The following summaries and excerpts from scientific literature pertain to the proposed Critical Area regulations for geologic hazard areas.

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1. Geologic Hazard Areas - Introduction

- Appendix A of the Critical Areas Assistance Handbook, published by the Department of Community, Trade, and Economic Development, provides a model code for updating critical areas ordinances (the Model). The Model language requires the designation of geologically hazardous areas, as defined in WAC 365-190-080(4)(a). Specifically, these include areas susceptible to erosion, landslide, or seismic hazards, or areas subject to other geological events such as coal mine or volcanic hazards (See WAC language, below). The existing Thurston County Critical Areas Ordinance (CAO) does not designate erosion hazard areas. The proposed revisions to the CAO include designation of erosion hazard areas and modification of the definitions/designation criteria for landslide, seismic, mine, and volcanic hazard areas, based on review of the best available science. The best available science review included research and review of relevant scientific literature and consultation with experts in the public and private sector. A bibliography of literature reviewed for this update is included in Appendix A. A Technical Advisory Committee, made up of a geotechnical engineer, a geologist, the Thurston County building official, planning staff, and members from the Thurston County Planning Commission met for a total of eight meetings to review the science and develop recommendations for the draft.

- Geologic hazard areas are defined in WAC 365-190-030(8) as “areas that because of their susceptibility to erosion, sliding, earthquake, or other geological events, are not suited to siting commercial, residential, or industrial development consistent with public health or safety concerns.” As implied here, geologically hazardous areas are not valued as critical areas for the same reasons that wetlands or wildlife habitat are valued. Geologic hazard areas pose threats to human health, safety, and welfare. Therefore, the point of this section of the critical areas ordinance is not necessarily to protect the critical area, but to protect the public from these hazard areas (Canning, 2001).

WAC 365-190-080(4)(a) further defines and designates geologically hazardous areas as follows:

(4) Geologically hazardous areas.

(a) Geologically hazardous areas include areas susceptible to erosion, sliding, earthquake, or other geological events. They pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices so that risks to health and safety are acceptable. When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided. This distinction should be considered by counties and cities that do not now classify geological hazards as they develop their classification scheme.
(a) Areas that are susceptible to one or more of the following types of hazards shall be classified as a geologically hazardous area:

(i) Erosion hazard;

(ii) Landslide hazard;

(iii) Seismic hazard; or

(iv) Areas subject to other geological events such as coal mine hazards and volcanic hazards including: Mass wasting, debris flows, rockfalls, and differential settlement.

(b) Counties and cities should classify geologically hazardous area as either:

(i) Known or suspected risk;

(ii) No risk;

(iii) Risk unknown - data are not available to determine the presence or absence of a geological hazard.

(c) Erosion hazard areas are at least those areas identified by the United States Department of Agriculture Soil Conservation Service as having a "severe" rill and inter-rill erosion hazard.

(d) Landslide hazard areas shall include areas potentially subject to landslides based on a combination of geologic, topographic, and hydrologic factors. They include any areas susceptible because of any combination of bedrock, soil, slope (gradient), slope aspect, structure, hydrology, or other factors. Example of these may include, but are not limited to the following:

(i) Areas of historic failures, such as:

(A) Those areas delineated by the United States Department of Agriculture Soil Conservation Service as having a "severe" limitation for building site development;

(B) Those areas mapped as class u (unstable), uos (unstable old slides), and urs (unstable recent slides) in the department of ecology coastal zone atlas; or

(C) Areas designated as quaternary slumps, earthflows, mudflows, lahars, or landslides on maps published as the United States Geological Survey or department of natural resources division of geology and earth resources.
(ii) Areas with all three of the following characteristics:

(A) Slopes steeper than fifteen percent; and

(B) Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock; and

(C) Springs or ground water seepage;

(iii) Areas that have shown movement during the holocene epoch (from ten thousand years ago to the present) or which are underlain or covered by mass wastage debris of that epoch;

(iv) Slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials;

(v) Slopes having gradients steeper than eighty percent subject to rockfall during seismic shaking;

(vi) Areas potentially unstable as a result of rapid stream incision, stream bank erosion, and undercutting by wave action;

(vii) Areas that show evidence of, or are at risk from snow avalanches;

(viii) Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flows or catastrophic flooding;

(ix) Any area with a slope of forty percent or steeper and with a vertical relief of ten or more feet except areas composed of consolidated rock. A slope is delineated by establishing its toe and top and measured by averaging the inclination over at least ten feet of vertical relief.

(e) Seismic hazard areas shall include areas subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement, soil liquefaction, or surface faulting. One indicator of potential for future earthquake damage is a record of earthquake damage in the past. Ground shaking is the primary cause of earthquake damage in Washington. The strength of ground shaking is primarily affected by:

(i) The magnitude of an earthquake;

(ii) The distance from the source of an earthquake;

(iii) The type of thickness of geologic materials at the surface; and
(iv) The type of subsurface geologic structure.

Settlement and soil liquefaction conditions occur in areas underlain by cohesionless soils of low density, typically in association with a shallow ground water table.

(f) Other geological events:

(i) Volcanic hazard areas shall include areas subject to pyroclastic flows, lava flows, debris avalanche, inundation by debris flows, mudflows, or related flooding resulting from volcanic activity.

(ii) Mine hazard areas are those areas underlain by, adjacent to, or affected by mine workings such as adits, gangways, tunnels, drifts, or air shafts. Factors which should be considered include: Proximity to development, depth from ground surface to the mine working, and geologic material.

• Canning, Douglas, J., Geologically Hazardous Areas, Publication #01-06-027, 2001. In reviewing local plans and development regulations, it would be good to keep in mind the words of George Mader (1974):

Where does the responsibility lie for protecting people and property? An often-heard argument is that if an individual want to take the risk of building in a hazardous area, he should be allowed to do so. The argument goes on that only he will suffer in the event of a failure. In an isolated location, this position might be acceptable. But in urban and suburban settings, land failure on an individual property usually has intense repercussions on the surrounding area. Decreased property values, possible fire hazards, costly public assistance, and possible physical impact on adjacent land are frequent major results.

Similarly, a developer often says he is willing to accept the risk in an unstable area. In the end, of course, that risk is passed on to purchasers in the development and to the public agency that assumes responsibility for streets and other public improvements, for the developer is usually out of the picture by the time a failure occurs. Thus the burden is unfairly shifted to all the taxpayers in the community.

It becomes clear that geologic hazards are not private matters, but concern the public in general. It is therefore incumbent upon government to protect the public interest.
2. Erosion Hazard Areas

- Erosion hazard areas refer to surface erosion caused by water. Surface erosion is the “removal of material from the surface soil, which is the part of the soil having an abundance of nutrients and organic matter vital to plant growth” (Muckel, 2004). Surface erosion, in its natural forms (water, wind, glacial, etc.) is a slow process that is difficult to detect. The primary problem is with the intensification of the erosion process, known as accelerated (surface) erosion. This accelerated erosion is the result of human activities (Menashe, 1998).

