LANDSLIDE HAZARD ZONATION PROJECT PROTOCOL

Version 2.1

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Adaptive Management Program

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ASSESSMENT METHODS

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I. BACKGROUND AND APPLICATIONS

Identification of unstable slopes to aid in mitigation of landslide hazards is now an integral part of land management and regulation in the state of Washington. Permanent Rules adopted by the Washington Forest Practices Board (WFPB) in 2001 address landslide hazards from specific landforms that exist across Washington State (WAC 222-16-050 (1)(d)).

This methodology was developed to provide standardized methods for conducting landslide inventories and producing unstable-slopes-hazard maps to support the forest practices rules in identification of unstable slopes. It also provides a framework for monitoring the success of new forest practices strategies related to unstable slopes. Standardized methods will lead to consistency both within and between regulatory and mass wasting monitoring efforts.

The methods presented here are similar to those used in the Washington State Watershed Analysis Mass Wasting module (WFPB, 1994), but have been adapted to include rule-identified landforms, to improve consistency between mappers, and to meet the specific needs of the Landslide Hazard Zonation (LHZ) project. All practitioners of this protocol should be thoroughly familiar with the Forest Practices Board Manual for Unstable Slopes prior to beginning an assessment. The board manual is located online at: www.dnr.wa.gov/forestpractices/board/manual/section16.pdf.

The LHZ Project was created to map potentially unstable slopes of the state. The goal of the LHZ Project is to eliminate errors of omission while identifying unstable landforms during the forest practices permitting process. To this end, a geotechnical advisory committee (UPSAG) has developed this mapping and analytical protocol, to be used in conjunction with information garnered from Geographic Information Systems (GIS) analyses.

The methods provide three types of information: a map of observed landslides, a map of landslide hazard areas, and a report detailing the landslide hazard findings for each watershed administrative unit. For forest practices review, these products will be used as a screening tool to guide and assist foresters and land managers in identifying potentially unstable slopes. Actual ground conditions will dictate the course of action, not the map or report products. For monitoring purposes, the mapping and landslide inventories will provide the framework for reporting changes in landslides rates associated with forest practices over time.

As each watershed is completed, the information will be posted on a public website for free download. Additionally, the compiled statewide data will also be posted on a quarterly basis for public access and download. GIS data and LHZ information products can be accessed at: www.dnr.wa.gov/forestpractices/data and www.dnr.wa.gov/forestpractices/lhzproject, respectively.

The maps will assist in refining the existing screening for potential high-hazard areas. Once mapped, these areas are intended to be substituted for the landforms described in

C.1(b)(i) of the Forests & Fish Report (1999). This protocol may also be used to update the Watershed Analysis mass wasting methodology, from which it is derived.

These methods differ from those of Watershed Analysis in the approach to landform mapping and development of a quantitative hazard assessment based on landslide areal density.

II. Critical Questions

The analysis is designed to answer the question:

- *What is the mass wasting potential in the watershed?*

The following questions will help to develop and support the required answer:

- *What mass wasting processes are active?*
- *How are active and dormant mass wasting features distributed on the landscape?*
- *Does mass wasting deliver sediment to stream channels or other waters, or threaten public works or safety?*
- *How do forest management activities create or contribute to instability?*
- *What areas of the landscape are susceptible to slope instability and how do they differ in their susceptibility?*

III. Assumptions

A number of fundamental assumptions underlie the approach developed here. Our primary assumptions include:

- Time-sequenced aerial photographs can be used to interpret and document the history of land use and mass wasting in a basin. Although some features are obscured by vegetation, a sufficient number of landslides can be identified on aerial photos to identify primary controls on landslide processes.
- Existing mass-movement features can be used to predict the likelihood of future instability. Areas prone to these processes can be mapped based on physical characteristics, as interpreted from aerial photographs, topographic maps, geologic and soils maps, and field verification.
- Although most landslides are at least partly caused by natural processes or events, mass wasting features associated in time and space with forest practices are assumed to be caused or expedited by those activities.

- It is feasible to extrapolate from one sub-basin, location, or area to another having similar characteristics, based on information obtained from maps and aerial photos. Such characteristics include topography, slope, lithology, structure, aspect, and elevation.

- Many of the forest practices activities potentially triggering mass wasting have been conducted in the past in some or all of the areas sharing similar erosive characteristics. These prior experiments can be used to infer future landscape sensitivity to forest practices.

IV. Overview of Approach and Products

This mass wasting assessment incorporates information from analysis of aerial photographs coupled with information provided by GIS analysis. Analysts will first use aerial photographs to develop a historical landslide inventory. They will then work with the photographs, the inventory, and a GIS-generated preliminary landform map to create a final landform map, with hazard ratings assigned to each landform. Hazard ratings will be based on landslide history. All landforms will have hazard ratings.

The resulting products will be two maps, available both as paper copies and as digital GIS-based datasets, and a written report of the work done. One map will be an inventory of landslides; the other map will show areas with potential landslide hazards, both at a 1:12,000 scale. The GIS-based datasets will be a digitized inventory of landslides and the landslide hazard areas. The written report will describe the analysis and include explanatory text, landform descriptions, and landslide triggering mechanisms.

Information of differing precision is required and provided by the analysis depending on the situation. For our purposes, mass wasting hazard assessment encompasses three levels of analysis, each requiring increasing detail of information and complexity of analysis. Level 1 analysis, comprising a landslide inventory and a “low hazard” rating, is reserved for stable landforms, usually flat or low-gradient areas without observed landslide activity, as described under the procedural discussion in Section VI B. Level 2 analysis requires landform mapping and development of a hazard rating, also described in Section VI B. A Level 3 analysis is for site-specific investigations and will not be discussed in this document. Landslide processes and landform descriptions will be field verified, commensurate with the mapping level. The present protocol describes work to be done for Level 1 and Level 2 analysis. Table 1 provides a comparison of the three levels of mapping.

Table 1. Landform Mapping Levels for Landslide Hazard Work

Mapping Level	Use	Method of Field Checking	Percentage (%) of Landform Polygons Typically Field Checked	Map Base
Level 1	Preliminary mapping prior to field work; low landslide hazard areas; reconnaissance	No field work – air photo and map interpretation only	None	1:24,000 scale USGS topographic maps or 10m DEM; LiDAR DEM if available
Level 2	Planning level; landslide hazard zonation; landscape level monitoring; e.g. includes areas with bedrock hollows	Foot and vehicle traverse, some flying	15 – 25%, depending on project needs	Stereo aerial photos; orthophotos or LiDAR DEM if available
Level 3	Site-level planning unit and road layout; geotechnical SEPA review; e.g., mapping of individual bedrock hollows	Foot traverse	100%	Stereo aerial photos; orthophotos; GPS; LiDAR DEM if available

V. Start-Up Materials and Resources

A. Aerial Photographs

Time-series aerial photography is key to the mapping process. The photographs should be as chronologically extensive as possible. The following factors should be considered when choosing years to analyze:

1. Preferably extending back to preharvest;
2. At least decadally;
3. Optimally showing landscape response to storms. For example, major storms occurred in some areas in 1977 and 1996; photo series immediately post-dating these events should be included if available;
4. Chosen to expose bare-ground conditions (recently post harvest) if possible (this will be especially useful for doing the landform mapping);
5. Include at least one set of high altitude photos (1:60,000), which will assist in identifying large deep-seated landslides. LiDAR, if available, may also be useful for identifying these features;

Orthographic aerial photographs (orthophotos) of townships and quarter-townships are available for most of Washington and may also prove useful.

B. Maps

In addition, the team will collect or be provided with these start-up products:

1. 1:12,000 scale base map, showing elevation contours, streams, roads, township-section range information, and known landslides; federal and tribal lands will be delineated. The registration tics on the GIS-generated base maps are critical for digitization of the final maps, so mapping must be done on this base map. *Note: Although federal and tribal lands will not be mapped as part of this project, any unstable slope data that is available for adjoining lands will be provided.*
2. A map with any pre-identified hazard areas shown (e.g., previous analyses such as the regional unstable landform mapping [RLIP] and GIS-based preliminary landform mapping);
3. Results of the DNR slope stability model (SLPSTAB).
4. Geologic maps: DNR Division of Geology & Earth Resources (DGER) maps at 1:100,000 (or larger) scale.
5. The DNR GIS also contains digital data on hydrology, forest roads and other information that may prove useful.

C. Other possible information sources

1. Soil maps (state, USDA Forest Service etc.)
2. LiDAR where available, may also be useful for identifying large deep-seated landslide features and other landforms that are obscured by vegetation.
3. Landslide maps have been published covering some parts of the state. Consult the DGER indices for availability. Adjoining national forests may also have useful maps.
4. Mass-wasting hazard maps have been produced for a few regions, mostly in urban areas. Consult the DGER indices.
5. Other maps that may be helpful if available:
   United States Geological Survey (USGS) geologic maps;
   maps of land use, vegetation cover, etc., might also be available from the USGS, local planning agencies and/or landowners.

