LANDSLIDE MAPPING FOR DPER:
POTENTIAL HAZARDS IN UNINCORPORATED KING COUNTY

Summary and Purpose

In early 2014, DPER began working with DNRP-WLRD and other departments to study landslide hazards in King County. The first phase of the work was to be a map showing potential landslide hazards that could be used by DPER to update the 1990-vintage Sensitive Areas Ordinance (SAO) landslide hazard mapping. Because of funding and geographic limitations at the time, a countywide map was not then possible. As a result, DPER began in early 2015 a separate but parallel program of mapping potential landslide hazards over all of unincorporated King County. This effort resulted in the map available today as well as a map of steep slope hazard areas (+40% grade slopes). These two maps are to be used in conjunction for land use and building permit reviews beginning mid-2016. A complete assessment of the potential landslide hazard on any specific property requires review of the mapped potential landslide hazards as well as a review of the proximity and nature of nearby steep slopes. Please note that this work attempts only to identify areas that are potential landslide hazards; it cannot be used to quantify risk at individual properties. Accurate hazard evaluation specific to a parcel requires on-site investigation by a licensed engineer or geologist.

Goals and Deliverables

DPER's countywide project had the following goals:

- Map potential landslide/steep slope hazards (using LiDAR and existing 7.5-minute geologic mapping) over unincorporated King County, excluding most of the forest production zone.
- Produce a map of potential landslide hazards and a second map of steep slope hazards that together serve the needs of DPER for permit screening and review. The potential landslide hazard map was designed to be a working document that will be revised as needed by staff following a simple protocol. The steep slope hazard map will only be revised upon the receipt of higher-quality LiDAR data.
- Following completion of the landslide hazards map, impacts to the existing Critical Areas code were examined. No changes to the existing steep slope and/or landslide hazard sections of the code (21A.24) are recommended at this time.

Methodology of Hazard Identification and Mapping

The methodology employed in creating a map of potential landslide and steep slope hazards is relatively straightforward. By using LiDAR-derived hillshade imagery (equivalent to shaded-relief topography with an artificial angle of solar illumination and shadows) and LiDAR slopeshade imagery (a hillshade image for which the illumination is from directly above, thereby eliminating shadows) in conjunction with existing, high-quality, 7.5-minute geologic mapping, geologists skilled in photointerpretation and mapping identified landslide features and landforms associated with mass wasting. These were recorded in ArcMap by using the polygon tool to digitize the perimeters of landslides and areas assessed as potential landslide hazards. Key to this effort was the experience of the mapping geologists. Extensive experience in surface mapping, photointerpretation, and familiarity with local geologic hazards and terrain are all required. In this case, DPER was in a unique position to ensure that the final map product would be of very high quality and widespread utility. Figures 1A-C and 2A-C include examples of the LiDAR hillshade and slopeshade imagery with interpreted landslide hazards, +40% slopes, and mapped geology, as described in more detail below.

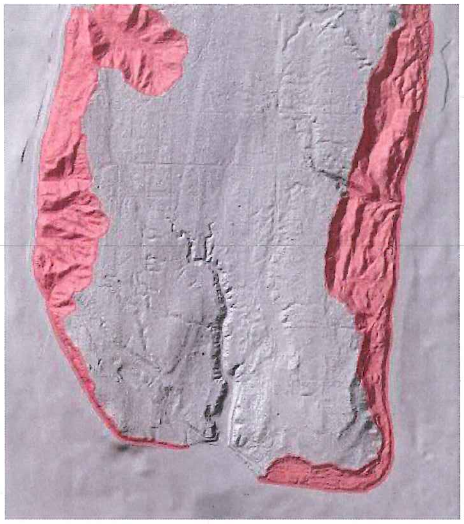

Figure 1A. LiDAR hillshade of the south end of Vashon Island, with potential landslide hazards shown in red. Northwest corner (upper left) is depicted in greater detail in Figure 9. Field of view is approximately 2 miles across.

Figure 1B. LiDAR slopeshade of the south end of Vashon Island.

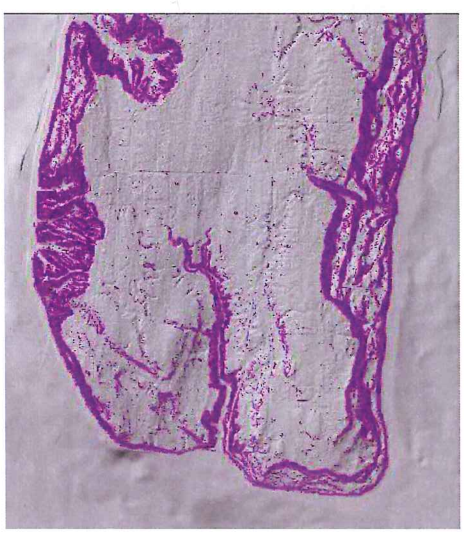

Figure 1C. South end of Vashon Island with LiDAR hillshade and slopes >40% grade in purple.

