Results of a Preliminary Landslide Investigation in King County, Washington Phase 1

Technical Memorandum

FINAL

March 2015

Prepared
by
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Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600
Seattle, WA 98104

In collaboration with
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KING COUNTY FLOOD CONTROL DISTRICT

King County

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EXECUTIVE SUMMARY

The SR 530 landslide event that occurred in 2014 near Oso, Washington triggered important discussions by technical practitioners and governmental entities about landslide hazard mapping. These conversations covered the quality and availability of information and the current scientific approaches used to identify hazard areas. Having improved information about potential hazards is an important tool used by government agencies for many purposes such as emergency response planning, land-use regulation and capital project planning for the implementation of public infrastructure. In continuing its effort to improve publically available hazard information, an assessment of existing landslide data was initiated in 2014 by King County and an approach to update available information about landslide hazards was determined.

Information about potential landslide areas within King County was based on early 1990s mapping, compiled by geologists using the resources then available. However, new technologies, such as Light Detection And Ranging (LiDAR) imagery, improved methodologies for modeling types of landslide hazards, and updated geologic maps are current day tools available to update landslide mapping. Given the age and quality of the County's existing landslide mapping and the demonstrated public safety risks associated with landslides, King County determined that landslide mapping should be updated and proposed a new landslide mapping effort using the newer technologies and updated maps to more accurately locate and thoroughly describe landslide hazards in King County.

Although the entirety of the County's available mapping is in need of updating, an initial effort was pursued along major fluvial valleys in the county including the Cedar, Green, Sammamish, South Fork Skykomish, Snoqualmie, and White Rivers and Issaquah Creek utilizing funding from the King County Flood Control District (FCD) and also for Vashon and Maury Islands with staffing support from the King County Department of Permitting and Environmental Review (DPER). While the study area is predominately within unincorporated King County, it also includes portions of eighteen cities located within the major river corridor valleys. The approach to update landslide information is being phased. Phase 1 provides an initial view of the distribution of the larger landslide features that are visible on LiDAR imagery and/or have been identified on existing geologic maps in glacial strata and in bedrock. Phase 2 is a detailed review of shallow landslides, deep-seated slumps, debris flows and fans, rockfall and runout in both the Puget Lowland and in the Cascade Mountains. This second phase would include mapping potential hazard areas, development of a database inventory, and outreach to stakeholders and the public.

This technical memorandum includes background information to describe the physical setting and types of landslide present in King County and the methodology applied for the Phase 1 investigation study area. The Phase 1 map (Appendix 1) shows the preliminary mapped extent of areas that have been subject to landslide movement as identified using the methodologies described above and illustrates larger-scale landslides and other mass

movements within the area of coverage that have been active in the past. However, the mapping does not include potential landslides and other features that might be subject to movement in the future.

The intent of the Phase 1 map was to provide a preliminary indication as to the character and distribution of landslide features recognizable using current techniques and resources. It is possible that the Phase 1 map does not delineate all areas with landslide potential. Adjustments to mapped landslide areas are to be expected as additional information is compiled and evaluated. The accuracy of the hazard information is dependent on many factors. It is not intended to provide a final determination of the stability or instability of any area. Individual parcel or site assessments should be performed by qualified geotechnical professionals based on site-specific data and evaluations. The Phase 1 Map is not intended to serve a regulatory purpose.

Phase 1 mapping was completed in October 2014 and represents an important first step in developing updated landslide mapping in King County. The risk of slope failures and significant mass wasting events within the formerly glaciated landscape of King County can have severe consequences.

Phase 2 will include a more detailed characterization of some of the landslides with an assessment of landslide type, relative age, runout potential, and the probability of debris dam formation. Historic landslide locations will be cataloged and mapped based on information compiled from a variety of sources.

The resulting updated landslide information will greatly benefit King County and its residents by providing improved understanding of hazards so that public agencies and the residents of King County can work toward reducing the risks associated with mass wasting events in the coming decades.

1.0 INTRODUCTION

The SR530 landslide occurred on March 22, 2014, on the North Fork Stillaguamish River near Oso, Washington in Snohomish County. This tragedy, which resulted in 43 deaths, raised awareness across the Pacific Northwest regarding the potential hazard posed by landslide events in this region. Although King County has a landslide hazard map, an assessment of landslide information was initiated in King County and completed by King County technical and managerial staff, including an approach to update available information. An issue raised was that the County's current landslide hazard map from the early 1990s was compiled by geologists using the resources then available, including stereo aerial photography, 1:24,000 United States Geological Survey (USGS) topographic mapping and scattered geologic mapping. This 1990s work predated the availability of Light Detection and Ranging (LiDAR) imagery, which can provide a detailed rendering of the ground surface topography even through dense vegetative cover. In addition, the early 1990s mapping efforts relied on the assumption that landslides were predominantly localized along the contact between permeable sand layers and impermeable silts and clays exposed near the base of many steep slopes.

Given the age and quality of the County's existing landslide mapping and the demonstrated public safety risks associated with landslides, King County initiated an update of the current map and proposed a new landslide mapping effort using current LiDAR and recent geologic mapping to more accurately locate and thoroughly describe landslide hazards in King County. The new mapping project was proposed to occur over a period of two years, with the work tasks being conducted by County geologists from the Department of Natural Resources and Parks (DNRP) and the Department of Permitting and Environmental Review (DPER). The effort was divided into two phases with Phase 1 providing the results of updated information with a preliminary indication as to the character and distribution of landslide features recognizable using current techniques and resources. Phase 2 would provide a detailed evaluation of the characteristics and types of landslides, development of a database inventory and outreach program.

