Deep-Seated Landslide Research Strategy
Landslide Mapping & Classification
Project Scoping Document

Prepared by the Upslope Processes Scientific Advisory Group (UPSAG)

for the

State of Washington

Forest Practices Board Adaptive Management Program

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1 FOREST PRACTICES CONTEXT AND BACKGROUND

Project Title: Landslide Mapping & Classification Project

Rule Group: Unstable Slopes Rule Group; Glacial Deep-Seated Landslides (GDSLs) Program (Rule Tool)

Forest Practice Rules: The Landslide Mapping & Classification Project, as part of the Deep-Seated Landslide Research Strategy (CMER 2018), is intended to ultimately inform WAC 222-16-050(1)(d)(i)(Classes of Forest Practices), WAC 222-10-030 (SEPA policies for potentially unstable slopes and landforms), and Board Manual Section 16 (Guidelines for Evaluating Potentially Unstable Slopes and Landforms; WFPB 2016a). The "Rule-Identified Landforms" related to deep-seated landslides (DSL) that may trigger a "Class IV-Special" forest practices classification include: (B) toes of deep-seated landslides, with slopes steeper than thirty-three degrees (sixty-five percent), (C) groundwater recharge areas for glacial deep-seated landslides, and (E) any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes (e.g., some bedrock DSLs (BDSLs) may be classified at Category E).

Adaptive Management Context: The Landslide Mapping & Classification Project combines two of twelve interrelated projects (4.5 and 4.6) included in the Deep-Seated Landslide Research Strategy approved by CMER (Fig. 1; CMER 2018). We think efficiencies can be gained by scoping these two projects together as one because they are directly linked. The Strategy addresses Critical Questions from both the Unstable Slopes Rule Group Glacial Deep-Seated Landslide Program and the Mass Wasting Effectiveness Program (CMER 2019) and additional questions posed by the Forest Practices Board and Policy in the 2016 Proposal Initiation (WFPB 2016b):

CMER Work Plan (2019) Rule Group Critical Questions:

1. Can relative levels of response to forest practices be predicted by key characteristics of glacial deep-seated landslides and/or their groundwater recharge areas?

2. Does harvesting of the recharge area of a glacial deep-seated landslide promote its instability?

3. Are unstable landforms being correctly and uniformly identified and evaluated for potential hazard?

Timeline: UPSAG anticipates project scoping will be complete with a preferred alternative for Policy to consider and approve in early FY 2021. Study design, Independent Scientific Peer Review, and CMER approval should occur in FY 2021.

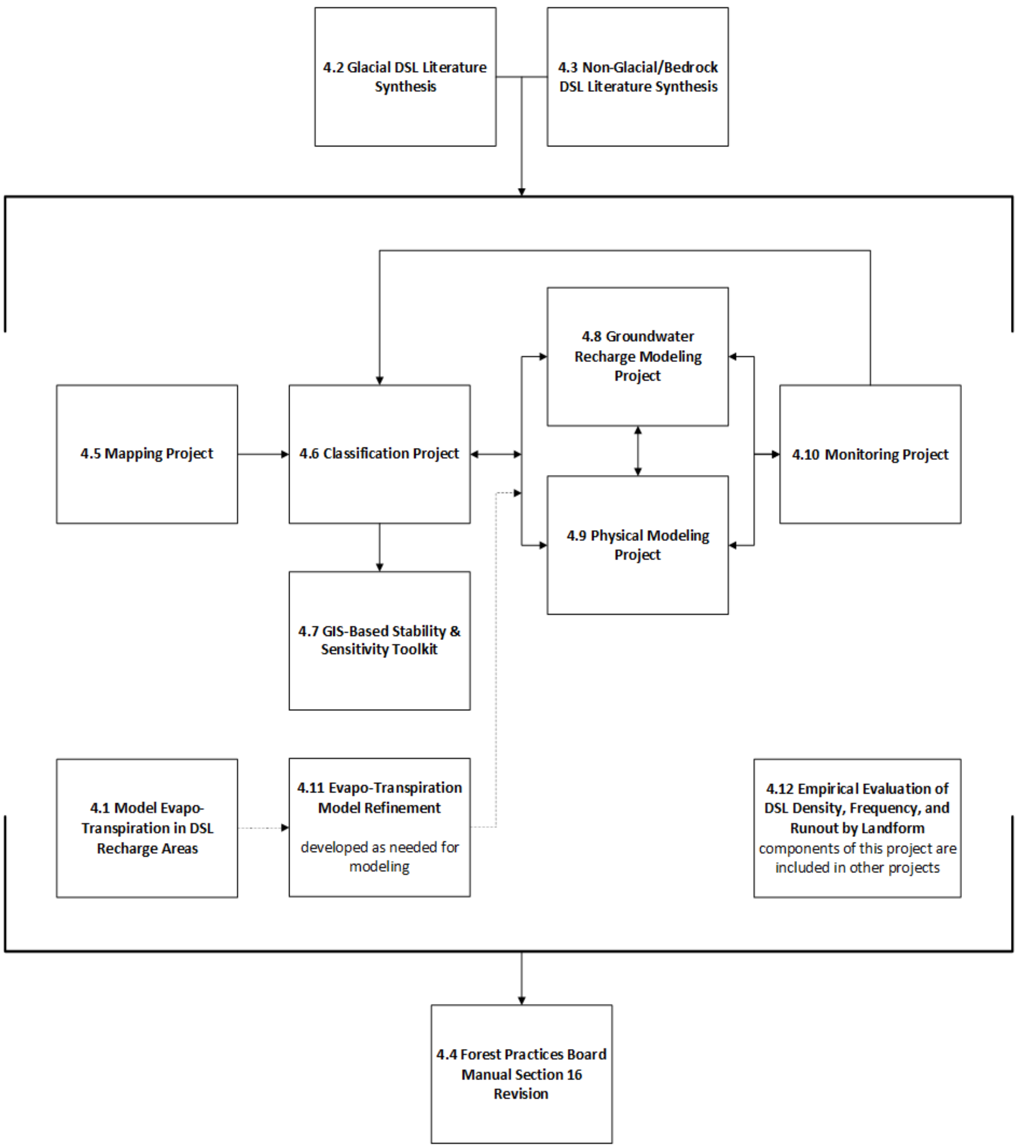

Figure 1: Conceptual linkage of the projects presented in the CMER Work Plan Deep-Seated Landslide Strategy.