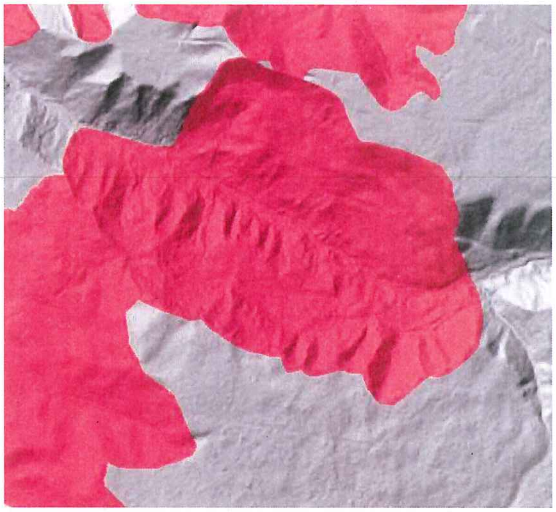

Figure 2A. Icy Creek, a tributary to the Raging River just downstream from Preston. LiDAR hillshade shown with potential landslide hazards shown in red. Field of view is roughly 3000 feet across.

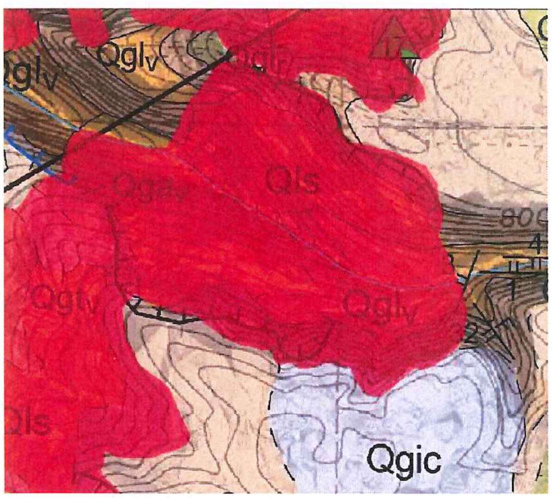

Figure 2B. Icy Creek showing available geologic mapping (Fall City quad by WaDNR) overlain with red landslides as above. In most places, the available geologic mapping is not nearly this good.

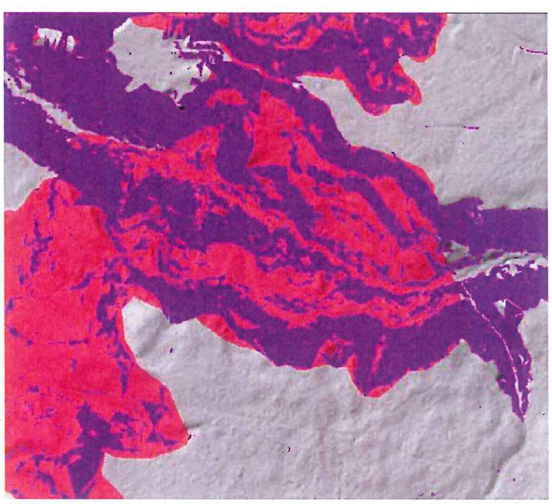

Figure 2C. Icy Creek showing combination of landslide hazards in red and slopes >40% grade in purple.

Using photointerpretation of LiDAR data with reference to available 7.5-minute geologic mapping, the following landslide types and potential landslide hazards can be remotely identified and mapped at landscape scales:

1. Slumps, spreads, rotational, translational and other deeper-seated landslides undifferentiated,
2. Rockfalls (to a degree),
3. Rock avalanches,
4. Debris/alluvial fans,
5. Snow avalanche zones (to a degree),
6. Oversteepened slopes, some of which are currently being undercut along a shoreline,
7. Undifferentiated or unclassified larger-scale mass wasting,
8. Slopes/landforms suggestive of enhanced instability and dominant mass wasting,
9. Slopes potentially susceptible to shallow landsliding (steep slopes).

Although LiDAR is an excellent tool for identifying large, historic and prehistoric landslides, smaller, shallow landslides ("skin failures") cannot be imaged given the resolution of available LiDAR data. Shallow, low-volume landslides/debris flows are the most common type of landslide and are the most likely to impact residential structures throughout King County, with hundreds of them occurring every winter. Nevertheless, they are largely invisible on LiDAR data and not noted on even the most detailed geologic maps that are available.