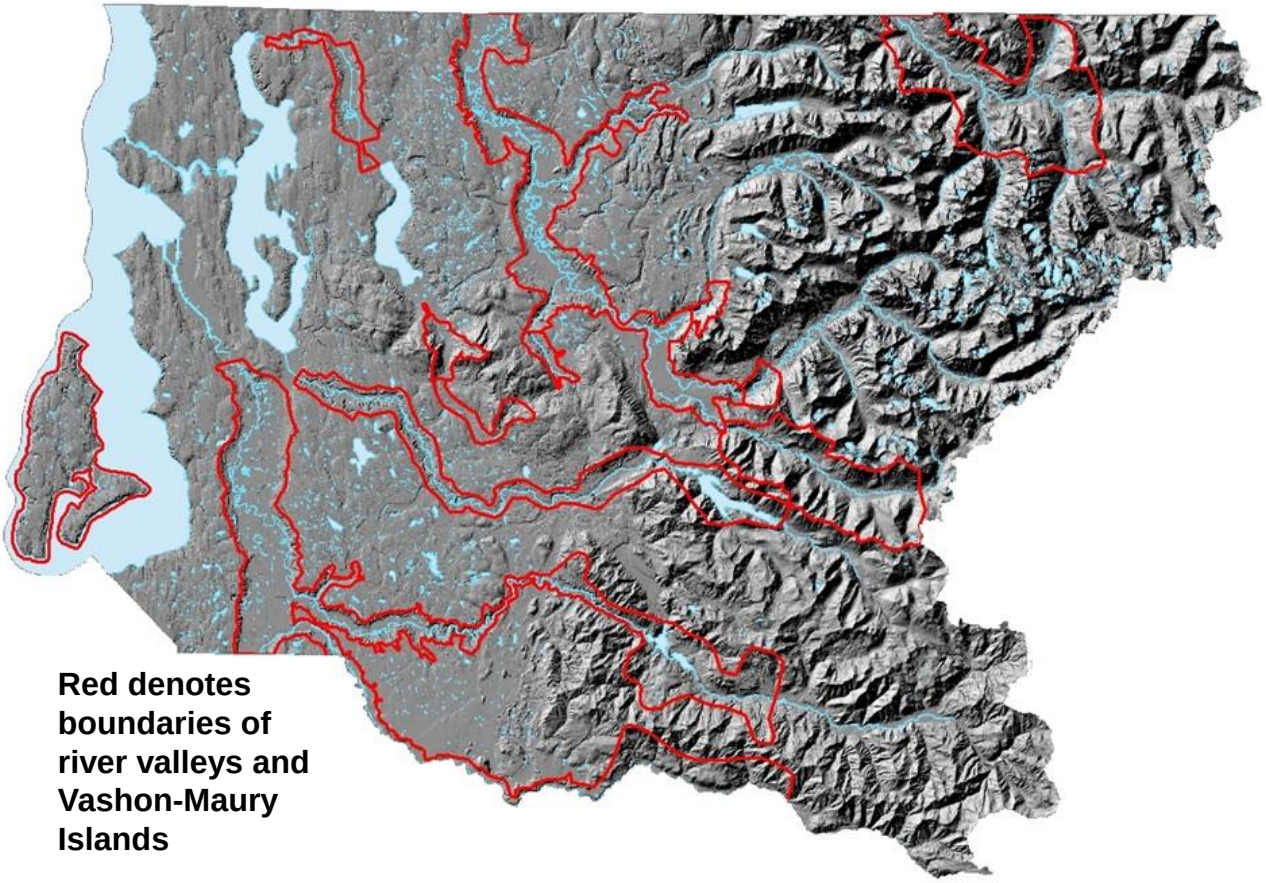
Updated information will greatly benefit King County and its residents. Public awareness of these hazards will increase and government agencies will utilize new information for emergency response planning, land-use regulation, and capital project development and implementation.

Initially, all of unincorporated King County outside the Forest Production District was meant to be assessed. However, funding sources allowed for Phase 1 investigation to include major rivers valley areas as related to the King County Flood Control District's (FCD) projects and programs with staffing support provided by the DPER for Vashon Maury Island. FCD is a special purpose government created to provide funding and policy oversight for flood protection projects and programs throughout incorporated and unincorporated areas of King County. For FCD the areas assessed are within the walls of

major river valleys (Cedar, Green, Sammamish, South Fork Skykomish, Snoqualmie, and White Rivers) and the major stream, Issaquah Creek, in both incorporated and unincorporated areas of King County (Figure 1). DPER conducted as assessment of areas along the shoreline bluffs of the Vashon-Maury Islands (Figure 1).

While the study area is predominately within unincorporated King County, it also includes portions of eighteen cities. Also, because the White River serves as the jurisdictional boundary between King and Pierce Counties, areas along the south bank of the White River that have large landslide features were included in the Phase 1 investigation.

Figure 1. Extent of Area for Phase 1 Mapping.



The Phase 1 investigation serves as a preliminary view of landslide areas based on visual inspection of LiDAR shaded hillshade relief and more recent geologic mapping. This phase provides improved information on existing landslide and mass wasting hazards. The updated, new mapping is compiled in a geographic information system (GIS) format with the capability of identifying site-specific landslide characteristics that can be accessed electronically and easily updated over time. The Phase 1 investigation did not differentiate between the type and severity of the landslide hazard. The initial proposal called for a status report, including a map showing work-to-date, to be prepared before October 2014. This status report and map is referred to as the Phase 1 work product, and this memorandum and accompanying map constitute Phase 1 (Appendix 1).

Phase 2 would include detailed information on site-specific landslide characteristics including recently active landslides, potentially notable run-out zones, and areas that are determined to be at particular risk for debris dam formation. At this time, it is expected that Phase 2 study limits are the same as Phase 1. Technical information compiled on landslide hazards will also be utilized to assess the potential public safety risks to residents and properties, and critical infrastructure such as roads and bridges. The Phase 2 study is scheduled for completion in July 2016.

1.1 Physical Setting

King County includes portions of two physiographic provinces, the Cascade Mountains in the eastern third of the county and the Puget Lowland in the western two-thirds. These areas have distinct topography, geology, and climate. As a result, they are areas subject to distinctly different types of landslide processes.

The Puget Lowland portion of the County includes the overwhelming majority of both population and infrastructure. Both the topography and geologic substrate in this area is a product of repeated continental glaciations that have occurred over the last two million years. The last continental glacial advance, which ended approximately 13,000 years ago, deposited most of the surficial sediments present today and sculpted the landscape across the Puget Lowland. Following ice retreat, the glacially sculpted surface began to be eroded by non-glacial processes. This erosion did not occur uniformly across the landscape but was localized along coastal bluffs and river valley walls.

1.2 Landslide Types

Landsliding is one of the major components of erosion occurring along coastal bluffs and river valley walls. Several types of landslides were and remain common in the area, especially slumps, debris slides, and debris flows. The study limits of the Phase 1 investigation determined that many of the largest and most active landslides are associated with the steep slopes adjacent to river corridors or along marine shorelines where glacial strata are eroded and steepened.