VI. Analysis procedure

The analysis comprises a three-step procedure. Each step is discussed in the detailed instructions below.

A. Conduct a Landslide Inventory.

B. Amend the GIS-derived Preliminary Landform map. Use the landslide inventory map, statistical analysis of the landslide data and geomorphic information provided by the GIS to create a landform map. Landforms will be differentiated based on slope gradient and shape, lithology, landslide density and sensitivity to forest practices. Specific rule-identified high hazard areas will also be individually identified in this process.

C. Set the hazard ratings for landforms. Hazard ratings will be assigned to the landforms based on observed landslide density over time.

A. Landslide Inventory

Overview

The purpose of the inventory is to collect information that will aid in understanding the distribution, timing, and relative size of mass wasting processes in the basin. This understanding will guide the creation of a basin-wide landform map.

Study the aerial photographs in stereo to identify landslides, their settings and land use triggers. Examine the time series of photographs, from the oldest to the youngest, and map all visible mass wasting events, evaluating each of them for certain characteristics. Each landslide should be shown and labeled on the base map in such a way that it can be entered into the GIS for Map A-1, the Mass Wasting Inventory Map. Keep in mind that the goal is to map (and tabulate) what mass wasting and unstable landforms are observed, so that the landslide inventory can guide the creation of landforms and identification of hazards. Complete the mass wasting assessment data form (Form A-1: Mass Wasting Inventory Data) attached at the end of this document.

The types of information to be collected for each landslide during the inventory are listed below, and subsequently discussed in more detail.

- Landslide Identification Information (Number and data source)
- Landslide Description (process, certainty, size, age)
- Landslide Geomorphic Setting (associated landforms, slope shape, gradient, delivery)
- Landslide Triggers (land use, elevation/precipitation zone)
- Reference Information (aerial photograph number)

This information, coupled with that provided by the GIS, will guide development of the landform map.

The Landslide Inventory (Form A-1)

The function of mapping landslides is to create a landslide dataset that is representative of unstable conditions in a watershed. The following is a key, with explanations, to the landslide inventory information to be entered on Form A-1. The numbered items correspond to columns in Form A-1. Starred * items are required; other information can be added if available.

- **Landslide Identification Information**

1. LSIUNIQID (Landslide Unique Identification Number)

Automatically calculated in the GIS entry process.

This number is not entered by the analyst, but will be generated by the GIS and provide an identification number for each landslide which is unique in the statewide inventory system.

2. *Slide id *(*Landslide Identification Number)

Up to five integers: *use the same number on the map and spreadsheet.*

The landslide identification number is assigned by the analyst while performing the inventory. Make this number unique within the WAU. This number should be unique for each landslide entity within a study area.

3. Source_idno (Source Identification Number)

991 = Priority 1 LHZ work

992 = Priority 2 LHZ work

993 = Priority 3 LHZ work

The source identification number indicates under which type of analysis the landslide was identified, and is an optional entry.

- **Landslide Description**

4. *Landslide Process

1= Shallow-undifferentiated

2 = Debris Flow

3= Debris Slide/Debris Avalanche

4= Deep-seated

7= Earth Flow

8= Rock Topples and Falls

9= Snow Avalanche

Below is a guide to designated landslide types for this analysis based on the remotely available data. Landslides are herein defined in a hierarchical structure; the first level of hierarchy is failure depth, shallow or deep. Depending on the quality of the air photo record and potential for field verification, greater detail in process descriptions may be possible.

1. Shallow Landslides

Shallow landslides are slope failures defined by a failure surface within the forest rooting zone (generally less than three meters) and above bedrock or in glacial sediments. The slope materials may include soil, regolith, colluvium, alluvium, or other sediments that mantle bedrock or dense, low permeability surficial deposits. The failure or movement tends to be rapid or short-lived. Some deep-seated landslides may be included in this group, as aerial photograph interpretation alone may not be able to differentiate between deep and shallow landslide types. Shallow landslides are herein defined as being of four types: debris flows, debris slides, topples and falls, and snow avalanches. Forest practices, by causing changes in slope hydrology and loss of root reinforcement of hillslopes, have demonstrated impacts on the frequency of shallow landsliding.

1) ***Debris Slide***: A shallow landslide that forms from the disaggregation of materials on a steep slope, involving the rapid movement of the soil and regolith over bedrock. This category includes those types of landslides also known as shallow-rapid, soil slips, and debris avalanches in Washington State's Watershed Analysis Method. The lack of significant water differentiates a debris slide from a debris flow.

2) ***Debris Flow***: A shallow landslide that flows within a channel formed either by the valley walls of a low-order tributary or by levees of its own making. It consists of soil and water with varying quantities of woody debris and is characterized by channelized flow, and often has a long runout path. This category may include those events referred to as mud flows, debris torrents, hyper-concentrated slurries, and landslide dam-break floods.

3) ***Topples & Falls***: Shallow topples and falls consist of the individual blocks of soil or rock that become detached from a steep slope and descend through the air by falling, bouncing, or rolling before coming to rest on gentler slopes. Soil topples and falls tend to disintegrate whereas rock topples and falls do not. Repeated topples and falls lead to soil blocks forming a convex colluvial foot-slope and rock blocks forming talus (includes all forms of topple and fall that can not be identified as deep-seated). These may contribute to deep-seated landslide activity by loading at the headscarp.

4) ***Snow Avalanche***: Failure within or at the base of the snow pack of alpine areas that results in the rapid down-slope movement of snow, woody debris, and minor surface sediment to the base of the slope. The avalanche path results in an elongate area devoid of timber in the alpine and subalpine areas and fan-shaped deposits of rock and wood at the base of the slope. They tend to repeatedly occur in the same area resulting in snow-avalanche chutes and fans.

The depth and failure mechanisms of landslides are not always identifiable from remote and time-distanced observation. Landslides may also not fall easily within the categories outlined: e.g., small rapid landslides may have a failure plane just below the rooting zone, large translational shallow failure may be observed. Such discrepancies should be discussed in the text of the mass wasting report, and be addressed explicitly in the landform descriptions (Form A-2).

In some instances, the density of landsliding will preclude an analyst's ability to map all of the landslides. Generally, this condition occurs when individual landslide initiation areas are overlapping, or when shallow landslides are more than about one per acre. In those instances where the density of landslides is such that mapping all of them is not possible within an individual landform, map the bigger ones and characterize those. Focus your energy on mapping debris flows or those larger landslides that appear to affect a resource. Put a dot at the initiation points of the rest of the smaller landslides; characterize one or two of these sites, and copy/paste that characterization to the rest of the initiation points within that landform. Specify an average size for that type of landslide. This method is valid only within an individual inner gorge or convergent headwall, not across multiple landforms (e.g. multiple inner gorges), as this method has the ability to affect the landform hazard calculation. Ensure that the landform description has adequate field descriptions for identifying the landslide risk onsite.

2. Deep-Seated Landslides

Deep-seated landslides are those in which most of the area of the slide plane or failure zone lies below the maximum rooting depth of forest trees, to depths from several to hundreds of meters (Washington Forest Practices Board, 2002). Deep-seated landslides involve glacial deposits, deep regolith, weathered rock, and/or bedrock, as well as surficial (pedogenic) soil. As used here, deep-seated landslides include large (acres to hundreds of acres) slope failures associated with geologic materials and structures.

These landslides are commonly associated with geologic weakness and may be triggered by seismic shaking or channel incision. Climatic changes, ranging from major (e.g., glacial-interglacial transitions), to intermediate (runs of several wet years), to short-term events (extreme storm precipitation which may be coupled with antecedent moisture, hydrologic loading of the slope (e.g. road drainage), added weight at the head scarp, modification of the toe slope, etc.) may also trigger or accelerate deep-seated landslides. Earth flows are included herein as a type of slow-moving, deep-seated landslide. Large rock slides are also included in this category.

Once formed, deep-seated landslides can persist for a few years to centuries. Debris from deep-seated landslides is typically supplied from the margins of the feature to a channel. The stream itself can be the cause of chronic movement if it periodically excavates the toe of the large slide mass. Small deep-seated landslides can occur within the slide mass at irregular intervals (by storms or earth movement), and subsequent erosion can modify the entire slide feature to the point where it is indiscernible on the landscape. Forest practices may impact the activity of deep landslides by causing changes in slope morphology or hydrology. Because movement may be affected by changes in hydrology, land use that affects hydrologic rates or timing can influence movement. In addition, road construction that significantly alters the distribution of material, in particular along the toes of slides, can also increase failure potential.