Attempts to differentiate shallow-landslide-susceptible slopes from slopes that are not susceptible to shallow landslides have been unsuccessful at landscape scales, principally because there is not enough detailed geotechnical and groundwater information to make such a distinction. These studies have shown only that on a landscape scale, shallow landslide susceptibility increases with slope angle. For example, recent modelling by DNRP-WLRD has suggested that slopes greater than 44% grade are susceptible to a moderately increased risk of shallow failure, with slopes greater than 54% grade subject to a severely increased risk. This conclusion was reached without detailed information on soil type or degree of saturation.

Largely because of existing Zoning Code restrictions regarding Steep Slope Critical Areas, DPER considers all slopes greater than 40% grade to be equally hazardous to landslide initiation until shown otherwise through a detailed site-specific evaluation. Furthermore, quantitative slope stability assessments by geotechnical consultants typically conclude that 40-44% slopes are subject to shallow failure under design earthquake loading. Existing LiDAR data are not precise enough to separate +40% slopes from +44% slopes reliably everywhere in King County, and it is widely accepted that the overwhelming majority of shallow landslides occur on slopes greater than 40% grade. For these reasons, and because +40%-grade slopes are already regulated in part because of their potential for instability, we include in the hazard category all slopes that are of 40%-grade and greater as determined from the LiDAR data. As such, a complete view of all potential landslide hazard areas must include <u>both</u> those landslides mapped from the LiDAR and all slopes greater than 40% grade.

Potential landslide hazards (other than steep slopes) are mapped using these guidelines:

1. ***Slumps, spreads, rotational, translational and other deeper-seated landslides undifferentiated:*** The LiDAR hillshade and slopeshade imagery is used in conjunction with the 7.5-minute geologic mapping to identify and outline visible slumps and deeper-seated landslides using standard photointerpretive techniques. Geologists skilled in surface geologic mapping and landslide identification map only the perimeters of the landslides, including source areas (head scarps) and deposited debris. Structures internal to each landslide mass (internal scarps, sag ponds, etc.) have not been differentiated at this time; the head scarp, flow path, and resulting debris field are all included in one polygon for each landslide. Some such landslides are quite visible (see Figure 3 below) but others are less apparent particularly if older and inactive. Some landslides are quite difficult to discern and still others transition into complex structures that might best be referred to as "unclassified mass wasting." Their exact geometry and origin may be unclear, but because the DPER mapping effort was done only to identify potential hazards for further in-depth study at some time in the future, we didn't require precise characterizations of the landslides.

