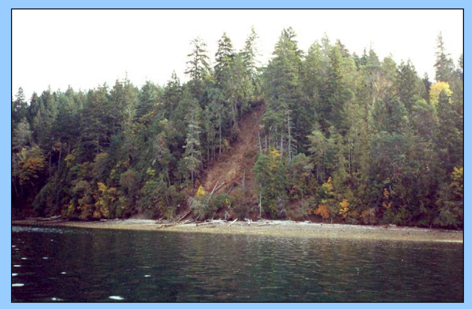
Paper #18-6

RECOGNITION OF NON-RULE IDENTIFIED HIGH HAZARD LANDFORMS IDENTIFIED DURING LANDSLIDE HAZARD ZONATION PROJECT MAPPING IN WASHINGTON STATE



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ABSTRACT. Mass wasting assessments currently underway by the Landslide Hazard Zonation Mapping Project (LHZ) seek to identify unstable slopes based on rules adopted by the Washington Forest Practices Board. Landforms in a watershed are assigned Overall Hazard Ratings (low, moderate, high, or very high) based on LHZ protocol. Qualitative ratings based on a semi-quantitative assessment take into account the number and area of landslides in each landform, normalized to the years of aerial photo coverage studied. Six statewide landforms are rule identified as high hazard due to their instability, likelihood to deliver sediment or debris to a public resource, or threat to public safety. These are: (1) inner gorges, (2) convergent headwalls, (3) bedrock hollows, (4) toes of deep-seated landslides with slopes >65%, (5) ground water recharge areas for glacial deep-seated landslides, and (6) outer edges of meander bends along valley walls or high terraces of unconfined meandering streams. Based on hazard ratings, these landforms require additional evaluation prior to forest management and other land use activities. The rules also provide the ability to identify instability based on a preponderance of evidence.

Here we describe additional landforms that have high or very high Overall Hazard Ratings and occur in multiple watersheds, but are not currently rule identified by name. These include: (1) Coastal Bluffs where wave action undercuts the toe of the slope, creating steep faces adjacent to the shoreline. Bluff failures commonly occur where glacial outwash-deposits overlie impermeable till, clay, or bedrock. This stratigraphy promotes development of perched water, which facilitates saturation and sliding of the top units. (2) Steep Terrace Faces along reservoirs, where repeated fluctuations in water level occur every year. Repeated wetting and de-watering causes changes in pore water pressure, leading to unstable conditions along the terrace faces. (3) Steep Hillside Slopes (>70%) mapped between bedrock hollows and inner gorges. These slopes often have shallow soils or steep bedrock surfaces. (4) Earthflow bodies and toes with multiple associated landslides. These occur with slopes <30% and exhibit water piping and sapping out of road cuts. Glacial deposits as well as highly weathered volcanic material show instability.

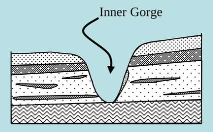
BACKGROUND. The Landslide Hazard Zonation Mapping Project (LHZ) produces maps and reports that identify unstable slopes to assist in mitigating landslide hazards. Each watershed administrative unit (WAU) is assessed for mass wasting potential and three products are developed: (1) a map delineating landslides identified from aerial photographs (five sets) and field verification (Map A-1), (2) a map of landforms based on landslide hazard areas, and (3) a report detailing the landslide hazard findings for each WAU.

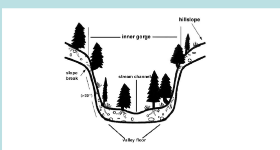
The methods the LHZ Project utilizes have been established to provide consistency in mapping landslide hazard landforms. After landform mapping is complete, landslide hazard values are calculated for each landform based on the number of landslides present, and normalized to the time interval represented by the aerial photographs.

To ensure consistency during mapping and hazard assessment, a set of six potentially hazardous landforms have been rule identified and described in terms of diagnostic field criteria. However, for other non-rule identified landforms each analyst may develop his or her own parameters. This may lead to a lack of uniformity between WAU assessments.

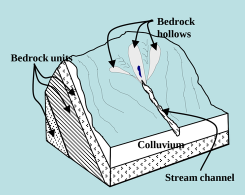
Four non-rule identified landforms have been selected from seven WAUs to show widespread occurrence of these hazardous landforms. The names assigned to these features are not the same in all reports, so a more general name is used here. Establishment of concise parameters for these and similar landforms would make for easier to define landslide hazards.