- Muckel, 2004. Erosion processes involve detachment and short transport of particles from the soil surface. Deposition is the process by which the soil particles come to rest. Soil particles are detached in two ways by water. Raindrops impacting an exposed soil surface exert a tremendous force that can dislodge particles. The dislodged particles are suspended by the raindrop splash and are moved away from the point of impact by sheet flow of water on the soil surface. The second way….is by the adhesive friction of concentrated flow in a rill. Once soil particles are detached, they can be transported a short distance by the flow of water until the flow velocity decreases because of reduced slope gradient or flow blockage. Accelerated erosion contributes to excess sediment in streams, lakes, and estuaries, and results in the loss of the most productive layer of soil.

- King County Best Available Science, February 2004. Erosion hazard is a measure of the susceptibility of an area of land to prevailing agents of erosion. It is determined by climate, topography, soil erodibility, and land use. Each specific land use has its own erosion hazard. According to Houghton and Charman, 1986, erosion hazard on land under cultivation and permanent pasture is long-term while erosion hazard in urban areas is often confined to the construction phase. While natural erosion provides sand, gravel, and cobbles that streams need to remain productive, the challenge is in determining what is a natural level of sediment input and what exceeds it.

- Brian Thompson, Thurston Conservation District, March 1, 2005 phone conversation. We discussed erodable soils in Thurston County. Brian stated that there are not many erodable soils within Thurston County and that slope/topography is the primary influence for erosion. His opinion is that 15 percent slope is an appropriate trigger for erosion concern. None of the soils in Thurston County are highly erodable if less than 15 percent slope. Anything beyond 8 percent slope is too steep for farming.

- Soil Survey of Thurston County, Washington, June, 1990. The “Soil Descriptions” section of the Soil Survey includes a discussion of the permeability and water erosion hazard for each soil type. Water erosion hazard is defined as slight, moderate, or severe (with one use of the term “high” when defining water erosion hazard). The proposed definition for erosion hazard area includes the terms severe and high. The table below lists the soils that are classified as having a severe or high water erosion hazard. Brian Thompson, a soils specialist with the Thurston Conservation District, confirmed (during a phone conversation on March 10, 2005) that using the soils classified as having severe high water erosion hazard as the definition for erosion hazard areas is appropriate.
Table 6-3 --Erosion Soils of Thurston County

<table>
<thead>
<tr>
<th>Map Symbol</th>
<th>Soil Name</th>
<th>Percent Slope</th>
<th>Water Erosion Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Alderwood gravelly sandy loam</td>
<td>30-50%</td>
<td>severe</td>
</tr>
<tr>
<td>8</td>
<td>Baldhill very stony sandy loam</td>
<td>30-60%</td>
<td>severe</td>
</tr>
<tr>
<td>10</td>
<td>Baumgard loam</td>
<td>40-65%</td>
<td>severe</td>
</tr>
<tr>
<td>12</td>
<td>Baumgard-Pheeney complex</td>
<td>40-65%</td>
<td>severe</td>
</tr>
<tr>
<td>13</td>
<td>Baumgard-Rock outcrop complex</td>
<td>40-65%</td>
<td>severe</td>
</tr>
<tr>
<td>30</td>
<td>Dystric Xerochrepts</td>
<td>60-90%</td>
<td>severe</td>
</tr>
<tr>
<td>35</td>
<td>Everett very gravelly sandy loam</td>
<td>30-50%</td>
<td>severe</td>
</tr>
<tr>
<td>49</td>
<td>Jonas silt loam</td>
<td>30-65%</td>
<td>severe</td>
</tr>
<tr>
<td>53</td>
<td>Kapowsin silt loam</td>
<td>30-50%</td>
<td>severe</td>
</tr>
<tr>
<td>61</td>
<td>Mal clay loam</td>
<td>30-65%</td>
<td>severe</td>
</tr>
<tr>
<td>63</td>
<td>Mashel loam</td>
<td>30-65%</td>
<td>severe</td>
</tr>
<tr>
<td>80</td>
<td>Pheeney gravelly loam</td>
<td>30-65%</td>
<td>severe</td>
</tr>
<tr>
<td>81</td>
<td>Pheeney-Baumgard complex</td>
<td>30-65%</td>
<td>severe</td>
</tr>
<tr>
<td>82</td>
<td>Pheeney-Rock outcrop complex</td>
<td>40-65%</td>
<td>severe</td>
</tr>
<tr>
<td>83</td>
<td>Pheeney-Rock outcrop complex</td>
<td>65-90%</td>
<td>severe</td>
</tr>
<tr>
<td>91</td>
<td>Rainier clay loam</td>
<td>30-65%</td>
<td>severe</td>
</tr>
<tr>
<td>96</td>
<td>Rock outcrop-Pheeney complex</td>
<td>40-90%</td>
<td>severe</td>
</tr>
<tr>
<td>119</td>
<td>Tacoma silt loam</td>
<td>30-60%</td>
<td>high</td>
</tr>
<tr>
<td>122</td>
<td>Vailton silt loam</td>
<td>30-65%</td>
<td>severe</td>
</tr>
</tbody>
</table>

- The current definition for erosion hazard areas relies on soils identified as highly erodable by the Soils Conservation Service. The Soil Conservation Service list of soils refers primarily to agricultural erosion. Muckel’s report, “Understanding Soil Risks and Hazards (2004), confirms that the soil surveys were oriented towards agricultural management until 12966 when the scope was expanded to include a wide variety of concerns, including urban development. According to Muckel, soil surveys were not intended to be used for site-specific evaluations.

WAC 365-190-030(5) defines erosion as follows: Erosion hazard areas are those areas containing soils which, according to the United States Department of Agriculture Soil Conservation Service Soil Classification System, may experience severe to very severe erosion. WAC 365-190-080(4)(c) further defines erosion as: Erosion hazard areas are at least those areas identified by the United States Department of Agriculture Soil Conservation Service as having a "severe" rill and inter-rill erosion hazard.

CTED’s Example Code Provisions defines erosion areas as including those areas identified as having “moderate to severe”, “severe”, or “very severe” rill and inter-rill erosion hazards AND also those areas impacted by shore land and/or stream bank erosion and those areas within a river’s channel migration zone. Thurston County’s CAO addresses marine shore land erosion under Marine Bluff Hazard Areas and addresses stream bank erosion and CMZ’s in separate chapters.
For comparative purposes, the definitions within Pierce and King County’s recently adopted CAO update are provided below:

**Pierce County:** "Erosion hazard areas" means those areas that because of natural characteristics, including vegetative cover, soil texture, slope, gradient, and rainfall patterns, or human-induced changes to such characteristics, are vulnerable to erosion.

**King County:** Erosion hazard area: an area underlain by soils that is subject to severe erosion when disturbed. These soils include, but are not limited to, those classified as having a severe to very severe erosion hazard according to the United States Department of Agriculture Soil Conservation Service, …or any subsequent revisions or additions, such as any occurrence of River Wash (Rh), or Coastal Beaches (Cb) and any of the following when they occur on slopes inclined at 15 percent or more: (Lists 7 soil types).