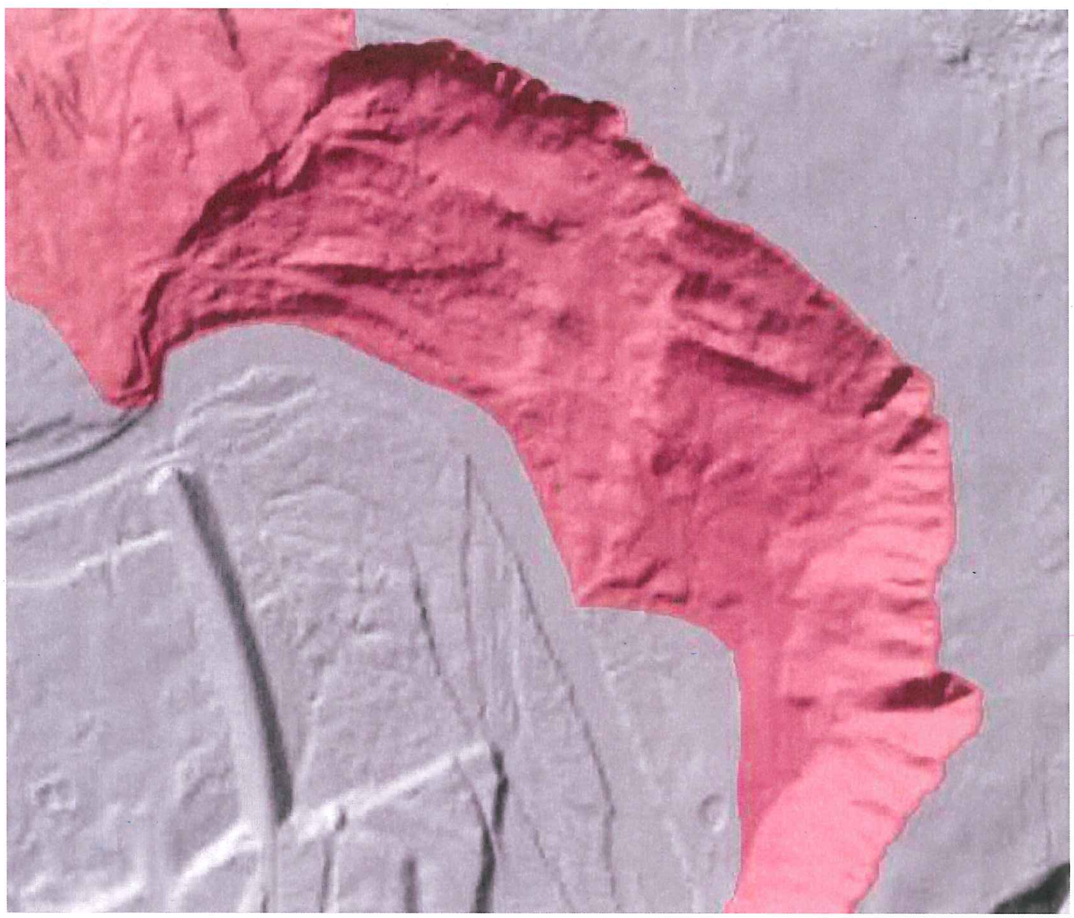

Figure 3. Large slump on the Cedar River at the Dorre Don Reach Natural Area. Field of view is roughly 2500 feet across.

2. ***Rockfalls:*** Only a handful of rockfall sites are within the area of interest, and these are known mostly from past experience and geotechnical studies that were completed for proposed building and land use activities. Very large rocks may be visible on the LiDAR hillshade, but mapping rock distribution solely from the LiDAR imagery is not a reliable method for determining the extent of rockfall hazards. As such, for the few sites known to host this hazard, past experience and available detailed studies were used along with the LiDAR imagery to map potential rockfall hazards.

3. ***Rock avalanches:*** A number of large landslides are present in the Cascade foothills that resemble rock or debris avalanches. With a few exceptions, little is known about them and it is not possible from the data available to us to determine much about these impressive features. Fortunately, most are largely within the forest production zone, so there are few residential parcels affected by their presence. Residential development was once proposed for the lower portion of the landslide pictured in Figure 4 below, but that activity was delayed when it became clear that little was known about this feature and that further study would be required. As far as we know, no geotechnical study has yet been completed for this feature.

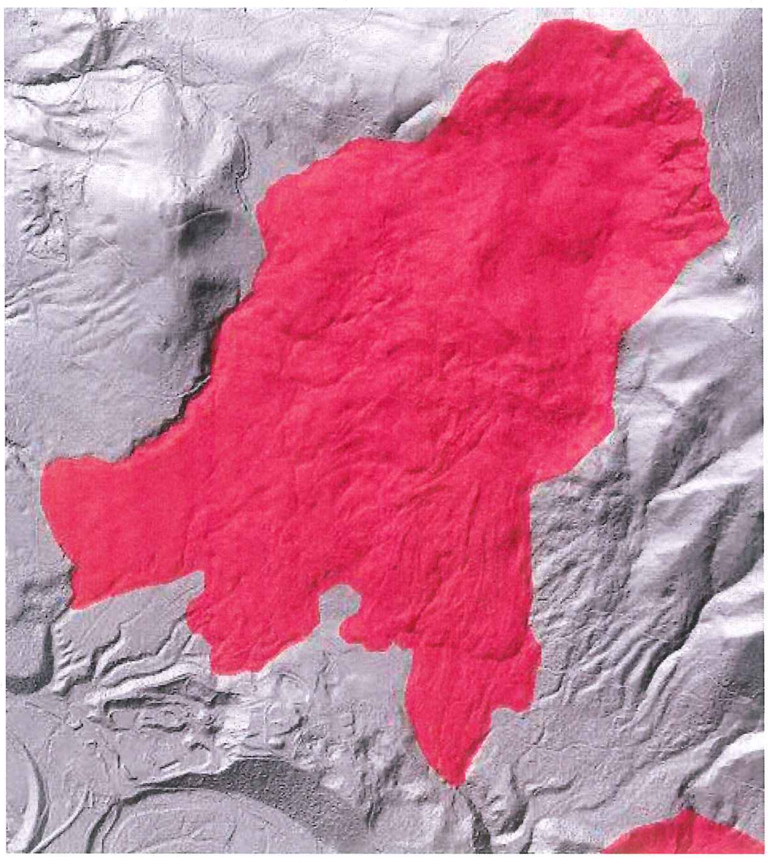

Figure 4. Rock/debris avalanche above the Green River northeast of Kanaskat. Evidence of multiple landslide events is apparent. Distance from the top of the slide to the southernmost toe is 1.5 miles.