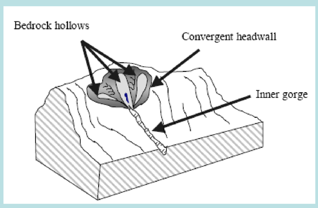
Rule Identified Potentially Unstable Landforms:



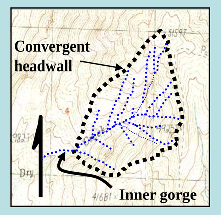


Inner gorge cross-section showing abrupt steepening directly below break in slope (Benda and others, 1998)





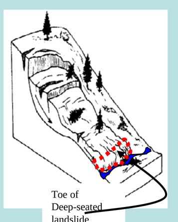
Typical hillslope relationship between bedrock hollows, convergent headwall, and inner gorge (Washington Forest Practices Board Manual, 2004)



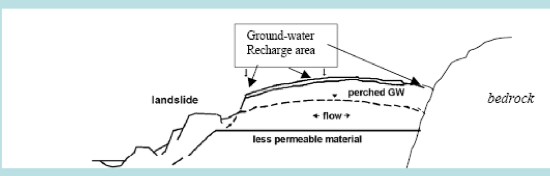
Inner gorges have steep, straight or concave side-slope walls that contain a distinctive break in slope. Landslides occur along slope walls.

Bedrock hollows have concave profiles and typical spoon shaped areas with convergent topography. Hollows can be partially filled with colluvial soils while recently evacuated hollows contain seeps or springs. Slopes >70%(~35º) are generally unstable, but failures can occur with varying steepness.

Convergent headwalls are funnel-shaped landforms, broad at the ridgetop and terminating where headwaters converge into a single channel. Slopes are typically >70%.

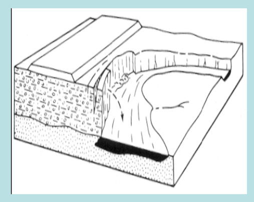


Toes of deep-seated landslides with slopes >65% have great potential for delivering to streams when being undercut by streams. Secondary landslides occur are oversteepened and promote additional movement.



Groundwater recharge area for a glacial deep-seated landslide. (Washington Forest Practices Board Manual, 2004)

Groundwater recharge area for glacial deep-seated landslides have been found to be susceptible to hydrologic changes due to forest practices.



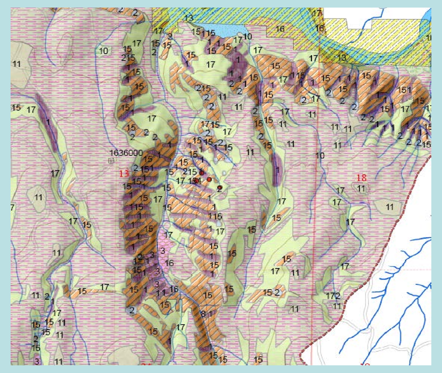
Drawing of an outer edge of a meander bend (Washington Forest Practices Board Manual,2004).

Outer edges of meander bends that undercut adjacent valley walls or terraces by streams can initiate shallow and deep-seated landsliding.

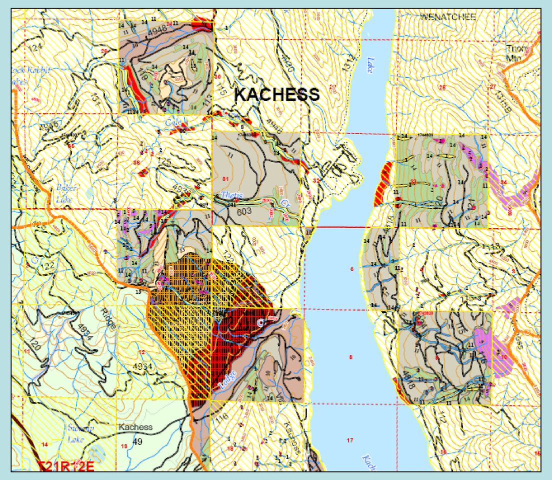
ACKNOWLEDGEMENTS. Much appreciation goes to Isabelle Sarikhan and Lorraine Powell with DNR's Division of Geology and Earth Resources for all the great field data collected while having a great time! Additional appreciation goes to Venice Goetz and Laura Vaugeois with DNR's Division of Forest Practices for assistance in editing and moral support.