- Buffers. Specific buffers are not proposed for erosion hazard areas. Buffers will be determined on a site specific basis due to the temporary condition of soil erosion hazards and the variability of soil conditions. A geological assessment, prepared by a professionally certified soils scientist, will determine the need for buffers for each project proposal.

3. **Landslide Hazard Areas/Marine Bluff Hazard Areas.**

**NOTE:** See Appendix A for a summary table of the key points from the best available science discussed below.

**Characteristics/Causes/Risks:**

  - Active bluff retreat – Continuing sloughing or calving of bluff sediments, resulting in a vertical or steep bluff face with no vegetation.
  - Pre-existing landslide – Landslide debris within an arcuate head scarpe.
  - Tension cracks – Ground fractures along and/or near the edge of the top of a bluff or ravine.
  - Structural damage – Settling and cracking of building foundations near edge of a bluff or ravine; also separation of steps or porch from the main structure.
  - Toppling, bowed, or jackstrawed trees – Disruption of the ground surface by active movement causes trees to lean and/or fall in different directions or to grow in a curve instead of straight.
  - Gulllying and surface erosion – Dissection of the bluff edge by natural drainage or discharge from pipes, culverts, and ditches.
  - Springs – Mid-slope ground-water seepage from the bluff face; particularly noteworthy are increases in flow.
The occurrence of landslides is governed by numerous factors, though geology, hydrology, and slope steepness are the most significant. Most landslides on Puget Sound occur in response to either heavy precipitation or elevated groundwater conditions (Thorsen, 1987). Different rainfall regimes may lead to different kinds of slides, reflecting the ability of heavy precipitation to saturate shallow soils or of extended wet periods to lead to a rise in regional groundwater levels. During the winter of 1996-1997, two major episodes of landsliding followed heavy rainfalls, a majority of which were relatively shallow failures. In contrast, during the winter of 1998-1999, shallow landslides were infrequent, but prolonged wet conditions led to the reactivation of numerous large, deep-seated landslides (Shipman, 2001).

The geology of the bluffs affects the geotechnical properties of the bluff soils, but its most significant impact on stability appears to be stratigraphic and hydrologic. Most landslides in the region occur where permeable sand and gravel units lie directly on top of less permeable silts and clays, allowing a perched water table to develop and soils to become locally saturated (Tubbs, 1974). The most common scenario is where advance outwash overlies proglacial lakebed clay. Groundwater percolates downward in the porous outwash and laterally toward the bluff face along the contact with the finer grained underlying material. When water levels rise, increased pore pressures lead to weakness and failure. Similar geologic conditions exist where glacial sediments overlie bedrock and where recessional outwash is found above impermeable glacial till.

Steeper slopes are generally more prone to failure as gravitational stresses are greater, but variations in rock strength and differences in hydrologic conditions make it difficult to predict landslides based on slope alone. On coastal bluffs, erosion of the toe by wave action ultimately leads to steepening of the slope and the increasing likelihood of failure, but whereas toe erosion is a relatively slow process on most Puget Sound bluffs, landslides typically occur in response to transient increases in groundwater or soil saturation. As a result, wave action and undercutting may set the stage for future slope failures but rarely precipitate landslides. The common practice of constructing shoreline bulkheads to prevent coastal bluff erosion often overemphasizes the role of waves in determining slope stability.

Gravity is the driving force of landsliding, but its effectiveness in producing landslides depends on certain other factors. One such factor is the type of material involved. The landslides in the Seattle area generally occurred in the unconsolidated or partially consolidated sediments. Although most of these sediments have been overridden and compacted by several thousand feet of glacial ice, they are not “solid rock”.

Tubbs, Landslides in Seattle, 1974. There is probably no such thing as a single cause of a landslide. A number of conditions usually interact to make a rock or soil mass susceptible to sliding, although commonly a single factor can be identified as finally triggering the movement (Page 6).
Another factor controlling the effect of gravity in causing landslides is topography…The relatively steep slopes surrounding many of the upland areas were left in an unstable condition when the ice receded. This instability has been increased in some places by wave and current erosion along the base of the slope.

During the early part of 1972 three climatic conditions combined to produce a period of particularly intense landsliding (wetter than normal, cold, intense rainfall). (Page 7)

- Shipman, Coastal Landsliding on Puget Sound, 2001. A variety of factors influence the distribution, occurrence, and timing of landslides, including slope steepness, slope materials, hydrologic conditions, and others [Varnes, 1978; Jochim and others, 1988]. Landslides result when the stresses acting on a slope (driving forces) exceed the resistance of the slope to downward movement (resisting strength). The primary driving force is gravity and its effectiveness depends directly on slope geometry and loading. Resistance to earth movement depends primarily on the properties of the geological materials, hydrology, and the presence of additional strengthening elements, such as retaining walls or tree roots. Slides can be triggered whenever one of these factors changes sufficiently to result in unstable conditions. Erosion by wave action can steepen a slope, causing a slide. Heavy rain can saturate soils, reducing their internal strength.

Many landslides, particularly in developed areas, are aggravated by human actions. Shannon & Wilson [2000] found that 84% of the landslides inventoried in Seattle were influenced, at least in part, by human activities. The most common contributors are the directing of runoff onto a steep slope or the failure of an existing drainage system on or above a slide-prone slope. Other situations include excavation and undermining of slopes, placement of fill material on slopes, failures of retaining walls, and clearing of vegetation. (Pages 15-16)

The 1996-1997 landslides were predominantly shallow landslides and debris avalanches on steep slopes, triggered by heavy rainstorms. They occurred over short time periods and occurred in conjunction with other rainstorm-related natural disasters such as urban and groundwater flooding and snow and ice damage. Notable examples include the Rolling Bay landslide on Bainbridge Island that took four lives, the widespread sliding in Seattle's steep-slope neighborhoods such as Magnolia and Alki, and the very large slump at Woodway, south of Edmonds, that carried a train into the Sound. (Page x)

In contrast, the 1998-1999 landslides occurred following extended periods of wet weather, but were not specifically related to individual storms. Most were large, deep-seated landslides involving the reactivation of much older landslide features in the landscape. Although devastating to property owners and communities, these slides received little regional publicity and did not trigger federal disaster declarations. The most prominent examples were the Carlyon Beach landslide in Olympia and the large slides that closed Highway 101 for extended periods of time along Hood Canal. (Page x)

Landsliding affects more than 600 miles of Puget Sound's shoreline, reflecting the pervasiveness of high, steep coastal bluffs and the widespread occurrence of geologic
conditions that can give rise to slope failures when groundwater levels rise rapidly. The risks from landsliding, and the level of associated damages, are exacerbated by the intense development pressure along the shoreline and the relative value of property located in or adjacent to steep, unstable slopes.

Landslides along the shoreline of Puget Sound cannot be completely prevented, nor should they. Landslides provide a critical function to maintaining our beaches and the geologic, biologic, and aesthetic diversity of our shoreline. The impacts of slides on humans and on the built environment can be reduced, however, by understanding where slides are likely and how to avoid or minimize their consequences.