Where fluvial or coastal erosion has created steep, high slopes in glacial sediments, these slopes sometimes fail in large deep-seated landslides that often entail rotation of the slide material and are termed **slumps** (Figure 2). These features are common on coastal bluffs and valleys walls; virtually all of these events failed initially in prehistoric times. Although old features, the failed landslide debris in slumps is sometimes remobilized in response to unusually high precipitation, earthquakes, or ill-advised human disturbance.

Landslides contiguous to rivers or major tributaries may also form debris dams that can produce significant flood hazards, both up and downstream. When landslide debris blocks the active river channel, backwaters cause inundation of lands upstream from the blockage.

After the debris dam is breached, the release of impounded water can produce deep, fast flow conditions resulting in catastrophic damages to downstream areas.

Figure 2. Slump Feature on Cedar River, River Mile 17, King County, WA.

Debris slides are a second common type of slope movement in the Puget Lowland that occurs when a thin layer of soil becomes saturated and moves downslope (Figure 3). These types of failures are too small to identify using LiDAR-based methods but are more widespread across the landscape. This type of failure is common during wet weather and can affect both natural and man-made slopes. Although comparatively small in scale, these shallow landslides often block transportation corridors, damage infrastructure, and can be damaging or even deadly if they impact occupied structures.

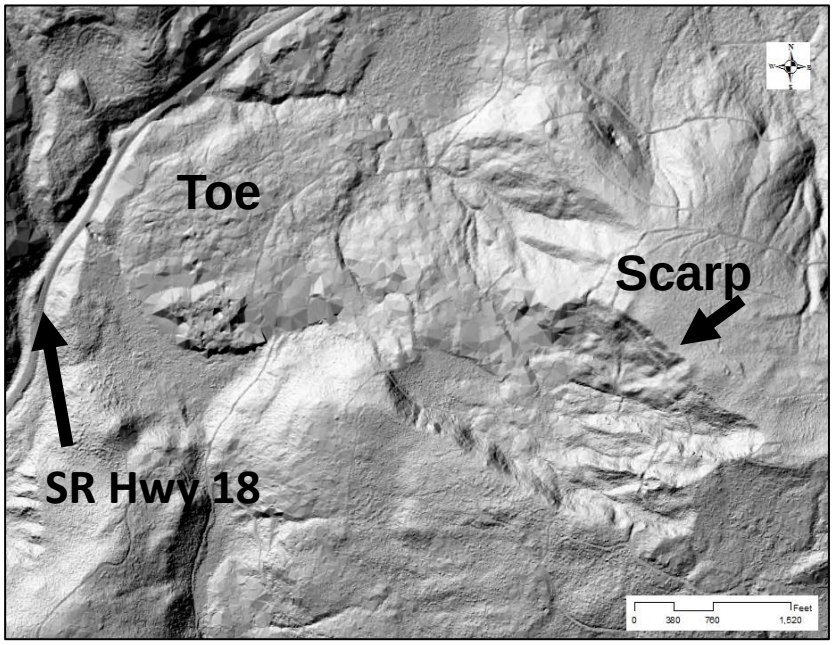
Figure 3. Shallow Debris Slide on West Valley Highway, King County, WA.
(Photo credit KC DOT, 2014)

Debris flows are the third relatively common type of landsliding process often occurs as a direct result of either a debris slide or reactivation of a prehistoric slump. If hillslope deposits become saturated and there is sufficient sediment available within a steep drainage course, the wet mass may travel down the drainage course as a thick slurry (Figure 4). Such debris flows can accumulate additional water and sediment as they flow downslope, often from the bed of small steep tributary channels, and pose a serious risk, especially when they emerge from the steep drainages where they originate and flow out onto level, potentially developed areas below.

Figure 4. Debris Flow above 156th Place SE, King County, WA.
(Photo credit KC, 2006)

In the Cascade Mountain physiographic province of eastern King County, the suite of landsliding processes changes due to more bedrock-controlled topography. While these areas are less populated than the Puget Lowland, there are still communities present in the mountains, as well as critical transportation and utility corridors. Like the Puget Sound Lowlands, the Cascade Mountains are also adjusting to the effects of recent glaciations, although these glaciers originated locally, in the mountains themselves, rather than flowing from the north as did the continental glaciers that affected the lowlands. Similar landslide types, such as large **deep prehistoric slumps** are also present, although in the alpine setting these slumps are often formed on bedrock valley walls (Figure 5).

Figure 5. Northwest Slope of Taylor Mountain, east of State Route Highway 18, King County WA.



Rockfall (Figure 6) is another locally significant mass-wasting process in alpine areas. Rockfall entails single or multiple rocks being dislodged and falling from steep cliff faces. Rockfall can be triggered by earthquakes or severe weather. Infrequently, an entire rock slope may collapse creating a **rock avalanche** (Figure 7). Although no rock avalanches have occurred in King County in historic times, there is clear evidence of such prehistoric failures. Debris flows, as described above, also occur in mountainous settings, and they occur with greater frequency and energy than in the lowlands.

Figure 6. Rockfall; Boulder on Moon Valley Road below Mt. Si, King County, WA.
(Photo credit J. Bethel, 2014)