For this analysis, deep-seated landslides will be characterized by both mechanism and activity level:

Activity Level: following guidance from the Keaton and DeGraff (1996), analysts will classify the age of landslides: (Table 2)

a) Active/ recent

b) Dormant – distinct

c) Dormant – indistinct

d) Relict

These characteristics are summarized in the Transportation Research Board's 1996 publication, Landslides Investigation and Mitigation, Table 9.1 (p. 186), (a modified version of the table is reproduced as Table 2 on the following page).

1) ***Type***: Where possible, analysts will differentiate between the following types of deep-seated landslides:
    a) Rotational
    b) Translational (includes large rock slides)
    c) Combination
    d) Earthflow.

Table 2. Deep-seated Landslide Activity Levels (modified from TRB, 1996)

Activity State	Main Scarp	Lateral Flanks	Internal Morphology	Vegetation+	Toe Relationships
Active/ recent*	Sharp; unvegetated	Sharp; unvegetated; streams at edge	Undrained depressions; hummocky topography; angular blocks separated by scarps	Absent or sparse on lateral and internal scarps; trees tilted and/or bent	Main Valley stream pushed by landslide; floodplain covered by debris; lake may be present
Dormant – distinct	Sharp; partly vegetated	Sharp; partly vegetated; small tributaries to lateral streams	Undrained and drained depressions; hummocky topography, internal cracks vegetated	Younger or different type or density than adjacent terrain; older tree trunks may be bent	Same as for active class but toe may be modified by modern stream
Dormant – indistinct	Smooth; vegetated	Smooth; vegetated; tributaries extend onto body of slide	Smooth, rolling topography; disturbed internal drainage network	Different type or density than adjacent terrain by same age	Terraces covered by slide debris; modern stream not constricted but wider upstream floodplain
Relict	Dissected; vegetated	Vague lateral margins; no lateral drainage	Smooth, undulating topography; normal stream pattern	Same age, type, and density as adjacent terrain	Terraces cut into slide debris; uniform modern floodplain

* Recent is defined as being within the photo history or within the period of forest management.

+ Vegetative indicators are identified as forest and not grasses, forbs, or shrubs. It is important to note that in most areas of western Washington, landslide scars re-vegetate within 15 years and may be difficult to detect from aerial photographs 10 to 15 years after the slide occurred.

Where it is possible (given the resolution of the mapping), differentiate (that is map as different parts) deep-seated landslide headscarps, bodies, and toes, as these may be useful in the next step of delineation of landforms and associated hazards. The entire landslide (headscarp, body, and toe) should be given the same landslide number.

- Landslide Description Information, continued

5. *Certainty

D = Definite: originator of landslide information is certain that this is a landslide

P = Probable: originator of landslide information is almost certain that this is a landslide

Q = Questionable: originator of landslide information is not certain that this is a landslide, but is including it for completeness of the inventory.

A variety of factors govern the certainty with which an analyst can remotely identify a landslide including ground cover, age and size of landslides, the scale, aspect, or lighting conditions of an aerial photograph. Note the certainty of landslide identification in this column. These are intended to be qualitative statements as to the certainty the analyst has that the observed feature is a landslide. Landslides with a “questionable” designation will not be included in the landslide hazard calculations, but are included to note that the analyst did observe the feature. Additionally, on the first set of photos, only map and tabulate those landslides for which you are definite and occurred recently to the time the photo was taken, as there is no way to ‘age date’ the landslide. Also, on the Westside of the state, it is common for landslide scars to re-vegetate within 15 years and there is little evidence onsite of the failure decades afterwards (unless it is very large). The assignment of relative certainty should also guide field verification, with ‘questionable’ and ‘probable’ calls given a priority to resolve in the field. Older or re-vegetated features may be difficult to see on subsequent aerial photos, but may still be identifiable on the ground.

6. *Id_date (Identified date of slide)

First year of landslide identification. Use photo year or best estimate of landslide age using a four digit year.

7. Ls_size (Landslide size – area in square yards)

Approximate size at Id_date

1 = very small (1-100 square yards)

2 = small (101-500 square yards)

3 = medium (501-2000 square yards)

4 = large (2001-5000 square yards)

5 = very large (greater than 5000 square yards)

Landslides should be drawn on the base map and their size estimated. Area will serve as a proxy for estimating landslide volumes. Note: the GIS will also generate a landslide area.

8. Id2_date (Second identified date of landslide)

Next year of landslide identification. This only needs to be filled in if slide has enlarged in size or shape. Use a four-digit year. If the landslide is growing larger with each successive photo year, then note the initial size and final observed size and note in the comments section that the slide has gotten larger over time and any triggering mechanisms, if known.

9. Id2_size (Size of landslide in a later year it was observed on aerial photograph) to be used for landslides that have grown larger over time.

Approximate size at ID2-Date (see LS_Size for details)

10. Init_elev (Initiation Elevation)

Elevation in feet of the landslide initiation site (integer)

11. Photo_num

The full photo number the slide was identified on (15 characters)

- **Landslide Geomorphic Information**

12. Landform

1 = inner gorge

2 = bedrock hollow

3 = avalanche chute

4 = terrace face

5 = headwall

6 = rock outcrop

7 = other

8 = deep-seated

9 = stream influenced

If the analyst observes that a landslide is appears on, or is associated with, one of these landforms, it should be noted as such. Often one cannot remotely sense (i.e., via photo interpretation) whether the slope criteria is explicitly met for a landform, but the intent is that if appears to occur on a named landform, it should be noted as occurring on that landform. If the landslide does not appear to be occurring on a named landform, call it 'other'.

13. * Slp_Shp (Slope Shape)

1 = convergent (some analysts refer to this as concave)

2 = convergent to planar

3 = planar

4 = planar-to divergent

5 = divergent (some analysts refer to this as convex)

14. *Gradient

Percent slope at the failure location (Often at the highest point of the landslide, also known as the initiation point)

15. *Delivery

Y = yes, delivery to a public resource or a threat to public safety is observed in the photo or in the field as having occurred

N = no, delivery to a public resource or a threat to public safety is neither observed in the photo nor in the field or there is a physical impediment to prevent delivery did not occur.

P = probably sediment delivered, that is, delivery to a public resource or a threat to public safety was not directly observed, but the likelihood is that it did. This value is to be used when one cannot unequivocally determine that sediment did not deliver, but <u>is likely</u> to have done so, based on proximity, lack of physical impediments, length of similar landslide runouts, or other information.

I = indeterminate, this value is to be used when one cannot unequivocally determine that sediment did or did not deliver to a public resource or a threatened public safety.

Analysts will attempt to determine whether debris from the landslide was delivered to public resources or has threatened public safety. Definitions of public resources are found in WAC 222-16 (definitions). Take care to be confident in making a "no delivery" call remotely, considering that stream channels may be obscured by ground cover.

The following considerations can help guide the delivery call:

- ***Shallow landslides***

- Generally, all shallow landslides will be assumed to deliver. The cases in which delivery definitely cannot be expected are few. (Often, smaller stream channels cannot be located with aerial photography.)
- However, the few areas where significant impediments to delivery are present should be identified. (A slope ending on a highly permeable outwash plain with no surface drainage is an example.)
- Landslides that enter overflow or side channels within a Channel Migration Zone are considered as delivering.
- Landslides entering wetlands are considered to deliver, except where the landslide enters a forested wetland without demonstrable connectivity.

- ***For deep-seated landslides***

  - For active deep-seated landslides it is assumed that the headscarps and toes deliver, unless evidence (field or photo) indicates otherwise.
  - For dormant and relict slides, it is assumed that the body of the slide does not deliver, but the headscarp and toes may.
  - Shallow landslides superimposed on deep-seated landslides are included in the calculation of the shallow landslide hazard.

- **Triggering Information**

14. *Land use (add pictographs-westside coniferous and deciduous)

1 = clearcut (timber 0-5 years)

2 = young stands (timber 5-15)

3 = submature timber (15-50 years)

4 = mature timber (> 50 years)

5 = road (includes landings, spur roads, and culvert failures)

6 = partial cut

7 = yarding

8 = alpine

9 = other: e.g., housing, agriculture

Record information on activities noted in association with the landslide. Pick the most likely situation. Make the assumption that if landslide and land use appear to be associated, that there is a causal relationship. Additional information (for example, types of road failure or secondary land uses) may be noted in the Comments column. To the best of your ability, tabulate all information as accurately as possible for each landslide, as the landslide inventory is the supporting documentation for the landform mapping. When beginning a watershed, it may be useful to spend a day with a forester from the area and a recent photo of the area to acclimate your eyes to the canopy cover and age classes. Pay special attention to the differences between young stands and submature timber so that as you review the photos it is easier to estimate the age class and land use. Generally, for deep-seated landslides, stand age designation should not be considered a triggering mechanism unless the documentation suggests otherwise. In spite of this, for deep-seated landslides, especially relict, dormant-indistinct, dormant-distinct types, the land use is predicated on what the stand age was when the landslide was first observed. If, over time, there are no observed timber harvest effects, then the landslide does not appear to be sensitive.

