundwater hydrology in the upper elevations of the watershed consists primarily of transmission through forest duff, but some groundwater flow through bedrock occurs because sandstones in the watershed retain about 10% primary porosity (Palmer and Lingley, 1989). Glacial outwash gravels on the Forks Prairie are highly permeable, so much so that some upper reaches of the Calawah River have only subsurface flow during summer dry periods (Leslie Lingley, Quinault Indian Nation, 2004, oral commun.).

2.4 Summary of Previous Mass Wasting Investigations

Detailed mapping in the Lower Calawah Valley WAU has yet to be accomplished. Gerstel (1999) prepared a reconnaissance deep-seated landslide inventory of the west-central Olympic Peninsula, but only one anomaly was identified in the study area (Gerstel Landslide I.D. No. 101). Subsequent investigation (PBS, 2000) of this anomaly indicated that it is not a landslide. No other geotechnical reports are on file in the Department of Natural Resources (DNR) Olympic Region office. A few small landslides were identified at the time of the PBS Environmental study (Leslie Lingley, Leslie Geological Services, Olympia, 2004 written commun.) and are included on Map A-1. Dieu and Schelmerdine (1997) and Lingley (1998) recognized essentially the same types and distribution of mass wasting in the North and South Forks Calawah watershed analyses as those identified during this study. Lingley and Lingley (2002) observe a positive correlation of landslide frequency with outcrop patterns of thin-bedded sedimentary rocks including those in the study area. They note that landslides become less frequent in a westerly step-wise pattern that is created by a series of westward-younging thrust fault blocks.

3.0 Summary of Methods

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

Seven sets of aerial photographs were viewed with a mirrored stereoscope with 3x magnification. These sets include images acquired between 1950 and1997. Unfortunately, some key images were missing from DNR's collection in Olympia and could not be viewed. New Clallam County black and white LIDAR images (Puget Sound Lidar Consortium, 2002) were viewed with pseudo-vertical illumination. Although the LIDAR data are intensely pixilated in the eastern portions of the study area, two soil liquefaction landslides that could not be identified with other data were readily apparent on the lidar image (Landslide I.D. Nos. 1025, 1026). In addition, several earthflows were easier to define with LIDAR. On all of the images, suspected landslides, containing landforms such as headscarps, lack of vegetation along slide paths, hummocky or benched topography, ponded water bodies, and marginal drainages were identified.

Table 2. Photographic surveys used in this study.

Year	Scale	Image	Flight Number	Reference/Ownership	Comment
1950	1:62,500	black & white	SYF	Carl Berry	2 images only
1967	1:12,000	black & white	WFPA66	DNR	some missing images
1975	1:12,000	color	OL-8_75	DNR	some missing images
1979	1:12,000	black & white	OBD-79	DNR	9 missing images
1985	1:12,000	black & white	OL-85	DNR	5 missing images
1990	1:12,000	black & white	OL-90	DNR	8 missing images
1997	1:8,000	black & white	OL-97	DNR	6 missing images
2002	Digital	black & white	LIDAR	Puget Sound Lidar Consortium	pixelated in east

Nine 'questionable' to 'definite slides were located during a reconnaissance field investigation of part of the area on February 25 and 26, 2004.

The landslides were mapped directly in ArcGIS as a single Landslide shapefile by registering the landslides on the Department of Natural Resources digital raster graphic ("drg75") topographic contours. This technique results in a maximum resolution of only 10 meters. A slope/convergence map (SLPSTAB; Vaugeois, 2000) and a slope-percent map derived from a USGS 10-meter digital elevation model (DEM) of the watershed aided in predicting areas of potential shallow-rapid slope failure and in assisting with the delineation of Mass Wasting Map Units (MWMUs).

The resulting landslide coverage is displayed as Map A-1. Pertinent attributes of the landslides are recorded on data sheets (Form A-1). These include: 1) the type of mass wasting process, 2) level of certainty of the observation, 3) whether the mass wasting feature delivered sediment to surface waters or other public resources, 4) associated land use, 5) the slope form (convergent, divergent, planar), 6) the photo-year in which the failure was initially recognized, and 7) the gradient or steepest slope increment within each landslide. The landslide process was recorded only where it could be rapidly determined, but most failures are lumped as "shallow rapid – undifferentiated" or "deep-seated – undifferentiated" categories.

Slope gradients were determined by exploring a DEM-derived slope percent map within each landslide polygon on the Landslide shapefile. Note that the steepest slope increment only corresponds to the "slope at failure" (*Angle of Slide*, See Jackson, 1997) for medium to large translational landslides. The slope angle cannot be reliably determined for small or narrow landslides where accuracy is limited by the 10-meter resolution of the DEM. Slopes derived from DEMs are generally lower than those measured in the field, but are less subjective. Conversely, the steepest slopes on rotational failures are on the failure plane and therefore steeper than the slope of the ground just before landslide initiation. As a result, the method of slope gradient estimation presented is an approximation.

Once the locations of mass wasting features were mapped and evaluated, areas of similar mass-wasting potential were grouped into Mass Wasting Map Units (MWMUs). These are shown on Map A-2 and described in Appendix B.

4.0 Summary of Analysis and Results

During this review, a representative sample of 76 'questionable' to 'definite, field-confirmed' landslides was inventoried using data obtained between 1950 and 2004 (Forms A-1 and A-3). Figures 1 through 7 characterize these failures. Compared to other watersheds of similar size on the Olympic Peninsula, these landslide frequencies are moderate to low (Table 3, also see Lingley, 1998; 2002; Dieu and Schelmerdine, 1997.)

Table 3. Landslide rate for the Lower Calawah WAU.

WAUs	Landslides (n)	Years	Study Area Acreage	Rate (n/ac-WAU/yr)
Lower Calawah Valley	76	54	8,032	$2x10^{-4}$

Of the landslides identified during this mass wasting assessment, 64% were mapped as shallow rapid - undifferentiated failures, 13% were debris flows, 3% were debris avalanches, 5% were deep-seated - undifferentiated, 3% were large persistent deep-seated, 11% were small sporadic deep seated landslides, and 1% were earthflows (Figure 1). Only four long-runout, large-volume debris flows were identified.

On managed lands, landslides associated with clear cuts (0 to 5 years), young timber (5 to 15 years), and sub-mature timber (15 to 50 years) represent 24%, 27%, and 27%, respectively (Figure 2). Road-related landslides represent 12% of recorded failures. Landslides in mature stands represent a combined total of 11% of observed slope failures. Note that failures in 'mature stands' include relict landslides.

Although road-related failures are not as common as some other watersheds, less than 10-miles of upland forest roads are present and the road along the western end of Elk Ridge (sections 1, 2, T28N, R13W) has been carefully abandoned with sidecast pullback, culvert removal, and revegetation. However, failures are common along the orphaned northwest extension of Road F1100 on the south side of Elk Creek. Here, loading from the road prism is sufficient to destabilize the underlying slope and create numerous short-runout, shallow rapid failures.