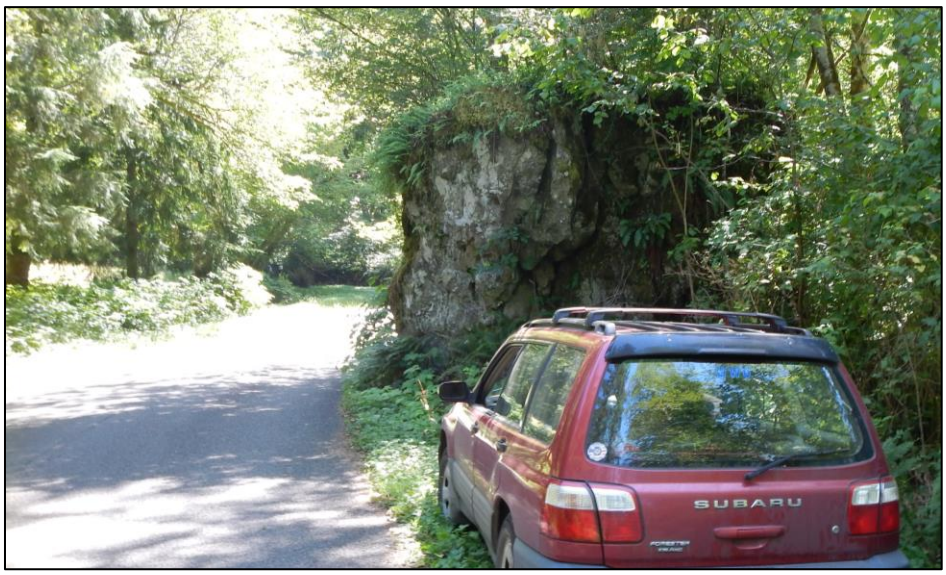
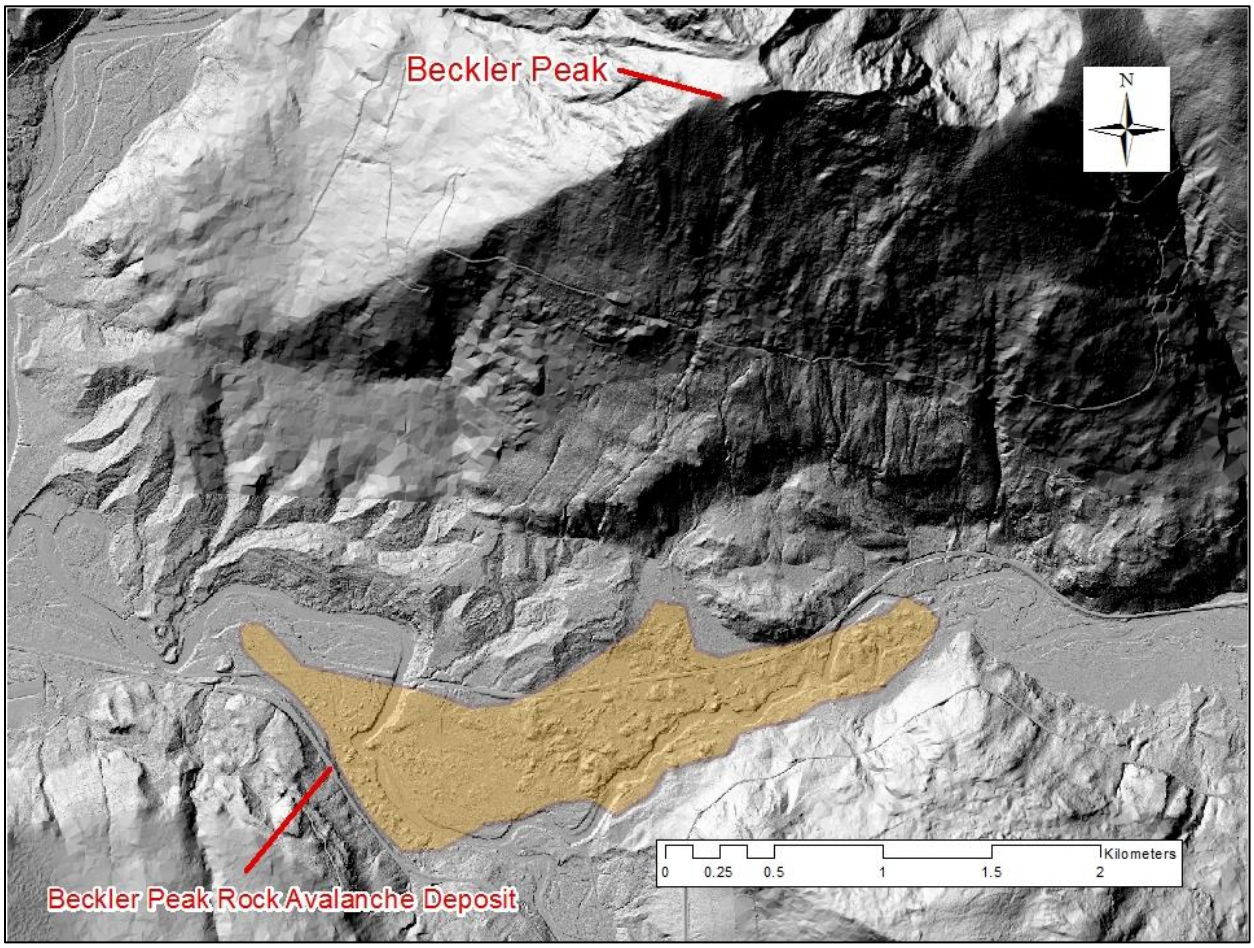


Figure 7. Rock Avalanche; Beckler Peak, King County, WA.



One type of mass movement may trigger another event creating **complex or compound** movements (Figure 8). The 2014 SR530 landslide is an example of a complex slide exhibiting multiple styles of movement occurring during a single event. The SR530 landslide appears to have failed initially as preexisting landslide debris was remobilized as a debris flow. Immediately thereafter, the initial movement created a loss of support that triggered a massive rotational slump (Keaton et al., 2014). The highly visible features characteristic of this type of compound slide often associated with large prehistoric slump zones along mountain river valleys are readily apparent using the LiDAR methodologies utilized for this study.

Figure 8. SR530 Landslide near Oso in Snohomish County, WA. *(Photo credit USGS March 22, 2014)*

2.0 METHODOLOGY

Since the early 1990s, the use of LiDAR data and digital imagery has come into wide use for a variety of landscape investigations. Specifically, the topography generated as a digital terrain model (DTM) from LiDAR data is essential to more accurate mapping of landslides and other geomorphic features. Remote detection of subtle yet important landforms, even where cloaked by mature forest, is now possible by visual inspection of the shaded hillshade relief.

For the Phase 1 investigation, King County geologists mapped deep-seated rotational or block failures, rock falls, and large-scale earth flows using LiDAR shaded hillshade relief and digital aerial imagery. King County provides this LiDAR elevation data and imagery for public use through the county's online Interactive Mapping Tool (iMap) at http://www.kingcounty.gov/operations/GIS/Maps/iMAP.aspx The LiDAR imagery used in the Phase 1 mapping effort was not of uniform quality or resolution, and is comprised of various flight dates. It is very likely that some ancient landslides were not identified in the Phase 1 investigation. The techniques used were also not sufficient to identify mass movement features that may have been obliterated through land development.

In addition to LiDAR imagery, geologic maps prepared by the USGS by the Washington State Division of Geology and Earth Resources (DGER) were utilized for the Phase 1 investigation (see Mapping Resources in Section 6.0 References).