- **Swanson, Managing Washington’s Coast: Washington’s Coastal Zone Management Program, 2001.** Washington’s coastal areas experience both shoreline erosion and landslides. These are natural processes that are the response to changing conditions in the environment. Heavy storm waves can eat at beaches, and normal wave current action can carry sand away. Beach erosion can also be the result of a decrease in sediment supply that feeds the beaches.

  Bluff erosion occurs naturally on Puget Sound. Many bluffs are naturally unstable because of soil, slope, and water conditions. Bluff erosion is affected by geology, waves, and weather. All three factors vary widely within the Puget Sound region, so bluff erosion rates can range from a fraction of an inch to more than two feet per year. The erosion rate for a bluff can be regular over the years, or it can change from near zero for decades to tens of feet in a matter of seconds. Once steepened to an unstable angle, bluffs can continue to erode without wave action. High glacial bluffs are subject to continuing erosion. Usually this process is not considered significant until people move onto the bluff or the shorelines nearby. To keep land, people often build bulkheads and other structures. Such structures, however, may remove a major source of beach building materials. Erosion can increase downdrift of the structures. Downdrift beaches often steepen and/or lower. Most slope failures are directly related to the buildup of water in the soil. Development activities, such as clearing vegetation and modifying site drainage, and on-site septic systems can make erosion worse. Increases in landslide frequency and magnitude within a watershed as a result of poor land use management, such as road building on steep, unstable slopes, result in harmful downstream impacts on the riparian vegetation, on fish populations, and on an array of other organisms using the riverine corridor.

- **Landslide Types and Processes, USGS Publication FS-2004-3072.** The term “landslide” describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. Although many types of mass movements are included in the general term “landslide,” the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material.
Slope saturation by water is a primary cause of landslides. This effect can occur in the form of intense rainfall, snowmelt, changes in ground-water levels, and water-level changes along coastlines, earth dams, and the banks of lakes, reservoirs, canals, and rivers. Landsliding and flooding are closely allied because both are related to precipitation, runoff, and the saturation of ground by water. In addition, debris flows and mudflows usually occur in small, steep stream channels and often are mistaken for floods; in fact, these two events often occur simultaneously in the same area.

**Types of Slides:**

- **Shipman, Coastal Landsliding on Puget Sound, 2001.** Shipman uses the following four broad categories to describe landslides in this report:
  - Shallow landslides and debris avalanches
  - Slumps and large landslides
  - Deep-seated landslides and ancient landslide complexes
  - Mud and debris flows

(Note: Shallow landslides and deep-seated landslides are discussed in greater detail than slumps and mud/debris flows below because of their higher occurrence in the Puget Sound region.)

*Shallow landslides* (Shipman, 2001, pages 9-10). **Shallow failures of soils and debris are the most common landslides observed on the steep slopes around the Sound.** These shallow slides typically involve a thickness of only a few feet of soil and weathered material, along with accompanying vegetation (See Figure 4). They are typically large relative to their depth, although their size is highly variable, from a few feet to a few hundred feet in lateral dimension. **(Emphasis added)**

They can occur on a wide range of geological substrates, including compact, fine grained materials, sands and gravels, and artificial fill. Shallow landslides may be initiated by a small slump, the failure of the slope above, erosion of the toe of the slope, or simply the saturation of the soils.
Shallow landslides typically occur during and immediately following periods of intense rainfall or after rain-on-snow events, when rapid infiltration saturates the soils and pore pressures build along the base of the weathered materials. They are easily aggravated by drainage concentrations (associated with rapid runoff or failed drain systems, for example) and by increased seepage of shallow groundwater.

**Slumps** (Shipman, 2001, pages 10-11). Slumps are generally defined as earth movements that occur along circular failure planes. They may be small, perhaps only a few feet in scale - or they can be very large, involving an acre or more. Many landslides could be technically considered slumps and many shallow slides (described in the previous section) may originate as small slumps. These deeper landslides and slumps are considerably less common on Puget Sound than the shallow landslides we observe on virtually all steep coastal slopes.

**Deep-seated landslides** (Shipman, 2001, pages 12-13). Puget Sound's shoreline contains many large, deep-seated landslides that originally formed many hundreds or thousands of years ago, but that are periodically reactivated by unusually wet conditions. Some of these slides may have formed as glacial ice retreated. The loss of the support from the ice, combined with the abundance of meltwater, may have led to severe instability along the steep sides of the glacial troughs that became Puget Sound. Other large slides may have developed more recently as sea level reached its current position and began to cut into the shoreline, undercutting the already steep slopes. Finally, some slides may have been initially triggered by large earthquakes - for example, Karlin and others [1995] describe massive slides into Lake Washington that resulted from movement on the Seattle fault about 1100 years ago and such slides may well have occurred along Puget Sound as well. Although these slides remain dormant during most years, movement is often observed during exceptionally wet periods. Movement is often incremental, with portions of the landslide dropping several feet during any particular cycle of reactivation. These slides often have complex internal structure and may consist of many separate landslide blocks that move somewhat independently. Most deep-seated landslides on Puget Sound exhibit rotational...
movement, with the toe pushing up and out as upper portions drop, and with individual blocks showing landward tilting (Figure 7).

The surface of the landslide often consists of a low bench characterized by irregular topography, backed by a distinct headscarp marking the landward limit of the slide.

Figure 7. Cartoon illustrating a deep-seated landslide.

Reactivation of deep-seated landslides is more likely as deep groundwater levels rise, which requires high volumes of infiltration and in most situations, considerable time. Such events would not be expected to respond to rain bursts as shallow slides do. The geology and mechanics of individual landslides varies significantly, however, and each will respond to hydrologic conditions differently. Determination of threshold conditions for reactivation may depend on long-term monitoring of rainfall, groundwater, and slope movement - and results are likely to be different for each slide. Human influences on deep slides may be different than on shallow slides as well, possibly reflecting land use changes over broad areas and over long periods of time.

Mud/debris flows (Shipman, 2001, page 14). When large amounts of water are present in soils and landslide material, landslides take on more fluid-like properties and become flows. Debris avalanches high on a steep coastal slope can turn into debris flows or mudflows as they travel down the slope (Figure 9). Flows often occur when a landslide enters or travels down a stream channel. Factors affecting whether a flow occurs or not depend on the character of the geological materials involved, the amount of water present, and the distance the slide has moved. The same factors may affect the velocity of a flow. Flows can cause significant damage to structures in their path, with damage generally reflecting the velocity and volume of the slide.

- Tubbs, Causes, mechanisms, and prediction of landsliding in Seattle, 1975:

  “The slope inclination for each of the 47 landslides included in Appendix 1 was determined from topographic maps in a manner similar to that described above, and the results are expressed in figure 20. All but three of the landslides occurred in areas sloping >15 percent, and those three slides occurred in areas sloping >10 percent. The use of 10 percent as the boundary for slope mapping would include the latter slides but would also increase the total area outlined by approximately 50 percent (Tubbs and Frederick, 1974). Increasing the boundary value to 20 percent would
exclude a total of four slides, but would not significantly decrease the area included from that outlined by the 15-percent criterion. Thus, for empirical as well as theoretical reasons, 15-percent slope appears to be a useful criterion for constructing maps of relative slope stability in the Seattle area.”