4. ***Debris/alluvial fans:*** Debris fans are mapped from the LiDAR-derived hillshade and topographic contours using a five-foot contour interval (Figure 5). DNRP-WLRD differentiated fans based on their potential to host damaging debris flows using a landscape-scale method, but DPER's work makes no such distinction because site-specific evaluations are required as needed during building and land-use permit review. The potential for debris flows to occur outside of mapped fans has not been addressed as yet, but future investigations by others may shed light on that issue.

Figure 5. Debris/alluvial fan on the west side of the Cedar River valley near Cedar Grove. Field of view is approximately 1000 feet across.

5. ***Snow avalanche zones:*** Only one general area of potential avalanche hazards affecting developments other than state or federal highways is known in the region of interest, and it is shown based in part on detailed studies from past investigations. Avalanche hazards affecting only highways are not be included on the current landslide hazard map.

6. ***Oversteepened slopes, some of which are actively undercut by streams, rivers, or wave action:*** Some additional sites have been flagged as having increased landslide potential

even though no past landslides may have been mapped at those sites. The most compelling examples of these includes steep slopes directly adjacent to active river channels that are currently being undercut by shoreline erosion and steep slopes adjacent to eroding and recessive marine shorelines. Such slopes are included in the County's definition of a landslide hazard (KCC 21A.06.680), where a landslide hazard area is defined as including "…any area potentially unstable as a result of rapid stream incision, stream bank erosion or undercutting by wave action…" An example is shown in Figure 6 below.

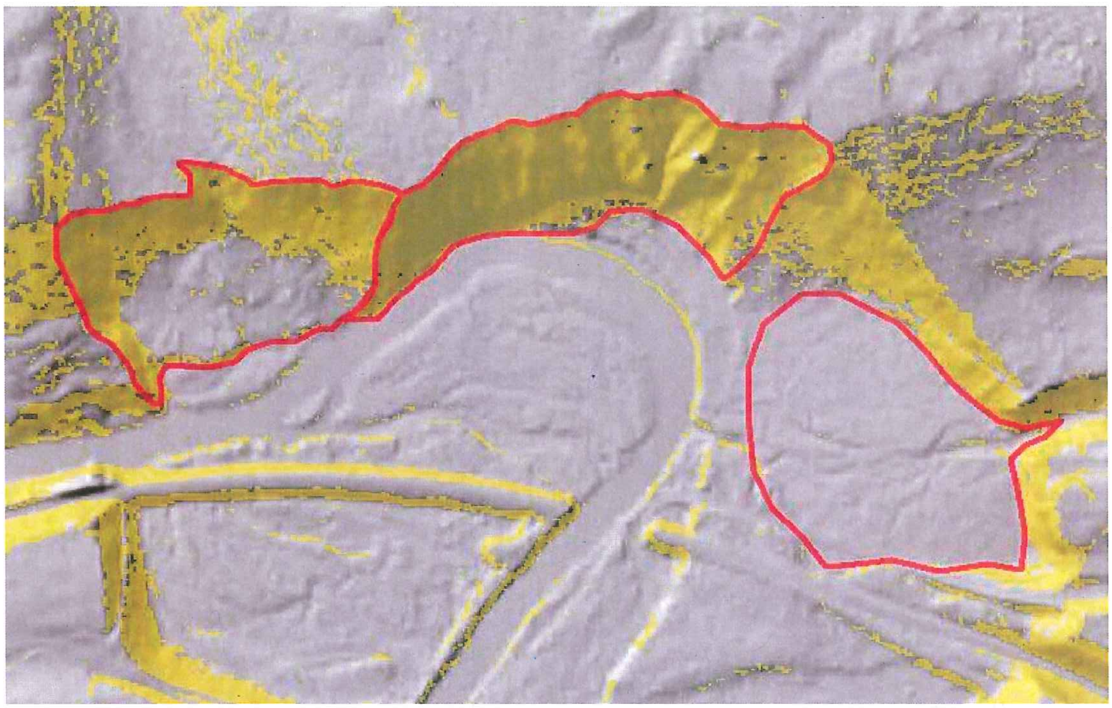

Figure 6. Oversteepened slope (center) being undercut by the Cedar River in the Big Bend Natural Area. Slopes >40% grade are colored yellow. Field of view is roughly 2500 feet across.

7. ***Undifferentiated or unclassified larger-scale mass wasting:*** The existing 7.5-minute geologic maps locally document landslide debris (usually as Qls or Qmw) that is indistinct on the LiDAR imagery, or that is suggestive of landsliding that occurred far enough in the past to have weathered significantly. At other sites, LiDAR-derived topography alone is suggestive of larger-scale mass wasting that is not distinct enough to be included in another category. For some of these features, evidence of debris may be weak and failure surfaces (head scarps) may be hidden or weathered and difficult to delineate. These features assume a variety of appearances, with identification largely dependent upon the expertise and discretion of the mapping geologist. One example is presented in Figure 7 below. Nearly all include or are within slopes that are already regulated as steep slopes.