Most failures are associated with convergent headwalls, inner gorges, and bedrock hollows (Figure 3). Undercutting along Calawah River meander bends also creates a high percentage of failures. Most of the mapped landslides are smaller than five acres (Figure 4) and small sporadic deep-seated landslides account for most of the area affected by mass wasting (Figure 5).

Most landslides have initiation/headscarp slopes of 34 to 76 percent (Figure 6). There is no apparent correlation between type of failure and initiation/headscarp slope, but an important point is that initiation/headscarp slopes in the Lower Calawah watershed are significantly flatter than in watersheds further to the east in Washington State (Figure 7). For example, the weighted mean initiation/headscarp slope in the Lower Calawah watershed is only 49% whereas the Jackman Creek – Corkindale watersheds in the North Cascades have a weighted mean initiation/headscarp slope of 90 percent (Lingley, 2004). This marked difference in the slope angle on which landslides occur is likely the result of differences in the strength and layering characteristics of the bedrock (Lingley and Lingley, 2002). The bedrock in the Lower Calawah River WAU is poorly consolidated and has sharp and planar layers (bedding planes) that are closely spaced (0.05 to 0.5 inches). As a consequence, the rock tends to break apart and weather quickly, and failures along the layers are common. Almost all of the inventoried landslides occur in convergent slope elements (Figure 8).

Natural failures resulting from erosion on the outside of meanders and incision along Calawah River are common and long-lived. These may be exacerbated by harvest and roading. Deep seated failures including earth slumps, small sporadic deep-seated slides, and earthflows (PBS, 2000) are present in many headwall areas.

The annual rate of landslides normalized for the 54-year study period and area of the watershed is 2×10^{-4}.

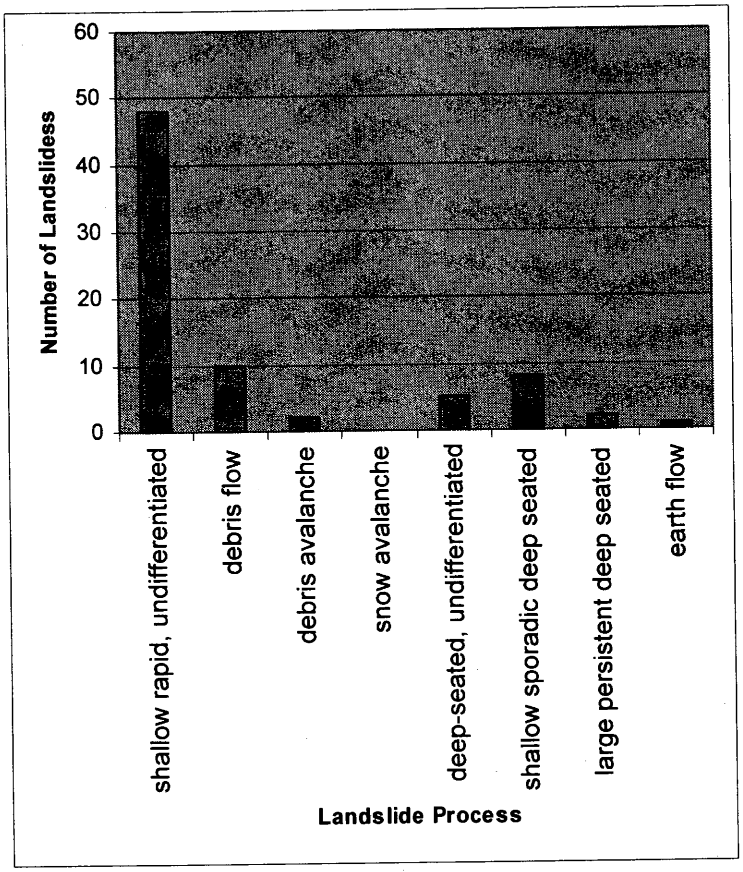

Figure 1. Number of landslides observed in the Lower Calawah River WAU by mass wasting process.

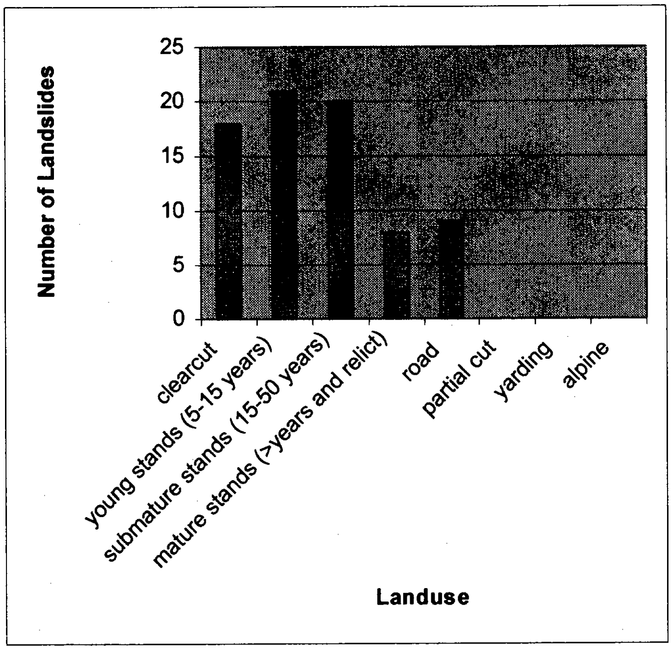

Figure 2. Number of landslides observed in the Lower Calawah River WAU by land use association.

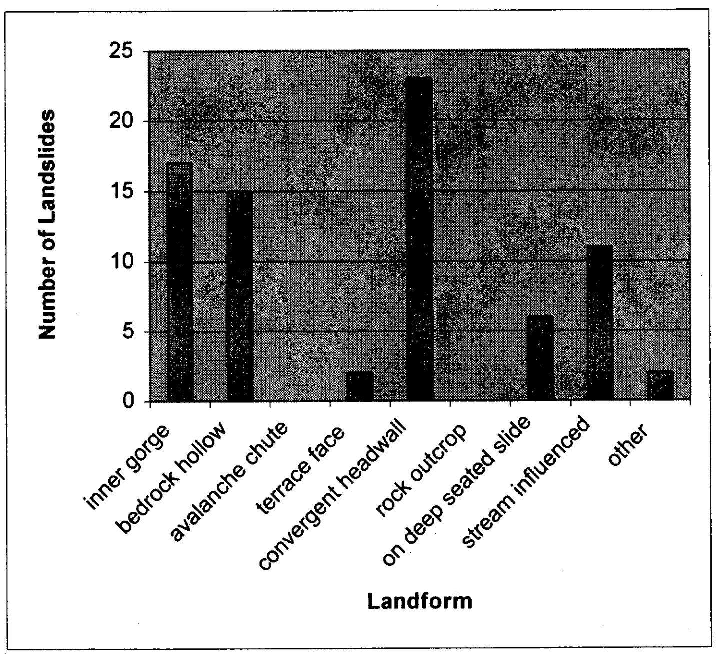

Figure 3. Number of landslides observed in the Lower Calawah River WAU by landform association.