2.1 Slumps

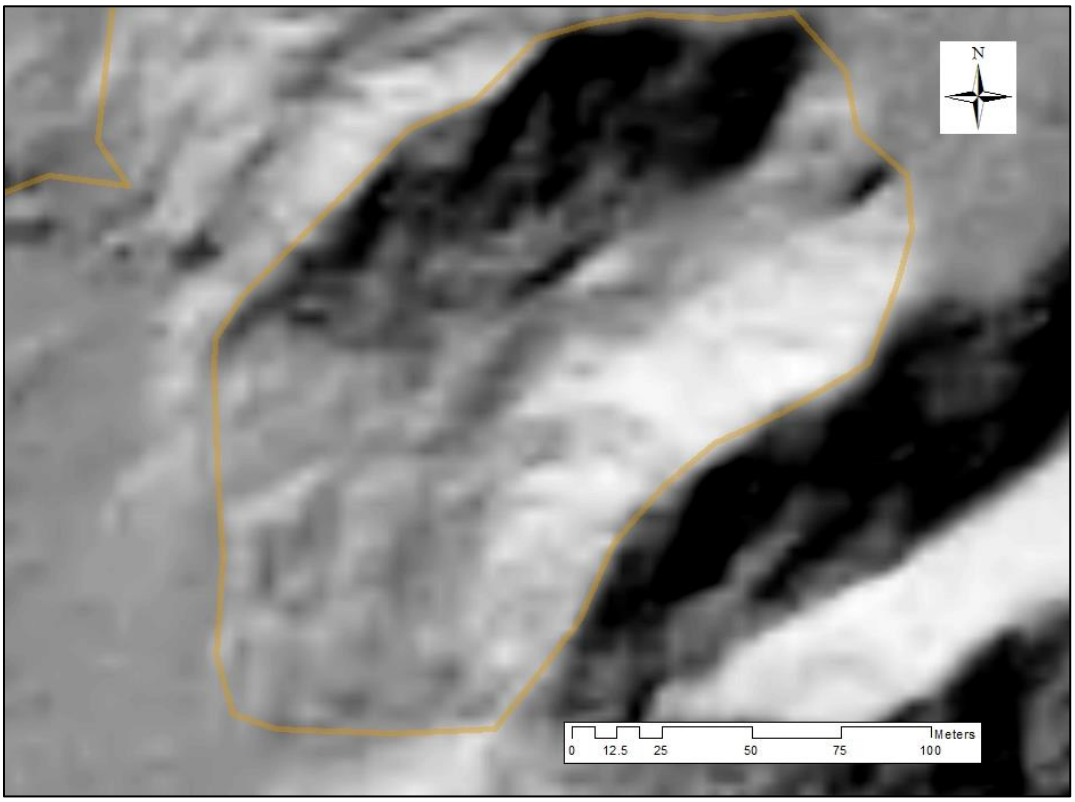
Prehistoric deep-seated slumps have been mapped based on their distinctive topographic signature as seen in hillshade images generated from LiDAR data. Slumps mapped in this study had both a steep, often arcuate headscarp defining the upslope limit of the slide and a distinct deposit of displaced debris downslope. The debris was identifiable by its lobate form and hummocky upper surface. These slumps varied in their topographic distinctness from features that appeared sharp and unambiguous (Figure 2), to features that were muted and subtle (Figure 9). It is likely that some features mapped as slumps based on their topographic character may have formed in other ways, and it also likely that prehistoric slumps present in the study area were not identified because they were not distinguishable with the available imaging.

2.2 Debris Flows and Fans

Records of modern debris flows as well as examination of geologic evidence show that debris flows in both Puget Lowland and Cascade Mountain settings often occur repeatedly from the same drainage course with periods between slides ranging from decades to centuries (May and Gresswell, 2004). Over time these repeated events build up a fan of debris at the mouth of the source ravine. A debris fan is physical evidence of the extent of

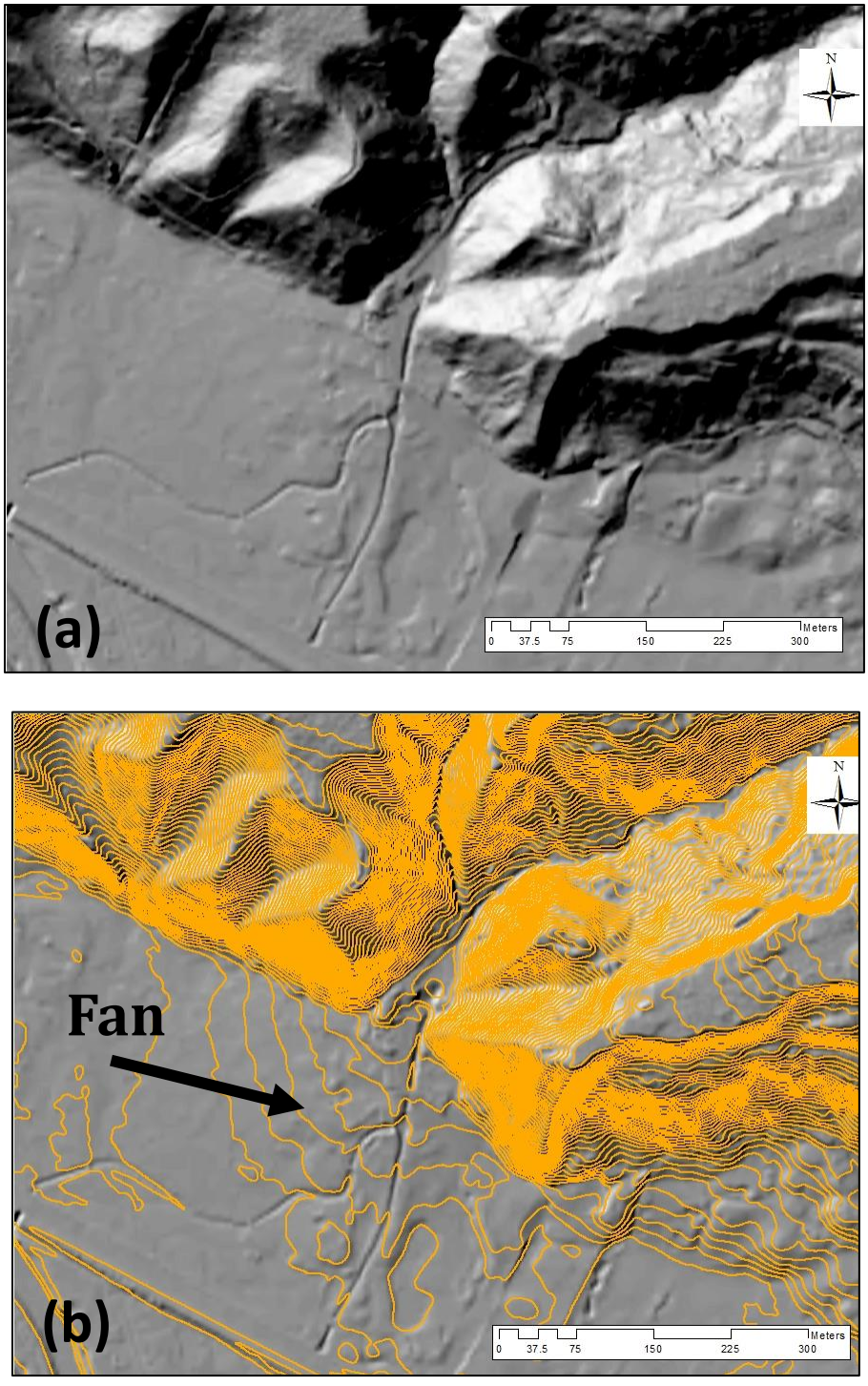
past debris deposition, and these features are indicators of potential future inundation. These depositional fans tend to be relatively low-gradient and are not readily apparent from hillshade imagery (Figure 10(a)). However, LiDAR data also provides digital terrain information that can be used to generate high resolution contour lines. Using closely spaced (5 foot interval) contours lines, the distinctive truncated cone shape of a debris fan can be identified (Figure 10(b)).