Resource Objectives, Issues and Performance Targets (per the Forests & Fish Report Schedules L-1 and L-2): The FFR Resource Objective reads: *Prevent the delivery of excessive sediment to streams by protecting stream bank integrity, providing vegetative filtering, protecting unstable slopes, and preventing the routing of sediment to streams.*

The Performance Targets for mass wasting sediment delivered to streams are:

- *Virtually none triggered by new roads;*
- *Virtually none triggered by new harvesting on high risk sites verified per Report criteria;*
- *No increase over natural background rates on a landscape scale on high risk sites; and*
- *Favorable trend on old roads.*

The Priority Effectiveness Monitoring and Research specifically called out in Schedule L-1 is: *Develop a screen for deep-seated landslides (needs to be done state-wide)*.

Since the writing of the FFR and Schedules L-1 and L-2, several additional projects have been added to the CMER (2019) Work Plan. Detailed descriptions of these projects and their origins are presented in the Deep-Seated Landslide Strategy (CMER 2019).

2 DEFINITIONS

The definitions provided in this section are necessary to understand this proposal. The first use of each term below this section is italicized.

Activity level - refers to the timing of landslide movements and ranges from active (current or recent movement) to dormant-distinct (has not moved in recent decades) to dormant-indistinct (has not moved in centuries) to relict (clearly developed in the geomorphic past under different conditions than currently present). The Washington Forest Practices Board Manual Section 16 provides guidance for the field determination of these activity levels.

Attribute - a numerical or qualitative characteristic of a landslide included in a landslide database. The information may be gathered in the field and/or the office.

Bedrock deep-seated landslide (BDSL) - A deep-seated landslide with a body and failure plane within bedrock.

Causal mechanism - the reason(s) for landslide failure or reactivation.

Classes - groups of DSLs with similar characteristics. Classes of DSLs can occur in spatially discontinuous areas (i.e., in different clusters, see below).

Clusters - sampling units encompassing proximal DSLs with similar geomorphology, topographic settings, hydrologic settings, and stratigraphic sequences. Preliminary clusters will be established with GIS tools and may be refined with field data. The intent is that landslides in a cluster are both located close together and their critical independent variables are homogeneous. The DSLs within a cluster are expected to respond to natural and anthropogenic triggers similarly, facilitating an analysis of sensitivity.

Critical Independent Variables - a subset of landslide characteristics converted into attribute data and used to define landslide classes. While not completely identified at this time, these are primarily the truly independent variables such as climate, topographic setting, and stratigraphy.

Deep-seated landslide (DSL) - A landslide with a body and failure plane. The failure plane lies below the tree root zone. This depth can range from ten feet to several hundreds of feet. Simple, rapid failures such as debris flows and debris avalanches are not deep-seated landslides regardless of failure depth.

Empirical - observed evidence, real-world data, metrics, and results that are verifiable by observation and experience rather than theories or concepts.

Forest practices – forestry related activities completed on lands regulated by the Washington Forest Practices rules (i.e. timber harvest, road construction and surface mining).

Glacial deep-seated landslide (GDSL) - A deep-seated landslide with a body and failure plane within glacial sediment.

Hydrologic sensitivity - the likelihood of landslide reactivation following a hydrologic change related to the movement and distribution of water.

Landslide sensitivity - the likelihood of landslide reactivation following a change (e.g., toe erosion, etc.).

Population of interest – existing GDSLs and BDSLs located on lands regulated by the Washington Forest Practices rules.

Stratigraphy - the relative positions, properties, and ages among geologic strata.

Trigger - the final factor that causes DSL failure at a moment in time.

3 PROBLEM STATEMENT

In Washington State, deep-seated landslides occur within many lithologies and across wide breadths of climate regimes and timescales. These differences in geologic materials, climates and timescales suggest that different geographies are more or less sensitive to contemporary natural and anthropogenic landslide triggering mechanisms. Of particular interest to the Adaptive Management Program are the potential effects of hydrologic inputs from forest management on different *classes* of deep-seated landslides, especially where landslides have the potential to degrade fish habitat and water quality, or threaten public safety.

As summarized by Miller (2016 and 2017), increases in groundwater recharge due to decreases in evapotranspiration from timber harvest may impact deep-seated landslide processes. However, few guidelines are available to determine if an individual deep-seated landslide will respond to harvest-induced changes in hydrology. Developing a deep-seated landslide classification system that is based on specific factors, such as material properties, geomorphic setting and hydrology, may provide a framework for *empirically* assessing geologic hazards and evaluating the relative *hydrologic sensitivity* due to timber harvest.

The Washington State Forest Practices Board Manual Section 16 is provided as guidance to field practitioners (e.g., geologists, forest engineers, and foresters) and interested parties for evaluating potentially unstable slopes and landforms (WFPB 2016a). Deep-seated landslides are first identified as occurring in either glacial materials or bedrock and then are further subdivided into four *activity levels*. This information and the location of the proposed forest practices are used to classify the forest practices application (e.g., Class III or Class IV-Special FPA) and to require varying levels of analysis and mitigation.

This first project is intended to provide a classification of deep-seated landslides inferred to represent a range of potential landslide susceptibility to natural and forest practice *triggers*. This effort will provide the framework needed to pursue additional projects as described in the Strategy. Traditionally, deep-seated landslides are studied individually. These studies are conducted in the context of construction projects, such as the building or repair of a segment of highway, as well as academic research focused on specific failure mechanisms. Consequently, broad classifications beyond simple type and activity level do not exist. An exploratory approach is appropriate for developing the methods needed to address this gap in our understanding. Considering the breadth of Washington State and the specific focus of forest practices rules on hundreds of *DSLs*, there is an imperative to create an effective classification system based on sound geologic principles.

4 PURPOSE STATEMENT

The purpose of the Landslide Mapping & Classification Project is to empirically define classes of deep-seated landslides based on *critical independent variables* that control the occurrence and type of failure. These critical independent variables include, but may not be limited to, climate, lithology, *stratigraphy*, and topographic setting.

This project will aid our stratification of landslides for future projects (e.g., hydrologic modeling efforts, physical modeling efforts - see Projects 4.8, 4.9). Moving forward, these classes will be used to identify and assess a potential subset of landslide types that may be prone to increased activity associated with forest practices, such as timber harvest or road construction.

5 CRITICAL SUB-QUESTIONS AND RESEARCH OBJECTIVES

Here, we define a more specific set of critical sub-questions and associated research objectives. The sub-questions are specific to the purpose of this project and are based on the Geo/Hydro/Geomorphic Landslide Classification Project (original scoping by Gerstel, 2007) and two recent DSL literature syntheses (Miller 2016, 2017). The research objectives describe the acquisition and/or analysis of data needed to answer the sub-questions.