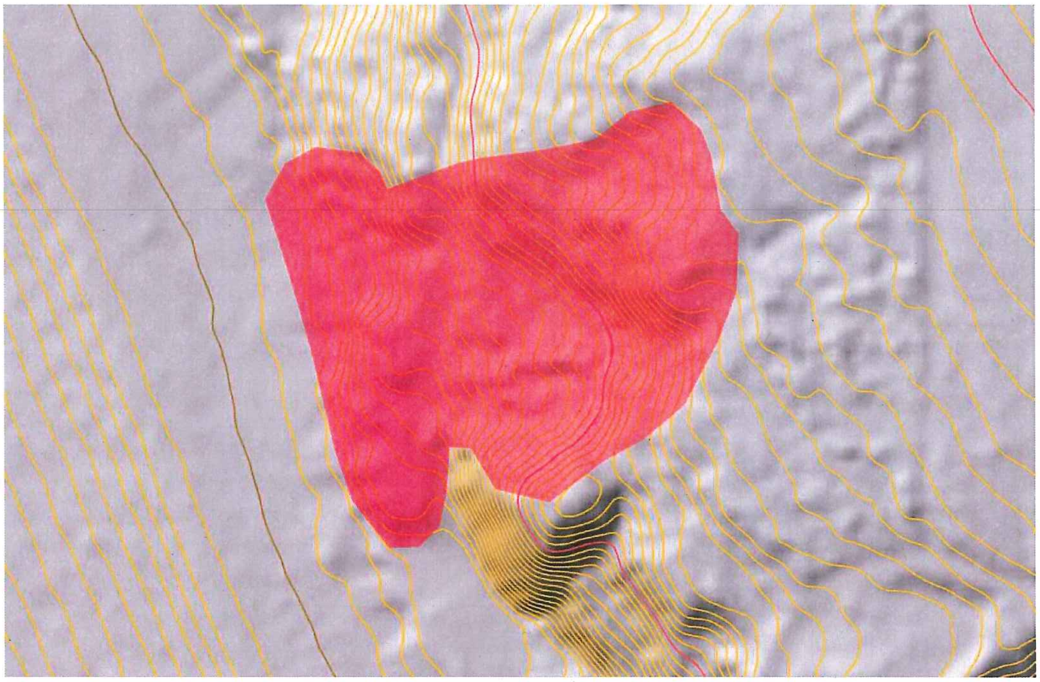

Figure 7. Unclassified mass wasting feature on the west side of Vashon Island. Feature measures 400 feet from top to toe.

8. ***Slopes/landforms suggestive of enhanced instability and dominant mass wasting:*** The existing 7.5-minute geologic maps locally document landslide debris associated with some landforms suggestive of increased rates of shallow landsliding, sapping erosion, or rapid soil creep not otherwise visible on the LiDAR imagery. These landforms typically have a "scalloped" appearance; the stream valleys are broad and U-shaped rather than V-shaped as is typical for dendritic drainages (Figures 8 and 9 below). Often the valley floors host numerous seeps, wetlands, and mapped colluvium. Some appear to be quite young features with ongoing rapid erosion/mass wasting, and others appear to have reached a more mature stage where landslide potential is reduced, perhaps reflecting changes in groundwater flow with time. As such, some are mapped as potential landslide hazards and others are not. In any case, all of them are associated with steep slopes, so that any development proposed in those areas will trigger further site-specific study that includes a consideration of mass wasting processes.

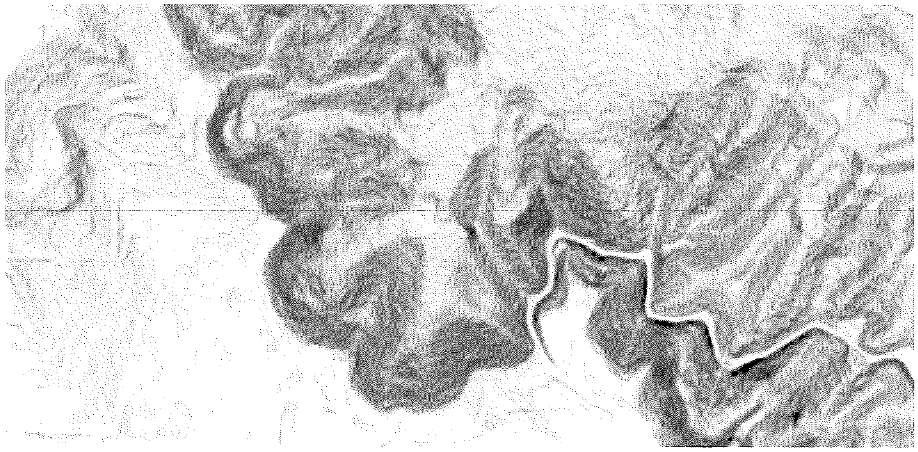

Figure 8. Scalloped basin southwest of Issaquah-Fall City Road and SE 40th St. Field of view is about 3000 feet across.