Non-Rule Identified High Hazard Landforms:

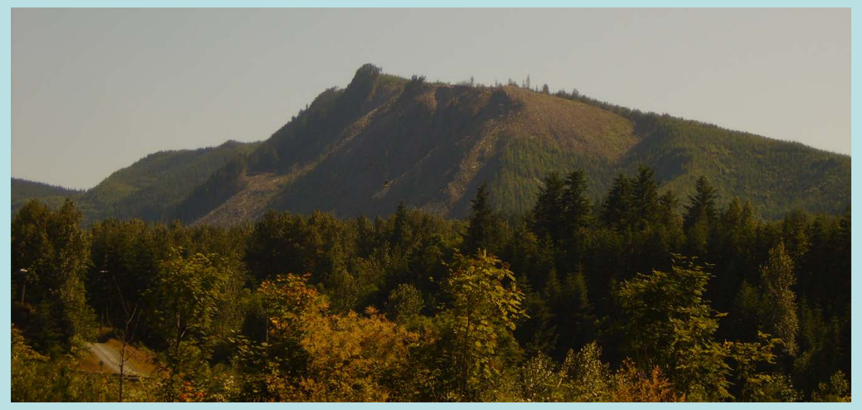
Steep-gradient Hillslopes are usually >70% (35º) and are often planar to convergent slopes. These are typically located at the upper end of drainage systems. These hillslopes are often found between bedrock hollows and inner gorges. Mud Mountain, Kachess, Mason, and Chehalis Sloughs WAUs are illustrated below.



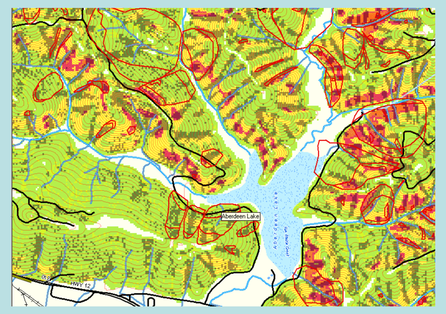
Mud Mtn. WAU steep gradient hillslopes are shown as orange striped (15) between inner gorges (1) (Serdar and Powell, 2006).



Kachess WAU Landform Map includes Steep Headwalls along the east side of Lake Kachess (Powell, 2006).

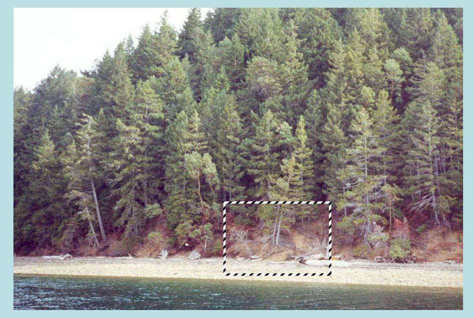


Mud Mountain WAU steep gradient hillslope, landslides hidden in shadows.



Portion of Chehalis Sloughs WAU currently under assessment, 2007. Red areas are steep gradient slopes between inner gorge features.

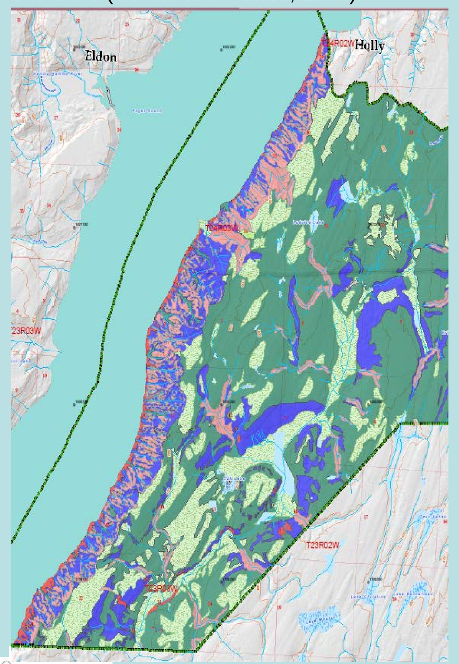
Coastal Bluffs Landform often caused by coastal wave action undercuts adjacent upland slopes. This landform may contain toes of deep-seated landslides. Great Bend and Mason WAUs are illustrated below.