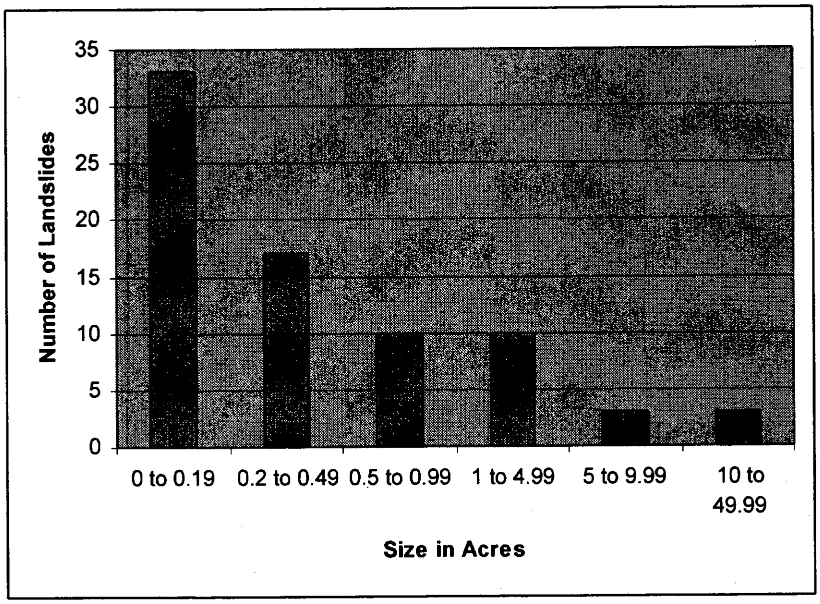

Figure 4. Size distribution of landslides in the Lower Calawah River WAU.

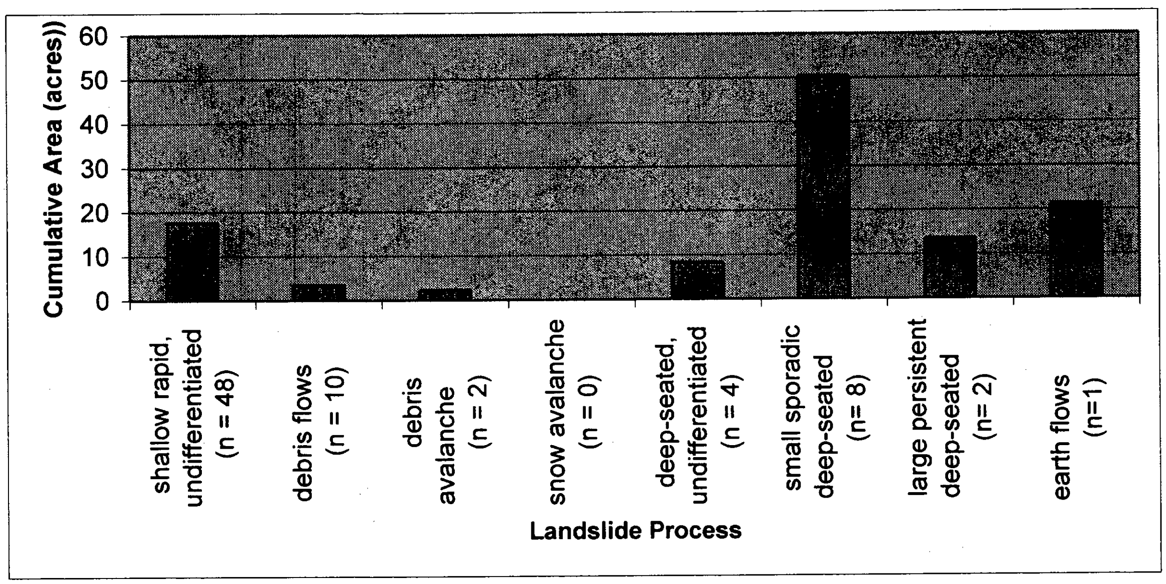

Figure 5. Cumulative area of landslides by landslide process in the Lower Calawah River WAU.

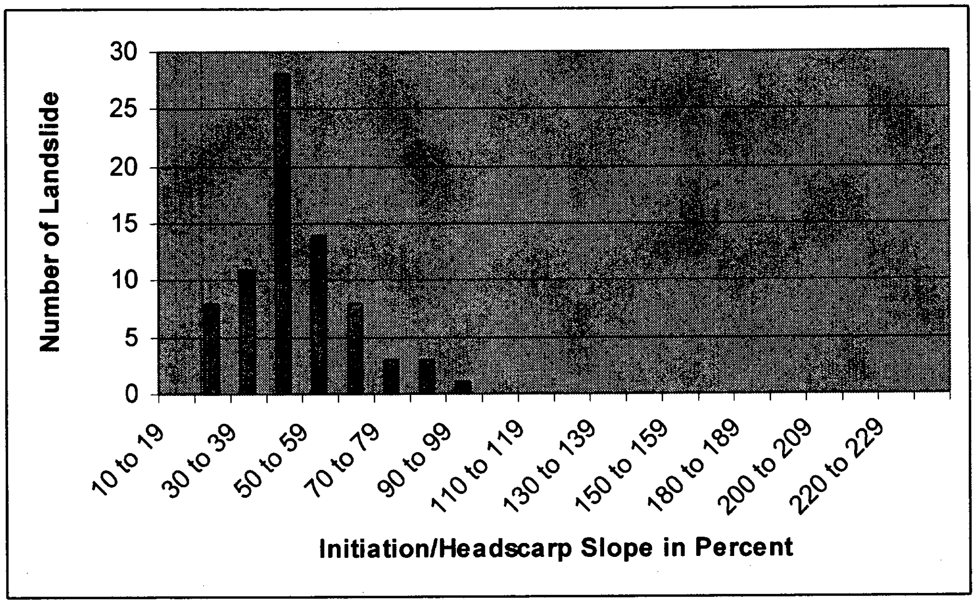

Figure 6. Distribution of landslides by slope class for the Lower Calawah River WAU.