Figure 9. Example of Muted and Subtle Slump Feature on LiDAR Imagery.



Debris fans, however, can be created by a variety of geomorphic processes besides debris flows. Fan features can also form by fluvial deposition and progressive channel migration where a higher energy sediment-rich tributary discharges onto the floodplain of a larger stream. Such fans are similar in form but typically not as steep as fans formed by debris flows. Benda and Cundy (1990) found that debris flows typically stop at slopes of a gradient of 3.5 percent or less.

Figure 10. Maplewood Creek Fan shown (a) using LiDAR Hillshade Imagery and (b) using Contours.



For Phase 1 mapping, all discernible fans were mapped, and then those fans or portions of fans with a gradient of less than 3.5 percent were removed. Review of the fans identified through this process suggests that many of the mapped features are largely fluvial in origin.

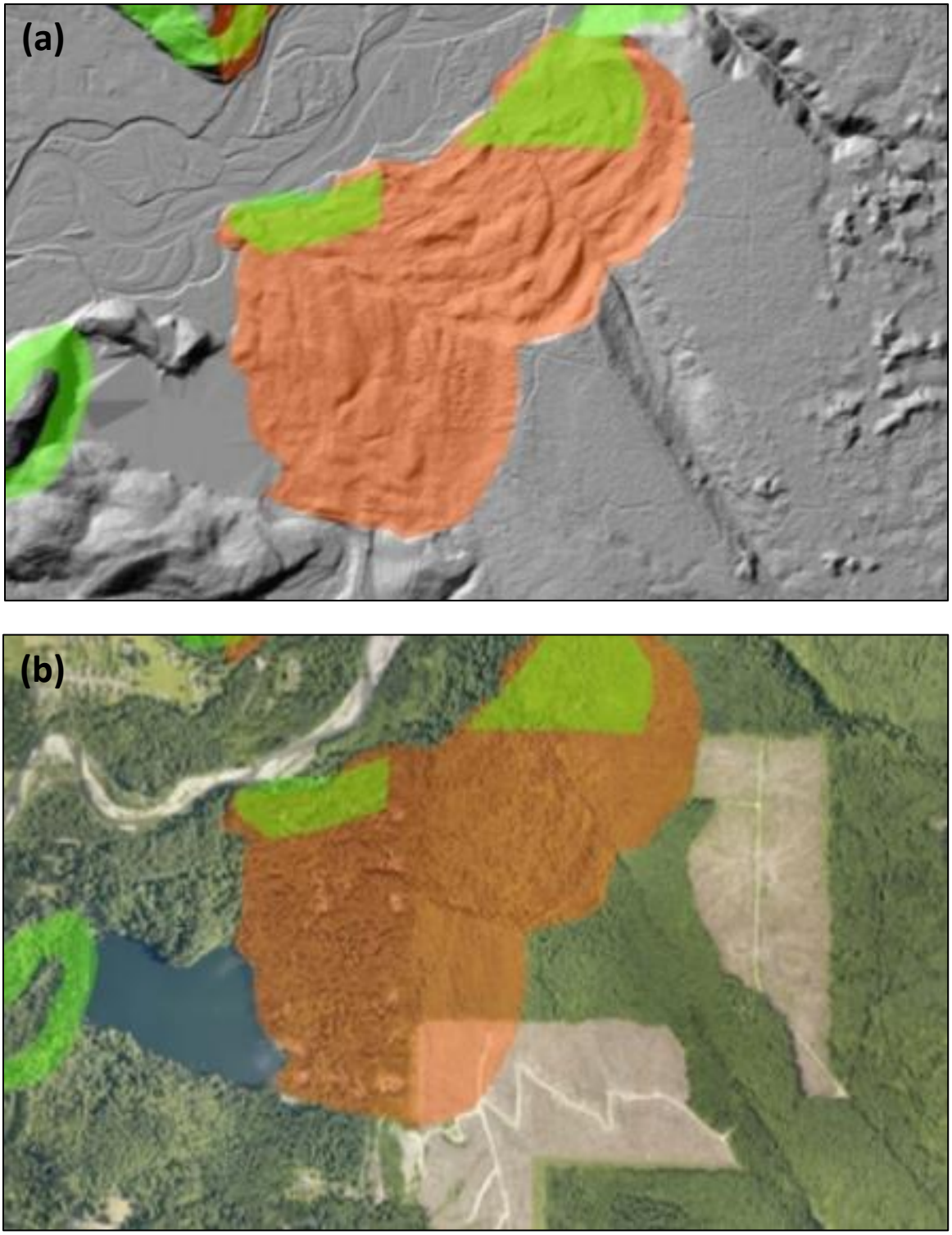
2.3 Shallow Slides

Shallow debris slides are a common phenomenon in both Puget Lowland and Cascade Mountain areas of King County. Areas at risk from such shallow landslides have not been mapped during Phase 1 because resolution of the currently available LiDAR imagery is not sufficient to discern these small but frequent and widespread events. Landscape-scale modeling methodologies are available to identify areas susceptible to these shallow landslides, and King County is working with DGER in refining such a model. The results of such modeling are planned for inclusion in the Phase 2 mapping.