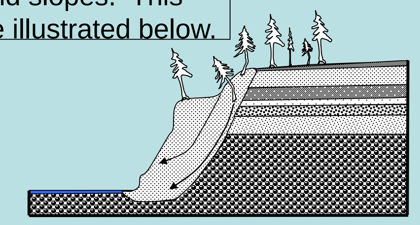


Note jack-strawed trees along coastal bluffs. Inset box is seen as an enlargement below.

Author standing adjacent to failing coastal bluff.

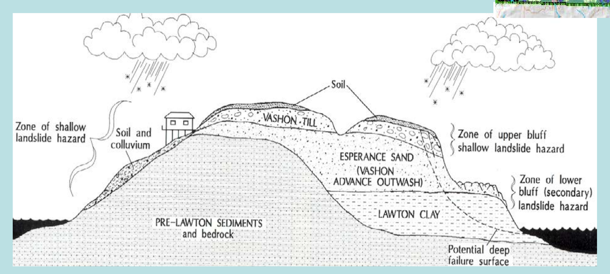
Great Bend WAU Coastal Bluffs Landform is shown below as a thin red strip along the shoreline (Serdar and Powell, 2006).





Landslides have been observed where groundwater perches on impermeable till, clay, and/or consolidated outwash deposits and saturates less consolidated deposits above the more competent layers.

Mason WAU Coastal Bluffs Landform is shown below as a thin purple strip along the shoreline. This shoreline is highly developed with residential housing. Photo above shows active landsliding along Totten Inlet.

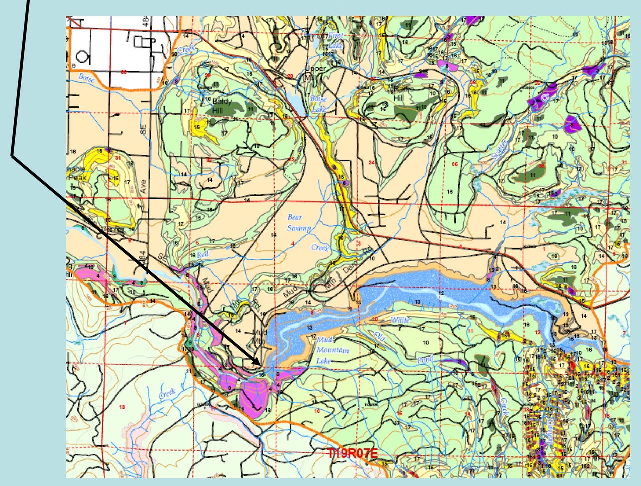


Cross-section depicting glacial sediments and landslide potential. Source: Gerstel and others, 1997, modified from Tubbs, 1974.

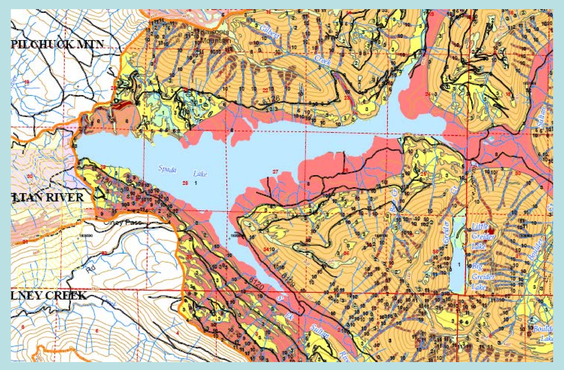
Landform	Coastal Bluffs		Reservoir Influenced Terrace Faces		Steep Hillside Slopes			Active Deep-seated Landslides & Earthflows		
Watershed Name	Great Bend	Mason	Mud Mtn.	Spada Lk.	Mud Mtn.	Kachess	Mason	Mud Mtn.	Skamokawa	Gray's Bay
Watershed Area	22,716 ac	165,462 ac	34,149 ac	32,660 ac	34,149 ac	6,266 ac	165,462 ac	34,149 ac	48,142 ac	51,137 ac
Area of landform (% of WAU area)	416 ac (1.8%)	334 ac (0.2%)	807 ac (2.4%)	2,910 ac (8.9%)	1,679 ac (4.9%)	227 ac (3.6%)	754 ac (0.5%)	223 ac (0.7%)	800 ac (1.7%)	217 ac (0.4%)
Delivrng landslides w/in landform (area of slides)	34 (8.6 ac)	79 (29.7 ac)	143 (70.8 ac)	24 (11.3 ac)	57 (22.8 ac)	5 (16.7 ac)	31 (91.2 ac)	6 (1.82 ac)	10 (5.4)	10 (2 ac)
% total delivering landslidesWAU % of total delivering landslides (by area)	14.5 % 5.8%	39.1% 23.4%	37.5 % 53.8%	5.7 % 2.4%	15.0 % 17.3%	8.9 % 12.8%	15.3 % 71.8%	1.6 % 1.4%	1.3 % 2.9%	2.1% 1.2%
A-4 Hazard Rating	Very High	Very High	Very High	High	Very High	High	Very High	High	Very High	Very High