5.I CRITICAL SUB-QUESTIONS

1. What are the distinguishing characteristics among DSLs within similar geomorphic, topographic, stratigraphic, hydrologic, and climatic settings?
2. Can activity levels of individual DSLs within and between *clusters* be linked to sensitivity to hydrologic change?
3. What are the critical independent variables necessary to define DSL classes?
4. Are there particular classes of DSLs that have a greater or lesser potential for instability?
5. What data are necessary to estimate the relative sensitivity of DSLs within a class?

5.II RESEARCH OBJECTIVES

1. To identify distinguishing characteristics within and between DSLs.
2. To investigate why landslides with similar characteristics may exhibit differences in activity level.
3. To develop *causal mechanism* hypotheses for individual landslides evaluated in the field. These mechanisms might include hydrogeologic characteristics visible in active landslides.
4. To determine the best remote sensing tools, field assessment and other methods to classify DSLs in a manner that will substantially improve our understanding of the relative potential for DSL reactivation or accelerated movement.
5. To define classes of DSLs within and across clusters using a suite of physical *attributes* based on *critical independent variables*. These classes will also be used to support future phases of the research strategy (i.e., which DSLs are most representative or illustrative for future research and modeling efforts based on the results of the classification project).
6. To evaluate if certain classes of landslides have a high or low potential for instability from forest practices and rank classes based on multiple sources of empirical evidence.

6 BEST AVAILABLE SCIENCE COMPARISON

This proposed Landslide Mapping & Classification Project is unique in that it was preceded by literature syntheses (Miller 2016, Miller 2017) that were part of the DSL Research Strategy (Projects 4.2 and 4.3). The two literature reviews that form the Best Available Science (BAS) for this project found that most of the literature consisted of individual case studies, geotechnical studies (including material properties and numerical stability models), and hydrologic studies (modeling evapotranspiration, soil-water budgets, and water yield). Only two studies explored the effects of forest practices on deep-seated landslides. Generally, the literature reviews concluded that the evidence of forest practice response can be subtle (i.e., Swanston et al. 1988) and that the data to characterize this sensitivity has not been systematically collected. Models to anticipate response of landslides to forest practices typically require numerous simplifying assumptions as detailed information on site stratigraphy, material properties, and subsurface hydrogeology are difficult to acquire (Miller and Sias 1998). Therefore, most of the questions posed by UPSAG, CMER, Policy and the Forest Practices Board are not directly addressed by either peer-reviewed or other published studies.

Deep-seated landslides occur at a variety of scales in Washington (from tens of square meters to tens of square kilometers), and are found in many types of geologic materials, range in activity level, and differ in their failure mechanisms. The assessment of individual DSLs requires substantial data in order to understand failure mechanisms and sensitivities to forest practices. It would be more expedient to classify landslides that belong in common groups for analysis rather than assessing each landslide on a case-by-case basis. A landslide classification system focused on CMER lands in Western Washington has the potential to allow practitioners to extrapolate failure mechanisms and sensitivities beyond the individual landslide to identify other landslides that have similar characteristics. These include geotechnical properties and hydrologic conditions and may respond in similar ways to changes in loading and unloading, hydrology, land use or other driving factors.

There are several classification methods that have been proposed for DSLs. A widely used classification is based on the type of movement (i.e., flows, slides and falls) and the material (i.e., rock or soil) (Hungr et al. 2014). Forest Practices Board Manual 16 classifies DSLs according to surface indicators of activity level (WFPB 2016a). Activity level is generally determined based on observations of geomorphic field indicators such as sharpness of scarps, relationships to other adjacent surfaces, and vegetation (Keaton and DeGraff 1996). Advances in topographic modeling and spatial analysis have improved our ability to differentiate between shallow and deep-seated landslides remotely (Mezaal et al. 2019). While these approaches are useful for identifying deep-seated landslides and some landslide processes, they do not provide the level of detail needed to stratify landslides by the key factors that influence deep-seated movement to evaluate the potential response to forest practices.

Although individual landslides can vary considerably, DSLs share common features and processes that allow for classification. The literature reviews found that primary drivers of deep-seated reactivation are (1) changes to seasonal or longer-term water balance, and (2) topography and geomorphology (both internal and external to the landslide), relative to lithology and stratigraphy, land use and land cover change, and climatic and tectonic or seismic forces. Identification of these factors will aid our landslide classification.

DSLs displace across a shear zone, where the body of the landslide becomes separated from the intact surrounding material. This differs from slope creep, where a distinct shear zone is not present. The shear zone is less cohesive than the material above and below and has a lower permeability, which can restrict or completely preclude groundwater flow from the landslide body to materials below the shear zone, or restrict recharge into the landslide body from below. Therefore, DSLs can be reactivated by an increase in pore pressures due to both externally driven changes in the seasonal or longer-term water balance and internal fluctuations associated with water delivery, storage or drainage. Besides pore pressure dynamics, reactivation is also caused by changes in the geometry of the landslide, such as through river erosion or adding mass to the slope.

The literature reviews identified several knowledge gaps that will need to be addressed as the classification project is developed. There is a lack of information on the range of landslide depositional and erosional histories, the resulting geomorphic settings, and the hydrologic, stratigraphic, and structural controls on movement of characteristic DSL types present in Washington.

While the general principles affecting the surface and groundwater budget of a DSL are understood, more detailed information on potential differences in the timing and structural controls that affect water delivery and storage within DSLs is often limited. Recent exploratory research on subsurface water pathways and mass movement dynamics *in related settings,* and better monitoring technologies such as Electrical Resistivity Tomography (ERT) may offer significant advances in the ability to identify specific hydrogeomorphic conditions that trigger DSL failure. Promising monitoring technologies such as Interferometric Synthetic Aperture Radar (InSAR) can show landslide change or movement. However, most peer-reviewed monitoring studies on hydrogeologic processes in terrains formed by mass movements, like most DSL research, are limited to a single location, sometimes with a temporal component. While some studies extrapolate these findings to similar systems, we lack a comparative inventory of DSLs based on systematically collected/organized comprehensive data.

7 RESEARCH ALTERNATIVES

The Landslide Mapping & Classification Project seeks to classify deep-seated landslides using critical independent variables such as stratigraphy and associated hydrology, and the topographic setting. Various landslide classifications exist; however, they focus primarily on landslide-forming materials (e.g., rock, debris, and earth of Varnes 1978) and movement mechanisms, such as "flows" or "falls." By expanding the amount of information utilized to classify DSLs, our objective is to provide a more detailed classification system, coupled with preliminary observations about causal mechanisms and triggers, which will aid in refining our stratification of landslides for future projects.