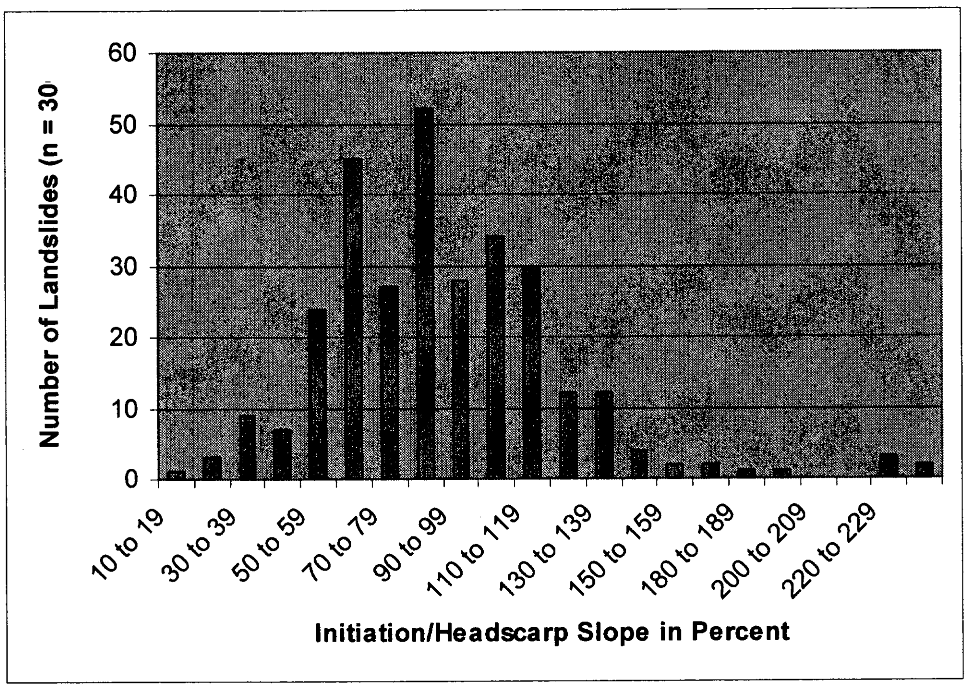

Figure 7. Distribution of landslides by slope class for the Jackman – Corkindale WAU, (from Lingley 2004).

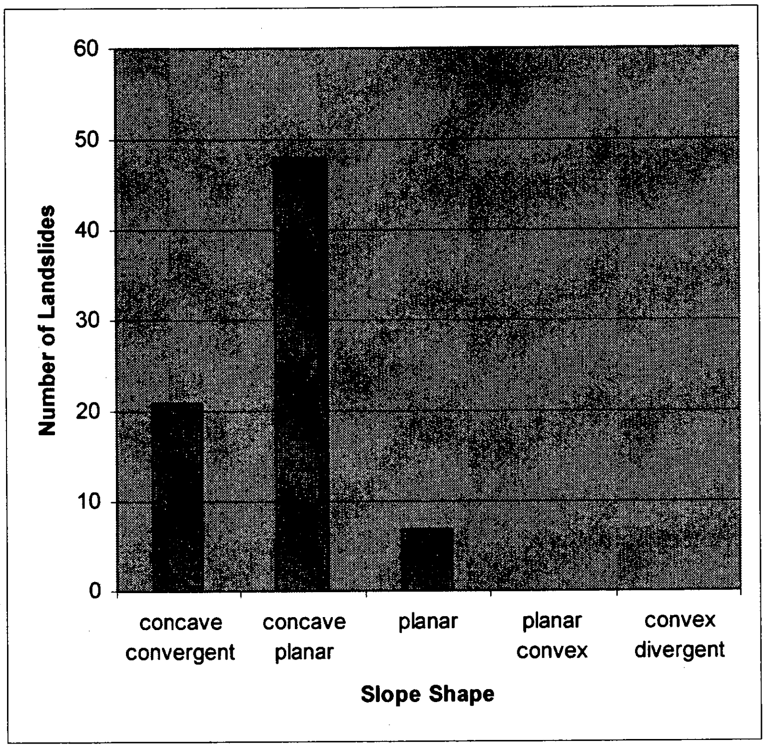

Figure 8. Distribution of landslides by slope shape in the Lower Calawah River WAU.

5.0 Mass Wasting Units

The distribution and area of the four Mass Wasting Map Units (MWMUs) for the Lower Calawah Valley study area are shown on Map A-2, Tables 4 and 5. These units have been delineated to depict areas having similar mass wasting potential and potential to deliver to public resources. Mass wasting potential is based mainly on landslide process, failure density, lithology, geomorphology, and topography. Hydrogeology is not considered as a critical variable for delineating MWMUs in this watershed. The following sections briefly describe the characteristics of each MWMU and additional information is given in Appendix B and C. Deliverability is discussed in a following section.

5.1 MWMU1: Moderate Inner Gorges, Hollows, and Convergent Headwalls

MWMU1 include moderate and less commonly, steep inner gorges, convergent headwalls, and bedrock hollows, mainly near ridge crests. These are generally confined to moderately concave slopes. Although it includes small areas of rule-identified landforms, many failures occur on lower angle slopes (Figure 3). Shallow rapid processes dominate Mass wasting in MWMU1, but small sporadic and other deep-seated landslide failures are also present. One large questionable earthflow (Landslide I.D. No. 1012) and one field confirmed earthflow (Landslide I.D. No. 1035, PBS, 2000) are also included. Most of the failures occur in thick soils derived from rapidly weathering, grayish-orange, thinly-bedded sandstone, siltstone, and shale. This unit appears susceptible to forest management, especially harvest on convergent headwalls and road construction and maintenance. The delivery potential of mass wasting occurring in MWMU1 is High, with a susceptibility factor of 404. MWMU1 is rated as having a high mass wasting potential with an observed landslide rate of 1.0 landslide per year between 1950 and 2004. The overall hazard rating of MWMU1 is high.

5.2 MWMU2: Other Hill Slopes

MWMU2 includes low to moderate angle hill slopes along Elk Creek and north of the Calawah River. A few shallow rapid landslides and earthflows are randomly distributed across the MWMU, but sensitivity to management generally appears low. However, analogy with MWMU1 indicates that MWMU2 may be highly sensitivity to road building, especially where thick side cast or end-hauled material loads the slope. Like MWMU1, most of the failures occur in thick grayish-orange soils derived from rapidly weathering thinly-bedded sandstone, siltstone, and shale. The delivery potential occurring in MWMU1 is low with a susceptibility factor of 24. MWMU2 is rated as having a moderate mass wasting potential with an observed landslide rate of 0.2 landslides per year between 1950 and 2004. The harvest hazard rating of MWMU2 is low, but for roading it is medium- to-high hazard, depending on road construction and maintenance techniques.