• Sidle, Hillslope stability and land use, 1985. Sidle discusses residential areas and hillslope stability. While Sidle does not rely solely on slope angle for determining stability (or lack of), he notes lower limits of slope gradient for various types of slides (slumps: approximately 10-20 degrees or 18-36%; earthflows: 4-20 degrees or 9-36%; debris avalanches, slides, and flows: 22-38 degrees or 40-78%). Sidle’s ranges for slumps, earthflows, slides, and debris flows support a 20% minimum.

Proposed Revisions to Definitions and Regulatory Methods:

Landslide Hazard Areas:

- The current definition of landslide hazard areas contains slope standards that are not supported by best available science. The proposed amendments modify the slope percentages that trigger the need for review. As part of this review, the definitions for top of slope, toe of slope, and steep slope were revised. These revisions are based on the best available science, as discussed in the previous sections.

- WAC 365-090-080(4)(d) uses 15% to define landslide hazard areas. The WAC definition is based on Tubbs’ dissertation, Causes, Mechanisms, and Prediction of Landsliding in Seattle, published in 1975. Soil differences in the Seattle area and Thurston County may mean 15% is not the appropriate slope percentage to use for Thurston County. Tubbs notes on page 28 of his dissertation that using 20% would only exclude 4 slides from his proposed study but would not significantly decrease the area
included from that area outlined by the 15 percent criterion. Tubbs’ chart, included below, illustrates that the majority of slides were triggered beginning at the 20% slope. However, there are no available landslide studies specific to Thurston County to provide the science to support deviating from the 15 percent slope criterion for defining a landslide hazard area. To be conservative in the absence of best available science that is specific to Thurston County soils and slopes, it is prudent to be consistent with the best available science utilized in the WAC and adopted by other Puget Sound jurisdictions.

Steep Slopes:

- WAC 365-190-080(4)(d) defines a steep slope as a slope of at least 40% with a vertical relief of 10 or more feet. King County adopted 40%/10 ft for steep slopes. Pierce County’s new ordinance revised the definition from 30%/10 ft to 40%/15ft. Based on the best available science, Thurston County’s definition for steep slope is proposed to change from 50% to 40% slope with a vertical height of 15 ft. Sidle’s ranges, discussed above, shows a lower limit of slope gradient of 40% for debris avalanches, slides, and flows. Sidle et al (1985) concluded that most slopes greater than 35 degrees (70%) are subject to rapid mass movement. Sidle concluded that slower processes, such as slumps and earth flows are generally initiated on gentler slopes ranging from 4 – 20 degrees (7% - 36%).

- ManTech, 1996. Slope gradient is generally the most important determinant of mass failure risk, although other factors such as wet soils, geology and soil texture susceptible to failure, and vegetation removal are also important. For purposes of salmon habitat conservation, ManTech reviewed various studies, including Swanston (1980) and Sidle (1985), and concluded that for all types of mass soil movements, risk is high on slopes greater than 30 degrees (57%). Swanston’s study published in PNW-GTR-392 in March 1997, assessed factors controlling soil stability on steep terrain in southeast Alaska. While the soil types found in Swanston’s study may be different from what is found in Thurston County, the general conclusions defined “moderately steep slopes” as 36% - 55%. Based on these studies and the definitions used in the WAC and other local jurisdictions, Thurston County proposes establishing 40% slope for defining steep slopes.

Toe of Slope:

- Shipman, Coastal Landsliding on Puget Sound, 2001. The greatest risk to public safety appears to be development located at the base of steep slopes, where vulnerability to debris avalanches and shallow landslides is severe. The Rolling Bay landslide of January, 1997, underscored the risk, but it was only unique in the tragedy that resulted. Many homes in similar beach communities around the Sound have been knocked off their foundations, but remarkably they have either been unoccupied or residents have simply clambered out.

Small, shallow landslides commonly move very rapidly and carry enough mud and debris to severely damage structures. Trees and woody debris contained within a debris flow can become projectiles, causing damage that might not occur by flowing mud alone. Damages can include debris breaking through walls and entering structures,
collapsing or burying structures, or simply pushing buildings off their foundations. The level of danger is related to a variety of site-specific conditions, including the size of the failure, the height and steepness of the slope, the kind of material involved, the distance from the toe of the slope, and the type of construction, among other factors.

Shallow landslides result in significant property damage at the toe of coastal bluffs to improvements besides homes. Even if homes avoid direct impact, communities at the toe of the bluff are impacted when access roads are buried, utilities disrupted, or when vehicles and accessory structures are struck by slide debris. Even in areas where homes are built above the bluff, we commonly hear reports and observe damage to beach stairs, tramways, boat houses, guest cabins, and bulkheads. These damages are less likely to be life-threatening than where homes are built at the slope toe, but the value of property affected may be comparable or greater, simply because so many more of these situations exist.

**Top of Slope:**
- **Shipman, Coastal Landsliding on Puget Sound, 2001.** Damages to structures located above steep slopes are relatively rare, largely because the more common shallow landslides do not cut deeply into the slope. On the other hand, deeper slumps and slides, including failures of the capping glacial till, can threaten structures located near the crest of the slope. Clearly, structures built with minimal setback, or older homes which have lost ground in multiple previous slides, are most at risk from such landslides. When slides cut close to structures at the top of the slope, repairs can be difficult and expensive. Reclaiming lost ground may require substantial retaining walls, complex engineering designs, and regrading of the slope, possibly through the addition of large amounts of engineered fill. With development located close to the crest of the slope, there is little room for uncertainty and conservative solutions may result in high costs. Relocation of the structure, though also expensive, may be a preferred solution on sites where alternative building sites are not precluded by shallow lots or by required setbacks for drainfields or from adjacent rights of way.

The greatest risk appears to be homes located with very minimal setback from the bluff edge or to structures in areas prone to deeper failures (areas not easily identified). Legal setbacks vary around the Sound and are tied to a variety of factors, some of which have little to do with the stability of the slope or the likelihood of a major failure. Many older homes may have been built with no setback requirements, or may simply be in jeopardy because slides in previous decades have progressively removed what may have at one time been perceived as an adequate setback. There is enormous pressure to build close to the edge of bluff in an effort to maximize views and proximity to the water. Even where counties or cities require 50 or 75 foot setbacks, variances are often sought by property owners believing that the threat of landsliding to their proposed home is minor and able to secure a professional opinion that building closer is acceptable. As a result, homes are often located at distances that, although safe in the short term, become significant risks in the future.
Fortunately, most failures along the top edge of coastal bluffs tend to be shallow - often only a few feet - and do not occur too often - maybe once every several decades. Occasional, very large slumps, such as at Woodway near Edmonds in 1997, can cut landward fifty or more feet, but little is known about where they are likely to occur. Were such a slide to occur in an area of dense shoreline development, the consequences would be large, for homes and safety both above and below the slope.