2.4 Comparison to 1990s Mapping

To understand the extent of differences that exist between landslide mapping completed in the early 1990s and what could be mapped using more current methods relying on LiDAR-based imagery, an example from the Lower Tolt River valley adjoining Carnation in eastern King County is depicted in Figures 11(a) and 11(b). The total area illustrated is roughly 8,800 feet by 5,500 feet; the north-south extent of coverage is a little more than one river mile in length. Both Figures 11(a) and 11(b) display the extent of the 1990s landslide hazard areas (shown in green) and landslides mapped as part of this Phase 1 study using LiDAR imagery (shown in orange). The LiDAR shaded relief topography (Figure 11(a)) shows that the 1990s mapping (shown in green) does not fully identify the extent of the mass movement features along this portion of the Tolt River. Figure 11(b) displays the same site on a 2013 aerial photograph, showing cleared areas associated with residences as well as logging and road construction within a slump feature (shown in orange) identified in the Phase 1 mapping that were not identified as being in a landslide hazard area based on the 1990s mapping.

Figure 11. Comparison of 1990s Landslide Hazard Mapping with (a) Current LiDAR Imagery (b) 2013 Aerial Image, Lower Tolt valley, King County, WA.



3.0 RESULTS

The Phase 1 investigation described in this technical memorandum includes preliminary identification of most of the landslide types described in Section 2. All of the types of landslides shown on the Phase 1 map (Appendix 1) are identified with a single shaded overlay, although each of these types requires different mapping criteria. The mass movements shown on the Phase 1 map using LiDAR topography are not differentiated based on indications of historical activity or anticipation of future activity; mass movements that are known to be active are not distinguished from those that show no indications of recent movement.

The Phase 1 map (Appendix 1) shows the preliminary mapped extent of areas that have been subject to landslide movement as identified using the methodologies described above and illustrates larger-scale landslides and other mass movements within the area of coverage that have been active in the past. However, the mapping does not include potential landslides and other features that might be subject to movement in the future.

All of the mass movement types included in the investigation resulting in the Phase 1 map is highlighted in Table 1 with the exception of debris slides (i.e., shallow landslides) which are generally too small to be visible on LiDAR imagery. The mass movements shown in Table 1 vary in both the amount and kind of debris detached from the hillslope as well as the extent of the run-out zone (Laprade and Tubbs, 2008).

Table 1. Mass Movement Types.

Type of movement			Type of material		
			Bedrock	Engineering soils	
				Predominantly fine	Predominantly coarse
Falls			Rockfall	Earth fall	Debris fall
Topples			Rock topple	Earth topple	Debris topple
Slides	Rotational		Rock slump	Earth slump	Debris slump
	Translational	Few units	Rock block slide	Earth block slide	Debris block slide
		Many units	Rock slide	Earth slide	Debris slide
Lateral spreads			Rock spread	Earth spread	Debris spread
Flows			Rock flow Rock avalanche	Earth flow	Debris flow Debris avalanche
			(Deep creep)	(Soil creep)	
Complex and compound			Combination in time and/or space of two or more principal types of movement		

4.0 DISCUSSION

The Phase 1 map is a preliminary step in providing accurate information about the distribution and character of landsliding in the study area. Adjustments to mapped landslide areas are to be expected as additional information is compiled and evaluated.

The Phase 1 investigation identified topographic features potentially susceptible to landsliding. This mapping has not been peer reviewed or verified by field inspection and is subject to revision. Additional geologic and geotechnical information is known to exist, but has not been used for this initial mapping effort. It is likely that the map does not delineate all areas with landslide potential. Conversely, the large number of landslides that were mapped could suggest that the landslide hazard is overstated, because a number of the mapped landslides could be proven stable. Both of these mapping errors are inherent to preliminary investigations and reflect the need for further evaluations, which will occur as part of Phase 2, a more accurate characterization of types and extents of landslide areas.

The accuracy of the hazard information is dependent on many factors. The Phase 1 map is an interpretation by professional geologists using only LiDAR and available geologic and soils mapping, and it is not intended to provide a final determination of the stability or instability of any area. Individual parcel or site assessments should be performed by qualified geotechnical professionals based on site-specific data and evaluations. The Phase 1 Map is not intended to serve a regulatory purpose.

5.0 NEXT STEPS

The Phase 1 mapping represents an important first step in developing updated landslide mapping in King County. The risk of slope failures and significant mass wasting events within the formerly glaciated landscape of King County can have severe consequences. Like the SR530 landslide and other locations in the Puget Sound region, many of the eroding valley walls along King County's rivers exhibit ancient landslide deposits and evidence of more recent movements. The Phase 1 mapping provides an initial view of the distribution of certain landslide features in the study area, but a more useful characterization of hazardous areas and risks to developed lands and infrastructure must include consideration of landslide characteristics including style of failure, geometry, debris composition, local hydrology, historic movement, and other factors.

Phase 2 will include a more detailed characterization of some of these landslides with an assessment of landslide type, relative age, run out potential, and the probability of debris dam formation. Historic landslide locations will be cataloged and mapped based on information compiled from a variety of sources. There will also be further refinement of the criteria used to delineate slopes prone to shallow failure. Methodologies for calculating landslide run-out will be reviewed. Potential run-out distances will be assessed along with the potential for the formation of debris dams that could lead to flooding. It is hoped that the initial mapping effort in Phase 1 in conjunction with a combination of better science and tools and the more comprehensive study in Phase 2 will provide essential information to reduce the risks associated with mass wasting events in the coming decades.