5.3 MWMU3: Incised Channel of the Calawah River

MWMU3 occurs in the steep inner gorge of the Calawah River, mostly along the outside of meander bends. However, the location of the meanders has remained in the same position since 1934. The remarkable absence of river scrolling across its floodplain is due to rapid uplift resulting from subduction and(or) glacial rebound. (Meander positions have been inherited from their pre-uplift geometry creating an 'antecedent' drainage.) The upper parts of MWMU3 are underlain by continental glacial outwash but older glacial and inter-glacial deposits may be present in the walls inner gorge of the river. The southwestern end of the older alpine glacial moraine northwest of Forks has failed continuously along the riverbank since at least 1967. Weak sediments that probably core the ridge exacerbating slope instability at this meander. Initiation slopes in MWMU3 landslides as measured in the field are considerably steeper than those of MWMU1 and are therefore rule-identified, even where meanders are not present. Mass wasting processes for MWMU3 include shallow rapid landslides and small sporadic deep-seated failures that occur on slopes greater than 70%, and(or) along the outside of slightly eroding meander bends.

MWMU3 lies entirely within in an riparian management zone and(or) channel migration zone (RMZ and(or) CMZ). As such, is unlikely to have continued forest management practices. The delivery potential of mass wasting occurring in MWMU3 is High, with all inventoried landslides delivering sediment to the Calawah River. The susceptibility factor for this unit is 405. The overall hazard rating of MWMU3 is high.

5.4 MWMU4: Forks Prairie

This unit encompasses the flat glacial outwash plain formed of gravel deposited as the continental ice sheet retreated. It extends from Mile 0 to Mile 10 along both sides of the Calawah River. Only two landslides were observed and both were unique. These are deep-seated soil liquefaction features on the northeast end of older alpine glacial deposits northwest of Forks (I.D. No. 1025) and in similar topography near the western edge of the study area. They were identified with LIDAR (Puget Sound LIDAR Consortium, 2002). Although slide I.D. No. 1025 delivered to an abandoned oxbow swamp stranded by subsequent incision of the mainstem, a relation between this landslide and management could not be established. MWMU4 has low deliverability and low mass wasting potential. It is rated as having a low overall hazard rating.

Table 4. Landslide summary for the Lower Calawah Valley WAU.

MWMU	Landslides	Delivering Landslides	Area (acres)
MWMU1	53	43	362
MWMU2	10	5	1881
MWMU3	11	11	389
MWMU4	2	1	5400
Totals	76	60	8032

6.0 Delivery

Delivery susceptibility factors for four Lower Calawah Valley MWMUs described below are present in Table 5. (The method for calculation of Delivery Susceptibility Factors is presented in Section 1.1.). Susceptibility factors for the Lower Calawah Valley watershed are lower than corresponding mass wasting map units in other watersheds studied to date (Table 1). Apparently instability in the Lower Calawah Valley WAU resulting from poorly consolidated bedrock and weakness imparted by the sharp and uniform layering are more than offset by the short panels of steeper topography and possible mechanical coupling between porous sandstone beds and overlying soils. Note, however, that susceptibility factors for MWMUs 1 and 3 are high, about 400, or an order of magnitude greater than the susceptibility factor of the low-hazard MWMU4.

The total area of delivering landslides in the study area is approximately 29.5 acres. The cumulative volume of all shallow-rapid landslides observed in the study area during the 54-year study period may be on the order of 250,000 cubic yards, assuming an average maximum thickness of 5-feet. For perspective, individual landslides in the Jackman Creek watershed may have delivered comparable volumes to surface waters.

Table 5. The annualized rate of landslides that deliver to public resources in terms of frequency and landslide area ('delivery susceptibility factor') during the 54-year study period. For the purposes of this analysis, 'delivering landslides' are taken to include those that move rapidly and have a 'probable' or 'yes' delivery rating. Delivering landslides do not include deep-seated landslides in this watershed as none have been shown to be influenced by management. (See Form A-1.)

MASS WASTING MAP UNIT	MWMU1	MWMU2	MWMU3	MWMU4	Study Area
Area of MWMU (acres)	362	1881	389	5400	8032
Number of 'Delivering' Landslides	34	5	11	1	51
Frequency of Delivery = (No. of delivering landslides) / (MWMU Area/54 years)	1739	70	744	5	167
Area of 'Delivering' Landslides (acres)	7.9	2.4	8.5	10.7	29.5
Susceptibility Factor = (area of delivering landslides) / (MWMU Area/54 years)	404	24	405	37	68

7.0 Summary of Critical Questions

In order to address the critical questions posed by the Standard Methods for Conducting Watershed Analysis, which have been adopted as part of the Landslide Hazard Zonation project protocols, the following summaries are included:

What evidence is present for mass wasting or mass wasting potential in the watershed?

During this mass wasting review of the Lower Calawah Valley WAU, a total 76 landslides were identified over a 54-year photo history. Most of these are relatively small shallow rapid failures, but deep-seated landslides are also present. Only four large debris flows were mapped. Four Mass Wasting Map Units are defined on the basis of similarities in slope form, landslide frequency, geology, and other factors. Within this WAU, there are two MWMUs identified as having both high mass wasting potential and high delivery potential. The overall mass wasting potential of the Lower Calawah Valley WAU is moderate when compared with other watersheds in other regions of the Cascades and Olympics (e.g. Parks, 2000, Lingley, 1998, 2002; Dieu and Schelmerdine, 1997).

What mass wasting processes are active?

Shallow rapid land sliding and debris flows with less common debris avalanches, rotational deep-seated landslides, and earthflow landslides are active mass wasting processes in the Lower Calawah Valley WAU (Form A-1).

How are mass wasting features distributed throughout the landscape?

See Map A-1. A preponderance of the landslides inventoried in this mass wasting assessment, from MWMU1, 2, and 3, are located within unstable landforms sensitive to forest practice management activities as defined in WAC 222-16-050. However, initiation slopes derived from the 10-meter DEM are typically lower than rule-identified thresholds and one and other WAUs (Figures 6, 7). Most of the landslides in the Lower Calawah Valley initiate on slopes between 40% and 80% as determined using DEM-derived slope classes. Field observation confirms this observation and suggests that some failures occur at angles lower than rule-identified thresholds.

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

Yes. About 80% of landslides observed in the Lower Calawah Valley probably or definitely delivered sediment to stream channels or other waters (Form A-1). Damage to other public resources has been minimal. Landslides initiating in bedrock hollows, inner gorges, and steep slopes deliver to first order tributaries of Elk Creek and the Calawah River. Landslides along the Calawah River initiate on the walls of its incised channel and deliver directly to the river.

Despite the high delivery frequency, the volumes of delivered sediment are relatively low, owing to short slope distances, a paucity of large debris flows, and low angle slopes.

How do forest management activities create or contribute to instability?

Of the observed mass wasting features in the Lower Calawah Valley WAU, 90% are associated with forest practice-related land uses. Harvest in convergent areas on the upper slopes of ridges and forest road construction and maintenance, in particular appear to be areas of potential instability. Some slopes in the watershed are sufficiently unstable that loading of fill on slopes at the outside of road prisms is sufficient to trigger shallow rapid failures. These slides typically extend only 300-feet along the slope, but many deliver to tributary channels and are of concern for road building and maintenance.