- The percent slopes used in the toe and top of slope definitions are revised to reflect the proposed changes in the definition of steep slope. The “10 foot rise within a 25-foot run” equates to a 40% slope.

Marine Bluff Hazard Areas:
- The WAC does not list marine bluff hazard areas as a separate category. Because marine bluffs have unique characteristics that may differ from other landslide hazard areas, Thurston County separates marine bluffs into a separate category within the existing CAO and proposes to continue this separate categorization within the revised CAO. For example, according to Shipman, 2004, coastal bluff erosion on Puget Sound is a complex process that includes the process of wave action and toe erosion as well as hillslope processes. These processes are further complicated because adjacent segments of a shoreline may be at different stages of a cycle, resulting in different erosion and mass-wasting over short distances (Shipman, 2004). Marine bluff protection is also interconnected with the preservation and/or restoration of habitat and ecological functions of the marine shoreline environment (Shipman, 2001).

Buffers:
- Much of the scientific literature that discusses mitigation techniques for landslide hazard areas recommends setbacks or buffers from the toe and top of the hazard area. However, there is no empirical evidence to support recommendations for specific or standardized setback requirements.

- King County Best Available Science, February 2004. Literature indicates that buffers should be established around the perimeter of mapped landslide hazard areas (Gerstel, Brunengo, Lingley Jr., Logan, Shipman, Walsh, 1997). More specifically, buffers should be established from the tops and toes of 40 percent slopes. …Development that is proposed within those buffers or within the slide area itself should meet scientifically based rigorous design and construction standards. Because of the extreme variability that is exhibited by areas that are subject to landsliding, site-specific studies may be required in order to design, construct, and safely occupy a structure that is to be built in or adjacent to one. The hazard area and proposed development should be evaluated by a geotechnical engineer or engineering geologist, including subsurface exploration of the area, soil sampling and testing, and development of a detailed construction sequencing and monitoring plan.

- Koloski, Jon W., LG, LEG, Senior Principal, Co-Founder of GeoEngineers. Email correspondence dated 1/25/2005. There is not any definitive science that supports a prescriptive buffer of any dimension for separation of development from the edge of a “marine bluff hazard area” or any other type of landslide hazard area. All of the buffers
in use today in land use regulatory documents are based strictly on “administrative convenience” and/or on the belief that some measure of a buffer of separation improves safety to the potentially impacted public or to property. Therefore, there are myriad factors that influence specific applicable hazard conditions and those vary so much from site to site, that individual investigation is realistically the only way to characterize an appropriate buffer or setback. The County must recognize that generalization simply has to be based on some factor such as administrative convenience.

- **Spiker, Elliott C., Gori, P. 2003. National landslide hazards mitigation strategy – a framework for loss reduction. Circular 1244.** The National Landslide Hazards Mitigation Strategy includes developing new partnerships among government at all levels, academia, and the private sector and expanding landslide research, mapping, assessment, real-time monitoring, forecasting, information management and dissemination, mitigation tools, and emergency preparedness and response. Such a strategy uses new technological advances, enlists the expertise associated with other related hazards such as floods, earthquakes and volcanic activity, and utilizes incentives for the adoption of loss reduction measures nationwide.

The reduction of landslide losses through land use planning and application of building and grading codes is the function of local government. Localities throughout the Nation differ in their regulatory authority and approach to reducing losses from landslide hazards. Local governments have the responsibility of issuing warnings of imminent landslides and managing emergency operations after a landslide. FEMA may become involved after a Presidentially declared disaster.

Landslide hazards have traditionally occupied a relatively modest place in public policy, embodied in zoning, legal liability, insurance, building codes, land use practices, and environmental quality. Maps showing historic landslides and areas susceptible to landslides have been used only sporadically for zoning and for purposes of real-estate disclosure. Building codes have been drafted for some localities to set minimum standards for construction on unstable slopes. Federal and State forestry practices in many localities include attention to landslide hazards. Building setbacks from coastal or riverine bluffs have been established in some areas on the basis of projected failure by landsliding. However, broad systematic policy approaches to landslide and other ground-failure hazards are rare, and most areas of the Nation lack the most fundamental technical information or policies to cope with their hazards.

- **Washington Department of Ecology, Puget Sound Landslides, [http://www.ecy.wa.gov/programs/sea/landslides/prevent/prevent.html](http://www.ecy.wa.gov/programs/sea/landslides/prevent/prevent.html).** Build a prudent distance from the top or bottom of steep slopes. Avoid sites that are too small to allow a safe setback from the slope. Allow adequate room for drainfields and driveways. Local setback requirements should be viewed as absolute minimums. Resist the urge to trade safety for a view.

Avoid trouble and stay out of harms way. Locate your home as far back as from the water or bluff edge as possible. Resist the urge to trade safety for an improved view. Consider local setback requirements absolute minimums.
• Shipman, H., 2004. Coastal Bluffs and Sea Cliffs on Puget Sound Washington. In U.S. Geological Survey Professional Paper 1693. Development along bluffs most commonly occurs at the top of the bluff. The distance a building is set back from the bluff edge depends on local regulations, the history and age of the structure, the topography of the site, lot lines, and the original property owner’s concept of risk and their desire for views. Property owners often build as close to the edge as allowed, in large part to maximize views in an otherwise forested area. The risk to bluff top homes is relatively low as a consequence of slow erosion rates, although a property owner’s perception of danger may be greatly enhanced by periodic landslides or related bluff failures.

Construction setbacks are the standard approach for guiding new development away from bluff hazards, but setbacks vary considerably between jurisdictions and property owners often seek and obtain variances to build closer to bluffs than the code recommends. Setbacks can range from arbitrary minimums to distances based on the height of the slope. Recent updates to Critical Areas Ordinances (under Growth Management) in some jurisdictions have increased setbacks, driven both by renewed awareness of landslide hazards brought by the winter of 1997-1998 and by greater emphasis on protecting shoreline habitat through avoiding development that is likely to require shoreline structures in the foreseeable future.

Shipman, Coastal Landsliding on Puget Sound, 2001. The greatest risk appears to be homes located with very minimal setback from the bluff edge or to structures in areas prone to deeper failures (areas not easily identified). Legal setbacks vary around the Sound and are tied to a variety of factors, some of which have little to do with the stability of the slope or the likelihood of a major failure. Many older homes may have been built with no setback requirements, or may simply be in jeopardy because slides in previous decades have progressively removed what may have at one time been perceived as an adequate setback. There is enormous pressure to build close to the edge of bluff in an effort to maximize views and proximity to the water. Even where counties or cities require 50 or 75-foot setbacks, variances are often sought by property owners believing that the threat of landsliding to their proposed home is minor and able to secure a professional opinion that building closer is acceptable. As a result, homes are often located at distances that, although safe in the short term, become significant risks in the future.