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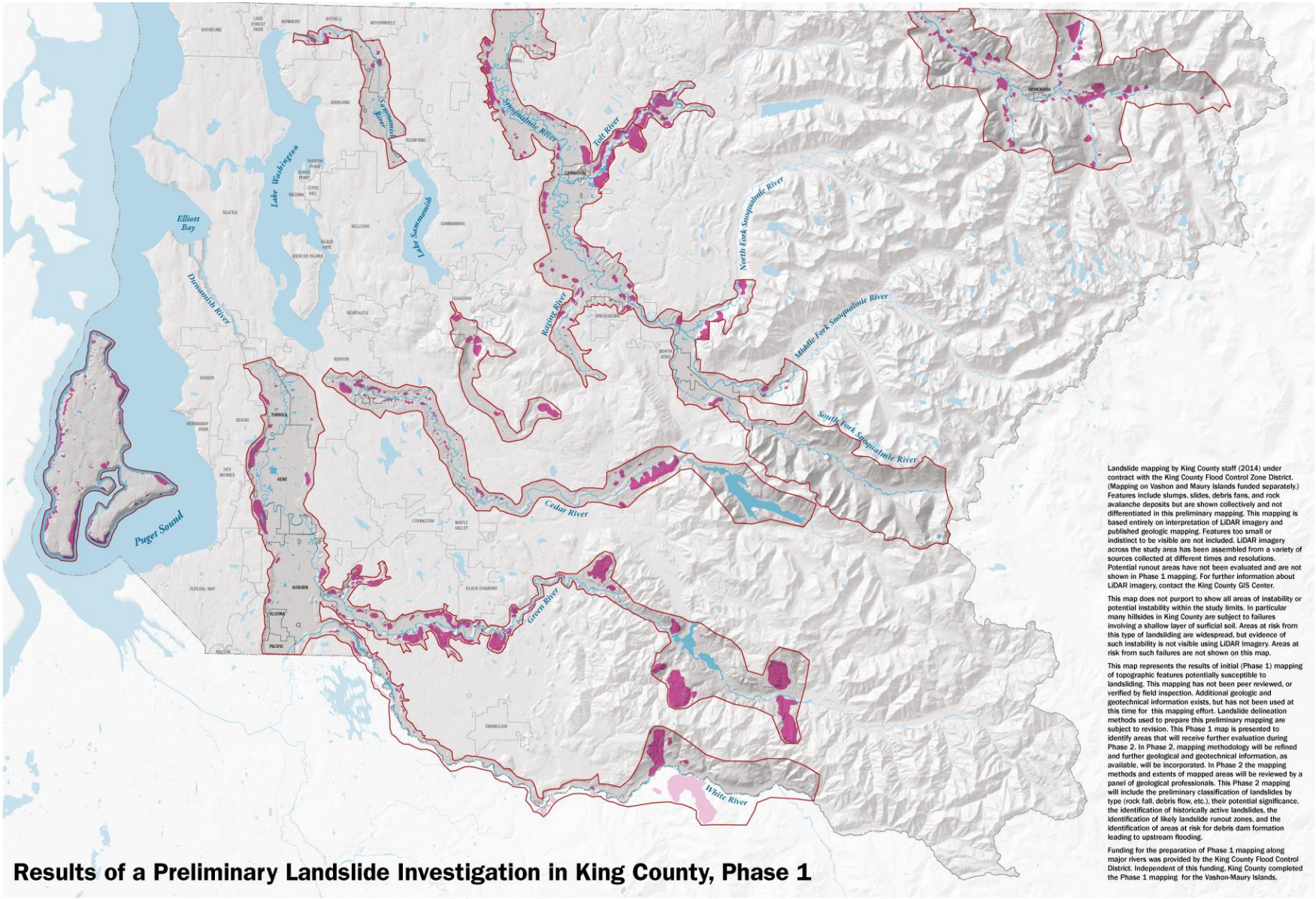
APPENDIX 1. PHASE 1 MAPPING RESULTS



Landslide mapping by King County staff (2014) under contract with the King County Flood Control Zone District. (Mapping on Vashon and Maury Islands funded separately.) Features include slumps, slides, debris fans, and rock avalanche deposits but are shown collectively and not differentiated in this preliminary mapping. This mapping is based entirely on interpretation of LiDAR imagery and published geologic mapping. Features too small or indistinct to be visible are not included. LiDAR imagery across the study area has been assembled from a variety of sources collected at different times and resolutions. Potential runout areas have not been evaluated and are not shown in Phase 1 mapping. For further information about LiDAR imagery, contact the King County GIS Center.

This map does not purport to show all areas of instability or potential instability within the study limits. In particular many hillsides in King County are subject to failures involving a shallow layer of surficial soil. Areas at risk from this type of landsliding are widespread, but evidence of such instability is not visible using LiDAR Imagery. Areas at risk from such failures are not shown on this map.

This map represents the results of initial (Phase 1) mapping of topographic features potentially susceptible to landsliding. This mapping has not been peer reviewed, or verified by field inspection. Additional geologic and geotechnical information exists, but has not been used at this time for this mapping effort. Landslide delineation methods used to prepare this preliminary mapping are subject to revision. This Phase 1 map is presented to identify areas that will receive further evaluation during Phase 2. In Phase 2, mapping methodology will be refined and further geological and geotechnical information, as available, will be incorporated. In Phase 2 the mapping methods and extents of mapped areas will be reviewed by a panel of geological professionals. This Phase 2 mapping will include the preliminary classification of landslides by type (rock fall, debris flow, etc.), their potential significance, the identification of historically active landslides, the identification of likely landslide runout zones, and the identification of areas at risk for debris dam formation leading to upstream flooding.

Funding for the preparation of Phase 1 mapping along major rivers was provided by the King County Flood Control District. Independent of this funding, King County completed the Phase 1 mapping for the Vashon-Maury Islands.

Results of a Preliminary Landslide Investigation in King County, Phase 1

Study Limits
Mapping (2014) by King County Staff
Incorporated Areas

N
0 3 6 Miles
October 2014

King County
Department of Natural Resources and Parks
Water and Land Resources Division
River and Floodplain Management Section

KING COUNTY FLOOD CONTROL DISTRICT

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Data sources: King County GIS Library, King County staff mapping, WA DNR DGER
File name: 1410_KSDN_landslideMAP_final

THE FOLLOWING TEXT IS FROM THE PHASE 1 MAP SEEN IN PREVIOUS PAGE:
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Data sources: King County GIS Library, King County staff mapping, WA DNR DGER
File name: 1410_4383w_landslideMAP_low.ai