What areas of the landscape are susceptible to slope instability?

Most landslides are associated with inner gorges, convergent headwaters, and bedrock hollows, but failures in these settings appear to occur at much lower slope angles than many watersheds in Washington. The incised channel of the Calawah River commonly fails owing to undercutting at meanders bends.

8.0 Confidence in Work Products

The confidence in this mass wasting assessment is moderate. This moderate rating results because the Landslide Hazard Zonation Project is designed to provide a watershed overview of slope stability in a timely manner. As a consequence, fieldwork and the number of aerial photograph sets examined are held to reasonable minimums.

It is critical for the reader to understand that while these decisions are sufficient to characterize aspects of the slope failure as functions of forest management, **this assessment would be entirely insufficient and misleading if it is used as a stand alone document for protecting private and public resources or for land use planning. Keep in mind that this is only a reconnaissance study, and undoubtedly, some landslides have been accidentally omitted and some benign features may be improperly mapped as landslides herein**.

In addition, there are several sources of systematic error that reduce the confidence in the work products of this analysis, those being omission, misinterpretation, accuracy, and precision. Omission occurs when mass wasting features are not identified on aerial photographs or in the field due to canopy cover, gaps in the aerial photo record, quality of aerial photos, or interpreter errors. Misinterpretation occurs when a mass-wasting feature is identified but incorrectly classified or data are transposed, and where unrecognized software/file instability occurs. Accuracy involves the degree to which the physical parameters of a mass-wasting feature are correctly measured, and precision describes how variability within an assessment can be controlled when making multiple measurements over varying time and spatial scales (Parks, 2000).

This mass wasting assessment was primarily conducted with aerial photographs, and as a result, there is a high likelihood that errors of omission occurred primarily in areas covered by mature forest canopies at any given time. The scarcity of mass wasting features identified under mature canopy conditions is not necessarily an indication of the relative stability of slopes with mature vegetation regimes.

Because many deep-seated landslide features are quite large, remain heavily vegetated during movement, and may not have obvious scars visible through the vegetation canopy, misinterpretation is more likely. A recent detailed study in Cowlitz County, Washington, suggests that up to 25 percent of inferred deep-seated landslides identified from aerial photograph analysis are misinterpreted (Wegmann, 2003). Therefore confidence in work products related to classification of landslide process is low to moderate.

Another important source of potential error in this assessment is in the accuracy and precision of measurements of mass wasting features. Because very few landslides were actually visited in the field, it is not possible to report the degree to which location and measurement error in the GIS environment compares to on-the-ground field measurements. Similarly, measurements of slope angle from digital elevation models typically misrepresent the true hill slope angle. Given these sources of error, the confidence in the precise location and accuracy of measurements of individual landslides is considered moderate.

9.0 Acknowledgement

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11.0 Appendix A -- A-1 Form: Landslide Inventory

Form A-1 Mass Wasting Inventory Data for the Lower Calawah Valley WAU

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient	Delivery	Landuse	Photo_num	Acreage	MWMU
1001	1	D	1979	5			9	2	41	Y	2	OBD79_14B_22	4.51	3
1002	1	D	1979	2	1990	4	9	2	35	Y	2	OBD79_14B_22	0.10	3
1003	1	D	1967	3	1979	3	9	3	35	Y	2	OBD79_16B_27	0.11	3
1004	1	D	1979	2			9	2	35	Y	2	OBD79_16B_27	0.04	3
1005	1	D	1967	4	1979	5	9	2	20	Y	2	OBD79_16B_27	0.88	3
1006	1	D	1979	3			9	2	22	Y	2	OBD79_16B_27	0.16	3
1007	1	P	1967	3	1979	4	2	3	35	I	3	OBD79_16B_26	0.26	1
1008	1	P	1967	3	1975	4	1	1	37	Y	2	OBD79_16B_26	0.36	2
1009	1	P	1979	2			1	1	43	N	5	OBD79_17C_4	0.09	1
1010	5	Q	1979	4			2	2	36	P	2	OBD79_17C_5	0.54	1
1011	5	Q	1979	5			2	2	30	P	2	OBD79_17C_5	1.36	1
1012	7	Q	1979	5			2	2	69	P	2	OBD79_17C_5	21.34	1
1013	1	P	1979	2			1	1	59	Y	1	OBD79_17C_5	0.04	1
1014	2	D	1979	3			1	1	53	Y	5	OBD79_17C_5	0.33	1
1015	1	D	1979	2			5	3	41	Y	1	OBD79_17C_5	0.04	1
1016	1	D	1979	3			5	3	41	Y	1	OBD79_17C_5	0.16	1
1017	1	D	1979	4			5	3	33	Y	1	OBD79_17C_5	0.43	1
1018	1	D	1979	3			5	2	26	Y	1	OBD79_17C_5	0.24	1
1019	1	D	1979	4			2	2	45	P	2	OBD79_17C_5	0.92	1
1020	2	P	1979	4	1997	4	1	1	52	Y	1	OBD79_17C_5	0.90	1
1021	1	Q	1979	3			2	2	57	P	2	OBD79_17C_5	0.39	1
1022	2	P	1979	3			1	1	51	Y	1	OBD79_17C_5	0.32	1
1023	1	D	1979	3			2	2	59	Y	2	OBD79_17C_5	0.32	1
1024	1	P	1979	2	1990	2	2	1	22	Y	3	OBD79_17C_5	0.02	2
1025	5	P	2002	5	2003		4	2	34	Y	4	Puget Sound Lidar, 2002	10.74	4
1026	5	P	2002	5	2003		4	2	22	N	4	Puget Sound Lidar, 2002	20.17	4
1027	1	D	1967	4	1979	5	9	2	46	Y	3	OBD79_17C_5	0.57	3
1028	3	Q	1979	5	1990	3	2	2	41	I	3	OBD79_17C_2	2.18	1
1029	1	P	1985	2			1	2	46	Y	2	OL85_20_021_178	0.04	1
1030	1	P	1985	2			5	2	43	P	2	OL85_20_021_178	0.06	1
1031	2	D	1985	3			1	1	43	Y	2	OL85_20_021_178	0.26	1
1032	1	P	1985	5			5	2	43	P	2	OL85_20_022_237	1.84	2
1033	1	D	1985	3			5	2	49	I	2	OL85_20_022_237	0.38	1
1034	1	P	1985	2			5	1	46	Y	1	OL85_20_022_237	0.04	1
1035	6	D	2000	5			2	2	90	Y	4	PBS (2000)	9.16	1
1036	5	Q	2000	5			5	2	78	Y	4	L. Lingley, 2000	6.16	1
1037	1	Q	2000	4			5	1	67	Y	5	L. Lingley, 2000	0.43	1
1038	6	Q	2002	2			5	2	42	Y	3	Puget Sound Lidar, 2002	4.50	1
1039	1	P	1985	2			1	1	69	Y	3	OL85_20_022_235	0.10	1