Figure 9. Scalloped basin at Camp Sealth, southwest Vashon Island. Field of view is roughly 2800 feet across.

9. ***Runout:*** Following upon the experience gained as a result of the SR 530 landslide at Oso, it makes sense to consider runout potential and highlight some landslide hazards as special concerns. However, we typically do not have enough detailed site-specific data to identify areas prone to excessive runout from future landsliding, and so at this time we only include potential runout areas if supported by available data. It is worth noting that runout has been mapped for those landslides that have already occurred; what can't be determined is where excessive runout will occur in the future. Further study is warranted.

10. ***Shallow landsliding potential:*** Shallow low-volume landslides/debris flows are the most common type of landslide and are those most likely to impact residential structures throughout King County, with hundreds of them occurring every winter. Nevertheless, they are largely invisible on LiDAR data and not noted on even the most detailed geologic maps. As discussed above, it is widely accepted that the overwhelming majority of shallow landslides occur on slopes greater than 40% grade. For this reason, and because +40%-grade slopes are regulated in the King County Zoning Code in part because of their potential for instability, we have generated a separate map of all slopes that are of 40%-grade and greater as determined from the LiDAR data. Filtering has been done to remove +40% slopes that are less than 10-feet high. This map should be used in conjunction with the map of other potential landslide hazards described here.

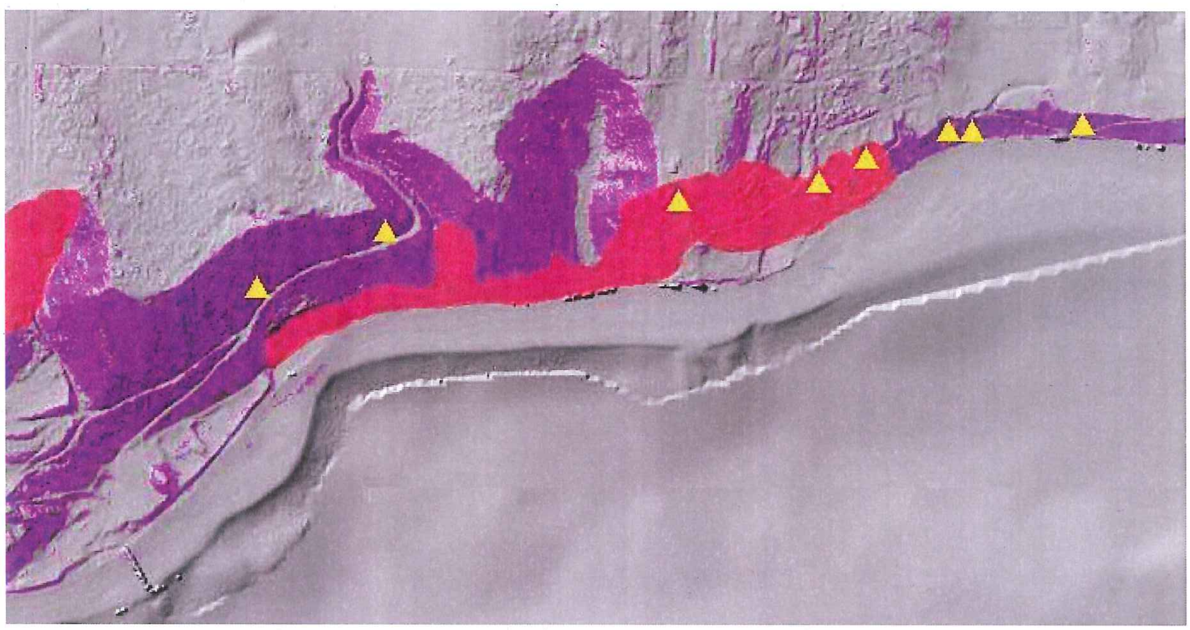

Figure 10. South shore of Maury Island at the Maury Island Marine Park. Larger landslide hazards are shown in red. Locations of small, shallow landslides (as taken from a database generated from building permit records and personal observations) are shown as yellow triangles. Steep slopes (+40% grade) shown in purple. Image shows roughly 6300 feet of shoreline.