B. Landform maps

Landform maps are developed after the landslide inventory phase of the analysis is complete. The goal of landform mapping is to divide the landscape into geomorphically distinct areas sharing similar landform characteristics, forest practice sensitivity, and delivery potential. Analysts will begin with a GIS-generated preliminary landform product and amend it as necessary, based on information from and analysis of the landslide inventory and aerial photograph interpretation.

As outlined below, the analyst will first identify stable areas of the landscape using Level 1 analysis, and then delineate rule-identified high hazard landforms (as required by Washington Administrative Code). Identifying these landforms will assist the analyst in distinguishing those areas clearly requiring a “low” or “high” hazard designation from those areas requiring more analysis. After these features are identified, the remaining areas will undergo a Level 2 analysis to delineate landforms with similar lithology, failure process (es), landslide density, and delivery potential to the degree of detail necessary to capture differences in landslide hazard. Level 3 analysis is site-specific associated with individual Forest Practice Applications and is not included in this protocol.

All landform polygons and associated values for slope, slope form, etc. will be entered into GIS as part of the landform polygon coverage, and each will receive a unique identifier. Many polygons may have the same descriptive name or code. The analyst may choose to digitize polygons directly into ArcMap or to delineate them onto maps or other medium for transfer to GIS.

1. Preliminary Landform Map

The GIS–derived preliminary landform map contains the following slope, topographic, and geologic attributes known to be positively correlated with slope stability overlaid in such a manner as to provide a basis for identifying unique landforms (see Figure X):

a. slope ranges

0-10% shown as **10**

11-40% shown as **40**

41-60% shown as **60**

61-80% shown as **80** (this range of slope values is used instead of the common rule-identified 70% slope break because most Digital Elevation Models underestimate slope by about 10%)

81% and steeper shown as **85**

b. lithology

mapped using State Geologic Map nomenclature

c. slope shape (based on the use of the SLPSTAB model, which is a curvature/slope model)

d. other standard map information (contours, township, range, section, hydrography, transportation)

2. Level One Analysis

Delineate the stable landforms listed below (e.g., low slope areas with no evidence of mass wasting); using the preliminary landform map, the landslide inventory, and aerial photograph interpretation of terrain conditions. Note: those photos that show a bare ground condition (shortly post-harvest) are best for doing the landform mapping.

a. Flat (e.g., prairies, floodplains) (**F**)

b. Ridgetops (**R**)

c. Low-gradient hillslopes (11-40%) (**LH**)-to be used as a low hazard landform under the following circumstances: failures are non-existent or rare, small and do not deliver.

Stable landforms are assigned a “low hazard” rating, and the Level 1 analysis is complete for these areas at this stage. Assignment into any of these categories implies that no further analysis was conducted. For these “low hazard” areas, provide descriptive text on the Level 1 Form A-2. As appropriate, these areas should be labeled as flat, ridge tops, or low-gradient hillslopes. Level 1 analysis is not appropriate for moderate or high hazard areas. In rare instances, portions of a watershed may not be forested or alpine, but are still part of the natural, managed landscape (e.g., wheat fields) where forest practices rules do not apply. In those instances, these areas should be identified on the landform map with a polygon that identifies them as ‘Not Applicable’, and the unit description for that polygon should identify what about them makes them not forest lands.

3. Level Two Analysis

Overview

For all remaining areas, divide the landscape into geomorphic landforms. Study the landslide inventory map in conjunction with the preliminary landform map. First, map the rule-identified landforms. For the remaining portions of the watershed, characterize other landforms based on slope gradient and form, lithology, and delivery potential. Each landform should be unique in terms of landslide density, sensitivity to forest practices, and/or delivery potential. Rule-identified landforms (identified in WAC 222 16-050) will receive a high hazard, and all landforms identified at Level 2 will be coded as discussed below. It is often most helpful to use the photography that shows the ground in a bare condition for identifying landforms. Field verify all landforms and develop unit descriptions and hazard calculations.

Step 1. ***Identify the named landforms*** (WAC 222 16-050). These named landforms may be further broken out as to the other characteristics such as slope and lithology <u>if practical and useful for guiding landside hazard evaluation</u>. Such distinctions might include types of inner gorges (bedrock, glacial, on deep-seated landslides, etc.) or terrace elevations, if relevant. When it is possible at the map resolution, the landform mapping should discriminate between the rule-identified landforms (e.g., bedrock hollows and inner gorges should be two separate units, not lumped together as one unit). For map legibility, landslide hazard map units (i.e., mapped landforms) should not be smaller than one half (0.5) acre (minimum mapping polygon size).

a. Inner gorge (**IG**)

b. Bedrock Hollow (**BH**) – may be mapped individually or as an area with a high concentration of bedrock hollows

c. Convergent Headwall (**CH**)

d. Toes of Deep-Seated Landslides (**TOE**) It is important to include this landform only when it is demonstrating failure potential. Landslides of questionable certainty may not have toes identified, as the analyst is not certain whether or not the landslide even exists.

e. Meander Bend (**MB**)

f. Avalanche Chute (**Avalc**) – may be mapped individually or as an area with a high concentration of avalanche chutes.

g. The following specific landform names may also be used, as necessary for hazard evaluation. These are not rule-identified landforms, but have been identified as a possible hazardous landform in several regions. Terrace Face (**Terr**)-to be included only if they present a hazard

h. Deep Seated Landslide (**DSLS**) -to be included only if they present a hazard

Note

Analysts will not identify groundwater recharge areas to glacial deep-seated landslides, but will identify deep-seated landslides which will be mapped as separate landforms in whatever lithology they occur. Groundwater recharge areas will be identified in Level 3 site-specific analyses.

Be sure that all rule-identified landforms have been specifically identified. Note that, as appropriate for the level of hazard they represent, Active Deep Seated Landslides may be identified as a separate landform.

For all rule-identified landforms, the hazard rating is considered high by default. Rule-identified landforms may later be "upgraded" to be flagged as having "very high" hazard call, but may not be "downgraded".

Special guidance to simplify landform mapping:

- Lumping landforms within landforms: In general, when rule-identified landforms are nested (that is, one landform exists within another) lumping is permissible and encouraged. In those instances, the map legend and database should indicate that landform 'X' is being mapped and contains landform 'Y'. In the database, landform 'X' would be the primary landform; landform 'Y' would be the secondary landform. An example of this is bedrock hollows that occur within an inner gorge. The inner gorge is the primary landform; the bedrock hollow within it is the secondary. If you have a secondary landform (e.g. bedrock hollow) that extends significantly beyond the primary feature (e.g. inner gorge) map both of them individually. (This approach implies that there is a hierarchy of rule-identified landforms, which is approximated by 1) convergent headwalls, 2) inner gorges, 3) bedrock hollows, and 4) toes of deep-seated landslides.)

- Lumping landforms adjacent to landforms: When it is difficult to differentiate between where one rule-identified landform begins and the other ends (e.g., a convergent headwall ending at an inner gorge), make your best estimate of the demarcation and code the polygons appropriately. This is especially important when triggering mechanisms or delivery potential are different. Landforms (e.g., inner gorges) can have varieties (e.g., glacial and bedrock), but as these are still varieties of the same landform they must be mapped as such (i.e., inner gorge) with a description in the text of the various types. It is not acceptable to map the different types of a particular landform as multiple landforms (e.g., inner gorge-A or inner gorge-B).

Step 2. Compare the inventory map with the preliminary landform map.

If there are no historic landslides in an area and that area is absent any other attributes of slope instability, then the area can be assigned a "low" hazard and it is not necessary to collect more information than slope category. For these "low hazard" areas, provide descriptive text in the assessment report including the slope range, lack of triggers, and the types of general landform(s) the unit includes, such as valley bottom, terrace surface, or low gradient hillside.

If landslides have occurred or there is the potential for landslides in an area based on the presence of landslides on similar ground elsewhere, create a set of basic information from an analysis of the landslide inventory to develop a set of physical signatures for the unnamed landforms. Delineate individual landform units based on the following criteria:

a. Minimum and Maximum Percent slope for the unit (mapped element)

b. Forest Practice Sensitivity

c. Convexity/slope form (i.e. P->H) (mapped element)

d. Lithology (based on the Washington State Geologic Map, as shown on the GIS or based on analyst observations; see analyst-provided information below)

e. Delivery: a polygon may need to be split if one portion has significant barriers to potential sediment delivery to streams.