Slide_id	Lsi_process	Certainty	Id_date	Ls_size	Id2_date	Id2_size	Landform	Slp_shp	Gradient	Delivery	Landuse	Photo_num	Acreage	MWMU
1040	1	P	1985	2			1	1	44	Y	3	OL85_20_022_235	0.05	1
1041	1	P	1985	2			1	1	46	Y	3	OL85_20_022_235	0.04	1
1042	1	P	1985	2	1990	2	8	1	55	Y	3	OL85_20_022_235	0.10	1
1043	5	Q	1985	5			5	2	58	Y	3	OL85_20_022_235	4.77	1
1044	5	Q	1985	5			5	2	58	Y	4	OL85_20_022_236	6.33	1
1045	1	P	1985	2			8	2	61	Y	1	OL85_20_022_236	0.08	1
1046	1	Q	1985	2			5	2	48	P	1	OL85_20_022_237	0.04	1
1047	1	Q	1967	2			5	2	42	I	1	WFPA66_63B_10	0.05	1
1048	1	P	1967	2			5	2	46	N	1	WFPA66_63B_10	0.06	1
1049	2	Q	1967	3			2	1	46	P	1	WFPA66_63B_10	0.19	1
1050	2	P	1967	4			8	1	46	Y	1	WFPA66_63B_10	0.51	1
1051	1	P	1967	1			8	3	49	I	1	WFPA66_63B_10	0.02	1
1052	2	P	1967	2			1	1	63	Y	2	WFPA66_63B_10	0.10	1
1053	2	P	1967	2			8	1	25	Y	1	WFPA66_63B_10	0.10	2
1054	1	P	1967	4			9	2	22	Y	3	WFPA66_63B_10	0.96	3
1055	1	P	1967	4			9	2	22	Y	3	WFPA66_63B_10	0.51	3
1056	1	P	1967	3			9	2	41	Y	3	WFPA66_63B_10	0.20	3
1057	1	D	1967	4			9	2	61	Y	3	WFPA66_63B_10	0.50	3
1058	1	P	1967	2			1	1	31	P	1	WFPA66_63B_10	0.07	2
1059	1	P	1975	3			2	2	48	I	5	OLC75_11B_27	0.28	1
1060	1	P	1975	2			2	2	89	I	5	OLC75_11B_27	0.10	1
1061	2	D	1990	2	1997	4	1	1	50	Y	5	OL97_26_21_102	0.64	1
1062	1	P	1997	1			2	2	52	P	3	OL97_26_21_102	0.01	1
1063	1	P	1997	2			1	2	49	Y	3	OL97_26_22_39	0.06	1
1064	1	D	1997	3			2	1	42	Y	1	OL97_30_23_166	0.13	1
1065	1	D	1950	4	2004	2	1	2	80	Y	2	Carl BerrySYF10_31	0.34	1
1066	1	D	1950	5	2004	4	1	2	76	Y	2	Carl BerrySYF10_31	0.37	1
1067	5	D	2004	2			7	2	44	N	5	Field Observation	0.32	2
1068	1	D	2004	3			5	2	54	Y	5	Field Observation	0.03	1
1069	3	D	2004	2			5	2	56	Y	5	Field Observation	0.08	1
1070	4	D	2004	5			5	2	74	N	4	Field Observation	4.40	1
1071	4	Q	2004	5			5	2	64	P	4	Field Observation	2.27	1
1072	2	P	2004	3			8	2	64	P	3	Field Observation	0.09	1
1073	1	P	2004	1			7	3	80	N	3	Field Observation	1.08	2
1074	4	Q	2004	5			5	2	47	N	4	Field Observation	0.03	2
1075	4	Q	2004	5			5	2	30	N	4	Field Observation	0.36	2
1076	4	P	2000	5			5	2	58	N	4	PBS (2000)	1.36	2

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

MWMU Number: 1 — Inner Gorges, Bedrock Hollows, and Convergent Headwalls

Description:

MWMU1 comprises inner gorges, bedrock hollows, and convergent headwalls, commonly at lower angles than rule-identified (WAC 222-16-050) slopes. MWMU1 covers 5% of the study area. Landslides commonly initiate in harvest units on steeper slopes near ridge crests and as a result of road construction and maintenance. Convergent headwall areas are of particular concern.

Materials:

Miocene to Eocene sandstone, siltstone, and shale of the Olympic Core Complex (Tabor and Cady, 1978; Gerstel and Lingley, 2000; Lingley and Lingley, 2002) along with overlying thick gummy soils and blocky colluvium derived from the bedrock.

Landform:

Inner gorges, bedrock hollows, and convergent headwalls; in the Calawah watershed, these are generally subdued with rounded topography and only rare v-shaped profiles. Includes several possible earthflows and small sporadic deep-seated landslides.

Slope (rounded off from DEM):	Min: 10%	Max: 122%	Typical: 40% - 50%
Elevation:	Min: 390'	Max: 1,560'	Typical: 900 to 1000'
Total Area:	362 acres		
Total Area of Landslides:	74.1 acres.		
Total Number of Landslides:	53		

MW Processes:

Shallow rapid processes, but relatively few large debris flows. Minor questionable earthflows and questionable to definite small sporadic deep-seated landslides. Landslides may initiate in any area of convergence, even on low angle slopes (40% to 70%). Landslides commonly occur as a result of the loading of the slope with sidecast in roaded areas of convergence.

Forest Practice Sensitivity:

High. Clear cuts, young stands, sub-mature stands, and roading accounting for 30%, 25%, 21%, and 15% of all landslides, respectively. Road maintenance and construction as well as end-haul sites of particular concern.

Mass Wasting Potential:

High. 53 landslides have been identified.

Number of Delivering Landslides:	34
Area of Delivering Landslides:	7.9 acres
Deliverability Susceptibility Factor:	404

Delivery Potential:

High. However, total delivery volume in the watershed is only moderate.

Delivery Criteria Used:

Fresh shallow rapid landslides observed to enter directly into various drainages.

Hazard Potential Rating: High.

Trigger Mechanisms:

Harvest in convergent headwalls and steeper slopes near ridge crests and failure of side-cast and/or fill material associated with forest roads and landings.

Confidence:

Moderate. Because of the low slope angles on which landslides initiate, there is concern that some landslides under the canopy have not been located and benign anomalies have been mis-identified as landslides.