11. ***Buffers:*** The King County Code assigns buffers and additional building setbacks to both landslide hazards and steep slopes through the critical areas regulations (KCC 21A.24). The initial buffer for both is 50 feet, and the building setback for both is 15 feet. The buffer may be reduced for either type of hazard given an approving evaluation and report by a consulting geotechnical/geological engineer or an engineering geologist. For this reason, buffers are important when it comes to screening development proposals, but buffers also are commonly reduced during permit review. For information purposes and to facilitate proper permit application screening, 50-foot buffers may be shown as well.

12. ***Peer Review and Editing:*** The final map products have been edited by in-house experts (geologists with DPER, DNRP-WLRD, and KCDOT) as well as selected outside reviewers from the University of Washington, the Washington Department of Natural Resources, Division of Geology and Earth Resources, and private industry. Uniformity of approach has been maintained throughout King County agencies doing this type of work, and all of DPER's work was parallel to and consistent with work at DNRP-WLRD as well as ongoing and planned efforts by the Washington Department of Natural Resources, Division of Geology and Earth Resources.

Appearance and Utility of the Potential Landslide and Steep Slope Hazards Maps

The "complete" potential landslide hazard map for unincorporated King County is a combination of potential landslide hazards with slopes that exceed 40% grade. "Potential landslide hazards" include the landslide features discussed above regardless of age or potential for remobilization. Except for a handful of the mapped landslides, no data exist to quantify the age or potential for remobilization for the mapped structures.

Given that we are using LiDAR principally to identify landslides that have already occurred, it is presumed that many of the mapped potential hazards probably are not accompanied by high risk because past landsliding has resulted in regained stability. It is true that landslides are most likely to occur where they have occurred before, but this may best be considered in a more regional sense, where landslides might be more likely to occur adjacent to old landslides or reactivate within portions of a metastable landslide mass.

It is perhaps more accurate to say that landslides are most likely to occur in areas where they have occurred in the past that are also being altered in ways that would enhance the potential for future landsliding, such as where a river is eroding the toe of a slump. However, even fully stabilized landslide masses present geotechnical challenges to construction including disturbed soils that are not suitable for new septic systems and colluvium that might have an insufficient bearing capacity requiring mitigation in the form of a special foundation design.

The potential landslide hazard and steep slope maps combined appear like Figure 2C above, or Figure 11 below minus the 1990-vintage SAO landslide hazard layer. Individual mapped potential landslide hazards in Figure 11 are shown here in red along with steep slopes (in purple) in sufficient detail to allow parcel-level review and screening. These maps are available as iMap layers on the county's web site, accompanied by explanations of what they mean and how to use them. Where the new mapping has been completed, the now-outdated SAO landslide hazard mapping will no longer be available.

What the Potential Landslide Hazard Mapping Will Not Include

All potential hazards are shown as of equal importance because the intent of this map is to flag sites for further investigation under building and land use permit reviews. We are aware of some mapped landslides that have experienced movement in the recent past and are likely to move again, but following our existing protocol, the current map will not show sites of enhanced hazard. Property owners and interested parties are invited to inquire at DPER as to whether more information is available for a specific property. Depending upon the nature of the hazard and level of concern, a site evaluation by a consulting geotechnical/geological engineer or engineering geologist may be in order.

Figure 11. Potential landslide hazards (red) and steep slopes (purple) at the mouth of Judd Creek, Vashon, in comparison to the correlative 1990-vintage SAO landslide hazard (diagonal green lines). Note the differences between the two vintages of map products. Image covers an area roughly 3600 ft. by 4000 ft. Parcel boundaries and county rights-of-way are shown.

Considerations for the Future

The completion and adoption of a compilation of potential landslide and steep slope hazards for permit screening by DPER does not mean that all landslide work by DPER is finished or that we can rely upon future consulting studies (in permit applications) as sufficient to address all landslide hazard issues. Consider, for example, the following:

- ☐ Any map we produce and use must be considered a working document that will require occasional updating. The updating will rely on geotechnical studies or other data submitted up to that time, which means that there must be a mechanism within DPER to capture and archive new geotechnical and geological data as they are received. This will be accomplished through the permit review process.
- ☐ There is also the possibility of identifying and highlighting higher-risk landslides that have been active historically and that are thought to be probable sites of movement in the future. Such an activity would be consistent with how we handle other geological hazards and regulated critical areas, such as coal mine hazards, flood hazards, and channel migration hazard zones.
- ☐ Any landslide hazard map that is released as a public reference must be accompanied by a mechanism whereby interested parties can get further information. Outreach and support by DPER's landslide and critical areas experts will be available following the release of the mapping and into the future.
- ☐ Impacts to other county regulations may be significant. The design requirements presented in the Surface Water Design Manual, for example, are based in part upon a now-outdated map of landslide hazard drainage areas. The SWDM may need revisions to address both potential landslide hazards and steep slopes.

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