Note that this is not an exclusive list: factors such as elevation and aspect may form the basis for unique landforms. The GIS may be queried for these characteristics to help in delineation.

When extrapolation of landform mapping is needed, see the project manager for guidance. This person will assist the analyst in determining areas acceptable for extrapolation on the basis of commonalities in elevation range, lithology, and precipitation regime. Extrapolation is only to be done with project manager permission, guidance, and documentation.

Mapping areas receiving landslide deposits – Alluvial fans, colluvial footslopes and other areas that are not unstable but prone to receiving landslide deposits may be mapped as separate hazard units.

Step 3. ***Landform Coding*** Each landform polygon has a minimum level of coding that is required. For named landforms (see Step 1 list a-f), the coding includes the landform 'name'. Landforms that are not on the Step 1 list of a. through h. will be described via a set of codes found in the hazone polygon attribute table (Attachment 4). The function of the coding (description) of the landform is to provide objective information about the landform that the land manager can use to identify the landform and unstable ground in the field. The preliminary landform map (and associated GIS database) contains most of the preliminary information for the analyst to either incorporate or amend as appropriate.

Non-regulatory landforms will be coded based on minimum and maximum slope gradient, slope form, lithology, forest practice sensitivity and delivery potential. Codes identified on the landform map will be written out for the Landform Descriptions, with descriptors (see Attachment 4).

NOTE: Hazard ratings for the landforms will be calculated based on the rate of landsliding in each landform, as described in the Hazard Rating Section. The analyst-interpreted slope and forest practice sensitivity calls discussed below are based on analysis of Form A-3, and will be presented in Form A-2, Landform Description. They are provided to inform foresters and Level 3 geotechnical analysts on the ground.

4. Prepare Landslide Description Forms and Summary Statistics.

After the Level 2 landforms have been delineated according to the criteria above, draft the landform description and landform descriptions and mass wasting summary tables (see Attachments 2, 3, and 4). Several iterations of evaluating the maps and developing statistical tables may be required to ensure that each landform is broken out appropriately. The function of the statistical analysis is to describe three criteria relative to landform delineation: Physical description of the landform, description of failure mechanisms, and probable land use cause(s) of failure (AKA: triggering mechanisms). Simple statistics are preferred (e.g., mean, standard deviation). Analyses such as gradient, curvature, and lithology versus landslide density or area assist in the development of physical descriptions. Analyses such as roads, land use, and precipitation versus landslide density or area assist in the development of triggering mechanisms. During this process, field visits may assist in refining landform delineations and improving confidence in the calls.

The following additional information will be developed for each landform, through analysis of the data presented in Forms A-1, A-2 (the Landform Description), and Form A-3 (the Mass Wasting Summary Form). This information can then be entered into the database for each landform. Abbreviated Form A-2 will be prepared for the Level 1 landforms. No Form A-3s are created for Level 1 landforms.

f. Delivery hazard (likelihood of delivery to resources/safety)

    no or unlikely

    moderate, sometimes, or partial

    high/certain/yes

    unknown

Delivery may be hampered by significant slope breaks between failures and public resources. Very small landslides may also fail to deliver if they occur away from resources on moderate slopes.

g. Sensitivity to forest practices (Roads, Harvest, Both), based on interpreted slope hazard descriptions above.

    R= Roads (cut and fill slopes, landings, drainage changes)

    H= Harvest (root strength changes, and hydrologic changes caused by both tree removal and yarding)

    B= Both. The landform is sensitive to both roads and harvest.

U= Uncertain. This sensitivity rating should be used with great caution, as it informs the map reader that the analyst does not understand the mechanisms of slope failure for this landform.

Sensitivity to forest practices should be based on evaluation of Forms A-1 and A-3 as prepared for each landform.

h. A flag as to whether GIS-derived lithology is acceptable or needs to be amended (yes- indicates the GIS derived lithology is acceptable; or no – the GIS lithology needs correcting. If no, note in the comments section what the actual lithology is)

i. Confidence in analysis based on field and photo work. Note that the confidence statement goes in the written report and not the database for hazard zones. Individual polygons may occasionally receive “low confidence” ratings. Landform types will not receive “low confidence” ratings.

High confidence:	Good photo coverage and visibility. Direct association with land use and landslides established. Field verified landform unit attributes in some or many of the unit polygons.
Moderate confidence:	Photo coverage and visibility good but a number of questionable landslide associations with land use in the landslide inventory. Limited field verification of landform attributes.
Low confidence:	The landslide inventory is non-representative because photo coverage was incomplete, of poor quality or missed important storm or harvest intervals. Many questionable landslides in the inventory or land use associations uncertain. No field verification of landform attributes due to difficult or no access.

All the above information is entered into landform descriptions Form A-2 (Attachment 2). After mapping and coding the landforms, a “calculated hazard” level is developed for all level 2 landforms, which is a numeric value described in section D.

In some watersheds, it is reasonable to map areas that receive landslide deposits, including alluvial fans, colluvial foot slopes and other areas that are not themselves unstable but prone to receiving landslide deposits. These may be mapped as separate hazard units. These units would receive a low instability potential rating and a high delivery rating, and the unit description should explain why they are being mapped as a separate unit. With the exception of alluvial fans, these units are to be used rarely.

C. Field Verification

Field visits serve to verify questionable landslides, possible triggering mechanisms or land use associations, and landform characteristics. The percentage of landslides and landforms visited will vary according to the complexity of the watershed and to achieve a standard of confidence in the products. Ultimately, the analyst needs sufficient information to describe the unstable ground for later field verification. This is particularly true for landforms containing both stable and unstable ground due to limits in mapping resolution (e.g., bedrock hollows).

The time spent in the field and the mapping work can be made more efficient by conducting pre-field interviews with land managers, regulators, and qualified geotechnical experts familiar with the watershed and with landslide processes. These people can identify areas of chronic road failures, culvert clogging, and landslides, as well as inform the analyst about the location of active logging sites, and closed, decommissioned or new roads, and other safety issues. At a minimum, pre-field interviews can serve to verify that access to the watershed has been obtained. Permission to access all state and private lands is required. Be conscientious about returning keys to landowners as soon as possible. Contact the forest practices forester for your area of interest, as they will know who the landowners are and may assist you in gaining access. The FPF may want to assist in preliminary fieldwork. Contact the landowner with your request, making sure to mention the CMER connection to the project. If you are unable to get landowner permission after the first couple of tries, contact the project manager.

Field visits to landslides and landforms may help resolve uncertainties regarding:

- Questionable landslide features and particularly areas where these features are concentrated;
- The physical conditions associated with landsliding and the particular characteristics used to delineate the landforms;
- Land use trigger mechanisms associated with slope instability (e.g., failure of road sidecast or maintenance grading on steep slopes where cutslopes are raveling, drainage diversions, undersized culverts);
- Delivery of landslide debris to public resources or ability to threaten public safety;
- Extrapolation of map units to lesser-known areas.

Specific targets for field visits might be features for which landslide identification was not certain, areas not viewed well through the aerial photographs (due to shadows for example, or incomplete records), sites where there is apparently no delivery but canopy cover may conceal streams, etc. Each landform type should be visited. Note which specific landslides and landforms were field checked.

D. Hazard Ratings

1. Introduction

For the purposes of this protocol, an **Overall Hazard Rating** is assigned to each landform. For all rule-identified landforms, the hazard rating is considered high by default. Rule-identified landforms may later be "upgraded" to be flagged as having "very high" hazard call, but may not be "downgraded". Some Overall Hazard Ratings described below are based on specific criteria, such as "rule-identified" status, or based on the professional experience of the analyst. More commonly, however, the Overall Hazard Rating will be assigned on the basis of a semi-quantitative assessment method. Deep-seated landslides are assigned hazard based on their delivery and activity status that is different than areas prone to shallow landsliding and debris flow where hazard is assigned based on calculated frequency rates.

Semi-quantitative Overall Hazard Ratings are derived from values that correspond to the number and area of landslides in each landform, normalized for a period of time spanned by aerial photographs used for the study, and the area of each landform (Table 3).

These values are referred to as the **Landslide Area Rate** and the **Landslide Frequency Rate.** The rates can be calculated for all landslides or restricted to those landslides that deliver sediment to public resources. For example, the **Landslide Area Rate For Delivery** is used as a proxy for the volume of material that might be delivered. (It is generally difficult to accurately estimate the depth of the failed mass; hence, area is used as a surrogate for volume.) The Landslide Frequency Rate is used to quantify the landslide density in each landform. The area and frequency calculations are performed once for all landslides regardless of delivery, and then again, excluding those that do not deliver.