This project has few antecedents in the peer-reviewed literature, and it would be prudent to first assess how to choose meaningful attributes from a relatively small landslide population before expanding the population. The alternatives described below inherently represent an iterative process of starting with a smaller geographic area and extending the classification across Western Washington. But even within the smallest geographic area, development of the methodology will be iterative. Cautious and thoughtful development of methodology for this unprecedented classification of DSLs enables expansion of efforts building on methods that worked well with an initially small population.

Below, we provide a discussion on "Methodology and Level of Investigative Detail" which outlines the basic methods shared by all four alternatives and explains the elements of remote-only classification versus remote classification coupled with field efforts. We briefly summarize the options of studying either *GDSLs* on their own or studying both GDSLs and *BDSLs* –

"Deep-Seated Landslide Type." Next, we present the "Spatial Extents" over which we could implement the project. Finally, within this framework, we present four alternatives. All of the alternatives address the critical sub-questions and meet the research objectives listed above in Section 4, but vary with respect to spatial extent and landslide type. We considered additional alternatives (see Appendix 1); however, they have not been developed further.

Methodology and Level of Investigative Detail

The first step is to acquire a landslide inventory from either published sources or new LiDAR-based mapping for this project. The inventory will be used to identify *'clusters'* of DSLs, areas where many landslides have failed within a defined landscape feature, such as along the edges of glacial terraces in a river valley. We will use high resolution LiDAR topography as an effective way to identify groups of landslides that are in close proximity to each other. The approach uses remotely collected information for the initial clustering. Field-work is then focused on specific landslides of interest within clusters. The details of field choices, protocols and attribute collection will be developed in an iterative fashion until it is clear that the methodology needed to classify DSLs is in place.

By grouping landslides into clusters, we will efficiently sample landslides that may be representative of a significant proportion of potential landslide classes on lands regulated by the Washington Forest Practices rules. This methodology also allows us to evaluate the key critical independent variables and attributes, at the relevant scales between landslides within a cluster without omitting potentially critical drivers from scrutiny.

This rationale is supported by the fact that geologic units that are close together are generally more similar than geologic units that are far apart. They may also be influenced by similar natural and anthropogenic factors that can promote slope instability (Stevens and Olsen 2004). Areas with many DSLs are thought to contain a common set of characteristics promoting instability provided that there are no stratigraphic breaks or other discontinuities that make particular landslides more reactive than others within the area (Keaton et al. 2014).

The identification of causal mechanisms and triggers for an individual DSL may be confounded in three ways, listed below. By clustering landslides we may minimize the number of variables that are evaluated. .

(1)The presence of multiple potential triggers during the period of active movement may muddle the identification of actual triggers. Using remote and field techniques, the project team will look for evidence of active DSLs within the cluster *compared* to those that show no evidence of historic activity. Evaluating causal mechanisms and triggers by comparing active landslides with dormant and relict landslides within clusters will allow the project team to develop a more effective method to identify factors that may have promoted instability.

(2)Weathering, erosion, soil development, altered hydrologic conditions, and rapid revegetation often erase or mask the causal mechanisms of dormant-indistinct and relict landslides.

(3) Because most DSLs have been dormant for hundreds to thousands of years, it is not possible to reconstruct the timing and frequency of past instability and correlation with climatic perturbations, seismic events, valley evolution, and so on.

As a result, empirical evaluation of dormant or relict DSLs, especially in Western Washington, provide less definitive information on *landslide sensitivity*. Identification of recent landslide activity is particularly apparent in the field; failure post-mortems are often the only time when causal mechanisms are more clearly evident. While field efforts will occur across a range of activity levels within a cluster, they may be primarily focused on active landslides in a manner that informs our interpretation of causal mechanisms and triggers on neighboring dormant and relict DSLs.

In addition to LiDAR mapping and field reconnaissance, the project team will use other salient data and existing information that is available including aerial photography [e.g., low elevation stereo photos and National Agriculture Imagery Program (NAIP) aerial imagery], surficial and geologic maps, topographic attributes, geotechnical reports, and interviews with experts. In some cases data from well-logs, carbon dating, stable isotope analysis, Electrical Resistivity Tomography (ERT), Structure from Motion (SfM - high resolution topographic models), or other investigations may be available. When we have defined preliminary classes of DSLs, we may ask selected geologists and geotechnical experts in Western Washington: “From your field experience, are you aware of a population of DSLs that does not fit within one of these classes?” The answers might point further efforts towards distinct DSL populations OR suggest that we have identified all meaningful classes within the study area. Collectively, these data will allow the project team to bolster our effort to create a robust, new DSL classification. Depending on the alternative, this step has the potential to significantly limit the effort needed to transition from a few counties to all of Western Washington and simplify an analysis of Eastern Washington.

Once the clusters are established, we will compare the similarities and differences within and between clusters using both the previously derived attributes (e.g., in existing inventories) and newly collected data. Based on this information, the project team will establish landslide classes. While these initial efforts may provide empirical inference about between class and within class sensitivity, subsequent research, as described in the Strategy, will ultimately be used to determine if certain classes of landslides have a particularly high or low potential for instability from forest practices and to rank classes based on multiple sources of evidence.

Deep-Seated Landslide Type

Although not directly stated, it is clear from Section 1 “Forest Practices Context and Background” above that the FFR, our current forest practices rules, and the CMER Work Plan and Rule Group Questions focus on the groundwater recharge areas of GDSLs because the authors of the FFR inferred that, among DSLs, GDSLs may be more susceptible to changes in hydrologic inputs. However, more recent efforts including the second literature review (Miller 2017), the Strategy, and the broader framing of this document in Sections 3 and 4, are purposefully including BDSLs because we recognize that similar susceptibility to changes in hydrologic inputs may exist among other types of DSLs. This scoping document provides alternatives that initially classify only GDSLs and other alternatives that also include BDSLs in the first effort. The intent of the Strategy is to then conduct more specific DSL modeling and monitoring projects.