Fortunately, most failures along the top edge of coastal bluffs tend to be shallow - often only a few feet - and do not occur too often - maybe once every several decades. Occasional, very large slumps, such as at Woodway near Edmonds in 1997, can cut landward fifty or more feet, but little is known about where they are likely to occur. Were such a slide to occur in an area of dense shoreline development, the consequences would be large, for homes and safety both above and below the slope.

• Shipman, Hugh. Washington Department of Ecology. Phone conversation March 2, 2005. Mr. Shipman confirmed the lack of science to support a specific setback/buffer along landslide hazard areas. He stated that buffers reflect specific concerns, and that buffers could differ depending on the concern being addressed.
or what is being protected. For example, there would be different buffer recommendations to protect a home as compared to protecting nearshore oyster beds. Along shorelines, there is enough variability in high bluffs with certain soil characteristics vs low bluffs and soils to support site-specific decisions. The closer homes are to a bluff, the more things there are to impact the bluff (such as drainage, landscaping, etc.). This supports the argument for more rigorous setback requirements to avoid the need to tight line runoff down the bluff. Piping water down the bluff is good for the bluff, but not necessarily good for the water quality.

Thurston County’s existing buffer requirement of 2:1 slope from the ordinary high water mark is reasonable and supportable. The 2:1 is based on the notion of angle of repose. In Mr. Shipman’s opinion, the 2:1 setback is more supportable than a 50-foot setback.

Erosion rates vary tremendously. The typical rate is less than 2 inches per year, but can result in a large chunk falling every 10 to 20 years. With an average erosion rate of one foot per decade, a 50-foot buffer can erode away in 50 years.

- As indicated above, there is a lack of empirical data to support a definitive setback from landslide hazard areas. However, there is support for local jurisdictions to play a role in mitigating the risks associated with landslide and marine bluff hazard areas. Shipman, 2001, recognized that “Occasional, very large slumps, such as at Woodway near Edmonds in 1997, can cut landward fifty or more feet, but little is known about where they are likely to occur.” The existing 50-foot buffer width remains the standard used by other local jurisdictions.

**Distances for Triggering a Geological Assessment:**
- McCabe, Martin, PhD, PE, and Sr. Geotechnical Engineer. URS Corporation, Seattle, WA., Telephone interview March 2, 2005. Discussed both buffers/setbacks and the distance for triggering the requirement for a geotechnical report. Mr. McCabe agreed that 50 feet is a typical buffer, but that it should be a minimum. The wet seasons of 1995-1997 resulted in 5 to 10 feet of bluff failure in some places to as much as 30 to 50 feet failure. It may be many years before this degree of bluff failure will happen again. However, Mr. McCabe stated that he believes that geotechnical professionals should not make the sole decision regarding buffers for a specific site. Instead, he would like to see a minimum buffer as a starting point for review. Regarding trigger distances for review, Mr. McCabe stated that it is not possible to know exactly where the edge of a hazard area or soil type is located. Therefore, there needs to be an area around the hazard area that will trigger geotechnical review. He believes that one hundred feet is too small. There is no best available science to support a specific distance. Based on engineering judgement, he believes that 200 to 300 feet is reasonable. This is supported by the WWGMHB case that is discussed below.

- Western Washington Growth Management Hearings Board Case No. 95-2-0073 (Geologically-Hazardous Areas), Compliance Hearing Order #14, July 13, 2001. This
case included an appeal of Mason County’s geologically hazardous areas. The petitioner claimed that the County had failed to include BAS, when its consultant, Mr. McCabe, offered only an “impromptu response” to the reduction of distances triggering geotechnical and geological studies. The petitioner characterized the allowance of an exception to the 50 foot buffer minimum as a further failure to include BAS. The WWGMHB found that the record did not show inclusion of BAS with regard to the August 29, 2000, reduction of distances triggering geotechnical reports and geological assessments.

“In this case we find that Mr. McCabe’s 1997 studies and remarks represented BAS. Mr. McCabe stated very clearly in the record that 300 feet was a sensible distance for triggering geotechnical studies. We infer that the “sensible” 300 or 400 feet triggering distance includes the 50-foot buffer, so that the minimum “sensible” distance recommended by Mr. McCabe would equal 250 feet, excluding the buffer.”

- Palmer, Stephen P., PhD, Geologist. Washington State Department of Natural Resources, Telephone interview April 27, 2005. Mr. Palmer confirmed that 300 feet, in his professional opinion, is a reasonable distance for triggering review of a landslide or marine bluff hazard area. Mr. Palmer acted as an advisor to state and local government agencies during the response to the Carlyon Beach landslides. He stated that a three hundred foot trigger area increases the ability to look beyond the project site and raises the potential to find indicators of slide activity. For example, there was visible ground cracking at least two years prior to the Carlyon Beach landslide. If the regulations in place at that time had contained a three hundred foot perimeter for triggering geotechnical review, these ground cracks may have been discovered.

Landslide and Marine Bluff Hazard Area Mapping:
- Canning, Douglas J., Geologically Hazardous Areas, Publication #01-06-027, 2001. Most landslide hazard mapping is generalized and useful only as a screening device. Site specific information is usually required for site-specific assessments. Therefore, while most landslide hazard mapping is inappropriate for site-specific regulatory purposes, it can be an excellent indicator of potential hazards and should be used by local governments as an adjunct to their critical area ordinance.

- Shipman, Coastal Landsliding on Puget Sound, 2001. The Coastal Zone Atlas of Washington [Washington Department of Ecology, 1977-1980] comprises the only comprehensive mapping of unstable slopes along the shores of Puget Sound and we believe it is the primary source for a variety of published estimates for the amount of shoreline susceptible to landsliding. Thorsen [1989] reports that Puget Sound's shoreline includes approximately 660 miles of unstable bluffs. Downing [1983], citing the Coastal Atlas, reports a similar number (Table 1).2 Chleborad [1994] cites 149 miles of landslides on Puget Sound. The lower number probably indicates that only mapped landslides were included, whereas the larger numbers include all unstable slopes. All of these numbers likely underestimate the pervasiveness of landslide-prone shorelines.
[Thorsen, 1989], simply because older slides were hard to identify and map, many slides were too small to adequately represent at the map scale (1:24,000), and many larger, dormant landslides may have been easily overlooked. For example, the large Carlyon Beach landslide in Thurston County that reactivated in 1999 was identified as an area of Intermediate slope stability in the Coastal Zone Atlas, yet larger scale mapping in the field might have recognized the more serious character of the prehistoric landslide feature.

4. Seismic Hazard Areas.

- **“Liquefaction Susceptibility Map of Thurston County, Washington” (published Sept 2004)**. The susceptibility ranges on the map go from high, moderate to high, and moderate down to very low. See proposed revisions to the definition, below. High risk areas have historical liquefaction and should automatically be regulated. Moderate risk areas have investigation/assessment.