After the quantitative rates of landsliding are determined, each is classified into a rating of Low, Moderate, High, or Very High rating (Table 4). The **Landslide Frequency Rate** and **Landslide Area Rate For Delivery** values are then entered into a matrix (Table 5) in order to determine the **Overall Hazard Rating, which is assigned to the unnamed landforms**. Table 5 is based in part on the assumption that the area of delivery is more directly related to total sediment delivery than the frequency of delivering landslides. In other words, several small landslides entering a public resource are of less consequence than several large failures. The **Landslide Area Rate** and **Landslide Area Rate For Delivery** are useful indicators of the potential of a landform to fail and the likelihood of those failures to deliver.

2. General Information

a. Inclusion/Exclusion Criteria

- Only landslides identified with "definite" certainty for the first photo set will be included in the calculation of the area and frequency rates. For subsequent years, landslides with "probable" or "definite" certainty will be used.
- In addition to summary landslide area and frequency rates, separate analyses will be performed for landslides associated with roads and those associated with all other forest practices.
- Deep-seated landslides (except those portions that fail in a shallow manner) are excluded from the landslide area and frequency ratings. Deep-seated landslide hazard calculations are addressed in a different method.

3. Determining the Landslide Area and Landslide Frequency Ratings

The Landslide Frequency Rate and the Landslide Area Rate reflect the total number and cumulative area of landslides per unit area of landform normalized for the period since the earliest set of photography was acquired. (Typically, sometime during the 1970s.) The normalized numbers, which are always small fractions, are then multiplied by one million and rounded in order to provide the nearest whole numbers. The Landslide Area Rate for Delivery includes only those landslides having "definite" or "probable" certainty for delivery, which is why it is important to resolve those landslides inventoried as 'questionable' in the field.

Areas or landform polygons with matching or similar characteristics (i.e., descriptors) within a landscape that have not been subject to forest practices, or are not covered by a reasonable photographic record, are not used in the calculation of Landslide Area and Landslide Frequency Rates, although the hazard mapping is extrapolated to these areas. If these areas were included, the predictive value of the method would be reduced because the apparent instability per unit area would be biased by inclusion of the areas protected by root-strength. Additionally, bias may arise because the canopy may obscure landslides in areas of mature forest. After the Rates have been assigned, the same rating is given to all landforms with matching characteristics.

The area of delivering landslides is identified as that area which failed and may include the area of 'bulking up' in the case of debris flows. However, the area of runout is not included in an area of hazard, only that area that failed should receive the interpretation of hazard. The originating unstable landform is the landform of concern when calculating landslide hazard.

Table 3 and Form A-4. Calculating Landslide Area Rates with hypothetical examples.

LANDFORMS	LANDFORM 1	LANDFORM 2	LANDFORM 3	LANDFORM 4	WAU
Landform Area (acres)	100000	10000	1000	100	111100
Number of 'Delivering' Landslides	250	300	200	20	770
Area of "Delivering" Landslides (acres)	225	225	8	8	466
Landslide Frequency Rate (Number of slides/Landform Area/Years) x 10^6	83	1000	6667	6667	231
Landslide Area Rate for Delivery (Delivering Landslide Area/Landform Area/Years) x 10^6	75	750	267	2667	140

Table 4. Qualitative ratings equivalency for the numerical Landslide Frequency Rate and Landslide Area Rate for Delivery for Delivery as of June 2004.

Qualitative Ratings (as of June 2004)	Landslide Frequency Rate	Landslide Area Rate for Delivery
Low	<100	<76
Moderate	100 to 199	76 to 150
High	200 to 999	151 to 799
Very High	>999	>799

4. Developing Overall Hazard Ratings

Assign a Low, Moderate, High, or Very High Hazard Rating to the landform based on Table 4. Where the hazard rating is different for landslide frequency versus landslide area rate, use the landslide area rate. Put these values into Table 5 to develop the Overall Hazard Rating in consideration of the additional criteria listed below. These results will provide the basis for comparison among watersheds throughout the State.

a. Criteria-Specific Assignment of Overall Hazard Ratings

- All rule-identified landforms are given a High Overall Hazard Rating, but numerical Landslide Area and Landslide Frequency Rates are calculated for future research purposes.
- The toes and headscarps of active deep-seated landslides are assigned "High" Overall Hazard Ratings where these were not previously flagged as "rule-identified" landforms. The bodies of deep-seated landslides may receive a Moderate Overall Hazard as appropriate, suggesting that a site visit to delimit forest management activities is prudent.
- Active deep-seated landslides may be identified as their own landform and given a high hazard, even if there is not a mappable toe.
- Dormant deep-seated landslides may be assigned High Overall Hazard Ratings for toes and headscarps. If the analyst observes that other areas of a deep-seated landslide have delivery potential, those areas should be included in the High Hazard area and that information should be included in the landform description.
- For landforms with potential for shallow landslides, two types of areas are likely to be flagged as hazardous:

- Landforms that occasionally generate landslides and have some documented sensitivity to forest practices may be assigned a Moderate Overall Hazard. One example is a steep planar slope with an occasional road drainage-related failure.

- Landforms with overall low or moderate landslide rates, generated from inclusions of unstable ground that cannot be located or mapped individually through remote analysis are assigned a Moderate or High Overall Hazard. <u>In these cases, the text of the overall landform description should include a description of the unstable high hazard areas within them.</u>

b. Using Landslide Frequency Rate and the Landslide Area Rate For Delivery for Assigning Overall Hazard Ratings

Except for rule-identified landforms, most Overall Hazard Ratings will be assigned on the basis of the semi-quantitative hazard ratings. The current guidelines for the Landslide Frequency Rate and the Landslide Area Rate for Delivery are based on 27 landforms analyzed as Priority II Watersheds under the Landslide Hazard Zonation Project (Lingley, 2004a, b; Wegmann, 2004), on the data used to define rule-identified landforms, and on the experience of the Landslide Hazard Zonation team.

Landslide Frequency Rate and the Landslide Area Rate For Delivery values are converted to qualitative ratings using Table 4, and these are entered into Table 5 to generate Overall Hazard Ratings. While this method provides a better means of comparing watersheds in different parts of Washington, users should keep in mind that Overall Hazard Ratings derived from this method are estimations only. This should be restated in each summary report. (Note that these semi-quantitative guidelines may be modified in the future as the Landslide Hazard Zonation project database expands.)

Table 5. Overall Landform Hazard Ratings.

		LANDSLIDE FREQUENCY RATE			
		Low	**Medium**	**High**	**Very High**
LANDSLIDE AREA RATE FOR DELIVERY	**Low**	*Low*	*Low*	*Low*	*Medium*
	Medium	*Low*	*Low*	*Medium*	*High*
	High	*Medium*	*High*	*High*	*Very High*
	Very High	*High*	*High*	*Very High*	*Very High*

VII. Mass Wasting Assessment - Products

Analysts will complete summary reports describing the methods and results of the analysis. An outline for the report format is attached (Attachment 4). Please note that uncited references are not acceptable.

This report will record methods and observations made during the analysis, as an aid to map users. Map users are typically land managers and foresters involved in planning and regulating forest practices, and geotechnical experts preparing and assessing Level 3 site assessments for areas covered in the analysis.

In addition to the text described in the attachment, the reports will include the following maps and forms:

Map A-1 **Landslide inventory map** containing, at a minimum, roads, streams, Township, Range, and section lines, contours, landslides with identification numbers that relate to the tabular (Form A1) data, a disclaimer, and a legend that includes all information presented on the map. The map scale will be 1:12,000. See Figure z for a sample map.

Map A-2 **Landslide hazard map**, containing, at a minimum, roads, streams, Township, Range, and section lines, contours, landforms with identification numbers that relate to the tabular (Form A2) data, a disclaimer, and a legend that includes all information presented on the map, as well as brief unit descriptions and hazard ratings. The map scale will be 1:12,000. See Figure y for a sample map.

Form A-1 Landslide Inventory Data Sheet
Form A-2 Landform Description
Form A-3 Landform Mass Wasting Summary
Form A-4 Landslide Area Hazard Rates

VIII. References

Forests & Fish Report (1999) U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Environmental Protection Agency, Office of the Governor of the State of Washington, Washington State Department of Natural Resources, Washington State Department of Fish and Wildlife, Washington State Department of Ecology, Colville Confederated Tribes, Northwest Indian Fisheries Commission and individual western Washington Tribes, Washington State Association of Counties, Washington Forest Protection Association, and Washington Farm Forestry Association, authors of the white paper that resulted in the 1999 emergency rule (and eventually final rule) package. Paper is found online at: www.dnr.wa.gov/forestpractices/rules/forestsandfish.pdf

Keaton, J. & DeGraff, J. 1996. Chapter 9 - Surface Observation and Geologic Mapping, *in* Landslides: Investigation and Mitigation, Turner, A. and Schuster, L R., *eds.*, Transportation Research Board Special report 247, p. 178-230.