Spatial Extent

The four alternatives presented below predicate on three levels of spatial extent (Table 1). Regardless of the spatial extent of the project chosen, an iterative approach may be considered, starting with just one of the counties and working up to the larger area. The smallest spatial extent, which utilizes the landslide mapping already (or soon to be) accomplished by the Washington State Geologic Survey (WGS) Landslide Hazards Program as well as additional existing datasets, would be based in Whatcom, Snohomish, King and Pierce counties (Mickelson et al. 2017, 2019, 2020; see Figure 2). The next larger spatial extent contains most of the GDSLs in Western Washington on CMER lands, and would add Clallam, Jefferson, Kitsap, Skagit and Lewis counties to the previous four counties. The largest spatial extent, which contains most of the GDSLs and BDSLs in Western Washington's CMER lands, would add the Columbia River Gorge to the previous nine counties (Mickelson et al. 2018). These choices are called "4-county spatial extent," "9-county spatial extent," and "9-county-plus-Gorge spatial extent." We recognize that DSLs exist in portions of forested Eastern Washington, and we may need to expand the classification project after completing the project in Western Washington.

Table 1: Alternatives as defined by landslide type and spatial extent.

Spatial Extent	Counties	GDSL	GDSL & BDSL
4-county	Whatcom, Snohomish, King, Pierce	Alt. 1	
4-county	Whatcom, Snohomish, King, Pierce		Alt. 2
9-county	Whatcom, Skagit, Snohomish, King, Pierce, Lewis, Kitsap, Clallam, Jefferson	Alt. 3	

9-county-plus-Gorge	Whatcom, Skagit, Snohomish, King, Pierce, Lewis, Kitsap, Clallam, Jefferson, and areas of the Columbia River Gorge		Alt. 4

7.I ALTERNATIVE 1: ATTRIBUTE AND CLASSIFY GDSLS WITHIN WHATCOM, SNOHOMISH, KING AND PIERCE COUNTIES.

Level of investigative detail: Remote sensing + fieldwork

Type of deep-seated landslide: Glacial deep-seated landslides (GDSLs)

Spatial extent: Whatcom, Snohomish, King and Pierce counties

***Summary**:* Alternative 1 is designed as a 'proof of concept' to test the effectiveness of using a combination of remote sensing and targeted field validation and assessment methods specific to the project. In the process, we would collect critical landslide attribute data. Because there are currently no studies that provide a model for how to efficiently classify inherent differences in deep-seated landslide sensitivity across the landscape, this smaller spatial extent would represent a targeted effort to refine the methodology used to choose appropriate DSLs for further study (see Strategy). Moreover, while it is the most limited option in both landslide type and spatial extent, Alternative 1 would define a range of critical independent variables that would allow for combining landslides into classes for testing hypotheses in the subsequent projects regarding the potential for forest practices to affect DSL stability.

Specifically, it would be prudent to first assess how to select critical independent variables that facilitate landslide classification and meaningful attributes that inform landslide variance and potential sensitivity from a relatively small landslide population (limited to the WGS inventory areas) before considering a larger-scale classification project. Alternative 1 would survey only GDSLs, and the spatial extent of the study area would be limited to Whatcom, Snohomish, King and Pierce counties.

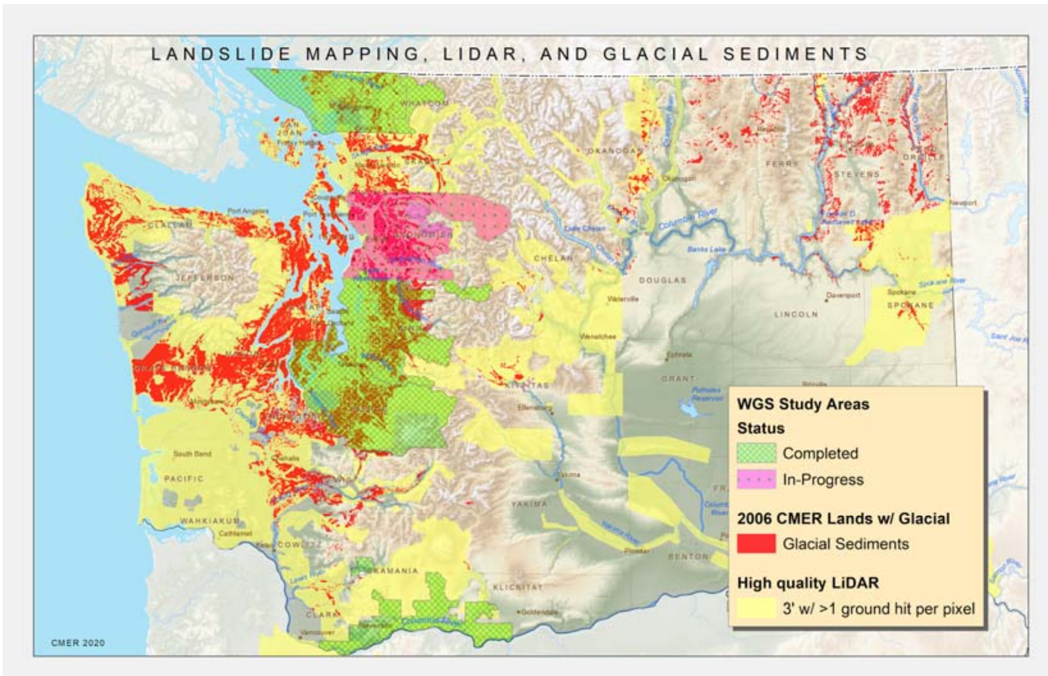

Figure 2: Potential study area for Alt. 1, where CMER lands with glacial deposits and quality LiDAR intersect.

***Landslide type**:* Alternative 1 focuses on GDSLs. GDSLs have been inferred to be more susceptible to changes in hydrologic inputs. Additionally, there would be a fundamental benefit in fine tuning and testing our preferred methodology for identifying DSL attributes before scaling up.

***Spatial Extent**:* Alternative 1 has a 4-county spatial extent, requiring the least cost upfront. It would allow us to test and fine tune our methodology before determining whether study expansion is warranted. Alternative 1 proposes to take advantage of existing inventories without the expensive process of fully mapping new areas of the state from existing LiDAR ahead of the WSG inventory process (Figure 2).

Benefits:

- This 4-county spatial extent is a manageable sample of GDSLs in Western Washington, facilitating the refinement of field reconnaissance methods and the identification of meaningful critical independent variables, attributes, and preliminary classes.
- For the four counties, WGS mapping and other quality inventories are available or will be shortly. The landslides have been consistently mapped using a standard protocol and are associated with LiDAR-derived attributes such as landslide dimensions, movement type, a confidence rating of whether the 'feature' is actually a landslide, and whether the feature was field verified.
- This project would build on the existing WGS geodatabase to include critical independent variables and attributes that aid classification.
- When preliminary classes of GDSLs have been defined, selected geologists and geotechnical experts in Western Washington could be asked "From your field experience, are you aware of a population of GDSLs that does not fit within one of these classes?" The answers might point further efforts towards distinct populations OR might suggest that all meaningful classes have been identified within the four counties.