Reservoir Influenced Terrace Faces along dammed reservoirs have high slope failure rates due to repeated fluctuations in water level every year. Repeated wetting and de-watering causes changes in pore water pressure, leading to unstable conditions along the terrace faces. Mud Mtn. and Spada Lake WAUs are illustrated below.

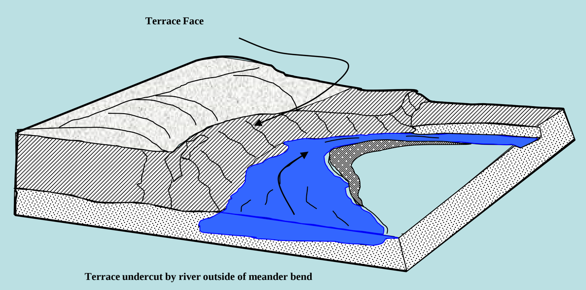
Landsliding upstream of the Mud Mountain Dam along the White River. Failures occur due to geologic materials that are constantly being wetted and de-watered during winter water retention periods of high stream flow.



Mud Mountain WAU Landform Map shows extent of water retention behind the dam (Serdar and Powell, 2006).



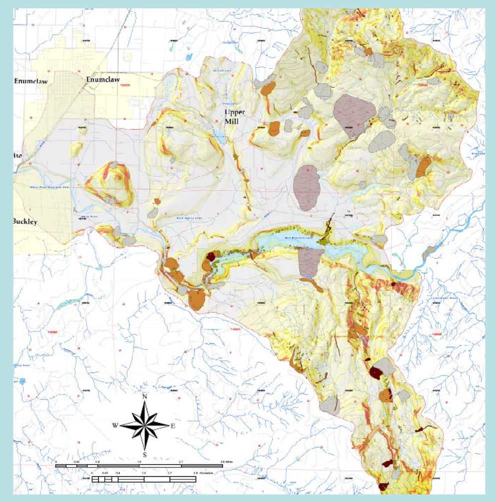
Spada WAU (Sultan Basin) has a reservoir that creates hydrostatic liquifaction landslides (Sarikhan and Walsh, 2006) .



Reservoir influenced terrace faces often have a stream undercutting the base of the slope for some time of the year. When water is retained behind a dam, the hydrostatic changes in pore water pressure create a higher than typical unstable condition for these terrace faces.

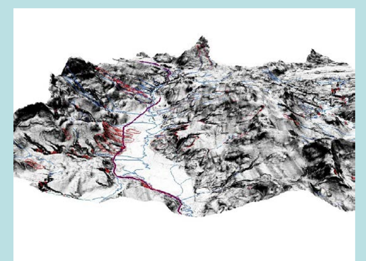
Active Deep-Seated Landslides including Earth Flows have high potential for secondary failing and delivery to streams when streams flow through bodies of deep-seated landslides. Additionally this landform includes landslides which exhibit recent movement (fresh headscarps, oversteepened toes, tension cracks, jackstrawed or split trees, and recent shallow landsliding). Some earthflows show secondary landsliding at 20% when roadcuts are created. Mud Mtn., Skamokawa, and Gray's Bay WAUs are illustrated below.

Photo above and below are 50' apart along a slope of an earthflow. Loading due to road above and additional water concentration may have activated this landslide (Chehlais Sloughs WAU).



Mud Mountain WAU Landslide Map shows large deep-seated landslides and earthflows in brown (Serdar and Powell, 2006).

Seeps and sapping occur in road cuts along earthflows.



Oblique lidar image of Kamilche Valley Earthflows cross Hwy 108, Mason WAU. (Sarikhan and Walsh, 2007)

Recommendations. Consistent landform mapping of non-rule identified landforms requires team members to work together in identifying specific criteria for each landform. This will lead to more regional landform mapping based on similar characteristics such as geology, slope shapes, and landuses. More consistent parameters defining a landform will lead to better hazard mapping and prevention of delivering sediment to streams.