Lingley, William, 2004a, Mass Wasting Assessment: Landslide Hazard Inventory Project, Lower Calawah River Watershed, Clallam County, Washington, 32p. with plates.

Lingley, William, 2004b, Mass Wasting Assessment: Landslide Hazard Inventory Project, Lower Finney and Miller Creek Watersheds, Skagit County, Washington, 62p. with plates.

Wegman, Karl, 2004, Mass Wasting Assessment: Landslide Hazard Zonation Project Level II Assessment, Lower Naselle Watershed, Pacific County, Washington, 54p. with plates.

WFPB (Washington Forest Practices Board), 1994, Standard methodology for conducting watershed analysis Version 1.0: Washington Department of Natural Resources Olympia Washington 1 v.

WFPB, 2002, Forest Practices Rules Board Manual Section 16 Guidelines for Evaluating Potentially Unstable Slopes and Landforms, Washington Department of Natural Resources Olympia Washington, 26p.

Attachment 1

Form A-1 Landslide Inventory

LSI_ UNIQID	**Slide_ id**	SOURCE _IDNO	**Lsi_ process**	**Certainty**	**Id_date**	**Ls_size**	**Id2_date**	**Id2_size**	**Landform**	**Slp_shp**	**Gradient**	**Delivery**	**Landuse**	**Init_elev**	**Photo num**

Attachment 2

Form A-2 Landform Assessment Descriptions

Landform Number

Name (Based on the Following)

Slope

Slope Shape

Lithology

Elevation

Total Area

Mass Wasting Processes

Non-road-related landslide density

Forest Practice Sensitivity

Mass Wasting Potential

Delivery Potential

Delivery Criteria Used

Hazard Potential Rating

Trigger Mechanisms'

Confidence

Comments

Attachment 3

Form A-3 Mass Wasting Summary Table

Landform

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

Attachment 4

Landform Description Summary Table (Spreadsheet data for the landform database)

HAZ_SRC_ID	MWMU_NO	MWMU_NM	PRI_LANDFORM	SEC_LANDFORM	SLOPE_MAX_PC	SLOPE_MIN_PC	SLOPE_SHAPE_CD	INTERP_INSTAB_CD	INTERP_DELIVERY_CD	FP_SENSITIVITY	CALC_HAZARD	GIS_LITHOLOGY_FLG

Attachment 4: Mass Wasting Assessment Report Template

<WATERSHED NAME>

LANDSLIDE HAZARD ZONATION PROJECT <COUNTYNAME>, Washington

Prepared By
<AUTHORNAME(S)>

SAMPLE PHOTO

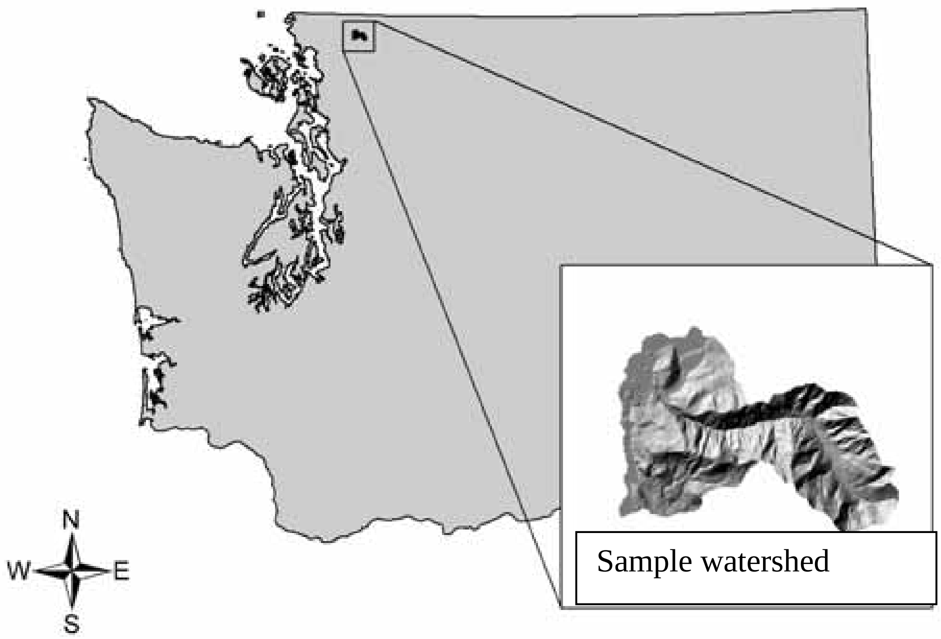
Forest Practices Division,
Adaptive Management Program
in coordination with the Washington Division
of Geology and Earth Resources

Priority <NUMBER>
Mass Wasting Assessment
<MONTH YEAR>

Forest Practices Division
PO Box 47012
Olympia, WA 98504-7012
Phone: 360-902-1400
Fax: 360-902-1428

Division of Geology and Earth Resources
PO Box 47007
Olympia, WA 98504-7007
360-902-1450
360-902-1785

Web sites: http://www.dnr.wa.gov/forestpractices/lhzproject
http://www.dnr.wa.gov/forestpractices/adaptivemanagement
http://www.dnr.wa.gov/geology/



Cover photo: SAMPLE TEXT TO DESCRIBE SAMPLE PHOTO

(i) CONTENTS

1.0 Introduction and Summary of Methods

1.0 Use of this report

The purpose of this mass wasting assessment is to identify non-federal, non-tribal areas within the <WATERSHED NAME> watershed (WAU) that have landforms[1] with moderate or high risk of landslides due to the effects of forest management (logging, roading, thinning, yarding, etc.). Maps of these watershed-specific landforms (Maps A1 and A2 herein) will be used by the Department of Natural Resources region staff to identify those forest practice applications (see Chapter 222-20 WAC) that will require a site investigation prior to assigning the class of forest practice relative to potential unstable slopes and landforms (Chapter 222-16-050). Additionally, these maps are designed to be used by land managers to assist in developing harvest strategies.

This is a reconnaissance study and its level of resolution must be kept in mind when using this document and Maps A1 and A2. For example, analysis of individual landslides or slopes is not an appropriate use of this report nor should it be used for zoning purposes. Moreover, the report was prepared according to the schedule necessary to produce a statewide screening tool as quickly as reasonably possible. For this reason, it is likely that some landslides or landforms have been accidentally omitted, some benign features are improperly mapped as landslides, and some data have been miscoded herein.

This assessment was conducted using aerial photographs, various maps, and field observations. Information was 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. The objective of the data collection is to generate information sufficient to establish:

- A generalized characterization of mass wasting processes active in the basin.
- Portions of the landscape sharing similar physical characteristics relating to mass-movement behavior.
- The relative potential for mass wasting within each landscape unit.

1.2 Previous Investigations

<Identify and briefly describe any comprehensive or site-specific studies of slope stability conducted in the watershed or region>

[1] Landforms as defined herein can be more inclusive than the small-scale unstable landforms commonly defined in rule (WAC 222-16-050). These rule-identified landforms include inner gorges, convergent headwalls, the outsides of meander bends, bedrock hollows, and the toes of deep-seated landslides. These will be referred to as “rule-identified landforms” herein.

1.3 Introduction to Mass Wasting Processes and Terminology

For the purposes of this study, most landslides that failed below rooting depth are categorized as deep-seated, consistent with the Forest Practices Board Manual. Those deep-seated landslides that moved rapidly and clearly deliver are included in the analyses of sediment delivery.

<X> types of mass wasting process were identified in the <Watershed> related to forest practices:

<example
1. Shallow landslides from side-cast failures
2. Debris flows from failed culverts
3. Debris flows from loss of root strength in soil
4. Deep-Seated landslides from excess water concentration>

1.4 Summary of Methods

This assessment follows the Landslide Hazard Inventory Protocol version <X>, dated <DATE> (http://www.dnr.wa.gov/forestpractices/lhzproject/lhz-protocol.doc), with minor modification (DESCRIBE THE MODIFICATION, IF USED).

<NUMBER> sets of aerial photographs acquired between <YEAR> through <YEAR> were viewed with a mirrored stereoscope with 3x magnification (Table <X>). <IF NECESSARY, DESCRIBE SIGNIFICANT GAPS IN THE PHOTO RECORD> In addition, <YEAR> orthophotographs were used as a layer during GIS analysis and mapping. LIDAR was/was not available for this area.

Table x. Photographic surveys used in this study.

Year	Scale	Image	Flight Number	Comment

Mapping was generally accomplished by heads-up digitizing the landslides on Department of Natural Resources (DNR) ortho-photographs, the USGS 10-meter Digital Elevation Model (DEM), DEM derived contours, slopes and hillshades. The maximum resolution of these techniques is about 10 meters. Small failures identified on the photos are not represented by the 10-meter DEM’s as slope distances of less than 10 meters are not represented and are averaged into gentler slopes above and below. Failed slopes of less than 5 meters are common in inner gorges and along the toes of deep-seated landslides and are not accurately reflected by the 10m DEM contour map.