Limitations:

- Restricting the study to the few counties using the WGS-mapped landslides may produce results that are not representative of all GDSL classes on CMER lands in Western Washington.
- Preliminary BDSL classes would not have been established at the end of Alternative 1, leading to subsequent duplication of field efforts in the 4-county spatial extent and potential duplication of other work (i.e., the geologist and geotechnical expert query).

Products:

- WGS mapped landslides in glacial deposits grouped by cluster, the identification of a subset of DSL classes and potential sensitivity, and a report describing the methods and key attributes.

- An efficient field protocol that could be applied to a larger sample of DSLs.

7.II <u>ALTERNATIVE 2:</u> ATTRIBUTE AND CLASSIFY GDSLS AND BDSLS WITHIN WHATCOM, SNOHOMISH, KING AND PIERCE COUNTIES.

<u>Level of investigative detail</u>: Remote sensing + fieldwork

<u>Type of deep-seated landslide</u>: Glacial deep-seated landslides (GDSLs) and bedrock deep-seated landslides (BDSLs)

<u>Spatial extent</u>: Whatcom, Snohomish, King and Pierce counties

<u>Summary</u>: Alternative 2 is designed as a 'proof of concept' to test the effectiveness of using a combination of remote sensing and targeted field validation and assessment methods specific to the project. In the process, we would collect critical landslide attribute data. Because there are currently no studies that provide a model for how to efficiently classify differences in deep-seated landslide sensitivity across the landscape, this effort is a necessary step in order to choose appropriate DSLs for further study (see Strategy).

Specifically, we feel it would be prudent to first assess how to choose meaningful attributes from a relatively small landslide population (limited to the WGS inventory areas) before committing to a larger-scale classification project. Alternative 2 would survey both GDSLs and BDSLs, and the spatial extent of the study area would be limited to Whatcom, Snohomish, King and Pierce counties.

Including both types of DSLs in this initial effort would likely result in several efficiencies, described in the following paragraphs. We have also made the assumption that DSLs in mapped glacial deposits are glacial landslides when, in fact, mapping is coarse and some landslides initially identified as one type may need to be reclassified in the field (such as where DSLs exhibit a glacial veneer on top of a BDSL). Having both landslide types in the same study may reduce the potential to have to exclude some landslides that have already received field visits which have turned out to be the wrong type of landslide for the study. To examine both types in the field within the same study may prove to be considerably more efficient.

Landslide type: Including both GDSLs and BDSLs in the 4-county spatial extent has two efficiencies related to the field reconnaissance effort. Visiting both DSL types during this first effort would best utilize travel expenses within the 4-county area, as opposed to visiting GDSLs first, and then returning to visit BDSLs in the future. Geologic maps often do not capture thin glacial veneers (maybe on purpose, so not necessarily a function of inaccurate mapping), which means some DSLs remotely mapped as BDSLs are really GDSLs. Conversely, where glacial veneers are mapped, DSLs mapped as a GDSLs may have failure planes within the lower bedrock. This means that the geologic mapping often does not predict DSL type. Thus, Alternatives 1 and 3 (GDSLs only) would lead to significant field reconnaissance that, while not necessarily wasted in the context of the broader goals, would not be useful to the immediate results.

Spatial Extent: Alternative 2 is the second most limited option, requiring the second lowest cost upfront. This 4-county spatial extent, as with Alternative 1, would allow us to test and fine tune our methodology before embarking on a larger study. The inclusion of BDSLs in the initial development of methodology and classification would synergistically facilitate subsequent classification efforts (e.g., completing the 9-county-plus-Gorge classification) and the additional modeling and monitoring research proposed in the Strategy. Alternative 2 proposes to take advantage of existing inventories without the expensive process of independently mapping new areas of the state from existing LiDAR ahead of the WGS inventory process (Figure 2).

<u>Benefits:</u>

- This 4-county spatial extent is a manageable sample of GDSLs and BDSLs in Western Washington, facilitating the refinement of field reconnaissance methods and the identification of meaningful critical independent variables, attributes, and preliminary classes.
- For the four counties, WGS mapping and other quality inventories are, or shortly will be, available. The landslides have been accurately mapped and are associated with basic LiDAR-derived attributes such as information on landslide dimensions, movement type, and a confidence rating of whether the ‘feature’ is actually a landslide.

- This existing geodatabase could be expanded to include this project's critical independent variables and attributes that aid classification.
- Studying both GDSLs and BDSLs in the 4-county spatial extent would maximize the efficiency of field work by limiting travel time and ensuring that all field efforts are immediately useful.
- With preliminary classes of both GDSLs and BDSLs identified, selected geologists and geotechnical experts in Western Washington could be asked "From your field experience, are you aware of a population of DSLs that does not fit within one of these classes?" The answers might point further efforts towards distinct populations OR might suggest that all meaningful classes have been identified within the four counties.
- Adding BDSLs to our sample would more than double the population of landslides in the WGS-mapped counties (Table 2), which would provide a significant benefit to understanding DSL characteristics and classes.
- Alternative 2 would allow us to test the inference that GDSLs are more susceptible to hydrologic inputs than BDSLs. This information could potentially simplify later iterations of the Classification Project.

Limitations:

- The additional number of BDSL clusters would likely greatly increase the time and resources needed to implement the project (i.e., increase the overall cost to this phase of the project).

Products:

- WGS mapped landslides in bedrock and glacial deposits grouped by a subset of DSL classes and potential sensitivity, and a report describing methods and key attributes.
- An efficient field protocol that could be applied to a larger sample of DSLs.

Table 2: Population of deep-seated landslides on CMER lands in counties proposed in Alternatives 1 and 2 that have been completed by WGS at this time. Percent SLIP refers to the subset of DSLs mapped using a streamlined landslide identification protocol.

County	Glacial Deep-Seated Landslides					Bedrock Deep-Seated Landslides				
	Mapping Confidence			Total	% SLIP	Mapping Confidence			Total	% SLIP
	Low	Mod	High			Low	Mod.	High		
King	564	533	259	1,356	3.1	266	247	140	653	26.8
Pierce	132	153	98	383	5.8	216	181	121	518	61.8
Whatcom	131	146	100	377	0.5	375	492	309	1176	0.3
Totals	827	832	2116			857	920	570	2347	

7.III ALTERNATIVE 3: ATTRIBUTE AND CLASSIFY GDSLS WITHIN WHATCOM, SKAGIT, SNOHOMISH, KING, PIERCE, LEWIS, KITSAP, CLALLAM AND JEFFERSON COUNTIES.