MWMU Number: 2 — Other Upland Areas

Description:

MWMU2 includes low to moderate angle hill slopes along Elk Creek and north of the Calawah River. A few shallow rapid landslides and earthflows are randomly distributed across the MWMU. Like MWMU1, most of the failures occur in thick grayish-orange soils derived from rapidly weathering, orangish-gray, thinly-bedded sandstone, siltstone, and shale. MWMU2 covers about 23% of the study area.

Materials:

Miocene to Eocene sandstone, siltstone, and shale of the Olympic Core Complex (Tabor and Cady, 1978; Gerstel and Lingley, 2000; Lingley and Lingley, 2002) along with overlying thick gummy soils and blocky colluvium derived from the bedrock.

Landform:

Low to moderate angle hill slopes and convergent basins. Also includes the alluvial flat of Elk Creek.

Slope (rounded off from DEM):	Min: 4%	Max: 52%	Typical: 25%
Elevation:	Min: 380'	Max: 1,520'	Typical: 750'
Total Area:	1881 acres		
Total Area of Landslides:	5.6 acres.		
Total Number of Landslides:	10		

MW Processes:

Shallow rapid and small sporadic deep-seated landslides.

Forest Practice Sensitivity:

Moderate. Clear cuts, young stands, sub-mature stands, and roading accounting for 60%, of all landslides. Analogy with MWMU1 indicates that MWMU2 may be highly sensitivity to road building, especially where thick side cast or end-hauled material loads the slope.

Mass Wasting Potential:

Medium. MWMU2 is rated as having a Medium mass wasting potential with an observed landslide rate of 0.2 landslides per year between 1950 and 2004.

Number of Delivering Landslides:	5
Area of Delivering Landslides:	2.4 acres
Deliverability Susceptibility Factor:	24

Delivery Potential:

Low. Only 50% of all landslides deliver and the estimated total volume of deliver is very low.

Delivery Criteria Used:

Shallow rapid tracks entering into drainages noted on aerial photography.

Hazard Potential Rating:

Low for harvest, moderate for road building and maintenance. However, road construction and maintenance have a moderate hazard potential rating and should be undertaken with care.

Trigger Mechanisms:

There are too few failures to adequately characterize with statistical rigor, but side-cast and/or fill material associated with forest roads and landings are of concern.

Confidence:

Medium.

MWMU Number: 3 — Incised Channel of the Calawah River
Description:

MWMU3 occurs in the steep, incised, channel of the Calawah River. The position of meanders within the gorge has remained essentially static since 1934. Under cutting along the outside of meanders and over-steepening by continuous incision create most failures. Slopes along the margin are commonly much steeper than they appear on aerial photography or DEM slope percent maps. MWMU3 covers about 5% of the study area.

Materials:

The upper parts of MWMU3 are underlain by continental glacial outwash but older glacial and inter-glacial deposits may be present on side slopes.

Landform:

A steep inner gorge having walls approximately 100-feet. The valley has the form of an antecedent drainage.

Slope (rounded off from DEM):	Min: 4%	Max: 52%	Typical: 25%
Elevation:	Min: 380'	Max: 1,520'	Typical: 750'
Total Area:	389 acres		
Total Area of Landslides:	8.5 acres.		
Total Number of Landslides:	11		

MW Processes:

Shallow rapid landslides and small sporadic deep-seated landslides.

Forest Practice Sensitivity:

Moderate. Although all slides appear in young stands or sub-mature forests, active under-cutting as the river incises its valley occurs continuously. MWMU lies within a riparian management zone and (or) channel migration zone.

Mass Wasting Potential:	Medium.
Number of Delivering Landslides:	11
Area of Delivering Landslides:	8.5 acres
Deliverability Susceptibility Factor:	405

Delivery Potential:

High. Although the estimated delivery volume is low, all slides enter directly into the river and persist as bare scars over periods of decades.

Delivery Criteria Used:

Landslides observed as continuously failing into the Calawah River over a long period.

Hazard Potential Rating:

High. However, the entire MWMU lies within the Calawah River channel migration zone.

Trigger Mechanisms:

Over-steepening during incision and minor undercutting on the outside of meander bends.

Confidence:

High.

MWMU Number: 4 — Forks Prairie

Description: The flat prairie on both sides of the Calawah River between the Bogachiel and Sol Duc Rivers.

Materials: Continental glacial and recent stream deposits both of which are mainly of sand and gravel. These sediments are seldom prone to failure because of their very low slope angles and because of their mechanical strength and high permeability. (As a result of its high transmissivity, groundwater does not tend to rise high enough to contribute to instability.) MWMU4 also includes one southwest–trending ridge (Section 5, T28N, R13W) that is composed of ancient alpine sediments from glaciers that flowed down from the central Olympic Mountains. Failure style on both ends of the ridge suggests it contain ancient till and glacial lacustrine clay that may be prone to liquefaction.

Landform: A flat outwash prairie plain typical of many areas in western Washington.

Slope (rounded off from DEM):	Min: 0%	Max: 41% (on ridge)	Typical: 2%
Elevation:	Min: 75 '	Max: 383'	Typical: 200'
Total Area:	5400 acres		
Total Area of Landslides:	30.9 acres.		
Total Number of Landslides:	2		
MW Processes:	Deep seated -- soil liquefaction (?).		
Forest Practice Sensitivity:	Low.		
Mass Wasting Potential:	Low.		
Number of Delivering Landslides:	1		
Area of Delivering Landslide:	10.7 acres		
Deliverability Susceptibility Factor:	37		

Delivery Potential:

Low – Delivers only to a poorly connected oxbow swamp with questionable connectivity.

Delivery Criteria Used:

Landslide I.D. No. 1025 observed to cross oxbow swamp on LIDAR.

Hazard Potential Rating:

Low. However, the potential for liquefaction failures on the southwest trending ridge may have safety implications for private landowners.

Trigger Mechanisms: Unknown.

Confidence:

High for areas covered by continental outwash and alluvium, which make up most of MWMU4. Low for the southwest-trending ridge.

13.0 Appendix C -- Mass Wasting Summary Tables

Mass Wasting Summary Table: MWMU#1

Activity	Shallow Rapid Landslides	Debris Flows	Debris Avalanches	Deep-Seated Landslides	Shallow Sporadic Deep-Seated Landslides	Large Persistent Deep-Seated Landslides	Earthflows	Totals
Clear Cut (timber 0-5 yrs)	12	4						**16**
Young Stands (timber 5-15 yrs)	8	2			2		1	**13**
Submature (timber 15-50 yrs)	7	1	1		1	1		**11**
Mature (timber > 50 yrs)				2	2	1		**5**
Road	5	2	1					**8**
Partial Cut								
Yarding								
Alpine								
Other (e.g. housing, agriculture)								

Mass Wasting Summary Table: MWMU#2

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

Mass Wasting Summary Table: MWMU#3

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

Mass Wasting Summary Table: MWMU#4

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