Slope gradients were determined by exploring a DEM-derived slope percent map within each feature polygon in its individual shape file. The slope angle cannot be reliably determined for small or narrow landslides where accuracy is limited by the 10-

meter resolution of the DEM. Slope angle is understated where steep slopes or inner gorge faces are less than 60 feet high as the 10-meter resolution averages gentler slopes above and below the steep face into the calculation. 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.

The landslide coverage is provided as Map A-1 with an additional sheet with the attributes of the landslides. These are available from the DNR, Forest Practices Division as PDF files, or ArcInfo coverages. Most of the landslides were recorded during an aerial photo analysis and complemented with field visits. These landslides range from 'questionable' to 'definite', depending on their size and the amount of obscuring canopy coverage. The aerial photo review also determined the land-use and landform features. A slope-percent map derived from the <SOURCE> digital elevation model (DEM) of the watershed and USGS 1:100,000 geologic map aided in evaluation of slope conditions prior to slope failures, assisted in predicting areas of potential future failures and aided in delineation of the landforms. All landslides were recorded into a GIS coverage to aid in identifying their delivery potential, slope shapes, gradient and elevation, primarily with DEM derived grids, and a modeled slope stability GRID (SLPSTAB; Vaugeois 2000). The information from these landslide features, once completed, were used to extrapolate the landform map (Form A-2).

The following landslide processes were used to identify and classify features observed on the stereo photos: shallow-rapid landslides (debris slides), debris flows, debris avalanches, deep-seated landslides, shallow sporadic deep-seated landslides, large persistent deep-seated landslides, earth flows, rock topple, and snow avalanches. Table <Y> provides a summary of the number and type of process features catalogued during this investigation.

Process	**Number of landslides**
Shallow undifferentiated landslides	
Debris Flows	
Debris slide/avalanche	
Deep-seated	
Earth flow	
Rock topples/falls	
Snow avalanche	

Table <Y>: A summary of the number and type of landslides in the Sultan watershed.

2.0 Physical Setting Pertinent to Mass-Wasting Interpretations

2.1 Introduction

The <WATERSHED NAME> covers <NUMBER> acres in <FURTHER GEOGRAPHIC IDENTIFIERS> in <COUNTY> County (Map A1).

The watershed ranges in elevation from <ELEVATION RANGE>.

Precipitation within the watershed <DESCRIPTION>, averaging <NUMBER> inches of rain a year. DESCRIBE Rain-on-snow AS NEEDED. Rain-on-snow events have triggered widespread slope failures in many watersheds within the Cascade foothills.

2.2 Topography

2.3 Land use and Historical Considerations

<BRIEFLY DESCRIBE THE LANDUSE HISTORY AS IT APPLIES TO SLOPE STABILITY E.G., OLD LOGGING TECHNIQUES OR ROAD CONSTRUCTION PROBLEMS>

2.4 Geology

2.4.1 Bedrock Units

2.4.2 Poorly-Consolidated Surficial Units

3.0 Summary of Results

In reviewing the <WATERSHED NAME>, a representative sample of <NUMBER> landslides were recorded on DNR-regulated lands. Of these landslides recorded, <NUMBER> were shallow landslides, <NUMBER> deep-seated landslides. <NUMBER> of these landslides were interpreted to have delivered and were used in construction of the overall hazard ratings (Form A-4). <NUMBER> of these landslides were not road related and were used to construct hazard ratings for harvest and other related forest practice uses.

No deep-seated landslides were included in these calculations, but their locations and statistics are presented within this report. These deep-seated features should be evaluated during field visits. A quick review of Form A-1 should determine whether the deep-seated landslides were identified as ‘definite’, ‘probable’, or ‘questionable’ and their activity level. Deep-seated landslides can range in age from about 14,000 years (glacial related deep-seated landslides) to present.

<IDENTIFY SPECIFIC AREAS THAT REQUIRE SPECIAL ATTENTION>

4.0 Landforms

PROVIDE A BRIEF OVERVIEW OF THE LANDFORMS IDENTIFIED.

The <WATERSHED NAME> has been delineated into <NUMBER> landforms that characterize areas having similar features. Of these landforms, the Landslide Hazard Zonation Project Protocol predefines 9 landforms. <NUMBER> additional landforms were added due to their unique features. These landforms have been delineated due to their similar landslide characteristics and potential to deliver to public resources. Landforms were based on a number of characteristics, such as geology, hydrology, geomorphology, topography, and landslide characteristics. The following section presents the results of this investigation, which has been split into low and high-hazard potential landforms. High-hazard landforms will require careful review and field investigation.

4.2 Landform Descriptions (also known as Form A2)
Low Hazard Descriptions

E. LANDFORM NUMBER:

LANDFORM NAME:
OVERALL HAZARD: Low

<EXAMPLE >Description:

Landform 1 (Alluvial Plains) and 2 (Valley Bottoms) are comprised of level (0-10%) slopes of recent outwash colluvium of the Sultan River (Geologic Unit: Qa), glacial outwash colluvium (Geologic Unit: Qgo), glacial till (Geologic Unit: Qgt), and swamps and peat bogs (Geologic Unit: Qp). Some small, non-delivering landslides were mapped in roadside casts, but present no danger to harvest or road construction. Landslide Rate Delivery is low. Confidence is high.

Moderate to High Hazard Descriptions

VII. <LANDFORM NUMBER> - <SHORT DESCRIPTION>

Description of Mass Wasting Unit:
Slopes:
Slope Shape:
Material:
Elevation:
Total Area:
Mass Wasting Process:

Forest Practice Sensitivity:

Mass Wasting Potential: This landform has a Landslide Frequency Rating of <NUMBER> and a Landslide Area Rating of <NUMBER>. This corresponds to a hazard potential of <VALUE>

Delivery Potential/Criteria: **<VALUE>** <PROVIDE DESRIPTION OF CRITERIA USED>.

Hazard Potential Rating: **<VALUE>** based on LHZ Protocol and Standard Forest Practices Rules.

Confidence: <VALUE>, based on <CRITERIA USED> (E.G. the number of landslides located in this landform, excellent photo quality and coverage, communication with field foresters, and field observations.)

5.0 Hazard Ratings

(Form A-4 contains all the data used to determine the calculations and hazard ratings) Overall Hazard Ratings was determined from the number of shallow landslides, rule-identified landforms (WAC 222-16-050) and the calculated Landslide Frequency Rate and Landslide Area Rate for Delivery (see Form A-4).

The Landslide Frequency Rate for Delivery is the area, in acres, of all the shallow landslides normalized for a period of full aerial photo coverage (usually the first photo set in the 1970's) and the area of each Landform. These values are then multiplied by one million for easier interpretation. The Landslide Area Rate for Delivery is calculated similarly, however the amount of area delivered (in acres) is used instead of the number of landslides. As of the writing of this report, the qualitative rating system below is used.

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

6.0 Note on Confidence in Work Products

The confidence in this mass wasting assessment is <VALUE>. This rating is based on<ANALYST PROVIDED INFORMATION>. The Landslide Hazard Zonation Project design to provide a watershed overview of slope stability in a timely manner with minimal field verification. As a consequence, fieldwork and the number of aerial photograph sets examined are held to reasonable minimums. Omissions will be present due to the limited field verification of individual features, particularly in heavy canopy forested areas.

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

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

This mass wasting assessment was primarily conducted with aerial photographs, and as a result, there is a high likelihood that errors of omission occurred, primarily in areas covered by mature forest canopies, steep north facing slopes always in shadow at any given time, and those areas covered with extensive glacial deposits. The scarcity of mass wasting features identified under mature canopy and steep north slope aspect shadow conditions is not necessarily an indication of the relative stability of slopes with mature vegetation regimes or steep north face aspects.

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

Another important source of potential error in this assessment is in the accuracy and precision of measurements of mass wasting features. Because less than <VALUE>% of 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 <VALUE>.

1. Acknowledgements

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7.0 References

Vaugeois, Laura, 2000, Creation of a Slope Stability Screening Tool from Landslide Prediction Models, Forest Practice Board Presentation: Washington Department of Natural Resources, Olympia, Washington

Wegmann, Karl W., 2003, Digital landslide inventory for the Cowlitz County urban corridor--Kelso to Woodland (Coweeman River to Lewis River), Cowlitz County, Washington: Washington Division of Geology and Earth Resources Report of Investigations 34, 1 CD-ROM disk.

Not included herein but included in the report are figures as needed to describe watershed, landslides, and hazards.

Not included herein but included in the report as appendices: All forms and maps.