Level of investigative detail: Remote sensing + fieldwork

Type of deep-seated landslide: Glacial deep-seated landslides (GDSLs)

Spatial extent: Whatcom, Skagit, Snohomish, King, Pierce, Lewis, Kitsap, Clallam and Jefferson counties

Summary*:* Alternative 3 would use the same remote analysis and field assessment protocols described in Alternatives 1 & 2. However, the expanded spatial extent of Alternative 3, adding Skagit, Clallam, Jefferson, Lewis, and Kitsap counties, would appreciably enlarge the DSL population size and, due to the lack of pre-existing WGS mapping in these counties, would significantly increase the required effort to perform the research. In order to facilitate classification in the counties that are outside of the current WGS dataset, the project would need to map GDSLs ahead of the WGS inventory process. This step would cause added challenges and potential coordination issues to the project. The WGS utilizes an established mapping protocol which relies on consistent and tested methodologies that are not designed for the purposes of this project. However, it would be more efficient to utilize the WGS inventory as a robust baseline, upon which data could be added as needed in order to classify deep-seated landslides.

The downside of limiting the project scope to the four counties currently mapped by WGS is that the initial project may fail to identify the full range of potential GDSL characteristics found in other physiographic regions across the state. As a result, we would likely miss potential DSL classes in the first round of study. However, because we lack a pre-existing template to follow for DSL classification, we are dependent on an iterative process to test the efficacy of our methods regardless of the initial spatial extent of the study design.

Landslide type: This option would be limited to GDSLs for the reasons described in Alternative 1.

Spatial Extent: Alternative 3 would greatly expand the spatial extent of the project, adding the expense of fully mapping new areas of the state from existing LiDAR data ahead of the WGS inventory process (Figure 2). The mapping effort would not attempt to map all GDSLs in these counties, but would focus on clusters of landslides identified using LiDAR. Characterizing a greater diversity of landslides within the region would allow us to better understand GDSLs and may aid in both the development of a more widely applicable classification system and in the development of a more complete range of testable hypotheses regarding the relative sensitivity of GDSLs to forest practices.

Benefits:

- The primary benefit of this alternative would be that it expands the spatial domain once the protocols to classify GDSLs have been tested and approved. Ultimately this means that the study would be representative of a larger population of interest and ensure that this effort would include all factors that might be necessary to classify GDSLs into comprehensive and meaningful groups within Western Washington.

Limitations:

- The primary downside of this alternative is that it would require a much greater effort to identify and map GDSLs in the counties that do not currently have a completed WGS inventory.
- It is unlikely, once preliminary classes of GDSLs are identified, that asking selected geologists and geotechnical experts “From your field experience, are you aware of a population of DSLs that does not fit within one of these classes?” would actually reveal additional classes because these nine counties appear to have most of the GDSLs in Western Washington. This means that Alternative 3 might be doing more work than necessary to achieve the objectives.
- This alternative would result in large increases to project cost and timeline due to increased travel costs, increased mapping efforts and increased data collection.

Products:

- Landslides in glacial deposits across a large percentage of CMER lands grouped by classes and potential sensitivity, along with a report describing methods and key attributes.
- An efficient field protocol that could be applied to a larger sample of DSLs.

7.IV <u>ALTERNATIVE 4:</u> ATTRIBUTE AND CLASSIFY GDSLS AND BDSLS WITHIN WHATCOM, SKAGIT, SNOHOMISH, KING, PIERCE, LEWIS, KITSAP, CLALLAM AND JEFFERSON COUNTIES AND THE COLUMBIA GORGE.

***Level of investigative detail**:* Remote sensing + fieldwork

***Type of deep-seated landslide**:* Glacial deep-seated landslides (GDSLs) and bedrock deep-seated landslides (BDSLs)

***Spatial extent**:* Whatcom, Skagit, Snohomish, King, Pierce, Lewis, Kitsap, Clallam and Jefferson counties and portions of the Columbia Gorge

***Summary**:* Alternative 4 would be an expansion of both landslide type and spatial extent options, thereby significantly enlarging the population size, cost, and required effort to perform this research. This alternative magnifies the benefits and limitations discussed in Alternatives 1, 2, and 3 above. Given the many unknowns associated with the major increase in scope, Alternative 4 would be the most difficult to accurately quantify cost and effort in the study design phase. However, we discuss it here to explore the implications of a classification schema that would characterize most DSLs across CMER lands within Western Washington. Alternative 4 would survey both GDSLs and BDSLs, and the spatial extent of the study area would include five counties that have not been surveyed systematically by WGS at this time.

Landslide type: Please see discussion for Alternative 2.

Spatial Extent: Alternative 4 would not be a comprehensive survey of all deep-seated landslides in Washington State. Among the 39 counties in the state, this option would be limited to 9 counties and parts of the Columbia Gorge, while excluding all of Eastern Washington. However, we believe that a high proportion of DSLs in Western Washington lie in these areas, such that the classes of DSLs which represent a population should be identified. As with Alternative 3, the mapping effort would not attempt to map all DSLs in these counties, but would focus on clusters of landslides identified using LiDAR.

Benefits:

- The primary benefit of this alternative would be that it combines the benefits of Alternative 2 and 3 with an expanded dataset that includes all DSL types across the largest proposed spatial extent.
- By including both DSL types and a greater range of lithologic and geomorphic variability, the study would allow us to characterize a larger number of potential differences between DSLs. These additions could generate a robust and comprehensive classification system, leading to stronger inference about hydrologic susceptibility to forest practices.
- We believe that evaluating DSLs within 9 counties may provide a robust set of landslide classes of Western Washington. Surveying the entire land area of Western Washington may not guarantee better results.
- The classification system that would be generated from this alternative would have the greatest potential for transferability across the differing geographies within Western Washington and potentially in Eastern Washington as well.

Limitations:

- The large spatial extent of this alternative may mean that expensive efforts unnecessary for the identification of meaningful classes may occur (i.e., lots of mapping and field work for no additional classes), decreasing the overall efficiency of the project.
- This alternative would require the greatest amount of time and would be the most expensive of the four alternatives.
- The execution of this alternative would be complex, and we lack some of the critical information needed to estimate costs and efficiently deploy project resources. Furthermore, regardless of how this effort is organized, it would be necessary to begin the project by validating, refining, and testing the methods described in Alternative 1 and 2. For this reason, this alternative might be best framed as the long term result of an iterative process.