- The CAO currently designates seismic areas as being those areas within a wetland, the filled site of a former wetland, or the 100-year floodplain of the Black, Chehalis, Deschutes, Nisqually, or Skookumchuck Rivers. These designation criteria are not relevant or accurate for identifying seismic hazard areas in Thurston County. The revised definition removes this designation criteria and relies on a map recently published by DNR entitled “Liquefaction Susceptibility Map of Thurston County, Washington” (published Sept 2004) to identify seismic hazard areas. The susceptibility ranges on the map go from high, moderate to high, and moderate down to very low. DNR staff recommends triggering review for those areas mapped from high to moderate.

- DNR staff requested that a “place holder” be used for surface faulting. DNR is doing research into surface faults and will have better mapping for Thurston County in the future. The definition of seismic hazard in WAC 365-190-080(4)(e) includes surface faulting, as well. WAC 365-190-080(4)(e) defines seismic areas as areas subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement, soil liquefaction, or surface faulting. One indicator of potential for future earthquake damage is a record of earthquake damage in the past. Ground shaking is the primary cause of earthquake damage in Washington.

- Buffers are not included for seismic hazard areas. The DNR liquefaction map will be used to identify seismic hazard areas. No buffers are required on liquefaction sites due to the ability to mitigate with construction techniques and to use soil remediation.

5. Volcanic Hazard Areas.

- Hoblitt, et al. USGS Open File Report 98-428. Plate 1 from OFR 98-428 identifies inundations zones with recurrence intervals < 100 years (Case III Lahars), 100 – 500 years (Case II Lahars, comparative to the 100-year flood), and 500 – 1,000 years (Case I Lahars). A portion of Plate 1 is included below. The area relevant to Thurston County is along the Nisqually River, both above and below Alder Dam. This area is mapped as
a Case I Lahar area above Alder Dam and a “sub-case of the Case I Lahar area” below Alder Dam. The average time interval between Case I Lahars on Mount Rainier is about 500 to 1,000 years. The “sub-case” is described as an area that could result from dam failure by lahar impact, displacement by the lahar of some of the water impounded by the reservoir, or possible continuation of the lahar past the dam site. The Report notes that the boundaries mapped for each hazard area are not absolute. The degree of hazard does not change abruptly at these boundaries, but instead decreases gradually away from the volcano and, for flows, with height above the valley floor. The uncertainty of the source, size, and mobility of future events makes it impossible to determine exact boundaries.

• The current definition of volcanic hazard area within the Thurston County Critical Areas Ordinance references the 500-year floodplain upstream of Alder Dam. The USGS mapping in USGS Open File Report 98-428, by Hoblitt, et al is a more accurate, science-based reference. This report revised the USGS Open File Report 95-273 published in 1995. Revisions relevant to Thurston County include the addition of a zone of potential inundation hazard in the lower Nisqually River valley caused by a Case I lahar entering and possibly flowing beyond Alder Reservoir. Map E from the Report illustrates this scenario and is included below. According to OFR 98-428, the storage capacity of Alder Lake is less than the Case I lahar volume. Alder Lake is never empty, creating concern that a Case I flow entering the reservoir could either cause the dam to fail or could catastrophically displace a significant volume of water being stored in the reservoir. The inundation zone mapped in the report is similar to a sudden failure of the dam.


• The proposed definition deletes the reference to Plate 1 within the definition. This map is outdated and incomplete. DNR suggests referencing “Coal Fields of Southwestern Washington” (Culver, Harold E, 1919, Washington Geological Bulletin 19).

Mine hazard areas are limited to coal mines in Thurston County. Coal mining was the only sub-surface mining in Thurston County and was located south of Tenino and Bucoda. Coal was generally mined at shallow depths. It may be difficult to identify a mine site until the hydrology changes or a building is sited there.
Best Available Science Review

Bibliography

Landslides/Marine Bluff/Erosion Hazards:


Volcanic Hazards


Mine Hazard Areas:


Seismic/Earthquake Hazard Areas:


Personal Communications:

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2. McCabe, Martin PhD, PE, and Sr. Engineer, URS Corporation, Seattle, WA.
3. Palmer, Stephen P. PhD and Geologist. Washington Department of Natural Resources, Division of Geology and Earth Resources.


5. Squires, Garry PE, LEG, LG. Associate, GeoEngineers, Inc., Tacoma, WA.


7. Walsh, Tim. Washington Department of Natural Resources, Department of Geologic Resources.
## Appendix A: Summary of Best Available Science – Landslide and Marine Bluff Hazard Areas

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<td></td>
<td>Two major types in Puget Sound:</td>
<td>- Shallow (most common): Can occur on a wide variety of substrates. May be initiated by small slump, failure of slope above, toe erosion, or soil saturation. - Deep-seated: Difficult to predict. Reactivated by exceptionally wet periods. More likely when deep groundwater levels rise due to high volumes of infiltration.</td>
<td>- Greatest risk to public safety appears to be development at base of steep slopes. (Highly vulnerable to shallow slides and debris flows). - At top of slope, greatest risk appears to be from minimal setbacks or building in areas prone to deep-seated slides, which are not easily identified. Failures at top of slope tend to be shallow. But large slumps can cut landward 50 feet or more (Woodway near Edmonds, 1997).</td>
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<td>- Geology (e.g. permeable sand and gravel units directly on top of less permeable silts/clays, with perched water table and saturated soils) - Hydrology - Slope steepness - Heavy precipitation - Elevated groundwater - Human actions (stormwater runoff, excavation/clearing, etc.)</td>
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| Mantech (1996) | | - Slope gradient - Wet soils - Geology - Soil texture - Vegetation removal | - For purposes of salmon habitat conservation, risk is high on slopes greater than 57% (30 degrees). | |

| Tubbs (1975) | | - Gravity - Soils - Topography - Climatic conditions (rainfall) | - 47 landslides studied. - 44 were on slopes > 15%. - 43 were on slopes > 20%. | |

<p>| Gerstel et al (1997) | | - Active bluff retreat - Pre-existing slide - Tension cracks - Structural damage - Toppling, bowed, jackstrawed trees - Gullying/surface erosion - Springs | | |</p>
<table>
<thead>
<tr>
<th>Types of Landslides</th>
<th>Characteristics/Causes of landslides</th>
<th>Risks</th>
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</thead>
<tbody>
<tr>
<td>Swanston (1997)</td>
<td>- Study in SE Alaska concluded that “moderately steep slopes” are defined as 36% - 55%.</td>
<td>- Slope gradient is generally the most important determinant of mass failure risk. - Risk is high on slopes greater than 67% (34 degrees). - Risk is medium on slopes between 55% and 67% (29 – 34 degrees). - Risk is low on slopes less than 55% (29 degrees).</td>
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<tr>
<td>Swanston (1980)</td>
<td>- Topographic (hummocky terrain, tension cracks) - Geology - Soils - Hydrology (groundwater and surface water) - Excavation of soil - Fill - Concentration or introduction of water - Vegetation removal - Rainfall intensity and duration</td>
<td>- Lower limits of slope gradient for slides: - Slumps: 18 – 36% - Earthflows: 9 – 36% - Debris flows: 40 – 78%</td>
<td></td>
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<tr>
<td>Sidle (1985)</td>
<td></td>
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<td>- Most slopes greater than</td>
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