Products: Landslides in both glacial and bedrock deposits across CMER lands, grouped by classes and potential sensitivity, and a report describing the methods and key attributes.

8 THE PREFERRED ALTERNATIVE

The members of UPSAG prefer Alternative 2 for the Landslide Mapping & Classification Project. There are several compelling logistical and budgetary reasons for limiting the spatial extent of this first project, as follows:

1. The finalization of field methodologies and the identification of critical independent variables useful for classification will be an iterative process;
2. Utilization of WGS and other mapping efforts defers the need to create our own mapping protocol and/or spend CMER funds to do work WGS will accomplish in the future;
3. Preliminary classification can be used to query selected geologists and geotechnical experts, which would help to focus future landslide classification efforts;
4. Studying both GDSLs and BDSLs in the 4-county spatial extent would maximize the efficiency of field work by limiting travel time and ensuring that all field efforts are immediately useful; and
5. Adding BDSLs to our sample would more than double the population of landslides in the WGS-mapped counties (Table 2), which would provide a significant benefit to understanding DSL characteristics and classes.

Alternative 2 would allow us to examine the inference made within current forest practice rules that GDSLs are more susceptible to hydrologic inputs than BDSLs. This information could potentially simplify later iterations of the Classification Project. It should enable us to learn enough about DSL characteristics to develop a robust baseline dataset that could be used to help estimate variability in landslide characteristics, activity levels, and potential trigger mechanisms. Knowing the variance may aid in determining whether the preliminary classes are representative and adequate to select sites for investigation as the next projects in the Strategy are scoped and developed.

9 BUDGET

Table 3: FY Budget estimates

	FY 22	FY 23	FY 24	FY 25	FY 26	Total
Alternative 1	$50,000	$125,000	$125,000	$75,000	$50,000	$425,000
Alternative 2	$50,000	$150,000	$150,000	$85,000	$50,000	$485,000
Alternative 3	$100,000	$200,000	$200,000	$150,000	$50,000	$700,000
Alternative 4	$125,000	$250,000	$225,000	$175,000	$50,000	$825,000

10 CMER/POLICY INTERACTION

See Prospective Six Questions Findings Report (attached).

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12 APPENDIX 1: OTHER STUDY TYPES CONSIDERED

In the process of developing this scoping document, there were many study types that were considered but were found to be inadequate in their ability to meet the overall objectives of the project and/or answer the critical questions that have been developed for the project. Although these study types are not being presented as alternatives, the team felt it would be beneficial to describe what other study types were considered and explain why the study type would be insufficient as a stand-alone alternative for the purposes of this project.

Remote Sensing/spatial analyses without field work

A study was considered that generated a classification system through the utilization of remote sensing and existing knowledge without the need to complete any field work. However, it was determined that by not completing any field work (even simple field validation) this study would be insufficient in its ability to answer the critical questions and to meet the study objectives of the project. Specifically, the inability of remote data to accurately detail stratigraphy and landform activity, which are foundational elements to the study objectives and the critical questions, was viewed as a terminal fault in this study type which then precluded it from being considered as an alternative.

Specifically, under the structure of this option, we would have likely started with the WGS's landslide mapping efforts in an attempt to identify additional factors that could be used to classify DSLs. Examples might include drainage network development and ground surface roughness as proxies for age and movement. We would probably have had to expand the effort into areas that the WGS has not mapped.

Sample Geotechnical Reports

While exploring information sources that could be utilized to complete a DSL classification while minimizing the overall cost of the project, UPSAG considered sampling from FPAs with geotechnical reports. After an attempt to put more detail into how a study like this would be completed, it was realized that sampling geotechnical reports would be better served as a methodology within a more robust alternative rather than as a stand-alone alternative itself. We feel that there is a lot of useful information that can be derived from geotechnical reports, but the information would not be sufficient to achieve the study objectives or answer critical questions without additional information or data collection.

Specifically, the study type we considered was to sample from FPAs with geotechnical reports in areas with LiDAR, and use remotely sensed information with the information contained in the geotechnical report to do the classification. Geotechnical reports are prepared by licensed qualified experts and are provided to the Department of Natural Resources by landowners when timber harvest or road construction is proposed on potentially unstable slopes.

A 2014 review of FPAs associated with GDSLs yielded 46 applications (Doug Hooks' summary, Sept 30, 2014). Of these, 37 included either a geotechnical report or a memo that mentioned the presence of a GDSL. It is unclear how many more geotechnical reports include analysis of a BDSL because BDSL are typically not evaluated unless they are showing signs of activity (Category E) or include harvest on the toe of the landslides (Category B). Other geotechnical reports are limited to inner gorge crossings and harvest on incised streams associated with a landslide. In many of these instances, the report will provide only a partial picture of the landslide attributes. Although this alternative may be unsatisfactory on its own for meeting our research objectives, the information in geotechnical reports can still be utilized to supplement other landslide classification approaches/alternatives.

Expert Panel

As part of our desire to provide study options with limited cost implications, we considered utilizing an expert panel to develop the DSL classification system. When discussing the functionality of this study type in the context of the project objectives and critical questions, it was realized that utilizing an expert panel would be better served as a methodology within a more robust alternative rather than as a stand-alone alternative itself. The information and results from an expert panel, in some form, would be useful and would have merit and thus, could be used within the study design methodology of the selected alternative.

Specifically, the study would have used an expert panel approach to synthesize existing published and unpublished knowledge, develop hypotheses, and summarize findings in a technical report. The panel would have been given a set of questions related to the classification of DSLs in glacial and bedrock settings and develop a classification system based on the available empirically-derived data as well as on their judgement and experience. The DSL classes proposed by the panel would have been used for future Strategy research projects.

The expert panel would have included approximately 10 licensed geologists with experience related to forestry, forest hydrology, hydrogeology, and engineering geology as evidenced by the Washington Qualified Expert designation. The experts would have independently reviewed the existing information related to the questions posed by UPSAG and then met in a moderated event to confer. The panel would have been supported by an objective and skilled administrator with expertise in decision analysis and methods to help the group summarize their work into a technical report.

This approach would have required carefully defined problems that can be investigated in a timely and economical way by the panel and a definition of what constitutes consensus for a recommendation. A modified version of this alternative is incorporated into our proposed alternatives as a suggested step.